View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by UNL | Libraries

University of Nebraska - Lincoln

DigitalCommons@University of Nebraska - Lincoln

Dissertations & Theses in Natural Resources

Natural Resources, School of

Fall 12-2012

Population Characteristics, Development of a Predictive Population Viability Model, and Catch Dynamics for Pallid Sturgeon in the Lower Missouri River

Kirk D. Steffensen
University of Nebraska-Lincoln, kirk.steffensen@nebraska.gov

Follow this and additional works at: https://digitalcommons.unl.edu/natresdiss

Part of the Aquaculture and Fisheries Commons, and the Population Biology Commons

Steffensen, Kirk D., "Population Characteristics, Development of a Predictive Population Viability Model, and Catch Dynamics for Pallid Sturgeon in the Lower Missouri River" (2012). *Dissertations & Theses in Natural Resources*. 62.
https://digitalcommons.unl.edu/natresdiss/62

This Article is brought to you for free and open access by the Natural Resources, School of at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Dissertations & Theses in Natural Resources by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

POPULATION CHARACTERISTICS, DEVELOPMENT OF A PREDICTIVE POPULATION VIABILITY MODEL, AND CATCH DYNAMICS FOR PALLID STURGEON IN THE LOWER MISSOURI RIVER

By

Kirk D. Steffensen

A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Natural Resource Sciences

Under the Supervision of Professor Mark A. Pegg

Lincoln, Nebraska

December 2012

POPULATION CHARACTERISTICS, DEVELOPMENT OF A PREDICTIVE POPULATION VIABILITY MODEL, AND CATCH DYNAMICS FOR PALLID STURGEON IN THE LOWER MISSOURI RIVER

Kirk D. Steffensen M.S.

University of Nebraska, 2012

Advisor: Mark A. Pegg

Population characteristics and long-term population trends of pallid sturgeon *Scaphirhynchus albus* in the lower Missouri River are relatively unknown. As recovery efforts continue, understanding and quantifying these characteristics and trends are critical for species recovery and future management decisions. Therefore, the objectives of this study were to determine the pallid sturgeon population characteristics, predict changes to the pallid sturgeon population based on different management and life history scenarios, and examine trot line catch dynamics in the lower Missouri River. Catch rates for pallid sturgeon collected with gill nets did not significantly change while catch rates using trot lines significantly declined for wild pallid sturgeon ($P=0.0001$) but did not differ among years for hatchery-reared fish ($P=0.0610$). The proportion of reproductively ready females to non-reproductively ready females was 1:2.0, compared to the male ratio of 1:0.9. The minimum female length-at-maturity was 788 mm and 798 mm for males while the minimum age-at-maturity for known aged hatchery-reared fish was age-9 for females and age-7 for males. The mean relative fecundity was 7%. Our population viability model was most sensitive to ≥age-1 survival rates. Fluctuating female spawning frequency by one year had minimal effect on the

overall population growth and age-at-maturity was less sensitive than spawning frequency. Catch per unit effort was 14.6 fish per trot line rigged with hook timers to study the catch dynamics; however, several hook timers were activated but did not capture a fish. Therefore, the corrected CPUE was 17.7 fish per line with over half of the hook timer activations occurring 4-h post-deployment. Detecting shifts in population characteristics is essential for understanding population dynamics as hatchery inputs and natural perturbations continue to change the population structure. Barring any unforeseen natural catastrophes, the pallid sturgeon population in the lower Missouri River is not in immediate danger of local extirpation; however, the population appears to be a far from viable nor self-sustaining.

ACKNOWLEDGEMENTS

First and foremost, I thank my family, friends, and coworkers that supported me through this educational endeavor. Most importantly, this achievement would not have been possible without the love and support from my wife, Laura, and our two awesome kids, Emma and Ben. You provided endless relief from the mind numbing days associated with preparing my thesis.

This thesis is dedicated to all of you!

Secondly, I am grateful to everyone who has been part of the Nebraska Game and Parks Commission's Missouri River crew the past several years and I'm especially appreciative to the members of the Pallid Sturgeon Population Assessment crew. Specifically, I thank Brandon Eder, Marty Hamel, Jeff Koch, Bill Garvey, Josh Wilhelm, Thad Huenemann, Dane Pauley, Derek Tomes, Adam Kendall, Erik Prenosil, Jim Brannen, Ben Neely, Blake Smith, and Luke Kowalewski. Without your efforts and commitment to our project, this would have been a lot more difficult and time consuming. Also, thanks to the Habitat Assessment and Monitor crew, Schuyler Sampson, Jerrod Hall, and Ken Hatten for their assistances during our Intensive Broodstock Collection efforts and substituting on other crews when needed.

Next, I thank my advisor at the University of Nebraska, Dr. Mark Pegg, and my supervisor at the Nebraska Game and Parks Commission, Gerald Mestl. Both of you provided several great ideas, encouragement, and reviews to improve my thesis. Also, I have a special appreciation toward Gerald for finally persuading me to continue my

fisheries education. I would also like to extend my gratitude to Dr. Kevin Pope and Dr. Richard Holland for serving on my graduate committee. Without your time and constructive review, my thesis would have been a lesser product.

Finally, I thank Tim Welker and George Williams with the US Army Corps of Engineers – Yankton, SD office. Without their commitment to the Missouri River Recovery Program and funding the Pallid Sturgeon Population Assessment Program, this thesis would not have been possible. Also, to Mark Drobish for leading and developing the Pallid Sturgeon Population Assessment during its early years and evolving the program into what it is today.

TABLE OF CONTENTS

CHAPTER 4 – TROTLINE EFFICIENCIES AND CATCH DYNAMICS IN A LARGE RIVER SYSTEM

CHAPTER 5 – CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1:

THESIS INTRODUCTION AND STUDY OBJECTIVES

The Missouri River originates at the confluence of the Jefferson and Madison rivers and is joined by the Gallatin River shortly downstream. The Missouri River flows 3,734 km to its confluence with the Mississippi River and drains approximately 1,371,017 km^2 in the United States and Canada (USFWS 2000; USFWS 2003). The Missouri River is the second longest river in the United States. Historically, the Missouri River was a large, free-flowing, dynamic river system; however, it has been highly modified and regulated over the past 150 years. Approximately 35% of the river has been impounded by mainstem dams, 32% has been channelized for navigation, and 33% remains riverine but is interspersed among reservoirs where temperature, flows, and turbidity have been greatly altered (Keenlyne 1989; Hesse and Mestl 1993; Poff et al. 1997). Dams and water management altered the natural hydrograph and changed the sediment transport system that historically created elements of the dynamic habitat necessary for native fauna and flora survival (Welker and Drobish 2011). Channelization also reduced or eliminated habitat diversity (Mosley 1983) including shallow water habitat and river connections with off-channel areas (Ward and Stanford 1995). Specific to the fishery, these modifications have blocked fish movement, destroyed or altered spawning areas, reduced food sources, altered water temperatures, reduced turbidity, and changed the hydrograph (Dryer and Sandvol 1993; Pegg et al. 2003). These major river modifications have resulted in a decline in native fish stocks including: blue sucker *Cycleptus elongatus*, sturgeon chub *Macrhybopsis gelida*, sicklefin chub *M. meeki*, paddlefish *Polyodon spathula*, lake sturgeon *Acipenser fluvescens*, and pallid sturgeon *Scaphirhynchus albus* (Hesse and Mestl 1993). Today, pallid sturgeon natural recruitment is minimal to nonexistent (Snyder 2000; Hrabik et al. 2007; USFWS 2007) across the lower reach of the Missouri River.

Pallid sturgeon is a benthic fish species endemic to the Yellowstone River, Missouri River, middle and lower Mississippi River basins and has evolved to survive in the riverine conditions associated with these large river systems (Bailey and Cross 1954). These river systems were characterized as having turbid, free-flowing, warm water with diverse habitats that are constantly changing (Dryer and Sandvol 1993). The Missouri River's dynamic changing conditions created multiple macrohabitats (i.e., islands, off-channel backwaters and chutes, and alluvial bars) that are required for all life stages of pallid sturgeon.

Pallid sturgeon were first described as a unique species in 1905 from specimens collected on the Mississippi River (Forbes and Richardson 1905). Most similar to pallid sturgeon are shovelnose sturgeon *Scaphirhynchus platorynchus*, which are the smallest and one of the most abundant sturgeon in the Mississippi and Missouri river basins. Conversely, pallid sturgeon is one of the largest and rarest species (Bettoli et al. 2009). Both species are long-living, highly-migratory, and late-maturing with multiple year intervals between spawning. The frequency of occurrences of pallid sturgeon suggests a probable decline since the species was differentiated from the shovelnose sturgeon (Kallemeyn 1983; Dryer and Sandvol 1993). Subsequent recruitment failures by pallid sturgeon are likely related to extensive modification of river corridors by dam construction, reservoir development, and river channelization. These modifications blocked pallid sturgeon migration corridors, affected their spawning areas, and reduced food availability. Overfishing and pollution also likely contributed to the species' population decline. Pallid sturgeon remained one of the rarest fish in the Missouri and Mississippi river basins throughout the 20th Century. Continued downward population trends into the latter 1900s ultimately resulted in the species being listed as federally endangered (55 FR 36641-36647) on September 6, 1990 (USFWS 1990). Many recovery actions were identified in the species recovery plan to assist in pallid sturgeon population improvement, including: (1) restore habitats and functions of the Missouri and Mississippi river ecosystems, (2) protect pallid sturgeon and their habitat from anthropogenic activities, (3) establish a captive broodstock population, (4) obtain information of population status and trends, (5) develop a pallid sturgeon propagation and stocking program, and (6) reintroduce pallid sturgeon and/or augment existing populations. Although all of these aforementioned recovery actions are critical to species recovery, preventing pallid sturgeon extirpation may depend largely on the success of the artificial propagation program (USFWS 2008). The primary goals of stocking pallid sturgeon in the lower Missouri River (Gavins Point Dam [river kilometer (rkm) 1,305.2] to the confluence of the Missouri and Mississippi rivers [rkm 0.0]) are to (1) establish multiple year-classes capable of recruiting to spawning age to reduce the threat of local extirpation; (2) establish or maintain refugia populations within the species' historic range; (3) mimic haplotype and genotype frequencies of the wild populations in hatchery broodstock and progeny; and (4) prevent the introduction of disease into the wild population (Dryer and Sandvol 1993; Steffensen 2010).

The artificial propagation program was initiated at the Missouri Department of Conservation's Blind Pony State Fish Hatchery in 1992 with broodstock that were captured from the Mississippi River (Krentz et al. 2005; USFWS 2008). These fish were later stocked in the lower Missouri and middle Mississippi rivers in 1994. Spawning of locally collected broodstock occurred again in 1997; however, from 1999 to 2007 the lower Missouri River pallid sturgeon stocking events were based on surplus from Upper Basin (Fort Peck, MT to headwaters of Lake Sakakawea) broodstock. Due to genetic concerns, the Pallid Sturgeon Recovery Team placed a moratorium on stocking Upper Basin origin fish in the lower Missouri River. Therefore, a need for local broodstock became apparent and local intensive broodstock collection efforts began. Since 2008, hatchery-reared pallid sturgeon have been produced from broodfish collected in the lower Missouri River, primarily around the Platte River, NE. Since the propagation program has started, multiple hatcheries have stocked pallid sturgeon at a variety of sizes, year-classes, and locations since 1994 (Krentz et al. 2005; Steffensen et al. 2010; Huenemann 2012).

Steffensen et al. (2010) completed a survival estimate analysis for these hatchery-reared pallid sturgeon and population estimates have also been quantified for a 80.5-rkm reach of the lower Missouri River (Steffensen et al. 2012). However, more work is needed to expand our understanding of population throughout the entire lower Missouri River. Further development and expansion of the information initially described by Steffensen et al. (2010) and Steffensen et al. (2012) that depicts the population characteristics of pallid sturgeon and development of a population viability model for the lower Missouri River will aid in assessing the recovery efforts by being able to model theoretical population management scenarios and evaluate potential changes to the population if aspects of pallid sturgeon life-histories (e.g., shifts in mortality rates, continuation of the stocking program) change. Continued monitoring and assessment of the pallid sturgeon population will likely detect shifts in population characteristics that are essential for understanding population dynamics as hatchery inputs or natural perturbations continue to change the population structure. The monitoring effort will also be valuable for assessing species' recovery efforts to ensure long-term species sustainability and will allow researchers to better quantify the model's input parameters and to validate its predictions.

Study Area

The lower Missouri River is defined as the reach from Gavins Point Dam (rkm 1,305) at Yankton, SD to the confluence of the Missouri and Mississippi rivers (rkm 0.0) at St. Louis, MO and consists of an unchannelized segment (Gavins Point Dam to Ponca, NE [rkm 1,211]) and a channel segment (Ponca, NE to confluence of the Missouri and Mississippi river). The upper-most section (Gavins Point Dam to confluence of the Missouri and Platte river [957.6]) is highly influence by water management from Gavins Point Dam while major tributaries (i.e., Platte River, Kansas River [rkm591.4], Grand River [rkm 402.3], and Osage River [rkm 209.2]) provide a more natural hydrograph downstream. The population viability model (Chapter 3) was created for the entire reach of the lower Missouri River as described above, while the characterization of the pallid sturgeon population (Chapter 2) study area included the upper channelized reach of the lower Missouri River from the Lower Ponca Bend (rkm 1,211.8) to the Nebraska / Kansas state line (rkm 788.4), and the catch dynamics (Chapter 4) study area included an 80.5-rkm reach of the upper channelized Missouri River from the confluence of the Platte and Missouri rivers (rkm 957.6) to Lower Barney Bend (rkm 877.1).

Thesis Objectives

Information and knowledge about pallid sturgeon in the lower Missouri River is limited. An increase in knowledge of population characteristics for wild and hatchery-reared pallid sturgeon populations and how the current Propagation Program's stocking rates are contributing to the pallid sturgeon population in the lower Missouri River will aid in the species recovery efforts. Therefore, the objectives of my study are to:

(1) Determine the population characteristics of the pallid sturgeon population in the lower Missouri River (Chapter 2).
    a. Determine the population demographics (i.e., size, gender ratio, reproductive readiness ratio) of pallid sturgeon by origin (hatchery-reared versus wild).
    b. Determine minimum size of maturity for wild pallid sturgeon and age of maturity for known-aged hatchery-reared pallid sturgeon.

   c. Determine if condition indices vary by reproductive conditions and gender.
   d. Determine fecundity rates for pallid sturgeon successfully spawned at Gavins Point National Fish Hatchery and Blind Pony State Fish Hatchery.
   e. Document the number of progeny that survive the hatchery-rearing process and are stocked into the Missouri River.

(2) Use data from Objective #1, along with existing known population information (i.e., survival estimate and population estimate), to develop a population viability model for the lower Missouri River (Chapter 3).
   a. Estimate the wild pallid sturgeon population size in the lower Missouri River and predict local responses to halting the propagation program.
   b. Estimate the survival and contribution of hatchery-reared pallid sturgeon to the population.
   c. Evaluate the overall population change (λ) under different levels of natural production.
   d. Determine which model input parameters are most sensitive to influence λ.

(3) Examine trot line catch dynamics in a large river system by using information gathered from LP Hook Timers (Chapter 4).

a. Determine activation rate of LP Hook Timers and if size affects activation.
b. Determine retention rate of trot lines and how fish escapement affects CPUE.
c. Document real time catch rates with information gathered from LP Hook Timers.
d. Document if activation rates increase around sunset and/or sunrise due to increase in fish feeding patterns.
e. Determine if hook duration affects the number of mortalities, stress, and distended mouth syndrome.

References

Bailey, R. M., and F. B. Cross. 1954. River sturgeons of the American genus *Scaphirhynchus*: characters, distribution and synonymy. Papers of the Michigan Academy of Science, Arts and Letters 39:169-208.

Bettoli, P. W., M. Casto-Yerty, G. D. Scholten, and E. Heist. 2009. Bycatch of the endangered pallid sturgeon (*Scaphirhynchus albus*) in a commercial fishery for shovelnose sturgeon (*S. platorynchus*). Journal of Applied Ichthyology 25:1-4.

Dryer, M. P., and A. J. Sandvol. 1993. Pallid sturgeon recovery plan. U.S. Fish and Wildlife Service, Bismarck, North Dakota.

Forbes, S.A., and R.E. Richardson. 1905. On a new shovelnose sturgeon from the Mississippi River. Bulletin of the Illinois State Laboratory of Natural History 7:37-44.

Hesse, L.W., and G.E. Mestl. 1993. An alternative hydrograph for the Missouri River based on the precontrol condition. North American Journal of Fisheries Management 13:360-366.

Hrabik, R. A., D. P. Herzog, D. E. Ostendorf, and M. D. Petersen. 2007. Larvae provide first evidence of successful reproduction by pallid sturgeon (*Scaphirhynchus albus*) in the Mississippi River. Journal of Applied Ichthyology 23:436-443.

Huenemann, T. W. 2012. Central lowlands and interior highlands pallid sturgeon spawning and stocking summary. Nebraska Game and Parks Commission, Lincoln, Nebraska.

Kallemeyn, L. 1983. Status of the pallid sturgeon. Fisheries 8:3-9.

Keenlyne, K. D. 1989. A report on the pallid sturgeon. U.S. Fish and Wildlife Service, Pierre, South Dakota. 20pp.

Krentz, S., R. Holm, H. Bollig, J. Dean, M. Rhodes, D. Hendrix, G. Heidrich, B Krise. 2005. Pallid sturgeon spawning and stocking summary report 1992-2004. U.S. Fish and Wildlife Service report, Bismarck, North Dakota.

Mosley, M. P. 1983. Variability of water temperatures in the braided Ashley and Rakaia Rivers. New Zealand Journal of Marine and Freshwater Research 17:331-342.

Pegg, M. A., C. L. Pierce, and A. Roy. 2003. Hydrological alteration along the Missouri River basin: a time series approach. Journal of Aquatic Science 65:63-72.

Poff, L. N., J. D. Allan, M. D. Bain, J. R. Karr, K. L. Prestegaard, B. L. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. BioScience 47:769-784.

Snyder, D. E. 2000. Identification of sturgeon larvae collected from the Missouri River at Lisbon Bottoms, MO, 13 August 1998 and 23 July 1999. Department of Fishery and Wildlife Biology, Larval Fish Laboratory, Colorado State University, Fort Collins, Colorado.

Steffensen, K. D., L. A. Powell, and J. D. Koch. 2010. Assessment of hatchery-reared pallid sturgeon survival in the lower Missouri River. North American Journal of Fisheries Management 30:671-678.

Steffensen, K.D. , L. A. Powell, and M. A. Pegg. 2012. Population size of hatchery-reared and wild pallid sturgeon in the lower Missouri River. North American Journal of Fisheries Management 32:159-166.

U.S. Fish and Wildlife Service. 1990. Endangered and threatened wildlife and plants; determinations of endangered status for the pallid sturgeon. Federal Register 55(173):36641-36647.

U.S. Fish and Wildlife Service. 2000. Biological opinion of the operation of the Missouri River main stem reservoir system, operation and maintenance of the Missouri River banks stabilization and navigation project and operation of the Kansas River reservoir system. U.S. Fish and Wildlife Service, Denver, Colorado.

U.S. Fish and Wildlife Service. 2003. Amendment to the 2000 biological opinion of the operation of the Missouri River main stem reservoir system, operation and maintenance of the Missouri River banks stabilization and navigation project and operation of the Kansas River reservoir system. U.S. Fish and Wildlife Service, Denver, Colorado.

U.S. Fish and Wildlife Service. 2007. Pallid sturgeon (*Scaphirhynchus albus*) 5-year review: summary and evaluation. U.S. Fish and Wildlife Service, Billings, Montana.

U.S. Fish and Wildlife Service. 2008. Pallid sturgeon (*Scaphirhynchus albus*) range-wide stocking and augmentation plan. U.S. Fish and Wildlife Service, Billings, Montana.

Ward, J. V., and J. A. Stanford. 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. Regulated River: Research and Management 11:105-119.

Welker, T. L. and M. R. Drobish (editors). 2011. Pallid sturgeon population assessment project, volume 1.6. U.S. Army Corps of Engineers, Omaha District, Yankton, South Dakota.

CHAPTER 2

Population Characteristics of Pallid Sturgeon in the Lower Missouri River

Abstract

Population characteristics of pallid sturgeon *Scaphirhynchus albus* in the lower Missouri River are relatively unknown. As recovery efforts continue, understanding and quantifying these characteristics are critical for predicting future population trends. Therefore, we synthesized data collected from the Nebraska Game and Parks Commission Pallid Sturgeon Population Assessment Program to (1) document the population structure of pallid sturgeon by origin (hatchery-reared or wild), gender, and reproductive readiness, (2) document the minimum size and age-at-maturity by gender, and (3) document the fecundity rates of the fish that were successfully spawned in the hatchery. During this four year study (2008-2011), relative abundance for wild and hatchery-reared pallid sturgeon collected with gill nets did not significantly change while relative abundance using trot lines significantly declined. The proportion of hatchery-reared pallid sturgeon increased annually with the population primarily being composed of hatchery-reared fish. The proportion of reproductively ready females to non-reproductively ready females was 1:2.0, compared to male ratios at 1:0.9. Minimum length-at-maturity was estimated for females at 788 mm and for male at 798 mm. The minimum age-at-maturity for hatchery-reared released fish was age-9 for females and age-7 for males. The highest relative fecundity, based on the Gonadosomatic Index, was 10% with an overall mean of 7%. The number of eggs / ml (egg size) was not correlated

with fork length (P = 0.0615) or weight (P = 0.0957). Relative condition factor (Kn) for females was significantly different by reproductive condition (P = 0.0014) and Kn for males did not differ between reproductive condition (P = 0.2634). Detecting shifts in population characteristics is essential for understanding population dynamics as hatchery inputs and natural perturbations continue to change the population structure and to assess species recovery efforts to ensure long-term species sustainability.

Introduction

Pallid sturgeon *Scaphirhynchus albus* is a benthic fish species endemic to the Yellowstone River, Missouri River, middle and lower Mississippi River basins that has evolved to survive in the riverine conditions associated with these large river systems (Bailey and Cross 1954; Kallemeyn 1983). Pallid sturgeon was first differentiated from shovelnose sturgeon *Scaphirhynchus platorynchus* in 1905 from specimens collected on the Mississippi River (Forbes and Richardson 1905) and occurs sympatrically with shovelnose sturgeon throughout the Mississippi and Missouri river basins. However, shovelnose sturgeon is one of the most abundant sturgeon species in North American while pallid sturgeon is one of the rarest (Bettoli et al. 2009). The frequency of historic records of pallid sturgeon collections suggests this species has always been relatively rare (Dryer and Sandvol 1993). Few captures of pallid sturgeon in the latter half of the 20th Century eventually led to listing the species as endangered on September 6, 1990 (55 FR 36641-36647; USFWS 1990), yet remains a species that has not been well studied. Initial declines were believed to be correlated with commercial harvest but subsequent recruitment failures are likely related to extensive modification of river corridors by dam construction, reservoir development, and river channelization. Many efforts were identified in the species recovery plan to assist pallid sturgeon populations. However, preventing pallid sturgeon extirpation may depend largely on the success of the artificial propagation component of the recovery program to augment the population (USFWS 2008a) because pallid sturgeon natural recruitment is currently minimal to nonexistent across the lower reach of the Missouri River and the Mississippi River (Snyder 2000; Hrabik et al. 2007; USFWS 2007).

The artificial propagation program was initiated in 1992 at the Missouri Department of Conservation's Blind Pony State Fish Hatchery (USFWS 2008a) and has continued at multiple hatcheries (Krentz et al. 2005; Huenemann 2012). Hatchery-reared pallid sturgeon have been stocked at a variety of sizes, ages, and locations since 1994 (Krentz et al. 2005; Steffensen et al. 2010; Huenemann 2012). Early stocking decisions were based on the number of progeny produced without knowledge of population characteristics. Survival rates of hatchery-reared pallid sturgeon have been quantified for the lower Missouri River (Steffensen et al. 2010). Similarly, estimates of population size have been quantified for an 80.5 river kilometer (rkm) reach of the lower Missouri River (Steffensen et al. 2012) but more work is needed to expand this estimate throughout the entire Missouri River. An accurate assessment of the population characteristics of pallid sturgeon in the lower Missouri River is critical for species recovery. As the number of reproductively ready fish in the system increases, the likelihood of capturing a reproductively ready fish for the propagation program and the probability of successful recruitment through natural spawning will also increase (Paragamian et al. 2005). Furthermore, an understanding of the population status guides the artificial propagation program as stocking rates should depend on population levels in the river relative to targeted recovery goals. Therefore, the objectives of this study are to (1) document the population abundance and structure of pallid sturgeon by origin (hatchery-reared vs. wild), gender, and reproductive readiness, (2) document the minimum size and age of maturity of pallid sturgeon by gender and if condition indices vary by reproductive condition, and (3) document fecundity for female pallid sturgeon that successfully spawned at the hatcheries.

Methods

The study area included the upper channelized reach of the lower Missouri River from the Lower Ponca Bend (rkm 1,211.8) to the Nebraska / Kansas state line (rkm 788.4; Figure 2-1) and is characterized by uniform channel morphology where the outside bends are revetted by limestone rock and the inside bends have a series of dike structures to direct flow toward the thalweg. The Platte River bisects this reach and has a major influence by altering the Missouri River’s hydrograph, water temperature, turbidity, substrate, and sediment load below their confluence (Welker and Drobish 2011a).

Data used for our analyses were acquired from the Nebraska Game and Parks Commission (NGPC) Pallid Sturgeon Population Assessment Program (PSA Program), including data collected during standardized sampling efforts and an annual intensive broodstock collection effort from 2008 to 2011. Annual samples were collected in the fall when water temperatures were below 12.7^{o}C until winter river conditions did not allow safe sampling conditions. Sampling then resumed when ice flow subsided until water temperature exceeded 12.7^{o}C. The intensive broodstock collection effort targeted sexually mature pallid sturgeon and was conducted during early April in an attempt to collect broodstock for the propagation program.

Gill nets and baited trot lines were used, following protocols outlined for the PSA Program (Welker and Drobish 2011a; Welker and Drobish 2011b). Depths and velocities on outside bends prevented sampling in those habitats, so sampling occurred on the inside bend between and around the wing dikes structures. The gill nets were eight panel, 91-m long experimental gill nets with a height of 2.4 m and had 7.6-m panels consisting of 38.1-mm, 50.8-mm, 76.2-mm, and 101.6-mm multifilament bar mesh. Gill nets were fished overnight with a maximum set time of 24 hours and catch per unit effort (CPUE) was calculated as the number of fish per net night.

Trot lines were 61 m long with 40 3/0 circle hooks per line and baited with night crawlers *Lumbricus terrestris*. Hooks were tied to a 38 cm leader and fastened to the main line using trot line snaps. Hooks were spaced every 1.5 m to avoid hook and fish entanglement. All trot lines were deployed parallel to the river's current on the inside bend. Trot lines were deployed in the early afternoon, pulled the following morning, and fished for a maximum of 24 hours (USFWS 2008b). CPUE was calculated as the number of fish per 40 hooks.

Mean annual CPUE data were checked for normality (PROC UNIVARIATE) in SAS 9.2 (SAS Institute, Cary, North Carolina). Data did not follow a normal distribution were log10 transformed; however, normality assumptions were still not met a. Therefore, to compare mean annual CPUE between years, Kruskal-Wallis non-parametric ANOVA statistical analysis were conducted. Significance was determined at $\alpha = 0.05$ for all tests.

All captured pallid sturgeon were examined for passive integrated transponder (PIT) tags, coded wire tags (CWT), elastomer marks, and scute removal to determine the origin of the individual (i.e., naturally produced [wild] or hatchery-reared; USFWS 2008b). If no tags were present, a genetic sample was collected from the caudal fin and analyzed to confirm origin (Schrey et al. 2007; Schrey and Heist 2007; DeHaan et al. 2008). Fish that genetically did not match any known parental crosses were presumed wild origin. Fish were then categorized by origin (wild or hatchery-reared) for this analysis.

All pallid sturgeon collected over 750-mm without tags or marks indicating that were hatchery-reared were transferred to Gavins Point National Fish Hatchery (Yankton, SD) or the Missouri Department of Conservation’s Blind Pony State Fish Hatchery (Sweet Springs, MO) for reproductive assessment. Gender and reproductive readiness was determined using ultrasound and endoscope techniques (Bryan et al. 2007; Divers et al. 2009). Fish were categorized as either reproductive, meaning they were sexually mature and ready to spawn the year collected, or non-reproductive, meaning they would not spawn during the year they were collected. All reproductively ready fish were held in the hatchery until egg polarity indices indicated they were ready to spawn

(USFWS 2005); whereas, non-reproductive fish were returned to the river as quickly as possible.

The ratios of hatchery-reared pallid sturgeon to naturally produced pallid sturgeon, gender distribution of potential broodfish, and reproductively ready to non-reproductively ready pallid sturgeon collected annually were determined using the reproductive assessments provided by USGS staff. Minimum sizes-at-maturity of pallid sturgeon were determined by using the smallest reproductively ready fish from the reproductive assessment conducted at the hatcheries while minimum ages-at-maturity were determined using the youngest hatchery-reared pallid sturgeon that were reproductively ready. Ages were established for hatchery stocked fish by identification marks present (i.e., PIT tags or scute removal) when captured (Steffensen et al. 2008).

Relative condition indices were calculated using the formula:

$$K_n = (W / W'),$$

where W is weight of the individual and W' is the length-specific mean weight predicted by the weight-length equation calculated for that population. Genders were statically compared (ANOVA) by reproductive condition using SAS 9.2. Shuman et al. (2011) provided a length-weight regression for pallid sturgeon throughout its range:

$$\log_{10} W' = -6.2561 + 3.2932 *(\log_{10} L),$$

where L is the fork length of the individual.

Relative fecundity was estimated using the Gonadosomatic Index (GSI), where:

$$\text{GSI} = (\text{Gonad Weight} / \text{Total Body Weight}) \times 100.$$

As females were spawned, the hatchery staff calculated the number of eggs released using volumetric estimation by counting the number of eggs / ml and multiplying by the number of ml's extracted from each female. The hatchery count estimation and the mean number of eggs per gram (100 eggs / gram; James Candrl, USGS pers. comm.) were used to determine the overall gonad weight.

Results

Crews deployed 997 gill nets and 2,280 trot lines from 2008 to 2011. A total of 1,174 pallid sturgeon were caught, 203 were genetically determined to be wild origin, 957 were hatchery-reared origin, and 14 remain unknown because their PIT tag number could not be linked to any stocking records or capture history (Table 2-1). Catch rates of wild pallid sturgeon sampled with gill nets did not change during this study (P = 0.8991) but catch rates with trot lines declined (P = 0.0001; Figure 2-2). The highest CPUE (0.14 fish per 40 hook nights) was observed in 2008 and declined to 0.06 fish per 40 hook nights in 2011. Catch rates of hatchery-reared pallid sturgeon sampled with gill nets (P = 0.2290) and trot lines (P = 0.0610) were variable but did not differ among years.

A total of 178 pallid sturgeon were transferred to Gavins Point National Fish Hatchery or Blind Pony State Fish Hatchery as potential broodstock in the artificial propagation program. Sixty-three (35%) were determined to be females and 21 of these were determined to be reproductively ready (Table 2-2). This resulted in a ratio of 1:2.0 for reproductively ready females to non-reproductive females. By comparison, the ratio for males was 1:0.9 with 61 males being reproductively ready. The overall ratio of reproductively ready pallid sturgeon was 1 female to 2.9 males.

Minimum length-at-maturity was 788 mm for females and for males at 798 mm. Both fish were captured in 2008. Minimum age-at-maturity for known-aged hatchery-reared fish, was age-9 for females and age-7 for males. The female was 950 mm and 3,248 g from the 2001 year class while the male, also from the 2001 year class, was 826 mm and 1,678 g.

Length frequency distributions for hatchery-reared pallid sturgeon sampled by year were similar during the first three years; however, the hatchery-reared pallid sturgeon collected during 2011 (range 290 – 983 mm) were smaller than 2008 ($P < 0.0001$; range 300 – 1,006 mm), 2009 ($P < 0.0001$; range 301 – 1,001 mm), and 2010 ($P < 0.0001$; range 306 – 950 mm; Figure 2-3). The length frequency distribution of wild pallid sturgeon ranged from 404 to 1,095 mm and were similar during the first three years; however, the wild pallid sturgeon collected during 2011 were larger than 2008 ($P = 0.0087$), 2009 ($P = 0.0222$), and 2010 ($P = 0.0041$;Figure 2-3) with the majority (82%) being broodfish sized (> 750 mm).

The 2002 hatchery-reared year class was the most frequently sampled year class during the first three years of sampling (2008, N = 74; 2009, N = 75; 2010, N = 76) followed by the 2001 year class (2008, N = 50; 2009, N = 56; 2010, N = 42; Table 2-3 and Figure 2-4). However, during the 2011 sampling season, the 2009 year class (N = 95) was the most frequently collected while only 35 pallid sturgeon from the 2002 year class and 24 from the 2001 year class were sampled. Age-0 fish were not sampled with gill nets or trotlines and age-1 were collected infrequently.

Of the 21 reproductively ready female pallid sturgeon collected during this study, 12 released eggs at the hatchery, four never released eggs, one was genetically determined to be of hatchery origin, and four were genetically not approved to be used for the artificial propagation program (Table 2-4). Absolute fecundity (total number of eggs released) varied from 12,220 to 54,705 (two fish were verified via surgical telemetry tag implantation as incomplete spawn and are not included in these calculations; A. DeLonay, USGS pers. comm.). The number of eggs / ml (egg size) was not correlated with fork length (P = 0.1987) or weight (P = 0.2848); however, fork length (P = 0.0114) and weight (P = 0.0042) were correlated with the number of eggs released (Figure 2-5). The highest relative fecundity was 10% with a mean of 7% (SD = 1.5%; Table 2-4). The mean survival rate from egg to stock sized fish was 15.1% (SD = 14.7%) but was highly variable ranging from 1.9% to 42.8% (four parental fish were not included in this range as their progeny are still being reared at Neosho National Fish Hatchery).

Relative condition factor for females was significantly different by reproductive condition (P = 0.0014; Figure 2-6). The mean for reproductively ready females was 0.97 (SE = 0.02) compared to 0.90 (SE = 0.01) for non-reproductively ready fish. Conversely, relative condition factor for males was not different between reproductively ready 0.88 (SE = 0.01) and non-reproductive fish 0.86 (SE = 0.0.01).

Discussion

Recovering an endangered species presents substantial challenges because understanding and quantifying the life history characteristics are difficult when the population size is reduced to the point species detection is very difficult. Also, detecting trends in species abundance on rare species needs to be viewed with caution because the collection of a few more or less fish can affect annual catch rates and therefore provide a statistical trend that is not necessarily representative. Catch rates of wild and hatchery-reared pallid sturgeon collected with gill nets did not change while catch rates of trot lines declined during this study. We suspect the decline observed with trot lines may be attributed to the gear's catchability in varying river conditions. The majority of trot lines deployed during 2011 were fished in above average river discharge and temperatures compared to previous years. Conversely, gill nets showed no change in abundance were fished during more similar conditions throughout the study therefore, minimizing the affects from changing river conditions. After taking these factors into consideration, these results suggest a stable population during our study. Continuing to monitor abundance of pallid sturgeon is vital to detect future population changes and to monitor the contribution and survivability of hatchery-reared fish as the propagation program continues stocking in the lower Missouri River.

Over 120,000 pallid sturgeon have been stocked into the lower Missouri River since the propagation program's inception (Huenemann 2012) and the impact of this effort is evident on the pallid sturgeon population structure. Peters and Parham (2008) reported the collection of 15 pallid sturgeon in the lower Platte River from 2001 to 2004 where six fish were known hatchery-reared individuals resulting in an approximate ratio of 1:1 for hatchery-reared to wild fish. This equal origin ratio was observed during the first several years (2003-2005) of sampling under the PSA Program (Steffensen and Mestl 2004; Steffensen and Mestl 2005; Barada and Steffensen 2006; Steffensen and Barada 2006) but has since diverged. Throughout our study (2008-2011), the ratio of wild to hatchery-reared pallid sturgeon increased annually. The population is now primarily hatchery-reared fish. As stocking hatchery-reared pallid sturgeon continues and these fish fully recruit to our gears and in the absence of natural recruitment, this population will likely continue to reflect greater proportions of hatchery-reared individuals. Until such time as there is natural recruitment this population of hatchery-reared pallid sturgeon will aid in understanding life-history and habitat requirements given the current population of wild pallid sturgeon is small. This is predicated on the assumption that hatchery fish behave similar to wild fish. More research is needed, but evidence from related species suggests little or no difference between wild and hatchery produced fish (Pracheil 2010).

Male pallid sturgeon were collected at twice the frequency as females while reproductive males were collected almost three times as frequently as reproductive females. Adult male pallid sturgeon were collected at a rate of one reproductively ready fish for every one non-reproductive fish suggesting that males may be able to spawn every other year in the upper channelized Missouri River. Adult female pallid sturgeon were collected at the rate of one reproductively fish for every two non-reproductive fish. This suggests that females could spawn every third year. A similar spawning periodicity was described for shovelnose sturgeon in the Missouri River in South Dakota (Moos 1978) and suggests the population would need to be 60% female to maintain a balanced (1 to 1) annual spawning ratio between males and females (Koch et al. 2009).

Spawning ratios for most sturgeon species are not known because most were heavily exploited over a century ago or were affected by anthropogenic (i.e., flow and temperature alterations due to river modifications, pollution) modifications (Birstein 1993; Boreman 1997) and are in a global decline (Birstein et al. 1997). Other studies have reported variable gender ratios for the sympatric shovelnose sturgeon. Jackson (2004) reported only 20% of the shovelnose sturgeon collected in the middle Mississippi River were females while Colombo et al. (2007) reported a 1:1 gender ratio. Koch et al. (2009) indicated the gender ratios (> 1.5:1) were skewed toward females in three pools from the Mississippi River; whereas on the open Wabash River, Kennedy et al. (2007) estimated the population to be 36% female. Similar variability has been observed in white sturgeon *Acipenser transmontanus* in the segmented Columbia River. Ward (1998) reported a female to male ratio of 1.6:1 from the Ice Harbor Reservoir reach compared to 1:2.1 ratio from the John Day Reservoir reach. We observed 35% females during this study and have no way of knowing if this a departure from the historic ratio or if this may be contributing to the lack of natural reproduction and recruitment. During this study, genetically confirmed hybrid sturgeon were collected ranging from 100 to 1000 mm, indicating ongoing hybridization (Steffensen and Huenemann 2012a; Steffensen and Huenemann 2012b).

Another major concern associated with pallid sturgeon recovery and perhaps the unbalanced gender ratio is the exploitation by commercial fishing. An increased demand for an additional caviar source, as harvest closed on Eurasian sturgeon stock, may result in increased exploitation of local *Acipenseridae* species. Commercial fishing for sturgeon along the Nebraska border has been closed since 1955 (Zuerlein 1988); however, commercial fishing was open to shovelnose sturgeon harvest in parts of the lower Missouri River through Missouri and the Mississippi River. The USFWS only recently closed commercial harvest of shovelnose sturgeon throughout their sympatric range of pallid sturgeon (55 CFR Part 17 53598-53606; USFWS 2010) thus protecting pallid sturgeon from incidental take. Pallid sturgeon have long migration routes (DeLonay et al. 2010; DeLonay et al. 2012) and can easily travel hundreds of miles through areas that were previously open to commercial fishing making females susceptible to incidental take for their eggs' market value. Bettoli et al. (2009) estimated 169 mature pallid sturgeon were harvested during two seasons in the Tennessee waters of the Mississippi River and suggest this is a conservative estimate. It is unlikely fish from Bettoli's study area would migrate into our study area but commercial fishing remained open in parts of the lower Missouri River until 2010 (USFWS 2010). If similar incidental take did occur on the lower Missouri River, as observed on the Mississippi River, this could be a substantial source of pallid sturgeon mortality and explains the unequal gender proportions observed in our reach as fish move throughout the system. Consistent protective management actions, provided by the similarity of appearance ruling (USFWS 2010), is likely to benefit the recovery of pallid sturgeon throughout their range as harassment and the incidental take is reduced.

Keenlyne and Jenkins (1993) studied reproductive characteristics of 14 pallid sturgeon (five males and nine females) that were incidentally collected by state and federal agencies from 1983 to 1991 in the Mississippi River drainage. They used fin rays to determine age, compared to our study where we used known-aged, hatchery-reared pallid. Several validation studies for aging sturgeon using fin rays have concluded that fin rays are not a reliable method and the results should be viewed with caution (Hurley et al. 2004; Whiteman et al. 2004; Koch et al. 2011). Keenlyne and Jenkins (1993) reported two male pallid sturgeon were in stage four of gonadal development and were age-8 (738-mm) and age-9 (710-mm) but based on annuli spacing they reported males mature at ages 5-7. Egg development was first observed in female pallid sturgeon at 9-12 years old and suggested that first spawning may not occur until age-17 or older. The only reproductively ready female pallid sturgeon available for the Keenlyne et al. (1992) study was a 41 year old specimen from North Dakota that was 1,404 mm. The use of known-aged, hatchery-reared pallid sturgeon in this study provided accurate and reliable ages. The youngest female pallid sturgeon we documented as reproductively ready was age-9 while the youngest male was age-7. Females appear to be maturing earlier in our reach of the Missouri River than that reported by Keenlyne and Jenkins (1993) and males are maturing within their reported range. Wild reproductively ready pallid sturgeon, both females (min FL = 788 mm) and males (min FL = 798 mm), were collected at smaller fork lengths then the known-aged reproductively ready hatchery-reared fish (female min FL = 950 mm; male min FL = 826 mm). These known aged hatchery-reared pallid sturgeon are progeny of parental stock captured from the upper basin (Fort Peck Dam [rkm 2,851] to the headwaters of Lake Sakakawea [rkm 2,524]) in more northern latitudes. The size and age-at-maturity of these hatchery-reared upper Missouri River fish may be genetically predisposed to mature at a later age and larger size than the local wild fish. This difference in size-at-maturity needs to be better understood because of its effects on recovery efforts as additional years would be needed before they potentially could contribute to the population. Therefore, continuing to monitor the age-of-maturity and maximum age for hatchery-reared fish is necessary to improve the understanding of pallid sturgeon life history.

Assuming wild pallid sturgeon exhibit similar growth rates as the hatchery-reared pallid sturgeon stocked into the Missouri River, this suggests that wild origin individuals of both genders may have the ability to become reproductively ready as early as age-7. The observed earlier maturation compared to other published studies of females may be a local adaptation in the lower Missouri River compared to other basins or is potentially a species response to a low population. For example, Zweiacker (1967) reported female shovelnose sturgeon in the Missouri River become sexually mature as small as 414 mm compared to the Mississippi River were females mature around 600 mm (Koch et al. 2009). If a similar trend occurs with pallid sturgeon, this could also account for the earlier age-at-maturity seen during this study.

Keenlyne et al. (1992) reported the mass of mature eggs (fecundity) of a single reproductively ready female pallid sturgeon collected in North Dakota at 11.4%. George et al. (2012) estimated fecundity (GSI) of two reproductive females (827-mm and 886-mm) from the lower Mississippi River at 13.8% and 20.0%. Our fecundity estimates are variable, ranging from 5% to 10%, and much lower than other published rates (Table 2-4). However ovarian mass was not measured, so our estimates are based on a mean of 100 eggs / gram rather than the entire gonads which may explain some of the observed differences. Siberian sturgeon *Acipenser baeri* and Danube sturgeon *Acipenser gueldenstaedti* have shown declines in fecundity, growth, spawning frequency, spawning success, and egg quality following habitat alteration and destruction (Artyukhin et al. 1978; Votinov and Kas'yanov 1978). Major modifications have occurred on the lower Missouri River with impoundment and channelization; therefore, pallid sturgeon in the lower Missouri River may be expressing similar responses. The upper channelized Missouri River's water velocities are swifter with fewer refugia than the Mississippi River. Potentially energy that is expended to survive in the higher velocity riverine conditions associated with the channelized Missouri River may result in less energy being put toward egg development. A similar phenomenon was observed in white sturgeon where fish captured in pooled-reservoir reaches had average fecundities slightly higher than in unimpounded reaches of the lower Columbia River (Beamesderfer et al. 1995).

Wei et al. (2004) reviewed the Chinese Acipenseriformes aquaculture industry (the world's largest sturgeon production) and determined the current sturgeon-rearing techniques results in an egg to "grow-out" (~ 12 months) survival estimate of 25%. Comparatively, within the pallid sturgeon propagation program, survival rates for pallid sturgeon from egg to stock-sized averaged 14.8% (range 1.9% to 42.8%). The best survival rates were observed from the smaller sized (< 860-mm) female pallid sturgeon during this study. This was likely their first spawning cycle based on the length-at-maturity analysis. Although not significant, absolute fecundity did increase with length and weight. Fecundity and egg size increase with body size in most sturgeon species (DeVore et al. 1995; Beamesderfer et al. 2007); however, Gisbert et al. (2000) concluded that egg size has no direct implications for larval survival of Siberian sturgeon. Other factors that contribute to survival of pallid sturgeon during the rearing process (i.e., males milt quality, hatchery water variables, etc.) and a detailed analysis throughout the entire propagation process could aid in identifying any rearing mortality bottlenecks.

Knowing population characteristics is essential for understanding population dynamics and assessing species recovery efforts. There is no single answer to species recovery, especially when dealing with a long-lived species that is highly-migratory and late-maturing; however, the artificial propagation program has greatly increased the number of pallid sturgeon in the system. As these hatchery-reared pallid sturgeon continue to mature, the number of reproductively ready pallid sturgeon will likely increase assuming their behavior is similar to wild fish. Known hatchery-reared pallid sturgeon have been documented to spawn in the lower Missouri River (DeLonay et al. 2012); however, survival and recruitment is yet to be documented and may be the major bottleneck that needs to be overcome to have a successful recovery process. The ultimate recovery goal of a self-sustaining population is still decades away and continued assessment is needed to document and describe population characteristic changes to ensure recovery efforts are moving in the correct direction.

References

Artyukhin, Y. K., A. D. Sukhoparova, and L. G. Fimukhira. 1978. The gonads of sturgeon, *Acipenser guldenstadti*, in the zone below the dam of the Volgrad water engineering system. Journal of Ichthyology 18:912-923.

Bailey, R. M., and F. B. Cross. 1954. River sturgeons of the American genus *Scaphirhynchus*: characters, distribution and synonymy. Papers of the Michigan Academy of Science, Arts and Letters 39:169-208.

Barada, A. J., and K.D. Steffensen. 2006. 2005 Annual Report, Pallid Sturgeon Population Assessment Project and Associated Fish Community Monitoring for the Missouri River: Segment 8. Nebraska Game and Parks Commission, Lincoln, Nebraska.

Beamesderfer, R.C.P., T. A. Rien, and A. A. Nigro. 1995. Difference in the dynamics and potential production of impounded and unimpounded white sturgeon populations in the lower Columbia River. Transactions of the American Fisheries Society 124:857-872.

Beamesderfer, R.C.P., M. L. Simpson, and G. J. Kopp. 2007. Use of life history information in a population model for Sacramento green sturgeon. Environmental Biology of Fishes 79:315-337.

Bettoli, P. W., M. Casto-Yerty, G. D. Scholten, and E. Heist. 2009. Bycatch of the endangered pallid sturgeon (*Scaphirhynchus albus*) in a commercial fishery for shovelnose sturgeon (*S. platorynchus*). Journal of Applied Ichthyology 25:1-4.

Birstein, V. J. 1993. Sturgeon and paddlefishes; threatened fishes in need of conservation. Conservation Biology 7:773-787.

Birstein, V. J., W. E. Bemis, and J. R. Waldman. 1997. The threatened status of acipenseriform species: a summary. Environmental Biology of Fishes 48:427-435.

Boreman, J. 1997. Sensitivity of North American sturgeons and paddlefish to fish mortality. Environmental Biology of Fishes 48:399-405.

Bryan, J. L., M. L. Wildhaber, D. M. Papoulias, A. J. DeLonay, D. E. Tillitt, and M. L. Annis. 2007. Estimation of gonad volume, fecundity, and reproductive state of shovelnose sturgeon using sonography and endoscopy with application of the endangered pallid sturgeon. Journal of Applied Ichthyology 23:411-419.

Colombo, R. E., J. E. Garvey, N. D. Jackson, R. Brooks, D. P. Herzog, R. A. Hrabik, and T. W. Spier. 2007. Harvest of Mississippi River sturgeon drives abundance and reproductive success: a harbinger of collapse? Journal of Applied Ichthyology 23:444-451.

DeHaan, P. W., G. R. Jordan, and W. R. Ardren. 2008. Use of genetic tags to identify captive-bred pallid sturgeon (Scaphirhynchus albus) in the wild: improving abundance estimates for an endangered species. Conservation Genetics 9:691-697.

DeLonay, A. J., R. B. Jacobson, D. M. Papoulias, M. L. Wildhaber, K. A. Chojnacki, E. K. Pherigo, C. L. Bergthold, and G. E. Mestl. 2010. Ecological requirements for pallid sturgeon reproduction and recruitment in the lower Missouri River: annual report 2009. U.S. Geological Survey Open-File Report 2010-1215. 64 p.

DeLonay, A. J., Jacobson, R. B., Papoulias, D. M., Wildhaber M. L., Chojnacki, K. A., Pherigo, E. K., Haas, J. D., and Mestl, G. E. 2012. Ecological requirements for pallid sturgeon reproduction and recruitment in the Lower Missouri River: Annual report 2010. U.S. Geological Survey, Columbia, Missouri.

DeVore, J. D., D. W. James, C. A. Tracy, and D. A. Hale. 1995. Dynamics and potential production of white sturgeon in the unimpounded lower Columbia River. Transaction of the American Fisheries Society 124:845-856.

Divers, S. J., S. S. Boone, J. J. Hoover, K. A. Boysen, K. J. Kilgore, C. E. Murphy, S. G. George, and A. C. Camus. 2009. Field endoscopy for identifying gender, reproductive stage and gonadal anomalies in free-ranging sturgeon (*Scaphirhynchus*) from the lower Mississippi River. Journal of Applied Ichthyology 25:68-74.

Dryer, M. P., and A. J. Sandvol. 1993. Pallid sturgeon recovery plan. U.S. Fish and Wildlife Service, Bismarck, North Dakota.

Forbes, S.A., and R.E. Richardson. 1905. On a new shovelnose sturgeon from the Mississippi River. Bulletin of the Illinois State Laboratory of Natural History 7:37-44.

Gisbert, E., P. Williot, and F. Castello-Orvay. 2000. Influence of egg size on growth and survival of early states of Siberian sturgeon under small scale hatchery conditions. Aquaculture 183:83-94.

George, S. G., W. T. Slack, and J. J. Hoover. 2012. A note on the fecundity of pallid sturgeon. Journal of Applied Ichthyology (p*ublished online*).

Hrabik, R. A., D. P. Herzog, D. E. Ostendorf, and M. D. Petersen. 2007. Larvae provide first evidence of successful reproduction by pallid sturgeon (*Scaphirhynchus albus*) in the Mississippi River. Journal of Applied Ichthyology 23:436-443.

Huenemann, T. W. 2012. Central lowlands and interior highlands pallid sturgeon spawning and stocking summary. Nebraska Game and Parks Commission, Lincoln, Nebraska.

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

Jackson, N. D. 2004. Age, growth, and mortality of shovelnose sturgeon, *Scaphirhynchus platorynchus*, in the middle Mississippi and the lower Wabash rivers, Illinois. Master's thesis. Southern Illinois University, Carbondale.

Kallemeyn, L. 1983. Status of the pallid sturgeon. Fisheries 8:3-9.

Keenlyne, K. D., E. M. Grossman, and L. G. Jenkins. 1992. Fecundity of pallid sturgeon. Transactions of the American Fisheries Society 121:139-140.

Keenlyne, K. D., and L. G. Jenkins. 1993. Age at sexual maturity of the pallid sturgeon. Transactions of the American Fisheries Society 122:393-396.

Kennedy, A. J., D. J. Daugherty, T. M. Sutton, and B. E. Fisher. 2007. Population characteristics of shovelnose sturgeon in the upper Wabash River, Indiana. North American Journal of Fisheries Management 27:52-62.

Koch, J. D., M. C. Quist, C. L. Pierce, K. A. Hansen, and M. J. Steuck. 2009. Effects of commercial harvest of shovelnose sturgeon in the upper Mississippi River. North American Journal of Fisheries Management 29:84-100.

Koch, J. D., K. D. Steffensen, and M. A. Pegg. 2011. Validation of age estimates obtained from juvenile pallid sturgeon *Scaphirhynchus albus* pectoral fin spines. Journal of Applied Ichthyology 27:209-212.

Krentz, S., R. Holm, H. Bollig, J. Dean, M. Rhodes, D. Hendrix, G. Heidrich, B Krise. 2005. Pallid sturgeon spawning and stocking summary report 1992-2004. U.S. Fish and Wildlife Service report, Bismarck, North Dakota.

Moos, R. E. 1978. Movement and reproduction of shovelnose sturgeon, *Scaphirhynchus platorynchus*, in the Missouri River, South Dakota. Doctoral dissertation. University of South Dakota, Vermillion.

Paragamian. V. L., R. C. P. Beanesderfer, and S. C. Ireland. 2005. Status, population dynamics, and future prospects of the endangered Kottenai River white sturgeon population with and without hatchery intervention. Transactions of the American Fisheries Society 134:518-532.

Peters, E. J., and J. E. Parham. 2008. Ecology and management of the sturgeon in the lower Platte River, Nebraska. Nebraska Technical Series Number 18. Nebraska Game and Parks Commission, Lincoln, Nebraska.

Pracheil, B. M. 2010. Multi-scale perspectives on paddlefish populations: implications for species conservation and management. Doctoral dissertation. University of Nebraska, Lincoln, Nebraska.

Schrey, A. W., B. L. Sloss, R. J. Sheehan, and E. J. Heist. 2007. Genetic Discrimination of Middle Mississippi River *Scaphirhynchus* Sturgeon into Pallid, Shovelnose, and Intermediate Classes with Multiple Microsatellite Loci. Conservation Genetics 8:683-693.

Schrey, A. W. and E. J. Heist. 2007. Stock Structure of Pallid Sturgeon Analyzed with Microsatellite Loci. Journal of Applied Ichthyology 23:297-303.

Shuman, D. A., R. A. Klumb, R. H. Wilson, M. E. Jaeger, T. Haddix, W. M. Gardner, W. J. Doyle, P. T. Horner, M. Ruggles, K. D. Steffensen, S. Stukel, and G. A. Wanner. 2011. Pallid sturgeon size structure, condition, and growth in the Missouri River basin. Journal of Applied Ichthyology 27:269-281.

Snyder, D. E. 2000. Identification of sturgeon larvae collected from the Missouri River at Lisbon Bottoms, MO, 13 August 1998 and 23 July 1999. Department of Fishery and Wildlife Biology, Larval Fish Laboratory, Colorado State University, Fort Collins, Colorado.

Steffensen, K. D. and G. E. Mestl. 2004. 2003 Annual Report, Pallid Sturgeon Population Assessment Project and Associated Fish Community Monitoring for the Missouri River: Segment 9. Nebraska Game and Parks Commission, Lincoln, Nebraska.

Steffensen, K. D. and G. E. Mestl. 2005. 2004 Annual Report, Pallid Sturgeon Population Assessment Project and Associated Fish Community Monitoring for the Missouri River: Segment 9. Nebraska Game and Parks Commission, Lincoln, Nebraska.

Steffensen, K. D. and A. J. Barada. 2006. 2005 Annual Report, Pallid Sturgeon Population Assessment Project and Associated Fish Community Monitoring for the Missouri River: Segment 9. Nebraska Game and Parks Commission, Lincoln, Nebraska.

Steffensen, K. D., R. A. Klumb, and W. J. Doyle. 2008. Protocols for tagging and marking hatchery reared pallid sturgeon in Recovery Priority Management Area #4. Nebraska Game and Parks Commission, Lincoln, Nebraska.

Steffensen, K. D., L. A. Powell, and J. D. Koch. 2010. Assessment of hatchery-reared pallid sturgeon survival in the lower Missouri River. North American Journal of Fisheries Management 30:671-678.

Steffensen, K.D., L. A. Powell, and M. A. Pegg. 2012. Population size of hatchery-reared and wild pallid sturgeon in the lower Missouri River. North American Journal of Fisheries Management 32:159-166.

Steffensen, K. D. and T. W. Huenemann. 2012a. 2011 Annual Report, Pallid Sturgeon Population Assessment Project and Associated Fish Community Monitoring for the Missouri River: Segment 8. Nebraska Game and Parks Commission, Lincoln, Nebraska.

Steffensen, K. D. and T. W. Huenemann. 2012b. 2011 Annual Report, Pallid Sturgeon Population Assessment Project and Associated Fish Community Monitoring for the Missouri River: Segment 9. Nebraska Game and Parks Commission, Lincoln, Nebraska.

U.S. Fish and Wildlife Service. 1990. Endangered and threatened wildlife and plants; determinations of endangered status for the pallid sturgeon. Federal Register 55(173):36641-36647.

U.S. Fish and Wildlife Service. 2005. Upper basin pallid sturgeon propagation plan. U.S. Fish and Wildlife Service, Billings, Montana.

U.S. Fish and Wildlife Service. 2007. Pallid sturgeon (*Scaphirhynchus albus*) 5-year review: summary and evaluation. U.S. Fish and Wildlife Service, Billings, Montana.

U.S. Fish and Wildlife Service. 2008a. Pallid sturgeon (*Scaphirhynchus albus*) range-wide stocking and augmentation plan. U.S. Fish and Wildlife Service, Billings, Montana.

U.S. Fish and Wildlife Service. 2008b. Biological procedures and protocols for researchers and managers handling pallid sturgeon. U.S. Fish and Wildlife Service, Billings, Montana.

U.S. Fish and Wildlife Service. 2010. Endangered and threatened wildlife and plants; threatened status for shovelnose sturgeon under the similarity of appearance provisions of the endangered species act. Federal Register 75(169):5359853606.

Votinov, N. P., and V. P. Kas'yanov. 1978. The ecology and reproductive efficiency of the Siberian sturgeon, *Acipenser baeri* in the Ob as affected by hydraulic engineering works. Journal of Ichthyology 18:20-29.

Ward, D. L. 1998. Effects of mitigative measures of productivity of white sturgeon populations in the Columbia River downstream of McNary Dam. Oregon Department of Fish and Wildlife, Portland, Oregon.

Wei, Q., J. He, D. Yang, W. Zheng, and L. Li. 2004. Status of sturgeon aquaculture and sturgeon trade in China: a review based on two recent nationwide surveys. Journal of Applied Ichthyology 20:321-332.

Welker, T. L. and M. R. Drobish (editor). 2011a. Pallid sturgeon population assessment project, volume 1.3. U.S. Army Corps of Engineers, Omaha District, Yankton, South Dakota.

Welker, T. L. and M. R. Drobish (editors). 2011b. Missouri River standard operating procedures for fish sampling and data collection, volume 1.5. U.S. Army Corps of Engineers, Omaha District, Yankton, South Dakota.

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

Zuerlein, G. 1988. Nebraska commercial fishing statistics; the Missouri River. Nebraska Game and Parks Commission, Lincoln, NE. 100p.

Zweiacker, P. L. 1967. Aspects of the life history of the shovelnose sturgeon *Scaphirhynchus platorynchus* in the Missouri River. Master’s thesis. University of South Dakota, Vermillion.

Table 2-1. Number of hatchery-reared, wild and unknown origin pallid sturgeon collected in the upper channelized reach of the lower Missouri River from Lower Ponca Bend (rkm 1,211.8) to the Nebraska / Kansas state line (rkm 788.4) from 2008 to 2011, including the ratio of wild to hatchery-reared fish. Genetic records for parental stocks are incomplete; therefore, fish are classified as "potentially wild." Pallid sturgeon of unknown origin did not have a genetic sample taken when captured and their stocking or capture history could not be determined by their passive integrated transponder (PIT) tag number.

Year	Pallid sturgeon origin			Annual total	Wild : Hatchery ratio
	Hatchery-reared	Wild	Unknown		
2008	188	54	5	247	1 : 3.5
2009	236	54	5	295	1 : 4.4
2010	241	46	3	290	1 : 5.2
2011	292	49	1	342	1 : 5.9
Totals	957	203	14	1,174	1 : 4.7

Table 2-2. Number of potential broodstock pallid sturgeon transferred to Gavins Point National Fish Hatchery or Blind Pony State Fish Hatchery from the upper channelized reach of the lower Missouri River from Lower Ponca Bend (rkm 1,211.8) to the Nebraska / Kansas state line (rkm 788.4) from 2008 to 2011 for reproduction assessment and the ratios of reproductive or non-reproductive fish by gender.

Year	Pallid sturgeon by gender								Repro ratio Female : Male
	Female				Male				
	Repro	Non-repro	Total	Repro ratio	Repro	Non-repro	Total	Repro ratio	
2008	3	3	6	1 : 1.0	22	6	28	1 : 0.3	1 : 7.3
2009	4	8	12	1 : 2.0	13	19	32	1 : 1.5	1 : 3.3
2010	6	11	17	1 : 1.8	11	14	25	1 : 1.3	1 : 1.8
2011	8	20	28	1 : 2.5	15	15	30	1 : 1.0	1 : 1.9
Totals	21	42	63	1 : 2.0	61	54	115	1 : 0.9	1 : 2.9

Table 2-3. Number of hatchery-reared pallid sturgeon stocked in the lower Missouri River from the Gavins Point Dam (rkm 1,305.2) to the confluence of the Missouri and Mississippi rivers (rkm 0.0) from 1992 to 2011 and the number recaptured by year class. Number stocked does not account for the estimated survival rates associated with age-at-stocking and year class was not determined on all recaptured fish. Stocked numbers reported are from Huenemann (2012).

Year Class	Number stocked	Number recaptured			
		2008	2009	2010	2011
1992	4,182	0	0	0	0
1997	2,851	3	1	0	0
1999	532	3	1	2	2
2001	7,453	50	56	42	24
2002	9,241	74	75	76	35
2003	10,129	22	22	15	10
2004	39,255	17	14	15	14
2005	3,654	11	25	27	23
2006	3,642	2	11	16	18
2007	4,515	0	18	12	27
2008	6,963	-----	0	13	21
2009	14,593	-----	-----	1	95
2010	6,812	-----	-----	-----	2
2011	5,289	-----	-----	-----	-----

Table 2-4. Number of eggs released and relative fecundity estimates for the 12 reproductively ready female pallid sturgeon captured in the upper channelized reach of the lower Missouri River from Lower Ponca Bend (rkm 1,211.8) to the Nebraska / Kansas state line (rkm 788.4) from 2008 to 2011 that were successfully spawned at Gavins Point National Fish Hatchery or Blind Pony State Fish Hatchery. Number of progeny stocked for each female contributed and survival rate from egg to stock size are also included. Numbers of progeny stocked was provided from Huenemann (2012). The superscripted "1" denotes a complete spawn (verified via telemetry tag implantation; A. DeLonay, per. comm.) while the superscripted "2" denotes an incomplete spawn. The asterisk denotes not all progeny have been stock from the individual female, therefore survival rates were not calculated.

Year	PIT Tag	Fork length	Weight	Number of eggs / ml	Absolute fecundity	Relative fecundity	Number of progeny	Survival rate
2008	470C467335 [1]	788	2,074	49	15,484	8%	4,466	28.8%
2009	434D30680D	816	2,084	46.3	18,289	9%	7,835	42.8%
2009	4704265B0C	1,067	4,778	42	26,752	6%	1,827	6.8%
2009	412C20001A	1,075	5,450	40	50,495	10%	3,647	6.7%
2010	434C38070F [1]	829	2,014	40	12,220	6%	431	3.5%
2010	486866124D [1]	860	2,480	39	19,600	8%	4,368	22.3%
2010	412C240973 [2]	1,034	4,456	37	20,400	5%	1,452	7.1%
2010	48665E2D76 [1]	1,060	5,334	31	28,950	5%	561	1.9%
2011	4868364835	864	2,714	33	24,155	9%	2,264 *	
2011	4626553E42	948	3,530	37	18,885	5%	3,165 *	
2011	4627111945	966	3,376	29	22,575	7%	2,177 *	
2011	412C275E0A [2]	1,079	5,136	22	885	2%	0 *	

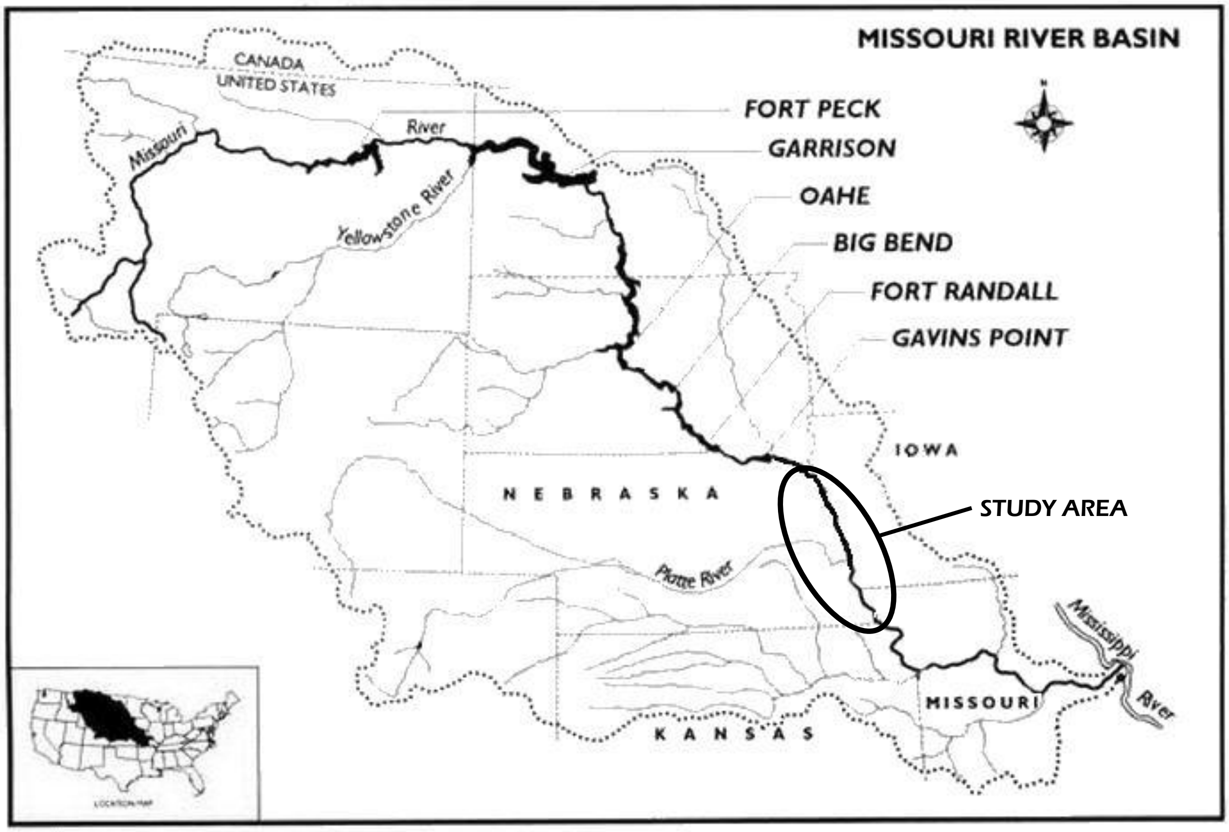

Figure 2-1. Map of the Missouri River basin with the 423 river kilometer (rkm) study reach of the lower Missouri River indicated in the oval.

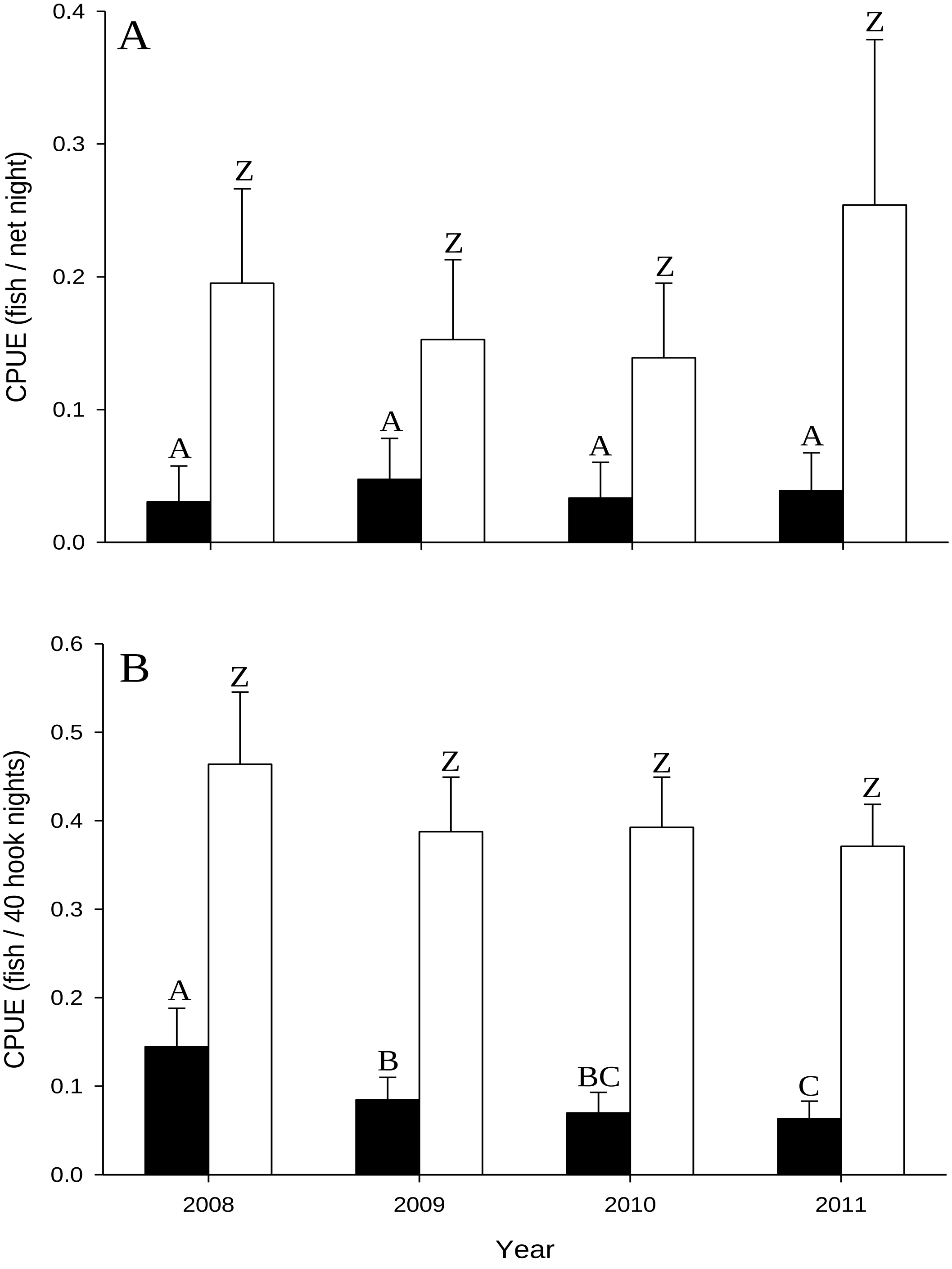

Figure 2-2. Catch per unit effort (CPUE; +/- 2 SE) for (A) gill nets and (B) trot lines by origin during 2008 to 2011 from Lower Ponca Bend (rkm 1,211.8) to the Nebraska / Kansas state line (rkm 788.4). Black bars represent wild fish while white bars are hatchery-reared fish. Letters denote significant differences (α = 0.05) in mean CPUE between years for each gear.

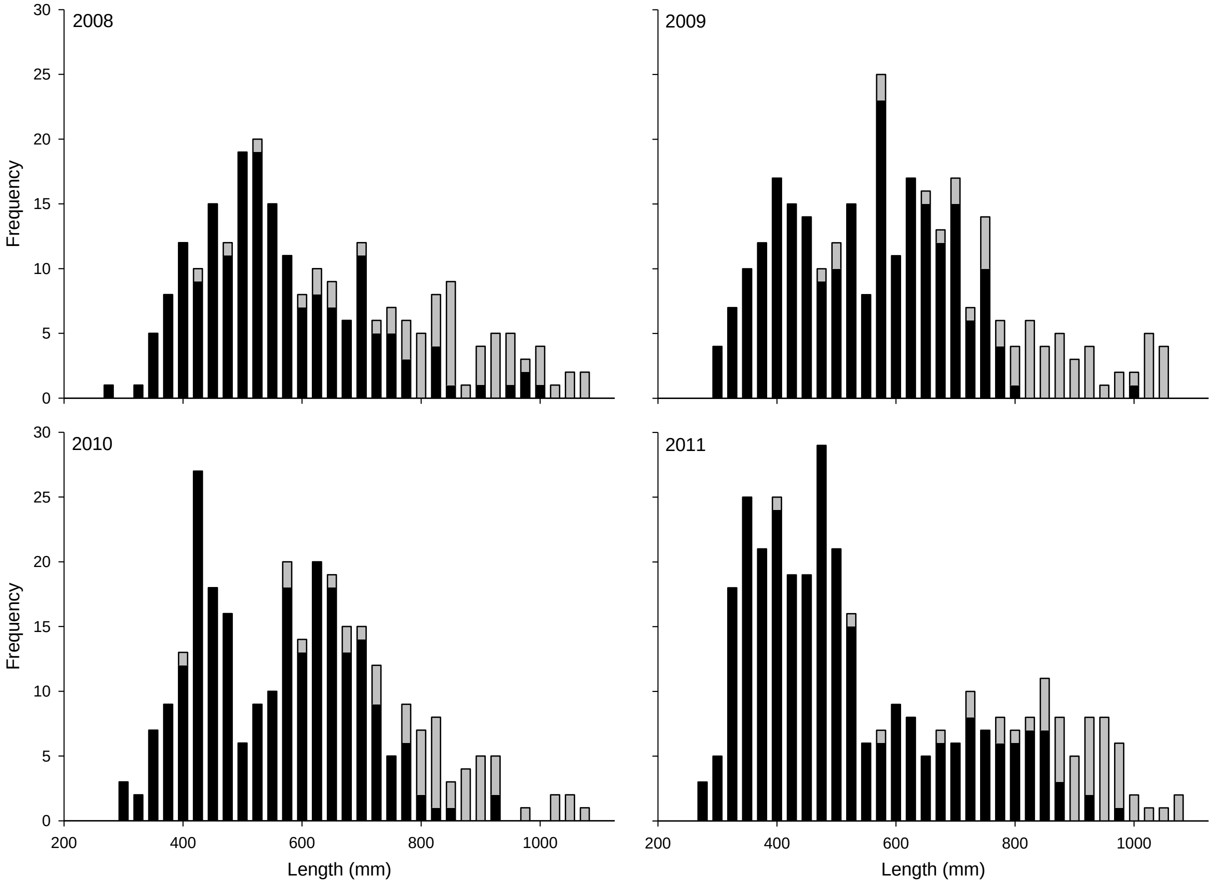

Figure 2-3. Length-frequency distribution of hatchery-reared pallid sturgeon (black bars) and wild pallid sturgeon (grey bars) collected in the upper channelized reach of the lower Missouri River from Lower Ponca Bend (rkm 1,211.8) to the Nebraska / Kansas state line (rkm 788.4) from 2008 to 2011 by year.

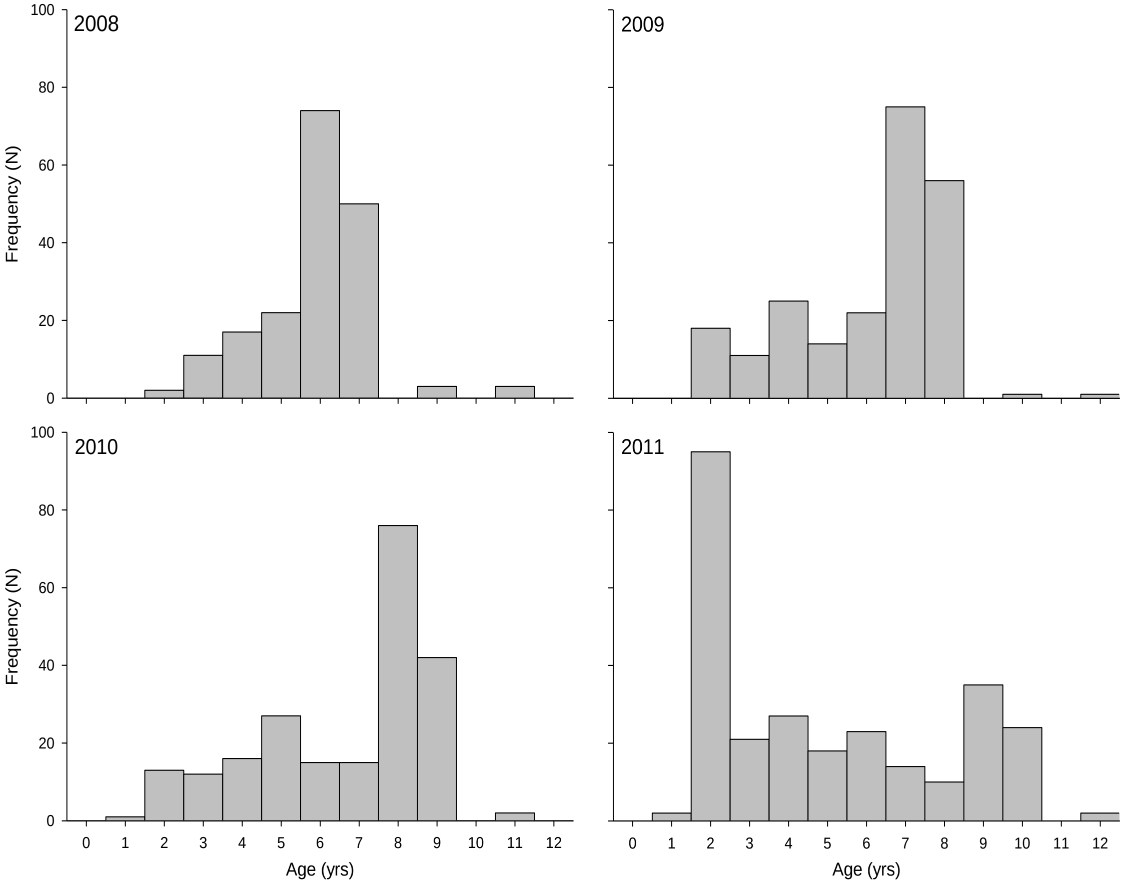

Figure 2-4. Age distribution of hatchery-reared pallid sturgeon collected in the upper channelized reach of the lower Missouri River from Lower Ponca Bend (rkm 1,211.8) to the Nebraska / Kansas state line (rkm 788.4) from 2008 to 2011 by year.

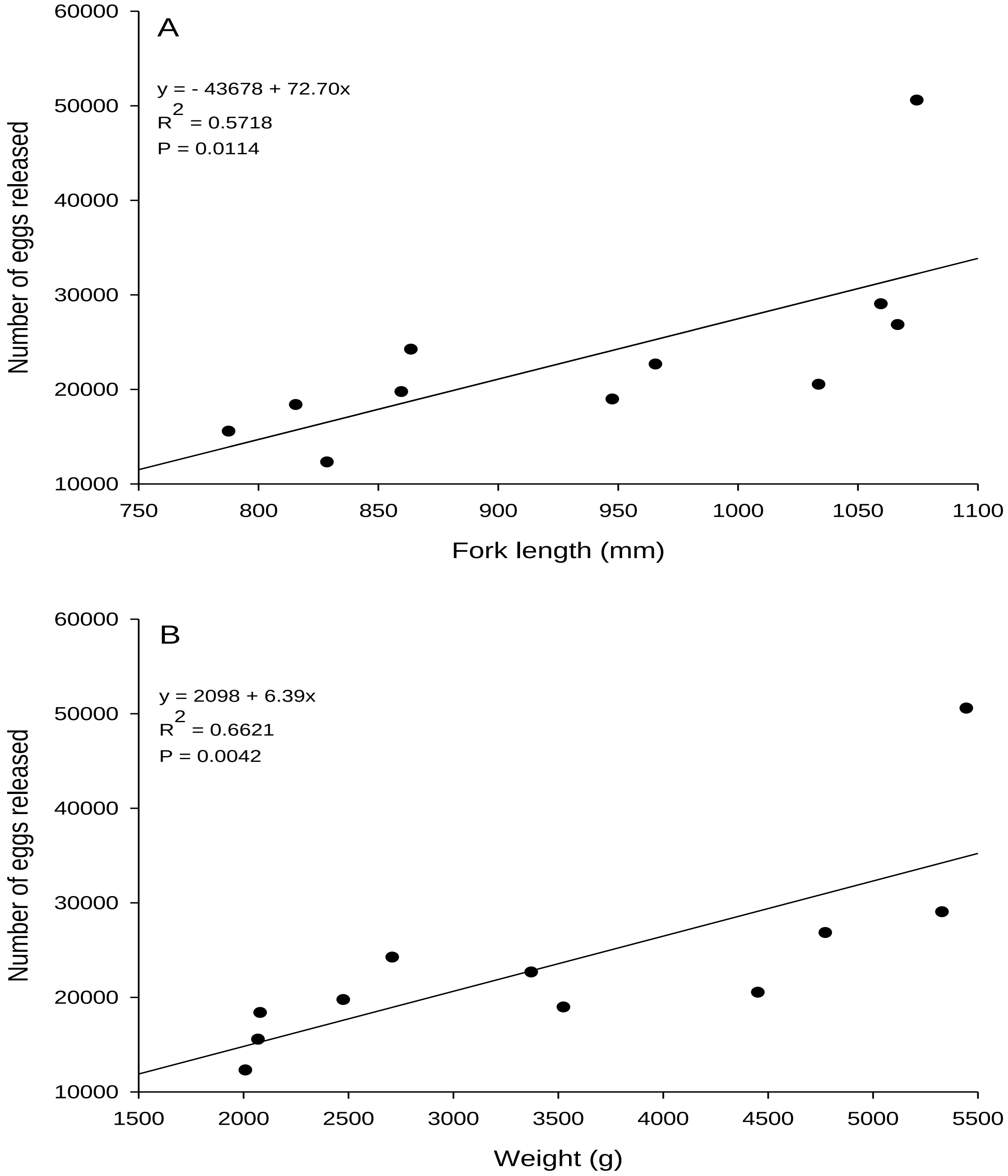

Figure 2-5. Number of eggs released by (A) length and (B) weight for the 11 reproductively ready female pallid sturgeon that were collected in the upper channelized reach of the lower Missouri River from Lower Ponca Bend (rkm 1,211.8) to the Nebraska / Kansas state line (rkm 788.4) from 2008 to 2011 and were successfully spawned at Gavins Point National Fish Hatchery or Blind Pony State Fish Hatchery.

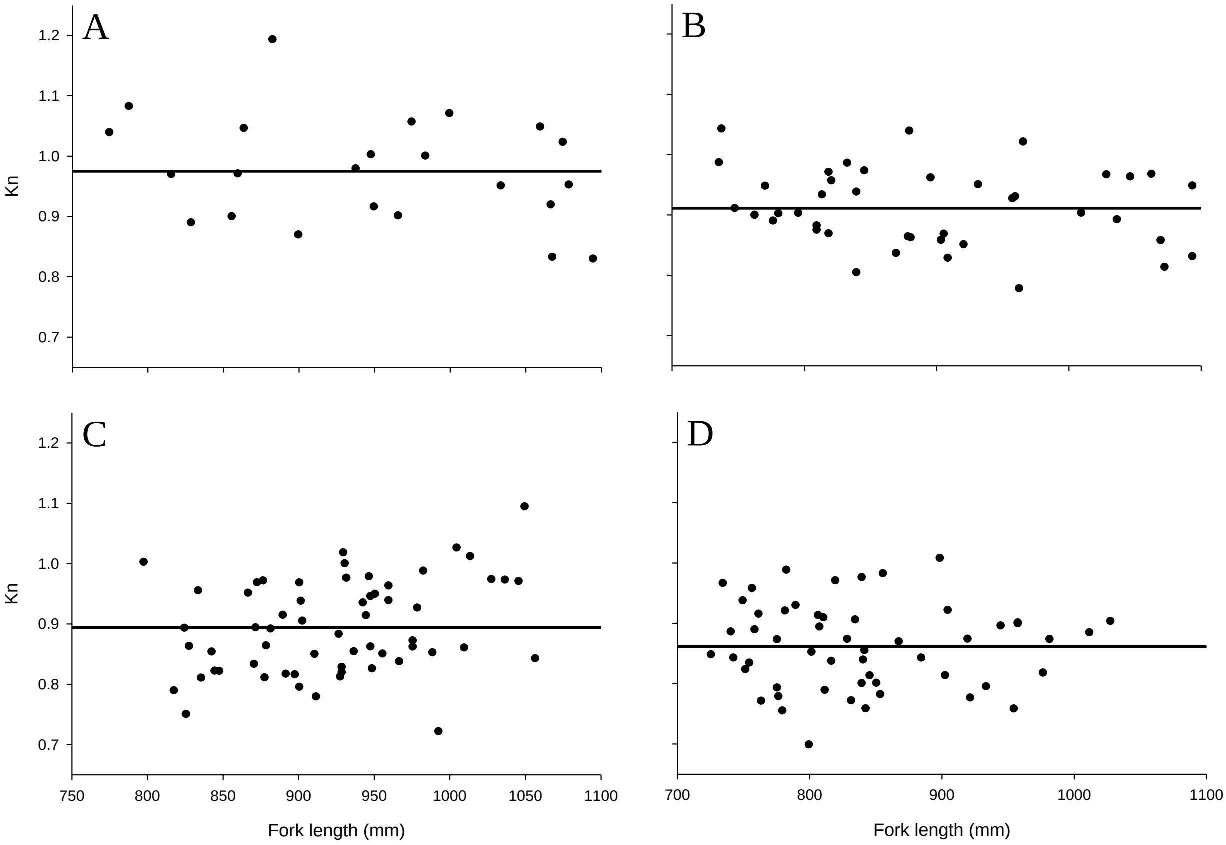

Figure 2-6. Relative condition factor (Kn) for (A) reproductively ready female, (B) non-reproductively ready female, (C) reproductively ready male, and (D) non-reproductively ready male pallid sturgeon collected in the upper channelized reach of the lower Missouri River from the Lower Ponca Bend (rkm 1,211.8) to the Nebraska / Kansas state line (rkm 788.4) from 2008 to 2011 by reproductive condition. The horizontal line represents the mean Kn.

CHAPTER 3

Population Prediction and Viability Model for Pallid Sturgeon in the Lower Missouri River

Abstract

The long-term population trends of pallid sturgeon *Scaphirhynchus albus* in the lower Missouri River were evaluated via a population viability model. The model incorporated published and unpublished studies throughout the range to predict how past and future management actions affect population trends and ultimately recovery. The intent of this model was to provide managers with an easy, straight forward (Microsoft Excel based) method to estimate and predict population trends for wild and hatchery-reared pallid sturgeon in the lower Missouri River. The model's input parameters can easily be changed to investigate and understand recruitment and recovery bottlenecks and determine the most sensitive input parameter(s). The model was most sensitive to survival rates for fish ≥ age-1 and less sensitive to age-0 survival rates and fecundity. Decreasing or increasing female spawning frequency by one year had minimal effect on the overall population trajectory. Recovering a species, such as pallid sturgeon, that is slow-growing, late-maturing, and does not reach reproductive readiness annually requires several years to quantify recovery and management decisions. Barring any unforeseen natural catastrophe, the pallid sturgeon population in the lower Missouri River is not in immediate danger of local extirpation; however, the population appears to be far from viable and self-sustaining. Therefore, continuation of

the artificial propagation and stocking program appears to be essential until successful natural production and recruitment is documented. Continued monitoring and assessment of the pallid sturgeon population will allow researchers to better quantify critical input parameters for this model and validate the model predictions to assist managers with recovery decisions.

Introduction

Pallid sturgeon *Scaphirhynchus albus* is a native, benthic fish species adapted to what were historically large, turbid, free-flowing systems of the Mississippi and Missouri rivers (Forbes and Richardson 1905; Bailey and Cross 1954; Kallemeyn 1983). Pallid sturgeon have always been rare but declining populations led to the fish being listed as federally endangered in 1990 (55 FR 36641-36647, USFWS 1990; Dryer and Sandvol 1993). Declines have been attributed to the loss and modification of pallid sturgeon habitat by human activities. These activities have blocked fish movement, destroyed or altered spawning areas, reduced food sources or their ability to obtain food, altered water temperatures, reduced turbidity, and changed the hydrograph (Keenlyne and Evenson 1989; Dryer and Sandvol 1993; Pegg et al. 2003) which caused an apparent lack of reproduction and recruitment (Snyder 2000; Hrabik et al. 2007; USFWS 2007).

The short-term recovery objectives for pallid sturgeon are to establish a captive broodstock program, implement suitable habitat restoration actions, and develop an artificial propagation program while providing protection for the remaining wild individuals from harm, harassment, or death (Dryer and Sandvol 1993). Artificial propagation and subsequent population augmentation (i.e., stocking) may be the only viable option to maintain pallid sturgeon populations in the lower Missouri River in the near term as recruitment appears nonexistent. Targeted collection efforts for sexually-mature wild pallid sturgeon began shortly after listing and the first successful propagation effort occurred at the Missouri Department of Conservation's Blind Pony State Fish Hatchery in 1992 and has continued at several state and federal hatcheries (Krentz et al. 2005, Huenemann 2012). The primary goals of stocking pallid sturgeon in the lower Missouri River are: (1) establish multiple year-classes capable of recruiting to spawning age to reduce the threat of local extirpation; (2) establish or maintain refugia populations within the species' historic range; (3) mimic the wild populations' haplotype and genotype frequencies in hatchery broodstock and progeny; and (4) prevent the introduction of disease into the wild population.

Since the inception of the stocking program, stocking rates of pallid sturgeon were primarily based on the number of reproductive adults collected by field crews. Their progeny were stocked without quantifying the stocking effects on the overall pallid sturgeon population. Although researchers are starting to learn more about the local population structure and population trends, the overall contribution of the stocking program (i.e., number of hatchery-reared pallid sturgeon expected to reach maturity) has not been quantified. Therefore, increased understanding of the effects of the stocking program on the population is a critical element to species recovery.

The goal of this study is to use the data from published and unpublished studies throughout the range of pallid sturgeon to develop a population viability analysis (PVA) model for the lower Missouri River. Population viability analysis models use mathematical iterations on given population dynamics parameters to simulate the sustainability of the population (Gao et al. 2009) and to identify which input parameters are most sensitive to change (Bajer and Wildhaber 2007). We developed a demographically (pallid sturgeon origin [i.e., naturally produced versus hatchery-reared]) structured, age-based (year-class for hatchery-reared fish) model to predict change in the pallid sturgeon population (λ). More specifically the objectives were to (1) estimate wild pallid sturgeon population size and predict local extirpation if natural recruitment remains low to nonexistent, (2) estimate the survival and contribution of hatchery-reared pallid sturgeon to the population, (3) evaluate the overall population change (λ) under different survival rates for natural production, and (4) determine which of the model parameters are most sensitive in terms of change in λ.

Methods

Model parameterization

The PVA model was created in Microsoft Excel and allows input parameters to be adjusted to examine different life history and management scenarios. Input parameters included in the model were gender ratio, maximum age, reproductive cycle (number of years between spawning events once mature), age-at-maturity, fecundity, and age specific survival rates. The model was constructed to allow different maximum age, reproductive cycles, and age-at-maturity by gender. A conceptual outline of the model illustrates how the model's parameters interact (Figure 3-1). Stochastic values for the input parameters were generated around a normal distribution of the mean estimate and standard deviation to allow for natural variation within the model. The model matrices were run through 1,000 iterations to account for natural variability.

Model sensitivity

We evaluated sensitivity of the model input parameters to determine the parameter's influence on λ. The tested parameter was changed by ± 5% (i.e., survival rates, fecundity) or by ± year(s) (i.e., spawning frequency, age-at-maturity) while all other life history parameters were fixed at their initial input values. We evaluated the individual age classes (i.e., age-1, age-2, age-3) survival rate sensitivity independently then we evaluated the model's sensitivity by life stage (i.e., sub-adult and adult). The model's sensitivity was calculated by comparing the change in λ to the initial population estimate. Only 5% increase to the model parameters are presented and discussed as a 5% decrease produced identical but negative values. The population size input parameters were also kept constant during the sensitivity analysis to avoid the effect of change in population distributions when assessing other life history parameters; therefore, variability around the estimate is not available.

Study area

Our study area was the lower Missouri River from Gavins Point Dam at Yankton, South Dakota (river kilometer [rkm] 1305.2) to the confluence with the Mississippi River at St. Louis, Missouri (rkm 0.0; Figure 3-2). Gavins Point Dam is a barrier to upriver migration; however, fish can readily pass between the Missouri and Mississippi rivers.

The probability emigration has not been analyzed, but some inter-basin movements have been documented. Immigration and emigration is accounted for in the robust design that Steffensen et al. (2012) used to estimate the population size of pallid sturgeon. Therefore, the wild population extrapolation method would include any movement probabilities while hatchery-reared fish movement has not been quantified. Therefore, we assumed the hatchery-reared population was closed in the lower Missouri River for this analysis.

Pallid sturgeon parameters.

Initial model input parameters were derived from Chapter 2 and other published data (Table 3-1). The starting date of the model was set at 1992 when pallid sturgeon propagation efforts started in the lower Missouri River and continued to 2050. Steffensen et al. (*submitted*) described the gender ratio, reproductive cycle, age-at-maturity, and fecundity estimates observed during annual intensive broodstock collection efforts from 2008-2011 for an 80.5 rkm reach of the lower Missouri River. Maximum age was set at 41 years (Keenlyne et al. 1992; Bajer and Wildhaber 2007). Steffensen et al. (2010) estimated survival rates for hatchery-reared pallid sturgeon based on stocking age for the lower Missouri River. Survival estimates for hatchery-reared pallid sturgeon increased from 0.051 for age-0 fish to 0.686 for age-1 to 0.922 for fish greater than age-1. Natural production was divided into four categories to allow better understanding of pallid sturgeon recruitment bottlenecks and transition probabilities, as conceptualized in Wildhaber et al. (2007): (1) gametes to developing embryos, (2) developing embryos to free embryos, (3) free embryos to exogenous feeding larva and (4) exogenous feeding larva to age-1. However, the lack of available information required that we use combined survival estimates from egg to age-1 of 0.00000, 0.00001, 0.00005, and 0.00010 to predict the annual number of naturally produced pallid sturgeon and the overall affects to the entire population. Egg to age-1 survival estimates were chosen *post-hoc* to account for zero chance of survival, a minimal chance of survival ($\text{Ø} = 0.00001$ and 0.00005), and to create a sustainable population ($\text{Ø} = 0.00010$). Hatchery-reared pallid sturgeon stocking information was obtained from Huenemann (2012). Steffensen et al. (2012) determined the population estimates for wild pallid sturgeon varied from 2.8 to 4.8 fish per rkm and from 22.5 to 25.6 fish per rkm for hatchery-reared pallid sturgeon in an 80.5 rkm reach of the lower Missouri River. Therefore, we used the estimated number of wild fish in the 2010 super population ($N = 459$) for this reach to extrapolate across the entire reach of the lower Missouri River. This method assumed similar distributions of pallid sturgeon across the entire lower river. The population was then back-calculated to 1992 and then projected through 2050 assuming an annual survival rate of 0.922 (Steffensen et al. 2010). We assumed all wild pallid sturgeon were mature because successful reproduction and recruitment has not been documented in the lower Missouri River. To estimate the population size of hatchery-reared pallid sturgeon, the stocking history was categorized by year-class and age-at-stocking then processed though a survival matrix and iterated 1,000 times to estimate an annual population mean and variance.

Pallid sturgeon population sensitivity

Life history input parameters (i.e., survival rates, fecundity, spawning frequency, age-at-maturity) were fixed while the wild pallid sturgeon population was modeled under ±5% error scenario. Finally, the effect of continuing the hatchery-reared supplemental project was evaluated by modeling the change to λ by stocking 10,000 age-1 fish annually. Changes in λ were recorded to assess the change in estimated population size predicted from the base model estimates.

Results

Initial model estimates

Our model estimates the wild, adult population size of pallid sturgeon at 5,991 (± 515) in 2012 (Figure 3-3). We predict the wild pallid sturgeon population size will decline to 2,659 (± 269) individuals in ten years, 1,181 (± 140) in twenty years, and 524 (± 73) in thirty years. However, a 5% increase in the survival estimate altered the 2012 projected population to 6,647 (± 545) and the 30 year estimate to 1,320 (± 182). Conversely, a 5% decrease reduced the 2012 predicted population to 5,645 (± 486) and the 30 year estimate to 202 (± 29) remaining fish.

Influence of stocking

Over the past two decades, 134,864 hatchery reared pallid sturgeon have been stocked in the lower Missouri River representing 14 year classes (Table 3-2). The majority have been stocked at age-0 (46.0%) and age-1 (49.7%) but some advanced age

(≥ age-2; N = 5,858) stocking has occurred. Our model predicted 42,343 (± 4,570) hatchery-reared pallid sturgeon remain in the lower Missouri River population in 2012 (Figure 3-4) with an estimated 13,867 (age-9 females = 3,537 [± 864]; age-7 males = 10,330 [± 1,787]) reproductively mature fish. The number of hatchery-reared pallid sturgeon peaked in 2004 at an estimated 49,142 (± 4,570) fish when over 30,000 age-0 fish were stocked; however the numbers quickly declined because of the low survival rates associated with stocking age-0 fish. The number of reproductively viable, based on age, hatchery-reared pallid sturgeon would peak in 2018 with an estimated 20,238 fish when the females from the 2009 year class and males from the 2011 year class reach reproductive readiness. If stocking efforts ceased, the number of hatchery-reared pallid sturgeon would rapidly decline. The population would decline to 17,192 (± 2,969) in ten years, 7,632 (± 1,393) in twenty years, and only 3,277 (±626) hatchery-reared pallid sturgeon would remain in thirty years.

Influence of natural reproduction and recruitment

The total (wild and hatchery-reared) pallid sturgeon population is estimated at 48,334 fish with 659 wild and 989 hatchery-reared reproductively ready female pallid sturgeon. Under an assumption of no natural recruitment, the population will continue to decline at approximately 8% annually with only 3,801 pallid sturgeon remaining in 30 years (Figure 3-5). If the naturally produced pallid sturgeon survival rate is 0.00001 from egg to age-1 then the annual population decline changed to 7% and the population size in 30 years would be estimated at 5,854 fish (Figure 3-6). A fivefold increase in the egg to age-1 survival rate (Ø = 0.00005) would result in an estimated population size in 2042 of 20,621 fish, an approximate 4% annual decline (Figure 3-7). Finally, an egg to age-1 survival rate of 0.00010 would result in a 1% annual decline and a projected population of estimate of 62,831 individuals in 2042 (Figure 3-8). An annual egg to age-1 survival rates of 0.00011 is predicted to maintain a stable population over the next 30 years.

Model sensitivity

Our sensitivity analyses suggest the pallid sturgeon population is most sensitive to ≥ age-1 survival rates. Changing age-1 survival by ±5% caused a ± 2.8% change in the population of pallid sturgeon (Figure 3-9). The influence on the overall pallid sturgeon population declined as age increased from age-1 but was less sensitive. Changing the hatchery-reared age-0 fish survival rates, natural production survival rates, and fecundity parameters by ± 5% yielded minimal effects (< 0.26% change in λ) on the model predictions. Testing the sensitivity for each life stage, an increase or decrease in the survival estimates of 5% for the age-1 to 8 age-group (sub-adults) changed the overall pallid sturgeon population by 16.9% (Figure 3-10), whereas changing the survival rates (± 5%) for adult (age-8 +) pallid sturgeon resulted in a 5% change to the predicted population size.

The original population estimates were based on female pallid sturgeon becoming reproductively ready at age-9 and spawning every three years. A change in the spawning frequency parameter to every other year would affect the overall population growth by 2.7% (Figure 3-11). Underestimation of this parameter with a spawning frequency of 4 or 5 years would predict a population decrease of 1.3% for 4 years and 2.0% for 5 years. Early female maturation by one year (age-8) only increased λ by 0.4% while early maturation by two years (age-7) resulted in a 1.0% increase in the overall population compared to the original estimate. Conversely, delaying the age-at-maturity to age-10 would decrease λ by 0.3% and by 0.6% for age-11.

Stocking projections

If no natural reproduction occurred and hatchery supplementation ceased, our model predicts 3,801 pallid sturgeon would remain in 30 years. Stocking 10,000 age-1 hatchery-reared pallid sturgeon for the next five years would double (N = 7,981) the predicted overall pallid sturgeon population size in 2042 while continuing that stocking effort for the next 10 years would increase λ by 375% and result in over 30,000 mature pallid sturgeon in the population by 2021 (Figure 3-12). To maintain the current pallid sturgeon population, 10,000 age-1 hatchery-reared fish would need to be stocked for the next 23 years.

Discussion

Understanding life history processes are critical components to species management or recovery. We used available pallid sturgeon life history data to develop a population viability model to predict the demographic rates and determine sensitivity of these life history processes. Minor changes in key life history processes (i.e., survival estimates) can greatly affect the predicted population size and alter management actions. For example, if survival for egg to age-1 naturally produced pallid sturgeon would be increased to a rate similar to Gulf sturgeon *Acipenser oxyrinchus desotoi* (Ø = 0.0004; Pine et al. 2001), our model predicts the pallid sturgeon population in the lower Missouri River would increase exponentially and hatchery supplementation would not be required. Pine et al. (2001) and Kennedy and Sutton (2007) showed high levels of sensitivity of egg to age-1 survival rates whereas age-1-8 were the more sensitive age groups for our model. The difference may be an artifact of the poor egg to age-1 survival probability theorized with pallid sturgeon in this reach of the Missouri River and used in our model. Increasing our egg to age-1 survival rates by 5% had little influence on an individual's chance of survival. Conversely, increasing egg to age-1 survival an order of magnitude (i.e., from 0.00001 to 0.00011) could provide a mechanism for population sustainability. However, egg to age-1 survival likely varies annually making this difficult to predict or manage.

Steffensen et al. (2012) estimated the wild and hatchery-reared populations in an 80.5 rkm reach in the lower Missouri River, a known pallid sturgeon "hot spot". The wild pallid sturgeon population estimate used here assumes similar distribution of pallid sturgeon throughout the lower Missouri River as the data are extrapolated from the 80.5 rkm reach. This extrapolation may overestimate the real population size in the lower Missouri River as more adult pallid sturgeon are captured in the upper reach of the lower Missouri River (Huenemann 2012). However, over or under estimating the initial population estimate by ±5% does not significantly affect the long-term population.

Our 2010 estimate of hatchery-reared pallid sturgeon (N = 35,709 ± 3,680) resulted in an average of 27.4 (± 2.8) fish per rkm. Steffensen et al. (2012) estimated the 2010 population for hatchery-reared fish at 32.3 (± 0.96) fish per rkm. Steffensen's estimate is slightly higher than our model predicted. However, the reach where Steffensen estimated the hatchery-reared population had several more stocking events than in the lower half of the lower Missouri River (Huenemann 2012). Therefore, we conclude our model is valid and accurately predicts the current population estimate as the estimated hatchery-reared population size predicted by this model is comparable to the population estimate (mark-recapture) method previously used.

In most sturgeon populations, adults comprise a small part of the total population (Jaric et al. 2010). Beamesderfer et al. (2007) estimated adult green sturgeon *Acipenser medirostris* in the Sacramento River comprised only 12% of the total population at equilibrium whereas Jaric et al. (2010) reported the proportion of adults in the Danube sturgeon population varied between 2.7% and 15.1%. We estimate adult pallid sturgeon comprise approximately 55% of the population and approximately 8% of the population are reproductively ready females annually. This confirms that natural recruitment in the lower Missouri River is very limited to non-existent as all the sub-adults being captured are known hatchery-reared fish.

Quantifying the age structure of the wild pallid sturgeon population was not possible as length-at-age information is not available in this reach of the Missouri River. Therefore, quantifying local extirpation of the wild pallid sturgeon population is difficult. Pallid sturgeon in the upper Missouri River (below Fort Peck Dam, Montana) have been documented at 50+ years (USFWS 2000) compared to estimates of pallid sturgeon in the middle and lower Mississippi River only surviving to age 14-21 (Killgore et al. 2007). Our model is based on a maximum age of 41 year old as described by Keenlyne et al. (1992) from a single female taken from the Missouri River near Fort Rice, ND. An issue this model did not address for and is lacking in the sturgeon literature is whether or not sturgeon senesce before they reach maximum age. Jaric et al. (2010) suggest senescence would not affect population viability unless sturgeon senescence is reached many years prior to their maximum age. Over-estimating the maximum age or if senescence occurs in pallid sturgeon affects the number of reproductive adults needed for the population to remain viable as the number of reproductive cycles each female could contribute to the population would be reduced.

Our model estimates approximately 20,000 (wild = 6,000; hatchery-reared = 14,000) mature pallid sturgeon were present in the lower Missouri River in 2012. Some evidence does exist that natural spawning has occurred (DeLonay et al. 2010; DeLonay et al. 2012). However, survival and recruitment has not been documented across the lower reach of the Missouri River and is minimal in the Mississippi River (Snyder 2000; Hrabik et al. 2007; USFWS 2007). Clearly, understanding the limitations to recruitment will be crucial in understanding pallid sturgeon population dynamics. Continuation of the stocking program can maintain a stock of pallid sturgeon in the lower Missouri River. However, egg to age-1 survival would likely need to be > 0.00010 for the population to approach a sustainable size that would likely result in the decision to reduce hatchery efforts.

Increasing survival of stocked hatchery-reared pallid sturgeon should be a priority in the short-term. Age-1 survival was the most sensitive parameter in our model. For example, stocking 10,000 age-0 hatchery-reared fish would yield approximately 220 (age-7 males = 155; age-9 females = 65) individuals that reach age-of-maturity. Conversely, stocking 10,000 age-1 hatchery-reared fish would yield approximately 4,300 (age-7 males = 3,000; age-9 females = 1,300) individuals that reach age-of maturity. We do not know the operational cost differences within the hatchery production system between the two described rearing scenarios, but we recommend maximizing the number of age-1 + fish stocked to optimize the number of individuals in the population for longer periods of time. Further efforts to determine age-specific survival rates beyond what is known would also benefit model sensitivity.

Recovering a species, such as pallid sturgeon, that is slow-growing, late-maturing, and does not achieve reproductive readiness annually require several years to quantify recovery and management decisions. As large numbers of hatchery-reared fish approach sexual maturity, continued evaluation of the benefits from the artificial propagation project are critical. Barring any unforeseen natural catastrophe, the pallid sturgeon population in the lower Missouri River is not in any immediate danger of local extirpation; however, the population appears to be far from viable and self-sustaining without continued supplementation. Continued monitoring and assessment of the pallid sturgeon population will allow researchers to better quantify the critical input parameters for this model and to validate its predicted numbers in providing information for recovery decision makers.

References

Bailey, R. M., and F. B. Cross. 1954. River sturgeons of the American genus *Scaphirhynchus*: characters, distribution and synonymy. Papers of the Michigan Academy of Science, Arts and Letters 39:169-208.

Bajer, P. G., and M. L. Wildhaber. 2007. Population viability analysis of the lower Missouri River shovelnose sturgeon with initial application to the pallid sturgeon. Journal of Applied Ichthyology 23:457-464.

Beamesderfer, R. C. P., M. L. Simpson, and G. J. Kopp. 2007. Use of life history information in a population model for Sacramento green sturgeon. Environmental Biology of Fishes 79:315-337.

DeLonay, A. J., R. B. Jacobson, D. M. Papoulias, M. L. Wildhaber, K. A. Chojnacki, E. K. Pherigo, C. L. Bergthold, and G. E. Mestl. 2010 Ecological requirements for pallid sturgeon reproduction and recruitment in the lower Missouri River: annual report 2009. U.S. Geological Survey Open-File Report 2010-1215. 64 p.

DeLonay, A. J., Jacobson, R. B., Papoulias, D. M., Wildhaber M. L., Chojnacki, K. A., Pherigo, E. K., Haas, J. D., and Mestl, G. E. 2012. Ecological requirements for pallid sturgeon reproduction and recruitment in the Lower Missouri River: Annual report 2010. U.S. Geological Survey, Columbia, Missouri.

Dryer, M. P., and A. J. Sandvol. 1993. Pallid sturgeon recovery plan. U.S. Fish and Wildlife Service, Bismarck, North Dakota.

Forbes, S.A., and R.E. Richardson. 1905. On a new shovelnose sturgeon from the Mississippi River. Bulletin of the Illinois State Laboratory of Natural History 7:37-44.

Gao, X., S. Brosse, Y. Chen, S. Lek, and J. Chang. 2009. Effects of damming on population sustainability of Chinese sturgeon, *Acipense sinensis*: evaluation of optimal conservation measures. Environmental Biology of Fishes 86:325-336.

Hrabik, R. A., D. P. Herzog, D. E. Ostendorf, and M. D. Petersen. 2007. Larvae provide first evidence of successful reproduction by pallid sturgeon (*Scaphirhynchus albus*) in the Mississippi River. Journal of Applied Ichthyology 23:436-443.

Huenemann, T. W. 2012. Central lowlands and interior highlands pallid sturgeon spawning and stocking summary. Nebraska Game and Parks Commission, Lincoln, Nebraska.

Jaric, I., T. Ebenhard, and M. Lenhardt. 2010. Population viability analysis of the Danube sturgeon populations in a Vortex simulation model. Reviews in Fish Biology and Fisheries 20:219-237.

Kallemeyn, L. 1983. Status of the pallid sturgeon. Fisheries 8:3-9.

Keenlyne, K. D., and P. D. Evenson. 1989. Standard and relative weight for the pallid sturgeon (*Scaphirhynchus albus*). Proceedings of the South Dakota Academy of Sciences 2:41-49.

Keenlyne, K. D., E. M. Grossman, and L. G. Jenkins. 1992. Fecundity of pallid sturgeon. Transactions of the American Fisheries Society 121:139-140.

Kennedy, A. J., and T. M. Sutton. 2007. Effects of harvest and length limits on shovelnose sturgeon in the upper Wabash River, Indiana. Journal of Applied Ichthyology 23:123-128.

Killgore, K. J., J. J. Hoover, J. P. Kirk, S. G. George, B. R. Lewis, and C. E. Murphy. 2007. Age and growth of pallid sturgeon in the free-flowing Mississippi River. Journal of Applied Ichthyology 23:452-456.

Krentz, S., R. Holm, H. Bollig, J. Dean, M. Rhodes, D. Hendrix, G. Heidrich, B Krise. 2005. Pallid sturgeon spawning and stocking summary report 1992-2004. U.S. Fish and Wildlife Service report, Bismarck, North Dakota.

Pegg, M. A., C. L. Pierce, and A. Roy. 2003. Hydrological alteration along the Missouri River basin: a time series approach. Journal of Aquatic Science 65:63-72.

Pine, W. E., M. S. Allen, V. J. Dreitz. 2001. Population viability of the Gulf of Mexico Sturgeon: Inferences for capture-recapture and age-structured models. Transactions of the American Fisheries Society 130:1164-1174.

Snyder, D. E. 2000. Identification of sturgeon larvae collected from the Missouri River at Lisbon Bottoms, MO, 13 August 1998 and 23 July 1999. Department of Fishery and Wildlife Biology, Larval Fish Laboratory, Colorado State University, Fort Collins, Colorado.

Steffensen, K. D., L. A. Powell, and J. D. Koch. 2010. Assessment of hatchery-reared pallid sturgeon survival in the lower Missouri River. North American Journal of Fisheries Management 30:671-678.

Steffensen, K.D., L. A. Powell, and M. A. Pegg. 2012. Population size of hatchery-reared and wild pallid sturgeon in the lower Missouri River. North American Journal of Fisheries Management 32:159-166.

U.S. Fish and Wildlife Service. 1990. Endangered and threatened wildlife and plants; determinations of endangered status for the pallid sturgeon. Federal Register 55(173):36641-36647.

U.S. Fish and Wildlife Service. 2000. Biological opinion of the operation of the Missouri River main stem reservoir system, operation and maintenance of the Missouri River banks stabilization and navigation project and operation of the Kansas River reservoir system. U.S. Fish and Wildlife Service, Denver, Colorado.

U.S. Fish and Wildlife Service. 2007. Pallid sturgeon (*Scaphirhynchus albus*) 5-year review: summary and evaluation. U.S. Fish and Wildlife Service, Billings, Montana.

Wildhaber, M. L., A. J. DeLonay, D. M. Papoulias, D. L. Galat, R. B. Jacobson, D. G. Simpkins, P. J. Braaten, C. E. Korschgen, and M. J. Mac. 2007. A conceptual life-history model for pallid and shovelnose sturgeon. U.S. Geological Survey Circular 1315, Columbia, Missouri.

Table 3-1. Input parameters and model default values used in the pallid sturgeon population viability model for the lower Missouri River.

Variable	Value	Reference
Gender ratio (female : male)	0.33 : 0.66	Steffensen et al. (*submitted*)
Maximum age	Age 41	Keenlyne 1992 Bajer and Wildhaber 2007
Reproductive cycle	Female – 3 years Males – 2 years	Steffensen et al. (*submitted*)
Age-at-maturity	Female – 9 years Males – 7 years	Steffensen et al. (*submitted*)
Fecundity	19,064	Steffensen et al. (*submitted*)
Survival rates	Age-0 – 0.051 Age-1 – 0.686 ≥ Age-2 – 0.922	Steffensen et al. (2010)
Stocking history	See Table 3-2	Huenemann (2012)
Wild population size	5.4 fish / rkm*	Steffensen et al. (2011)

* 2010 population estimate extrapolated for the entire lower Missouri River.

Table 3-2. Number of hatchery-reared pallid sturgeon stocked in the lower Missouri River from 1992, when the artificial propagation program began, to the fall of 2012 by age-at-stocking (Huenemann 2012).

	Age-at-stocking							
Year Class	Age-0	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6	Age-7
1992			4083				84	15
1993								
1994								
1995								
1996								
1997	2816					35		
1998								
1999				532				
2000								
2001		7453						
2002		9241						
2003	5364	4765						
2004	30628	8612	15					
2005		3654						
2006		3642						
2007	2000	1421	1094					
2008	6663							
2009	3981	10612						
2010	2974	3838						
2011	7606	13736						
2012								

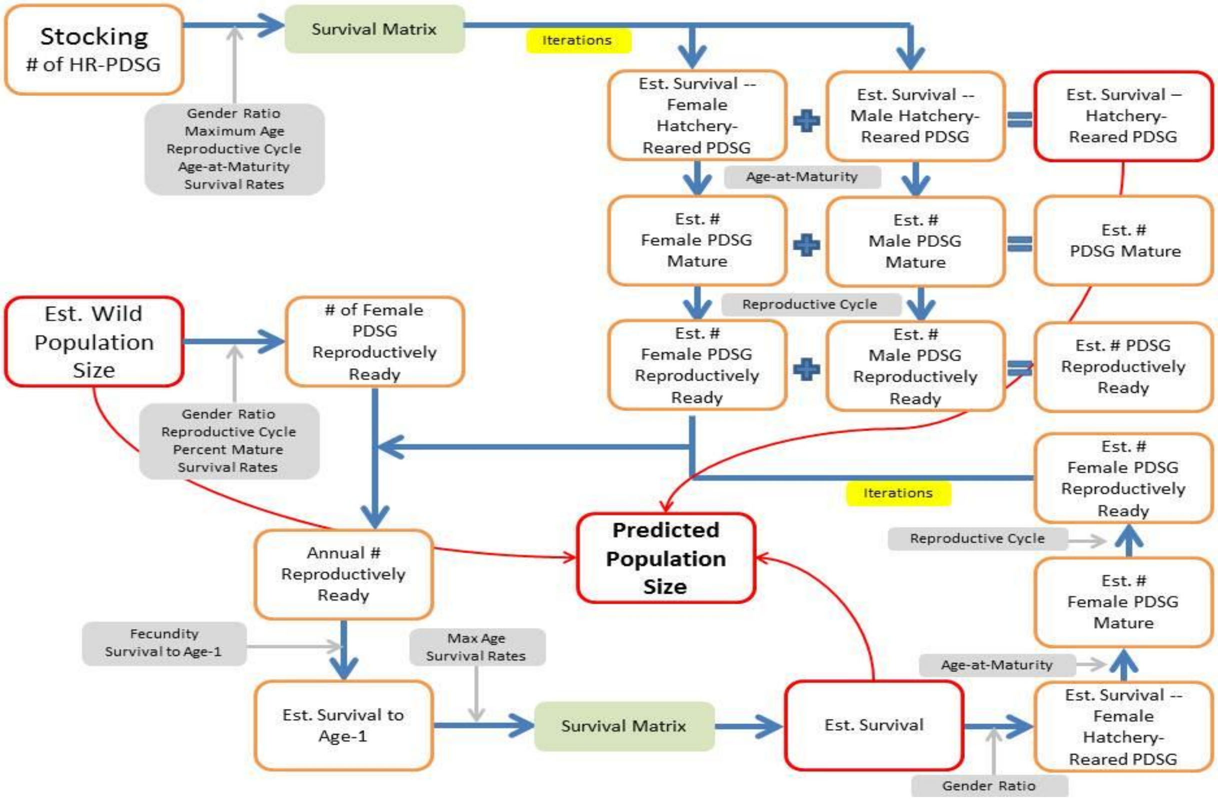

Figure 3-1. Conceptualization of the population viability analysis (PVA) model for the lower Missouri River. Open boxes are input parameters gathered from published and unpublished data while the gray boxes represent input parameters that can be adjusted within the model.

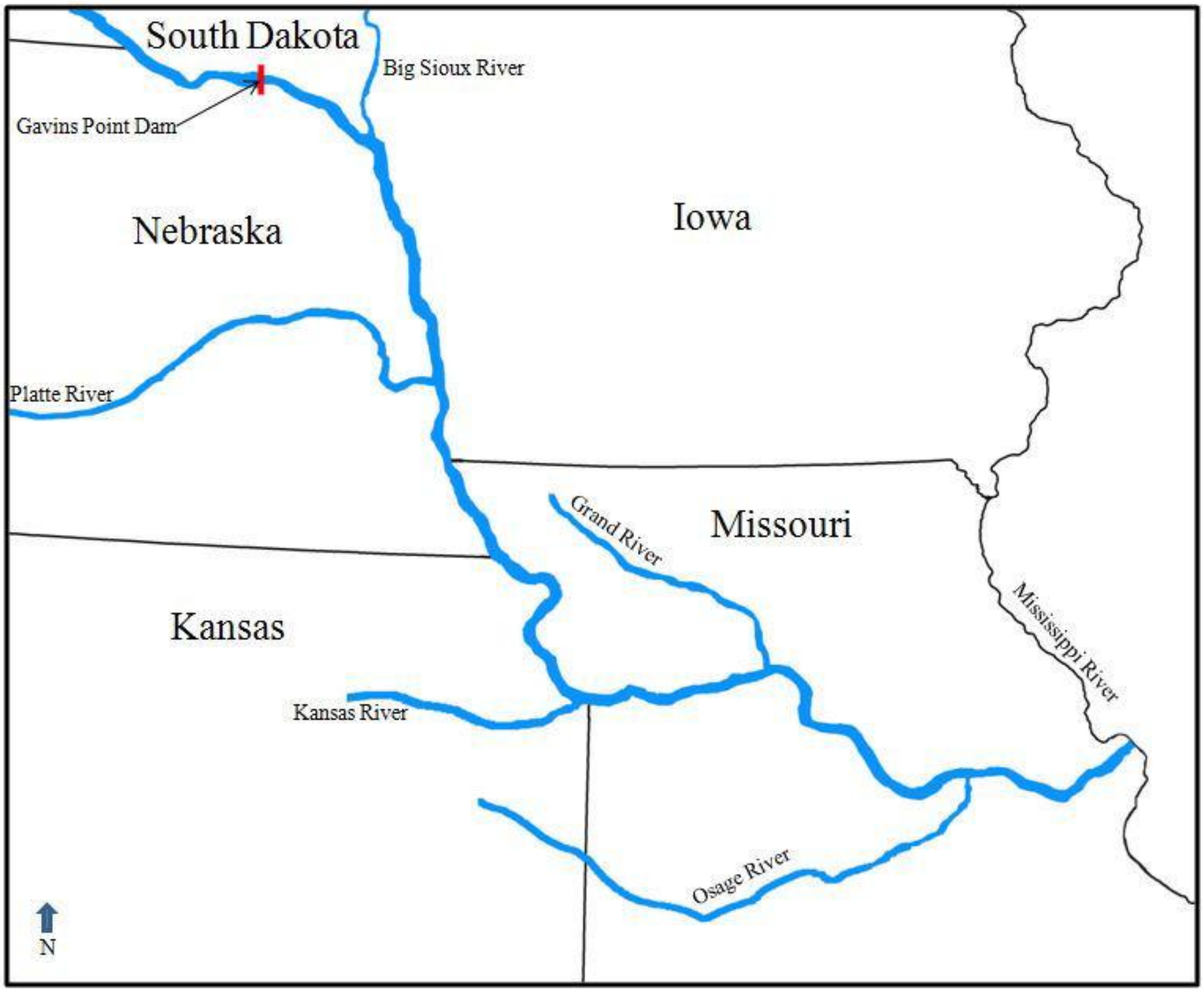

Figure 3-2. Map of the lower Missouri River from Gavins Point Dam at Yankton, SD (rkm 1,305.2) to the confluence (rkm 0.0) with the Mississippi River at St. Louis, MO.

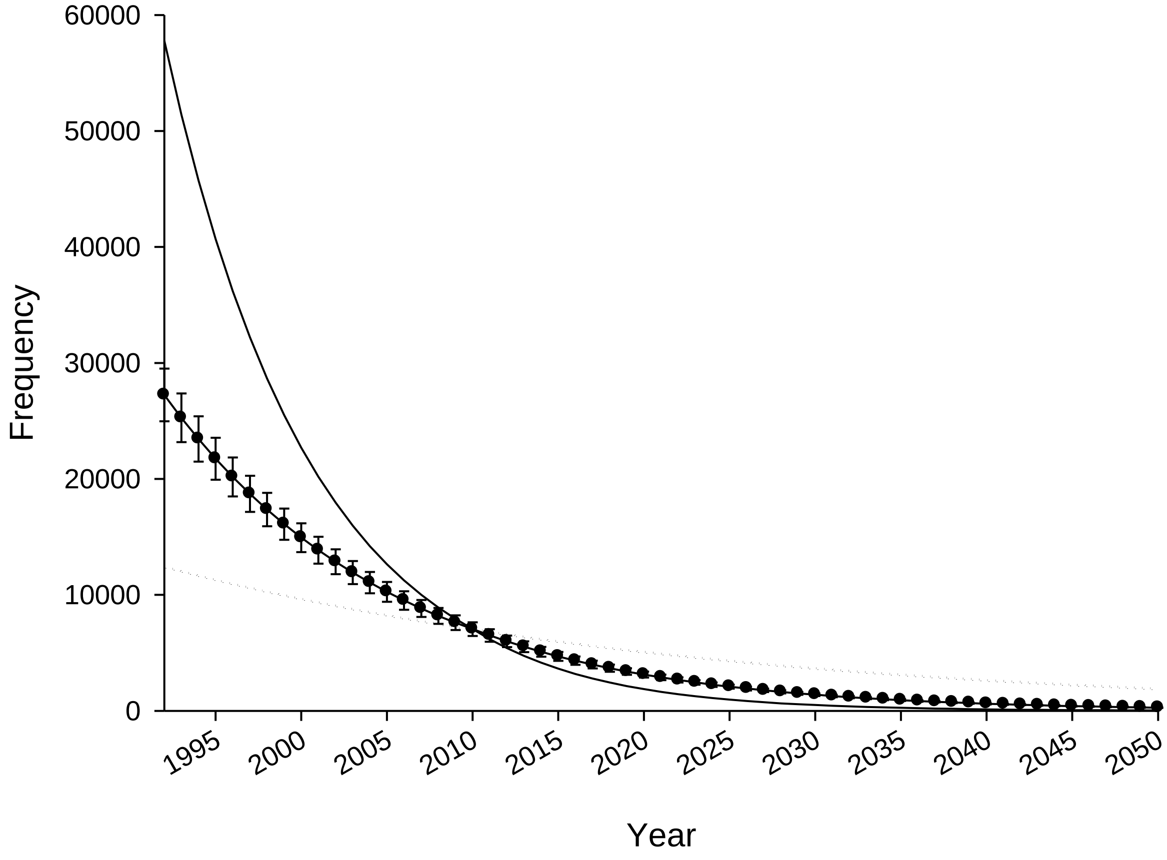

Figure 3-3. Annual population estimates for wild pallid sturgeon in the lower Missouri River from 1992 to 2050. Error bars represent the variation around the predicted mean population estimate. The solid line shows the mean population if the survival estimate were under estimated by 5% while the dashed line shows a 5% over estimate of survival rate.

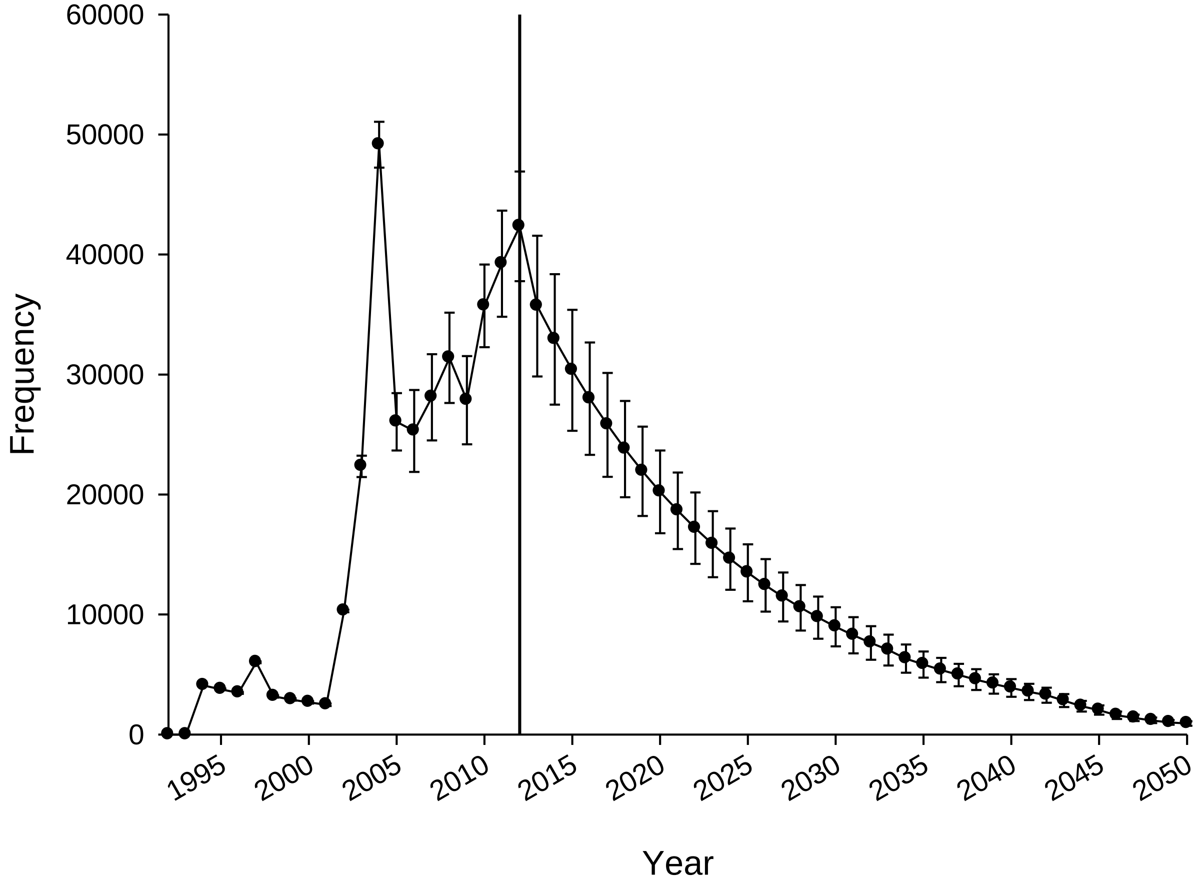

Figure 3-4. Annual population estimate for hatchery-reared pallid sturgeon in the lower Missouri River from 1992 to 2050, assumes artificial supplementation ceases in 2012 (solid vertical line). Error bars represent the variation around the mean.

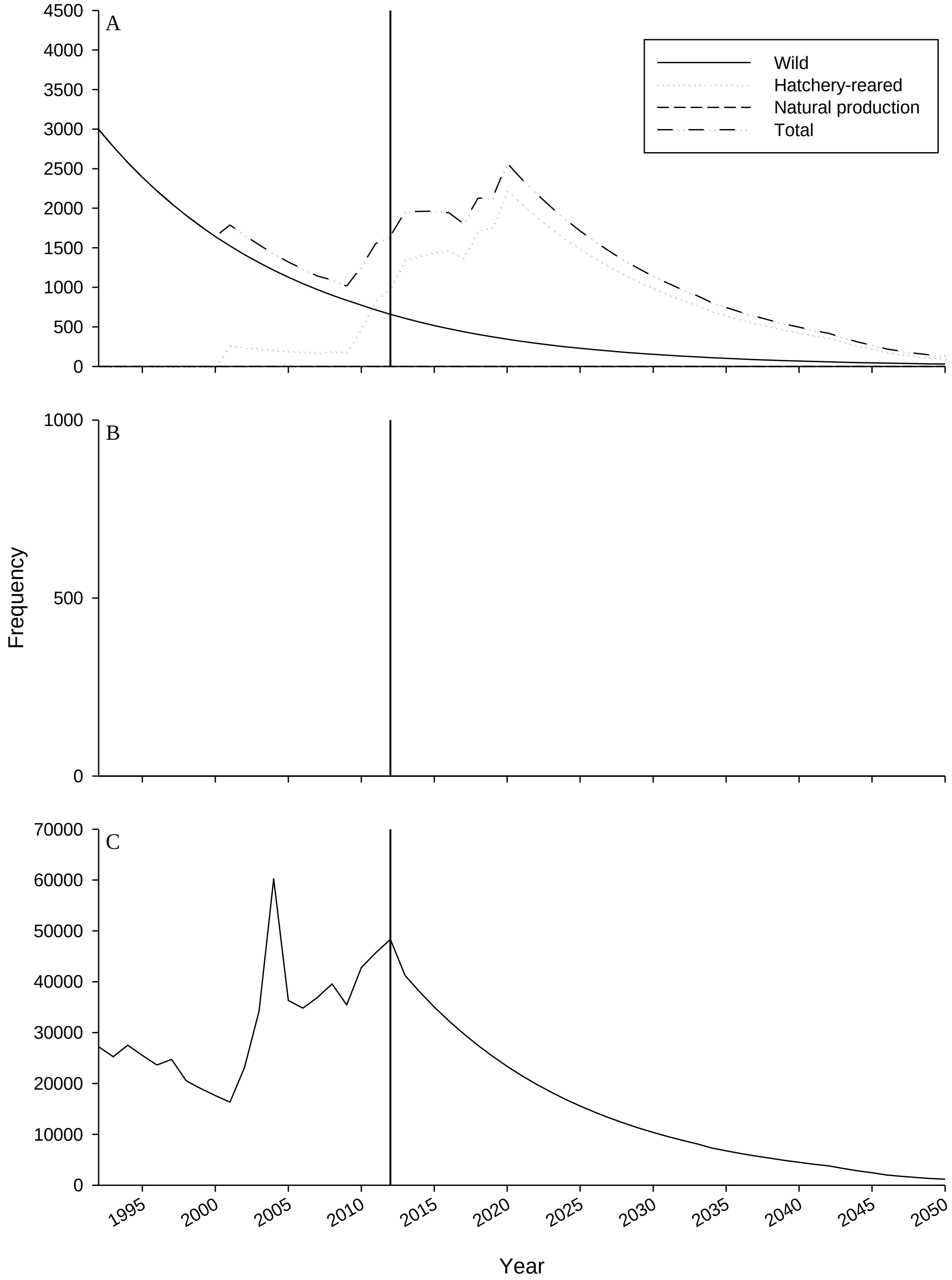

Figure 3-5. Predicted population change for all pallid sturgeon under the assumption of 0.00000 recruitment from egg to age-1 and assumes artificial supplementation ceased in 2012 (solid vertical line). Predicted number of (A) reproductively ready female pallid sturgeon by origin in the lower Missouri River, (B) number of naturally produced pallid sturgeon that survive to age-1, and (C) overall pallid sturgeon population.

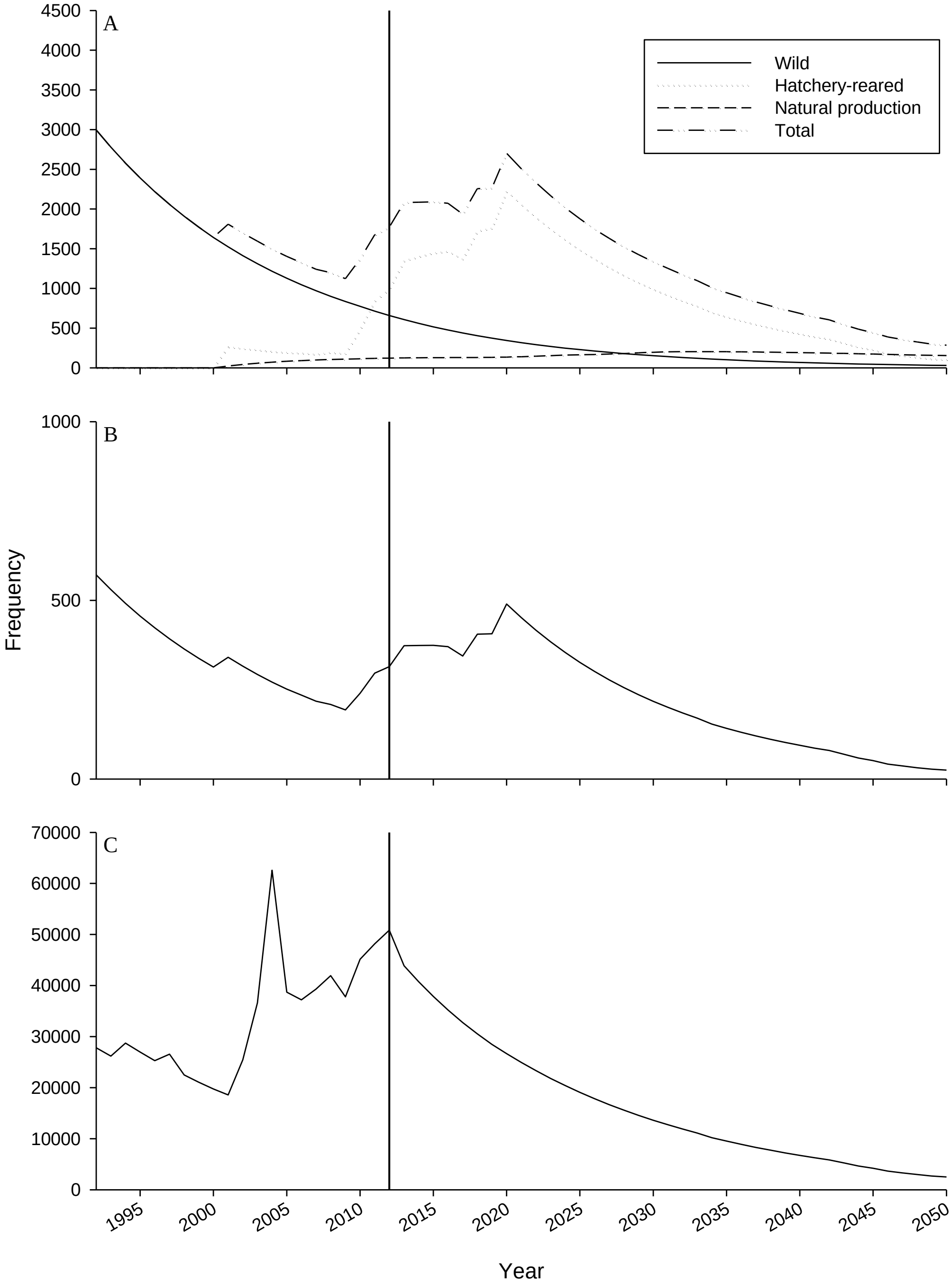

Figure 3-6. Predicted population change for all pallid sturgeon under the assumption of 0.00001 recruitment from egg to age-1 and assumes artificial supplementation ceased in 2012 (solid vertical line). Predicted number of (A) reproductively ready female pallid sturgeon by origin in the lower Missouri River, (B) number of naturally produced pallid sturgeon that survive to age-1, and (C) overall pallid sturgeon population.

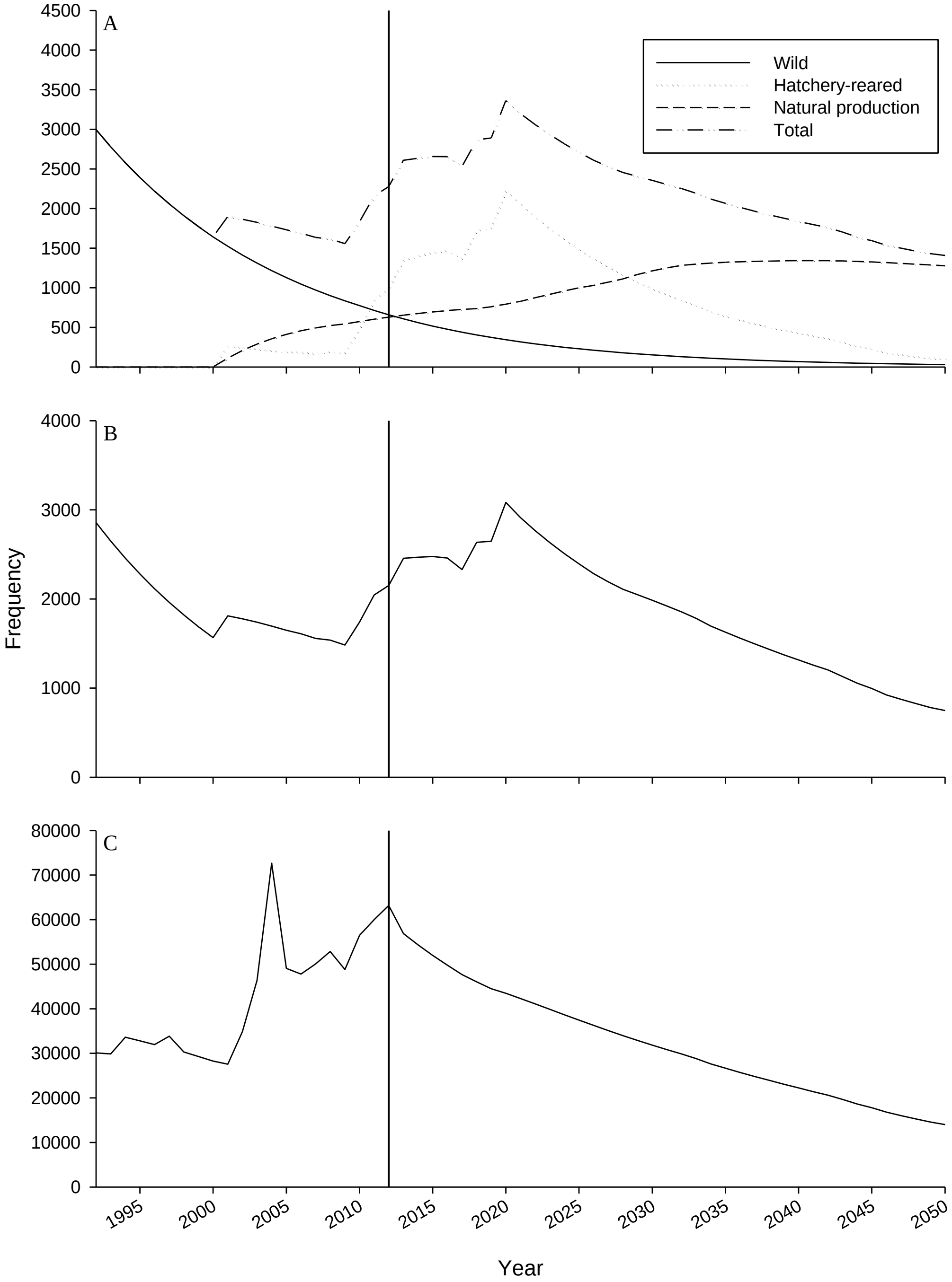

Figure 3-7. Predicted population change for all pallid sturgeon under the assumption of 0.00005 recruitment from egg to age-1 and assumes artificial supplementation ceased in 2012 (solid vertical line). Predicted number of (A) reproductively ready female pallid sturgeon by origin in the lower Missouri River, (B) number of naturally produced pallid sturgeon that survive to age-1, and (C) overall pallid sturgeon population.

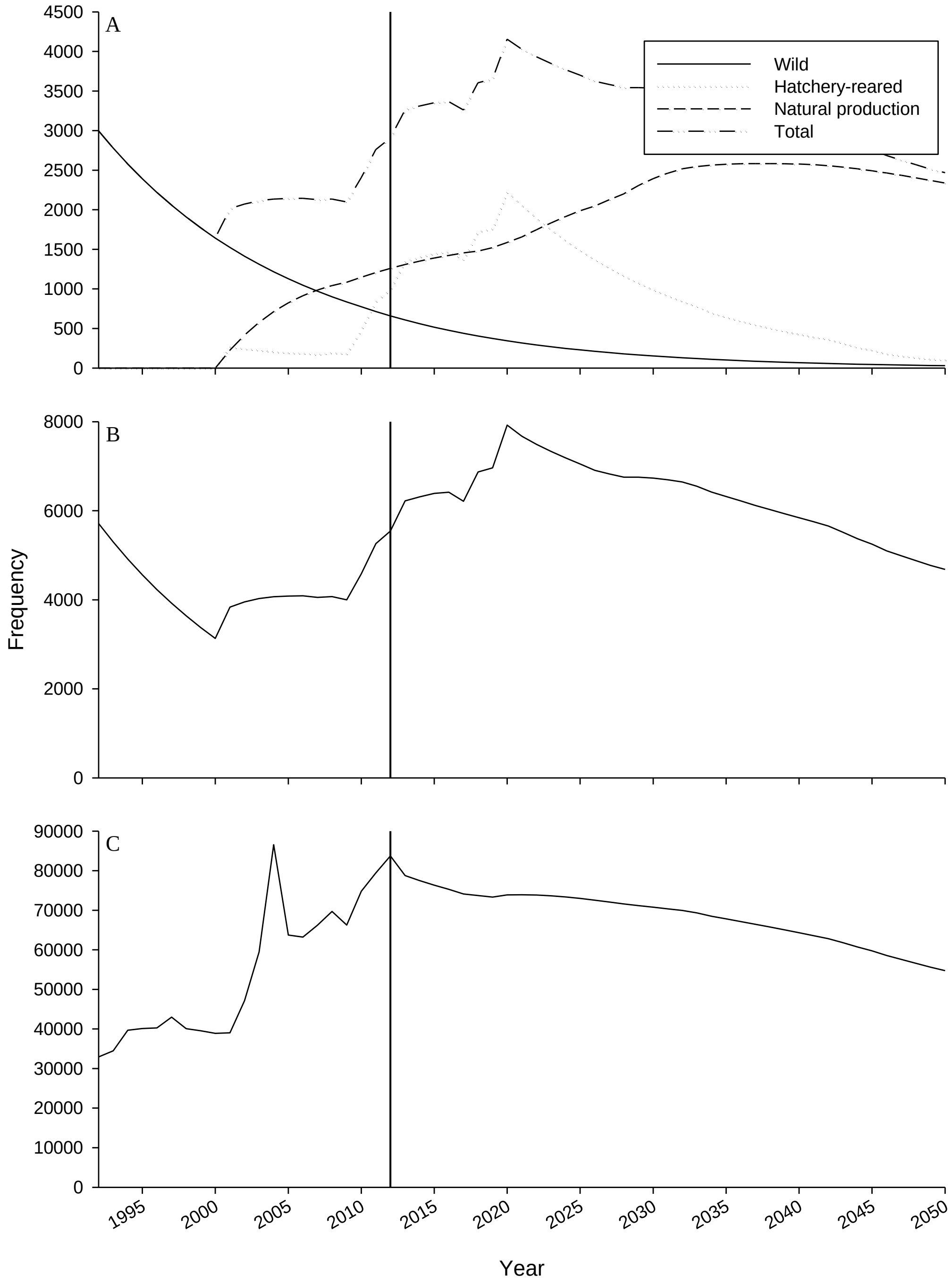

Figure 3-8. Predicted population change for all pallid sturgeon under the assumption of 0.00010 recruitment from egg to age-1 and assumes artificial supplementation ceased in 2012 (solid vertical line). Predicted number of (A) reproductively ready female pallid sturgeon by origin in the lower Missouri River, (B) number of naturally produced pallid sturgeon that survive to age-1, and (C) overall pallid sturgeon population.

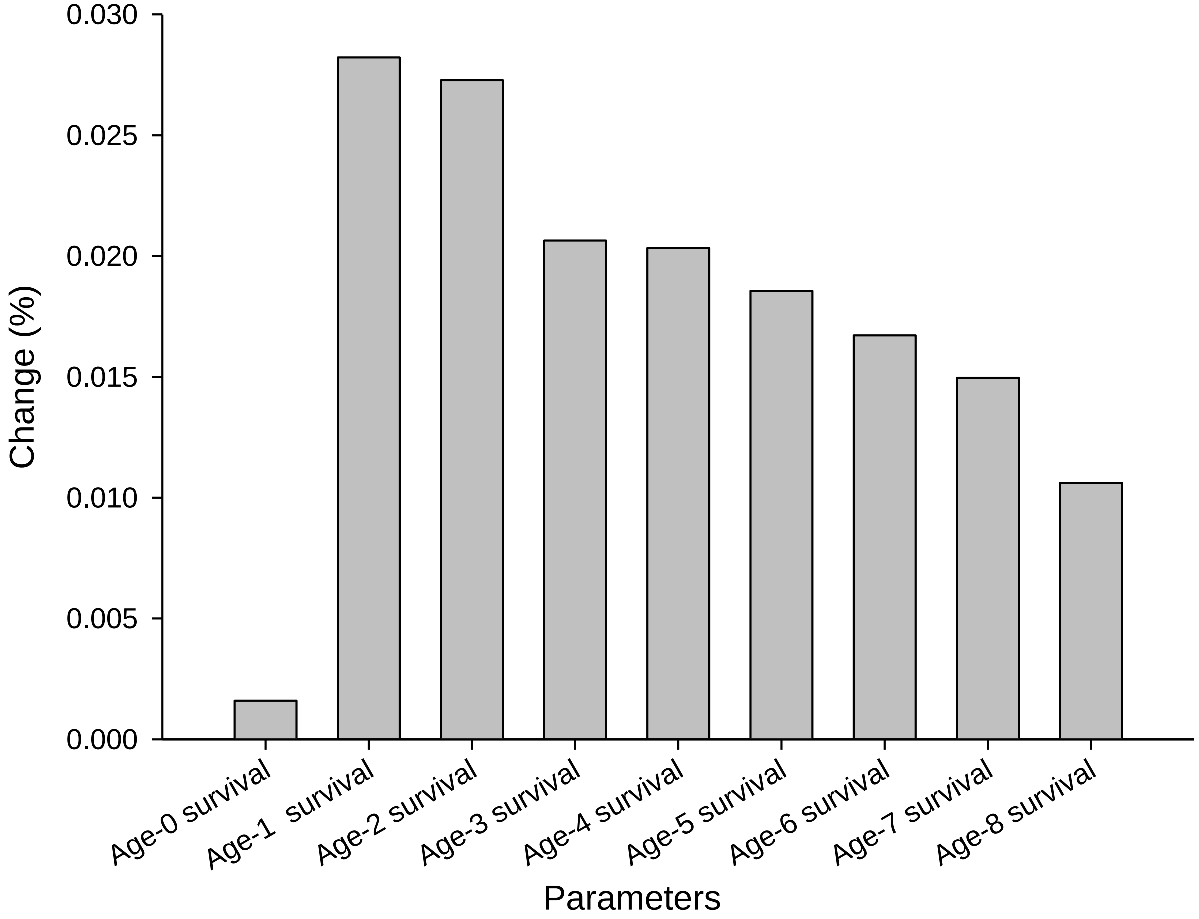

Figure 3-9. Sensitivity analysis for the survival input parameters incorporated in our population viability analysis with the predicted change (%) in λ developed for pallid sturgeon in the lower Missouri River. Individual parameter values were increased and decreased by 5% while the stochasticity was removed on all remaining parameters.

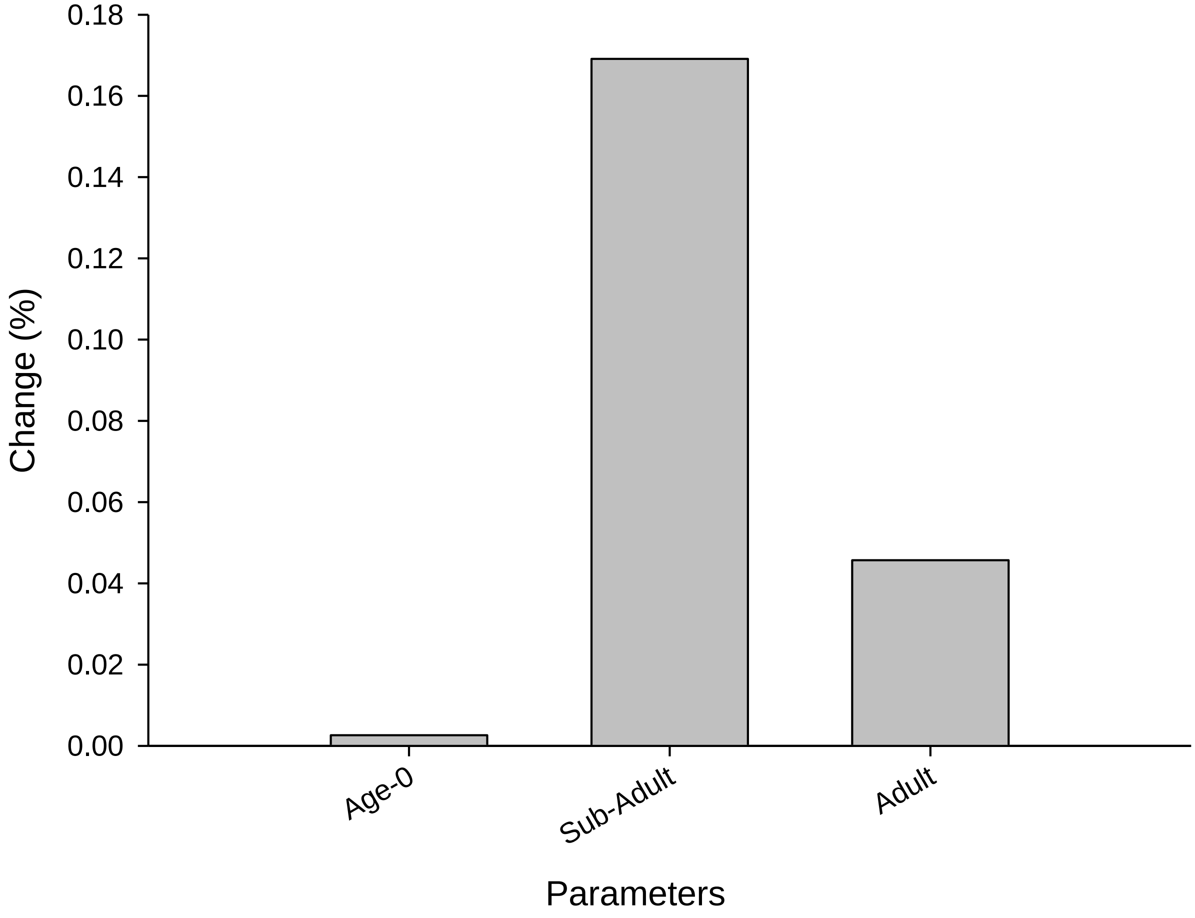

Figure 3-10. Sensitivity analysis of the survival estimates by life stage with the predicted change in λ (%). Age-0 represents hatchery-reared fish stocked at age-0 and any natural reproduction that occurs, sub-adult included age-1 through age-8, and adults included age-9 through predicted maximum age.

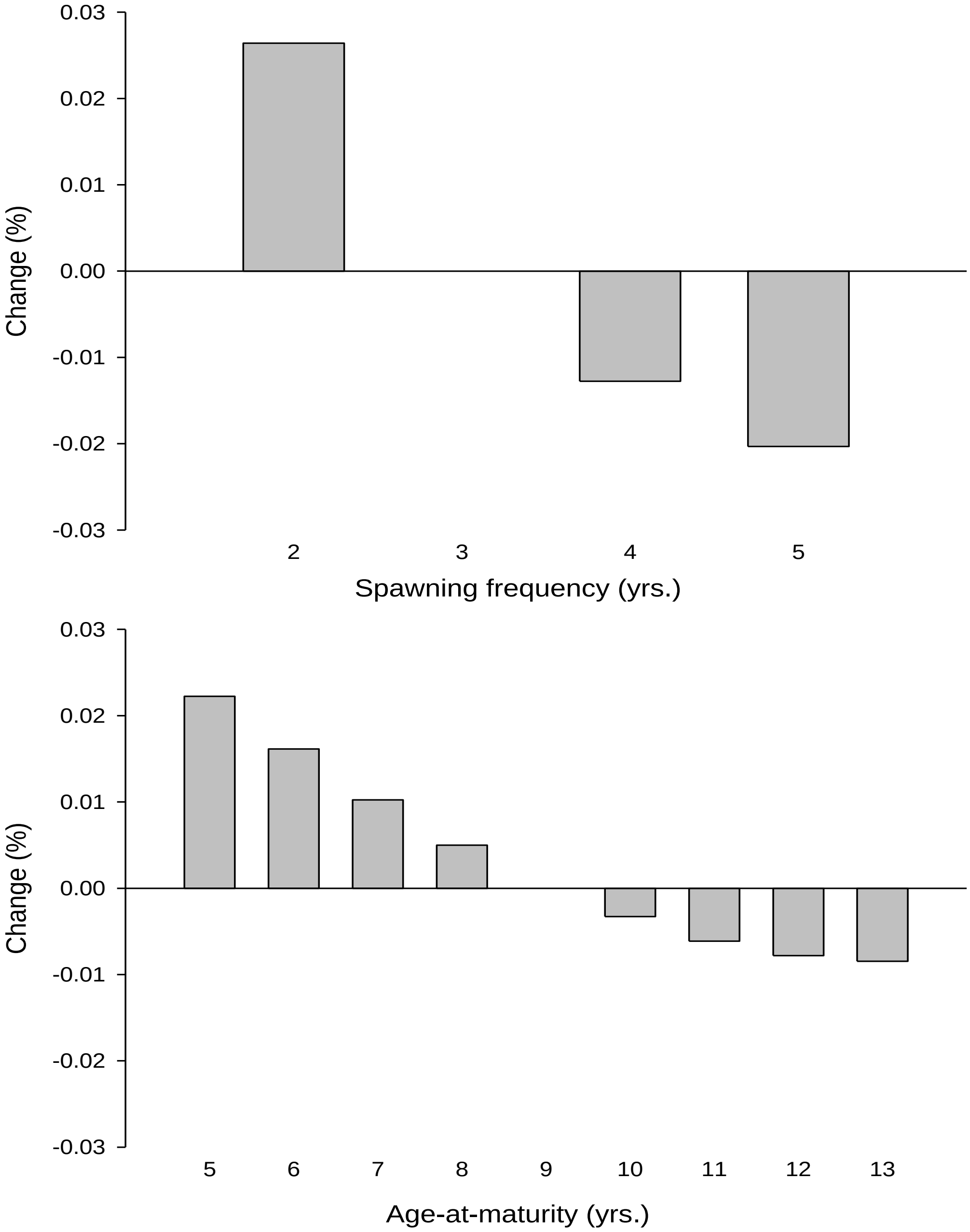

Figure 3-11. Predicted change in λ (%) with (A) increasing and decreasing spawning frequency and (B) changing age-at-maturation for pallid sturgeon in the lower Missouri River.

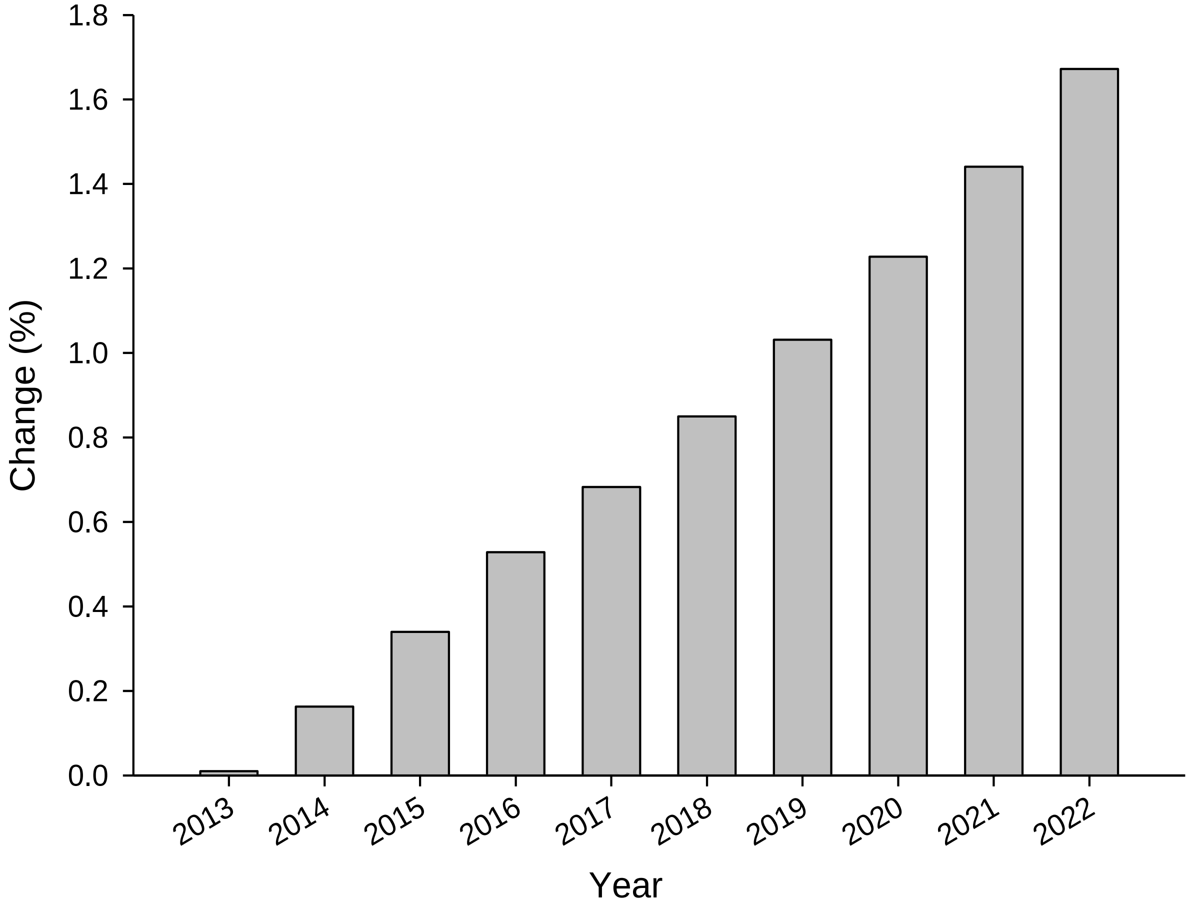

Figure 3-12. Predicted change in λ (%) for pallid sturgeon in the lower Missouri River when continuing the artificial propagation program and stocking 10,000 age-1 hatchery-reared pallid sturgeon annually through 2022. Survival from egg to age-1 was fixed at 0.00001.

CHAPTER 4

Trotline Efficiencies and Catch Dynamics in a Large River System

Abstract

Trotlines have proven to be an effective collection method for riverine species. However, an understanding of fish-gear interaction post-deployment is lacking. Lindgren-Pitman (LP) Hook Timers are a proven means to evaluate such fish-gear interactions because they identify when a fish activated the timer, allowing researchers to identify when fish are captured and the escapement rate of hooked fish. The objectives of this study were to determine the activation rate of LP Hook Timers, determine retention rate of trot lines and how fish escapement affects CPUE, document real time catch rates, and document if hook duration causes stress or mortalities. Sampling occurred during the spring 2011 in the upper channelized Missouri River. Trot lines rigged with 40 LP hook timers were deployed, resulting in 3,997 hook timer deployments and collected 1,423 fish (9 species). Catch per unit effort (CPUE) for all species was 14.6 fish per line; however, 307 hook timers were activated but did not capture a fish. Assuming a fish was hooked and consequently escaped before gear retrieval, the resulting CPUE for lost fish per line was 3.1. Therefore, a corrected CPUE was 17.7 fish per line when escaped individuals were included. Overall, 20% of the hook timer activations occurred within 1 h of deployment and over half of the activations occurred within 4 h post-deployment. Stress associated with trotlines does not appear to be correlated with hook duration. Detailed information can be ascertained from the

use of trotlines rigged with LP Hook Timers that will aid in understanding trotline dynamics.

Introduction

Trotlines are generally used in warmwater inland fisheries (Starrett and Barnickol 1955) and have proven to be an effective method for collecting large river species, especially *Ictalurid* (Graham 1997; Vokoun and Rabeni 1999; Arterburn and Berry 2001) and *Scaphirhynchus* species, including the federally endangered pallid sturgeon *S. albus* (Killgore et al. 2007; Peters and Parham 2008; Bettoli et al. 2009; Steffensen 2011). Trot lines are an attractant, passive gear where bait and hooks need to be available to capture a fish. The gear's ability to collect fish is greatest immediately after deployment as all the hooks are available and baited; however, catchability declines throughout the set time as fish are captured and bait is lost (Steffensen et al. 2011). Ward et al. (2005) reported the probability of an animal being captured (hooked) is dependent on the target species' local abundance, vulnerability to the fishing gear, and the availability of the gear. Catch rates with trotlines are generally measured as the number of fish captured divided by the number of hooks over a period of time (e.g., number of fish / 40 hook nights) and are influenced by hook availability where a fish that encounters a trotline can only be captured (hooked) if baited hooks are available. However, number of fish / hook night is not a good indicator of true effort because hook night catch rates are dependent on hook availability throughout the gear's deployment. Further, this approach to estimating abundance does not account for gear saturation issues like the number of fish already hooked or the number of fishless hooks that have bait remaining. Therefore, whenever a fish is captured and retained, the probability of collecting another fish on that hook approaches zero. Also, bait such as nightcrawlers *Lumbricus terrestris* may fall off during deployment, deteriorate over time, or be removed by fish that are not retained. As this happens, the probability of collecting a fish on a baitless hook is assumed to be near zero.

Gear saturation affects catch rates, efficiency, and catchability, especially for trotlines (Hubert and Fabrizio 2007). Ricker (1975) reported gear saturation occurs as the number of baited hooks approach zero before the gear is retrieved and cannot continuously collect fish. As fish are hooked or as bait is removed from the hooks, trotlines become unavailable to additional fish encounters. Therefore, trotline saturation can easily be determined when all the hooks have collected a fish or had the bait removed. The difficulty is determining at what rate gear saturation occurs, which influences relative abundance estimates because catch is not continuously increasing as a function of time (Ricker 1975).

Finally, interspecific competition for the available hooks in a multi-species fishery also influences catch rate information. By-catch depletes the gear's fishing ability (# of hooks) within the area being fished, especially if the abundance of a non-targeted species greatly out numbers the targeted species. The ability to measure the exact capture time would allow researchers to determine if and when trotlines reach saturation, if interspecific competition is affecting the catch rates of other target species, and if fish are escaping the hook prior to the gear's retrieval.

Lindgren-Pitman (Pompano Beach, Florida, USA) developed a timing device designed for underwater use. It was designed to acquire accurate data for bait take or time of interaction for longline fishing. These battery powered digital clocks are encased in a plastic housing and are activated when a fish strikes the hook, pulling a magnetic reed switch and activating the timer (Somerton et al. 1988; Steffensen et al. 2011). Similar timer devices have assisted marine longline fishers to target optimal times, depths, areas, and temperatures as their lines sink to a predetermined depth (Somerton et al. 1988; Boggs 1992; Somerton and Kikkawa 1995; Berkeley and Edwards 1998; Erickson et al. 2000; Bach et al. 2002) and have also provided information useful to determine feeding times of targeted species, reduce mortalities, and increase capture efficiency through identifying optimal soak duration.

A preliminary, small-scale assessment of trot lines rigged with hook timers (8 trotline deployments [320 hook timers]) in the lower Missouri River concluded that hook timers do not affect catch rates compared to trot lines without hook timers, that hook timers can withstand harsh riverine conditions, and 69% of fish caught activated the timer (Steffensen et al. 2011). However, this preliminary study occurred during the fall resulting in lower catch rates as fish activity levels declined going into the cold water months. Our study was conducted during spring (early-April) when riverine species, especially sturgeon, are more readily collected to better aid the understanding of fish / trotline interactions. Our objectives were to (1) verify the activation rate of LP Hook Timers and determine if fish size affected activation, (2) document retention rates of trot lines and determine how fish escapement affects CPUE, (3) document real-time catch rates and determine if catch rates are influenced by set times or increase around sunset and sunrise due to an increase in fish activities during crepuscular periods, (4) determine the rate at which gear saturation occurred, and (5) determine if hook duration affects the number of fish exhibiting stress or distended mouth syndrome.

Methods

The study area included an 80.5 rkm reach of the upper channelized Missouri River from the confluence of the Platte and Missouri rivers (rkm 957.6) to Lower Barney Bend (877.1; Figure 4-1). Sampling occurred from 28 March 2011 to 14 April 2011 following the Pallid Sturgeon Population Assessment Project protocols (Welker and Drobish 2011) with water temperatures ranging from 3.0^{o} to 13.4^{o}C. Trot lines were deployed in channel border habitats, parallel to the river's current on inside bends. The channel border habitat is immediately downstream of the pool habitats formed by wing dikes and is between the bank and thalweg where depths are greater than 1.2 m. Trot lines were deployed in the early afternoon and pulled the following morning, not exceeding 24 hours soak duration (USFWS 2008).

Trot lines were 61-m long with 40, 3/0 circle hooks per line baited with nightcrawlers. Hooks were spaced every 1.5 m to avoid hook and fish entanglement. The LP Hook Timers were attached to the dropper line between the main line and the hook with a 38-cm leader and fastened to the main line using trot line snaps (Figure 4-2). The timer's digital display was activated by the removal of the plug which had a magnetic trigger located on the hook end of the timer. The timer recorded when the timer was activated (up to 24 h,) and we assumed the timers were activated immediately after the fish being hooked. Timers were constructed to activate at approximately 0.5 to 1 kg of pull. Hook timers that were activated less than 5 minutes after deployment and were fishless were assumed to have been pulled during deployment and were omitted from analysis. Similarly, hook timers activated less than 5 minutes prior to retrieval and fishless were assumed to have been pulled during the retrieval process were also omitted from the analysis. Any other hook that had the hook timer activated and was without bait was assumed to be a fish lost during the trotline's soak time. Set and retrieval times were recorded for each deployment and the hook timer display was recorded for every activated timer.

Catch rates were calculated as catch per unit effort (CPUE), or the number of individuals collected per trotline (40 hooks) set. Exact capture times were determined for each individual fish by determining when the fish activated the hook timer minus the retrieval time of the trot line. For hourly CPUE comparisons, CPUE was calculated based on real time hook availability. For example, when the trotline was first deployed the number of available hooks was 40. However, after a fish was captured (hooked), the number of available hooks was reduced to 39 to adjust catch rates throughout the entire soak time. However, this method only accounted for hook timers that were successfully activated. We could not account for fish that unsuccessfully activated the hook timer.

Results

We deployed 100 trot lines rigged with LP hook timers, but three of the hook timers were lost due to snags; therefore, we had 3,997 successful hook timer deployments. Timed trotlines collected 1,423 fish (9 species) and an additional 307 hook timers were activated but did not result in a capture (Table 4-1). Catches on any one line ranged from 0 to 40 fish per line. Of the fish collected, 813 (57%) successfully activated the hook timers while 610 fish were unable to activate the hook timers. Shovelnose sturgeon *S. platorynchus* were the most frequently collected species (N = 1,308) and activated hook timers 58% of the time, followed by pallid sturgeon (N = 58; 53% activation rate) and channel catfish *Ictalurus punctatus* (N = 29; 14% activation rate).

The size of pallid sturgeon that successfully activated hook timers (mean fork length (FL) = 750 mm; SE = 175) versus those that did not (mean FL = 447 mm; SE = 72) was significantly different (P < 0.001; Table 4-1). However, the size of shovelnose sturgeon (P = 0.191) and channel catfish (P = 0.175) that activated the timers were not different. All other species were collected at low frequencies (N < 15); therefore, comparing hook timer activation by size was not completed.

Mean catch per unit effort for all species collected on trotlines rigged with hook timers was 14.6 fish per line with sturgeon species accounting for 14.0 fish per line (Table 4-2). However, 307 hook timers were activated but did not capture a fish, resulting in a mean CPUE of 3.1 lost fish per line. Therefore, retention rate for trotlines is estimated at 73%. Consequently, adjusting for the lost fish would result in an extrapolated CPUE of 17.7 fish per line if all fish hooked were retained.

Overall, 20% of the hook timer activations occurred within 1 h of deployment with an additional 13% in the second hour and 12% in the third hour of deployment (Figure 4-3). Over half (55%) of all fish were collected within 4 h of deployment and only 15% (N = 121) of fish were collected after trotlines were deployed for greater than 10 h. Hook timers that were activated but did not capture a fish mimicked the distribution of collected fish with 18% activated within 1 h and 51% in the first four hours. When accounting for reduced hook availability as fish are collected, the percentage of fish collected per h declines through time (Figure 4-4). Fish were collected on 8% of the available hooks during the first hour of deployment and this declined to 5% for each of the next 2 hrs.

Species specific hourly catch rates (based on hook availability, not total number of hooks) indicate that the highest CPUE (0.0029; SE = 0.0011) for pallid sturgeon occurred during 0-1 h post deployment followed by the 3-4 h post deployment (CPUE = 0.0018; SE = 0.0007; Figure 4-5). Overall, 68% of pallid sturgeon were collected within 4 h but were collected as late as 19 h 57 min post-deployment. Shovelnose sturgeon were also most frequently collected during the first hour (CPUE = 0.051; SE = 0.006) and catch rates continued to decline through time (Figure 4-5).

The median set time for the trotlines was 1437 hours (range, 1156 to 1643). Over half, 62% (N = 508) of the fish collected were collected before sunset (median sunset, 1956). An additional 266 fish (33%) were collected after sunset and before sunrise (median sunrise, 0654) whereas only 39 fish (5%) were captured after sunrise (median pull time, 1047 [range, 0839 to 1245]). The highest CPUE for pallid sturgeon occurred from 1500 to 1600 hours (0.0019; SE = 0.0007) followed by the period from 1700 to 1800 hours (CPUE = 0.0014; SE = 0.0006; Figure 4-6). Similar to pallid sturgeon, CPUE for shovelnose sturgeon was highest during the 1500 to 1600 hours.

Six fish (one pallid sturgeon and five shovelnose sturgeon) were thought to be stressed (visually red in color and swelling of small blood vessels around the mouth and in the fins) upon trotline retrieval. Only two of the stressed individuals (both shovelnose sturgeon) activated the hook timer. One individual was hooked for at least 14 hours 14 minutes and the other fish was hooked for at least 9 hours 49 minutes. In addition to the stress, 46 sturgeon (five pallid sturgeon and 41 shovelnose sturgeon) were suffering from distended mouth syndrome. Hook duration for fish suffering from distended mouth syndrome was highly variable (range, 6 hours 37 minutes to 20 hours 50 minutes). Finally, one mortality occurred during this study; however, the fish did not activate the hook timer so hook time duration could not be determined. The fish was an adult shovelnose sturgeon (FL = 565 mm; W = 665 g) and was not abnormally hooked.

Discussion

Trotlines are primarily used recreationally and commercially in freshwater systems but have proven to be a useful gear for research. Trot lines are used to track relative abundance, target sampling areas (i.e., areas full of snags) where other sampling methods are not feasible, and target reproductively ready adult fish for propagation purposes or telemetry projects. Integrating hook timers provides more detailed information such as real-time catch rates, retention rates, and the effect of retention rate on relative abundance measurements. In our study, the main intent was to collect pallid sturgeon in reproductive condition for artificial propagation. With the use of hook timers, it is possible to discern any collection patterns when these targeted fish are collected.

Hubert (1996) noted that trotlines are rarely used to sample or monitor inland fish stocks because they are very selective and catch rates vary widely. Our results support this statement because in the season and conditions that our study was conducted, the majority (96%) of fish collected was sturgeon with catch rates averaging 14.6 fish per line but varying from 0 to 40 fish per line. Researchers can take advantage of this bias, when the goal is to target a species known to be susceptible to trotlines. The impetus for our study was to gain an understanding of trotlines and their capacity to catch a target species (i.e., pallid sturgeon) and to gain a better understanding of how trotlines temporally collect fish. However, trotlines may be a viable gear for sampling other species (i.e., catfish) when temporal and spatial conditions make a particular species susceptible to being captured by trotlines.

Understanding the interaction of fish with the gears used to collect them is a critical element of our understanding of that gear's efficacy and application. This is especially true for trot lines because they have a limited number of possible catches based on the number of hooks available. We observed little evidence of stress on the fish collected by trotlines. In our study, trotline effects on sturgeon species appeared minimal as only one shovelnose sturgeon mortality occurred and only six fish showed signs of stress. These conditions did not appear to be correlated with hook duration, but rather entanglement with the main line. Sturgeon have a soft cartilaginous mouth and some sturgeon experienced distended mouth syndrome (the inability to retract their mouth for a short period of time) as a result of being hooked. Similar to stress, this did not appear to be correlated with hook duration and sturgeon quickly recovered after removal from the hook.

As trotlines are used more frequently as an assessment tool, the associated gear biases need to be understood. For example, the size structure trotlines collect is affected by the size of hook selected. Our study used a 3/0 circle hook and collected sturgeon from 333 to 999 mm; therefore, this gear was not effective at sampling small bodied fishes. Using smaller hooks could possibly increase the likelihood of capturing smaller fish but would likely result in increased by-catch of other smaller bodied fish and increase the likelihood of a hooking mortality of target species that swallow the hook.

Catch rates are affected by the number of baited hooks available because the probability of capturing a fish on a hook without bait is likely zero. We observed, during retrieval of the gear, that the majority of hooks (approximately 95%) no longer had bait and had likely been unable to attract fish for at least some portion of the soak time. Bait can be depleted due to a fish removing the bait and escaping the hook prior to gear retrieval, small fish “picking” the worm off the hook without activating the hook timer, or the worm physically falling off due to deterioration. Therefore, future studies should quantify the rate bait loss occurs to assess when hooks become unavailable to capture fish.

Further investigation using hook timers may determine the optimal time to deploy gear to better improve catch rates. The median deployment time during our study was 1437 hours (range, 1156 to 1643). Determining optimal deployment time was not part of our study design; rather, sampling crews pulled trotlines in the morning and depending on crew size, experience, and number of fish collected, redeployment generally occurred in early afternoon. Future studies should include deploying gear at other times of the day to evaluate deployment times and the influence on catch rates.

The information gathered from this study and further investigation with hook timers could aid in targeting specific times of day and set duration to more efficiently collect target species. We found that more than half of all fish were caught within the first four hours of deployment. Therefore, short duration trotline deployments (i.e., 4-h) would collect approximately 50% of the fish and may reduce escapement rates. Multiple, short duration sets per day could also keep bait on the hooks, potentially improve catch and retention rates, and reduce stress and possible mortalities. Detailed information can be ascertained from the use of trotlines rigged with hook timers and will aid our understanding of fish-trotline interactions.

References

Arterburn, J. E., and C. R. Berry. 2001. Effect of hook style, bait type, and river location on trotline catches of flathead and channel catfish. North American Journal of Fisheries Management 22:573-578.

Bach, P., L. Dagorn, A. Bertrand, E. Josse, and C. Misselis. 2002. Acoustic telemetry versus monitored longline fishing for studying the vertical distribution of pelagic fish: bigeye tuna (*Thunnus obesus*) in French Polynesia. Fisheries Research 60:281-292.

Berkeley, S. A., and R. E. Edwards. 1998. Factors affecting billfish capture and survival in longline fisheries; potential application for reducing bycatch mortality. Collective Volume of Scientific Paper. International Commission for the Conservation of Atlantic Tunas 48:255-262.

Bettoli, P. W., M. Casto-Yerty, G. D. Scholten, and E. Heist. 2009. Bycatch of the endangered pallid sturgeon (*Scaphirhynchus albus*) in a commercial fishery for shovelnose sturgeon (*S. platorynchus*). Journal of Applied Ichthyology 25:1-4.

Boggs, C. H. 1992. Depth, capture time, and hooked longevity of longline-caught pelagic fish: timing bites of fish with chips. Fishery Bulletin 90:642-658.

Erickson, D., S. Goldhor, and R. Giurea. 2000. Efficiency and species selectivity of fabricated baits used in Alaska demersal longline fisheries. International Council for the Exploration of the Sea, ICES CM 2000/J:04.

Graham, L. K. 1997. A study of catfish in the tailwaters of Harry S. Truman Dam and upper Lake of the Ozarks. Missouri Department of Conservation, Sport Fish Restoration Project F-1-R-46, Study S-38, Final Report, Jefferson City, Missouri.

Hubert, W. A. 1996. Passive capture techniques. Pages 157-181 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Hubert, W. A., and M. C. Fabrizio. 2007. Relative abundance and catch per unit effort. Pages 279-325 *in* C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Killgore, K. J., J. J. Hoover, J. P. Kirk, S. G. George, B. R. Lewis, and C. E. Murphy. 2007. Distribution, relative abundance and movement of pallid sturgeon in the free-flowing Missisippi River. Journal of Applied Ichthyology 23:476-483.

Peters, E. J., and J. E. Parham. 2008. Ecology and management of the sturgeon in the lower Platte River, Nebraska. Nebraska Technical Series Number 18. Nebraska Game and Parks Commission, Lincoln, Nebraska.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191:1-382.

Somerton, D. A., B. S. Kikkawa, and C. D. Wilson. 1988. Hook timers to measure the capture time of individual fish. Marine Fisheries Review 50:1-5.

Somerton, D. A., and B. S. Kikkawa. 1995. A stock survey technique using the time to capture individual fish of longlines. Canadian Journal of Fisheries and Aquatic Sciences 52:260-267.

Starrett, W. C., and P. G. Barnickol. 1955. Efficiency and selectivity of commercial fishing devices used on the Mississippi River. Illinois Natural History Survey Bulletin 26:325-366.

Steffensen K. D., B. L. Eder, and M. A. Pegg. 2011. Using Lindgren-Pitman hook timers to understand the dynamics of trotline catches in a large river. North American Journal of Fisheries Management 31:980-985.

U.S. Fish and Wildlife Service. 2008. Biological procedures and protocols for researchers and managers handling pallid sturgeon. U.S. Fish and Wildlife Service, Billings, Montana.

Vokoun, J. C., and C. F. Rabeni. 1999. Catfish sampling in rivers and streams: a review of strategies, gears, and methods. Pages 271-286 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and R. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Ward, P., R. A. Ransom, and W. Blanchard. 2005. A fish lost at sea: the effect of soak time on pelagic longline catches. Fishery Bulletin 102:179-195.

Welker, T. L., and M. R. Drobish (editors). 2011. Missouri River standard operating procedures for fish sampling and data collection, volume 1.6. U.S. Army Corps of Engineers, Omaha District, Yankton, South Dakota.

Table 4-1. Total number of fish collected on hook timer trotlines, the total number that did and did not activate the timer, and their mean fork length (FL) including the minimum and maximum size by species in the upper channelized Missouri River, Nebraska.

Species	Total collected	Hook timer activated									
		Yes					No				
		Number	Mean FL	SD	Min	Max	Number	Mean FL	SD	Min	Max
Blue sucker	7	7	767.1	63.6	693	858					
Channel catfish	29	4	310.5	87.5	208	415	25	299.8	55.8	192	390
Common carp	3	3	667.6	101.5	592	783					
Freshwater drum	2	1	439.0				1	310.0			
Grass carp	3	3	630.3	41.5	593	675					
Pallid sturgeon	58	31	749.9	175.3	385	979	27	446.9	71.8	333	696
Shovelnose sturgeon	1308	761	568.9	47.7	395	742	547	538.6	50.2	353	701
Smallmouth buffalo	2	2	609.5	34.6	585	634					
Stonecat	11	1	163.0				10	163.6	12.2	150	186
Lost fish	307	307									

Table 4-2. Mean catch per unit effort (fish / line) for all species collected during this study on hook timer trotlines that did or did not activate the timer in the upper channelized Missouri River, Nebraska.

Species	Activated hook timers		Non-activated hook timers		Overall	
	CPUE	SE	CPUE	SE	CPUE	SE
Blue sucker	0.1	< 0.1			0.1	< 0.1
Channel catfish	< 0.1	< 0.1	0.3	0.1	0.3	0.1
Common carp	< 0.1	< 0.1			< 0.1	< 0.1
Freshwater drum	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Grass carp	< 0.1	< 0.1			< 0.1	< 0.1
Pallid sturgeon	0.3	0.1	0.3	0.1	0.6	< 0.1
Shovelnose sturgeon	7.8	0.6	5.6	0.1	13.4	1.1
Smallmouth buffalo	< 0.1	< 0.1			< 0.1	< 0.1
Stonecat	< 0.1	< 0.1	0.1	< 0.1	0.1	0.1
Lost fish	3.1	0.3	N/A	N/A		
				Overall	14.6	1.5
				Extrapolated overall CPUE	17.7	1.3

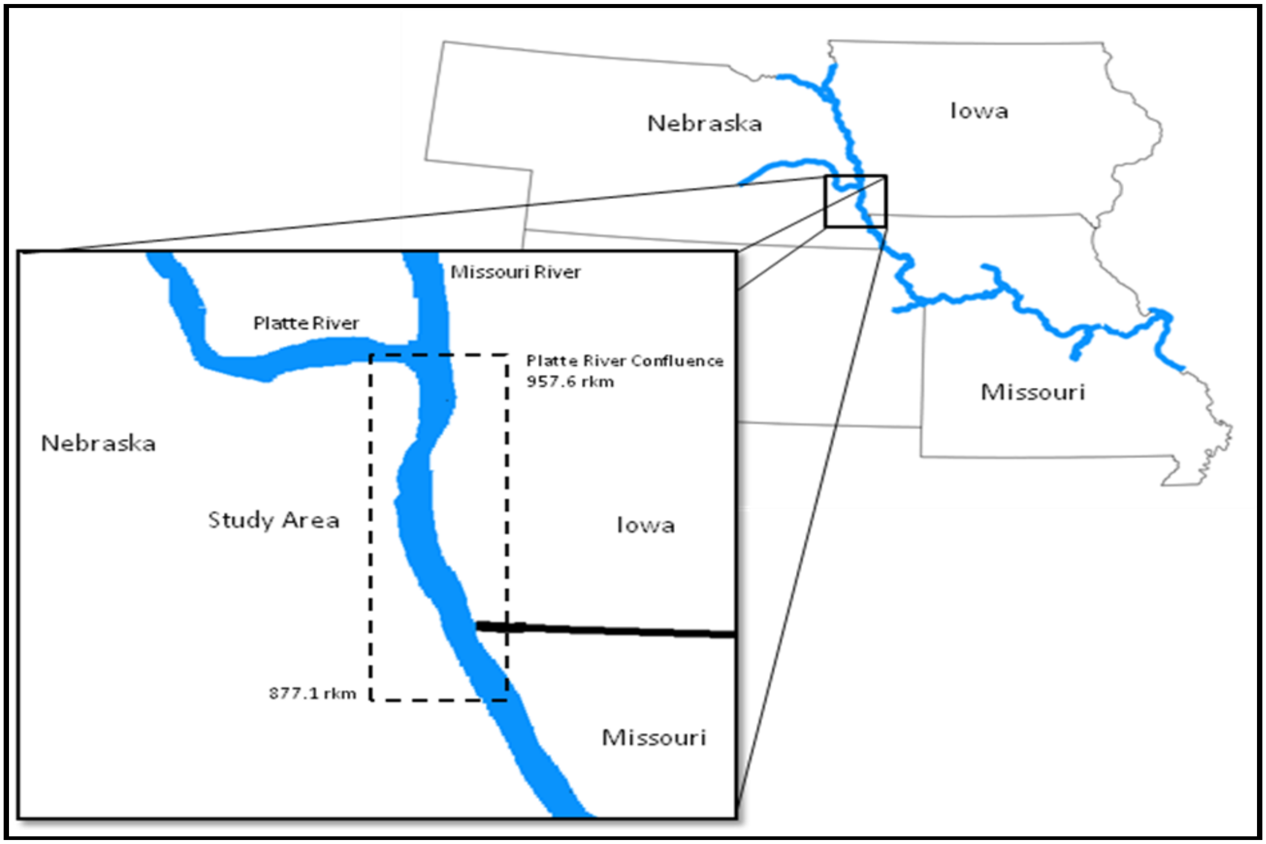

Figure 4-1. The study area encompassing the 80.5 river-kilometer (rkm) sampling reach from the confluence of the Missouri and Platte River at rkm 957.6 downstream to rkm 877.1 in the upper channelized Missouri River, Nebraska.

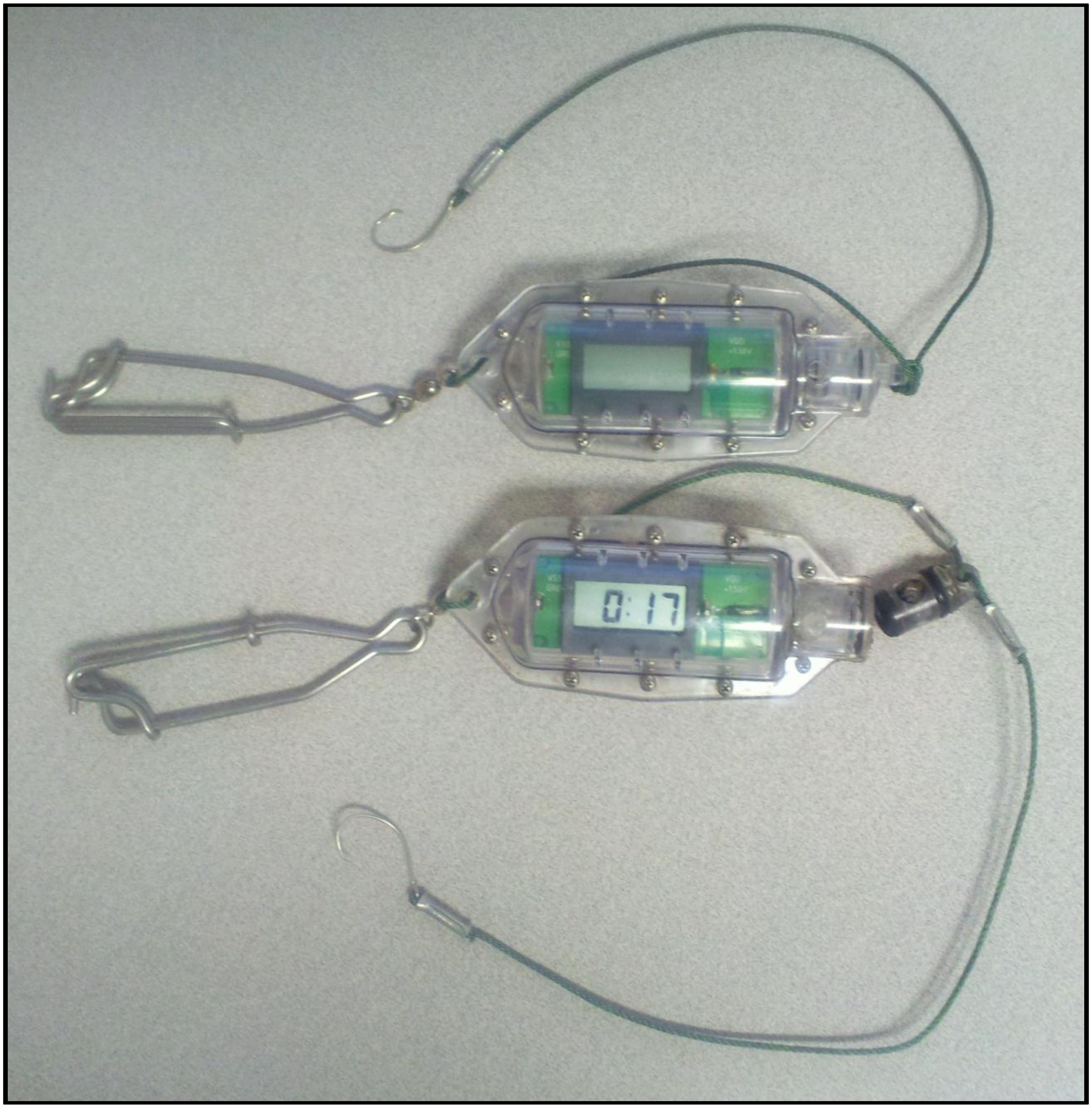

Figure 4-2. Rigged Lindgren-Pitman hook timer, the timer on the top has the activation plug in place while the bottom timer was activated by removing the magnetic plug 17 minutes ago.

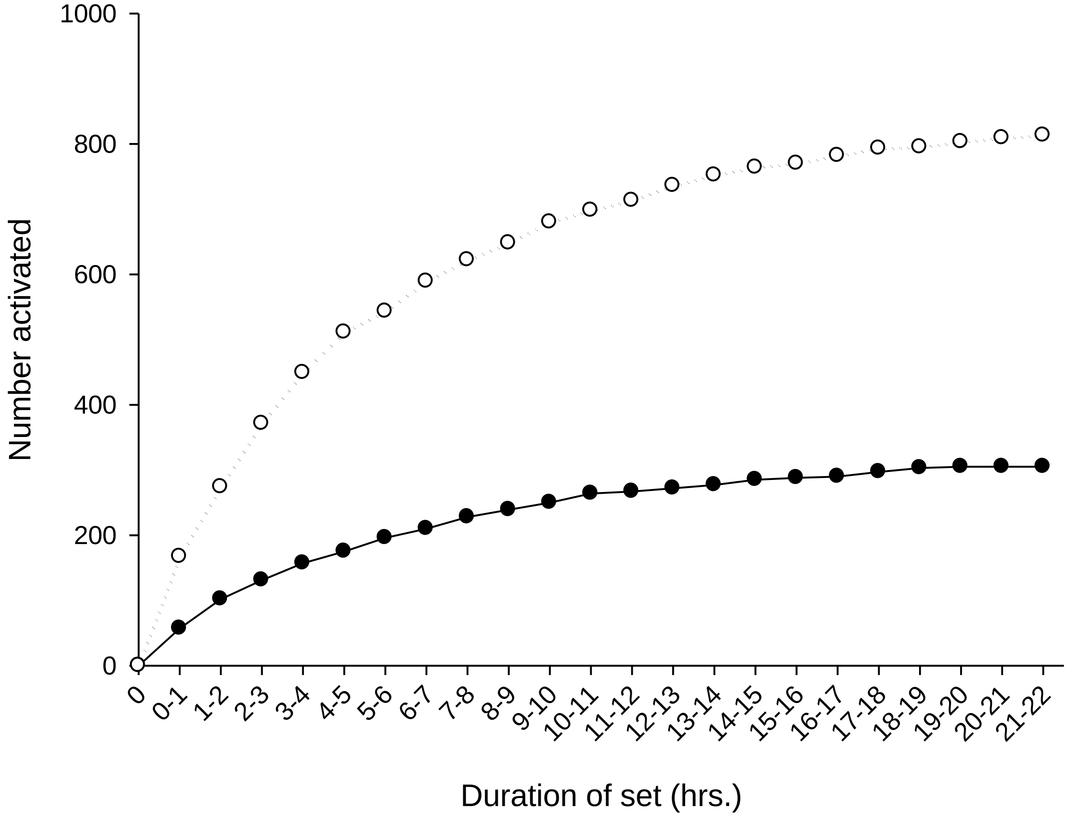

Figure 4-3. Number of hook timers activated during this study in the upper channelized Missouri River for all fish by 1-h intervals post deployment. Open circles are fish that activated the hook timer and were retained until the trotline was retrieved. Solid circles represent hook timers that were activated but did not collect a fish.

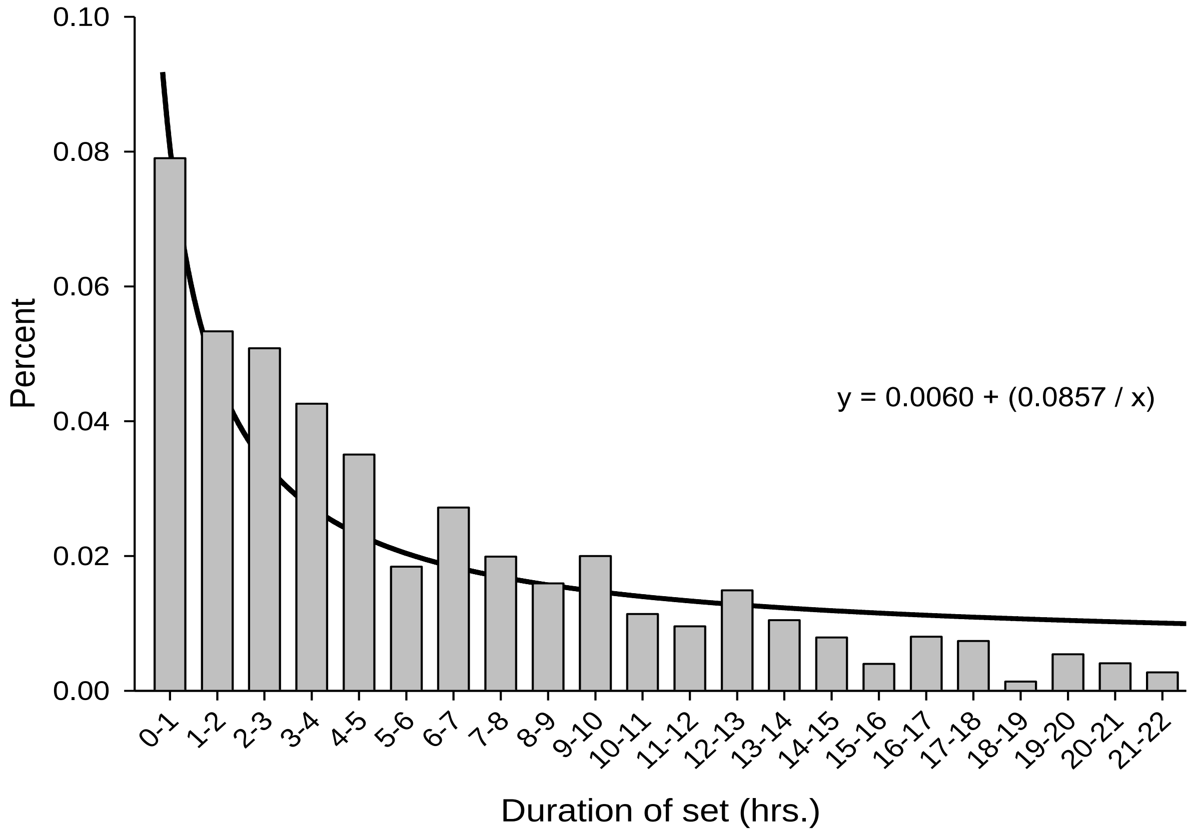

Figure 4-4. Percent of total fish collected during this study in the upper channelized Missouri River based on hook availability by 1-h intervals post deployment. Hook availability is based on real-time effort and adjusted when a fish is collected by reducing the number of hook available.

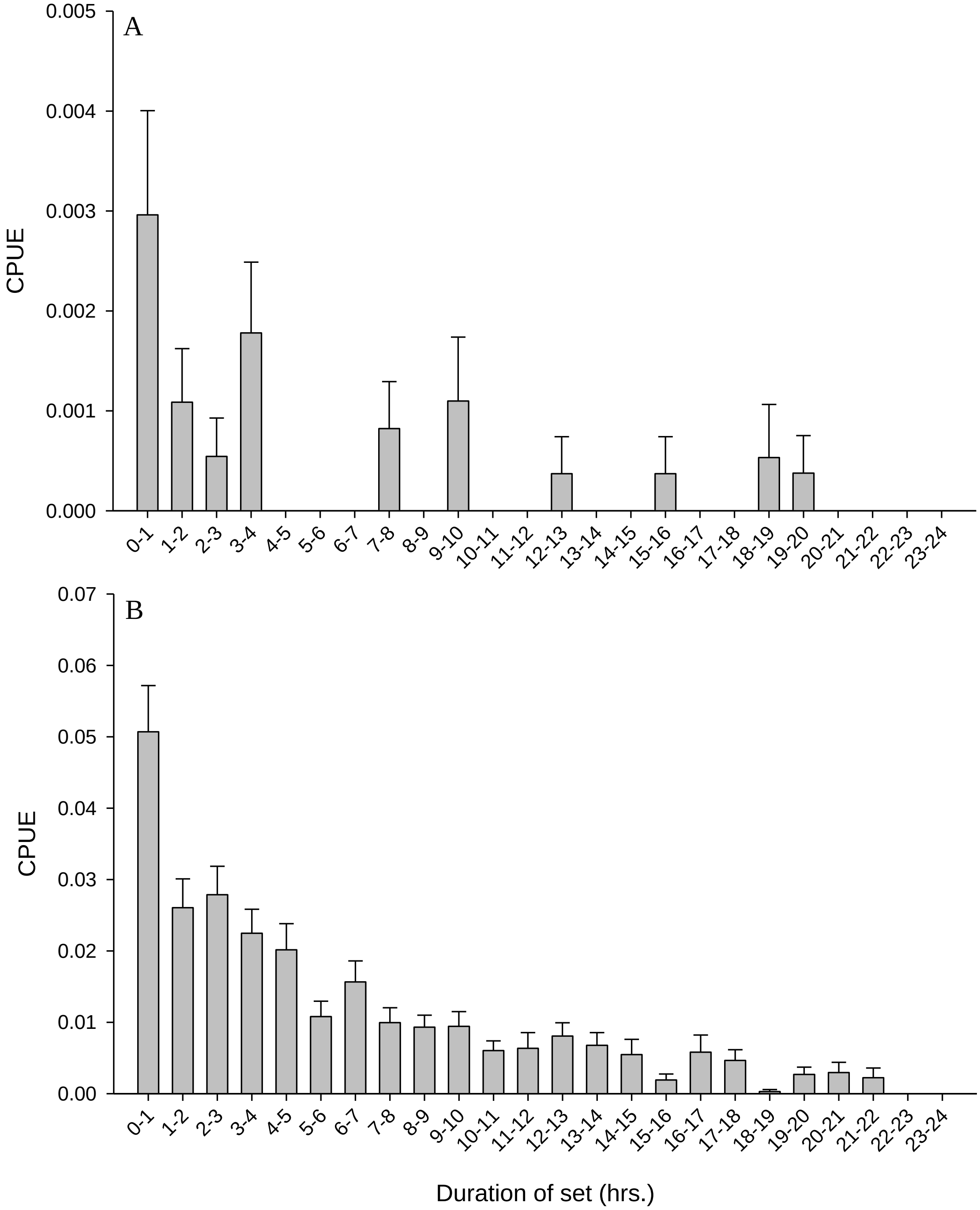

Figure 4-5. Mean catch per unit effort during this study in the upper channelized Missouri River based on hook availability for (A) pallid sturgeon and (B) shovelnose sturgeon by 1-h intervals post deployment. Hook availability is based on real-time effort and adjusted when a fish is collected by reducing the number of hooks available. Error bars represent ±2SE.

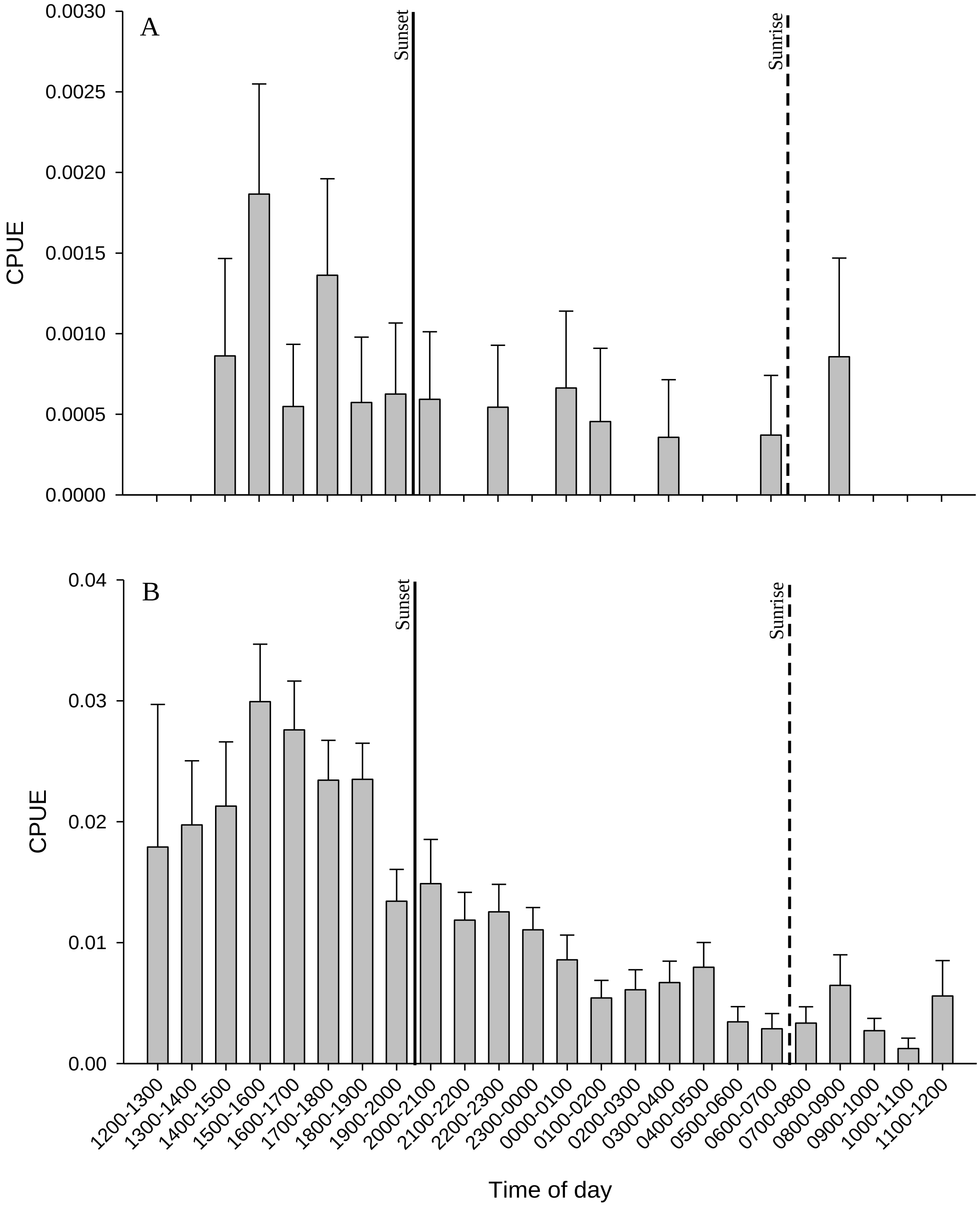

Figure 4-6. Mean catch per unit effort during this study in the upper channelized Missouri River based on hook availability for (A) pallid sturgeon and (B) shovelnose sturgeon by time of day (1-h intervals). Hook availability is based on real-time effort and adjusted when a fish is collected by reducing the number of hook available. Error bars represent ±2SE.

CHAPTER 5:

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Pallid sturgeon range from the upper Missouri River to the lower Mississippi and Atchafalaya rivers and are currently managed within four management units (USFWS 2008; Figure 1). These units are based on being reproductively isolated (i.e., Great Plains Management Unit [GPMU]) and genetic and morphologic differences (i.e., Central Lowlands Management Unit [CLMU], Interior Highlands Management Unit [IHMU], and Coastal Plains Management Unit [CPMU]). Inter-jurisdictional management within state and federal governmental agencies is necessary because the lower Missouri River fishery is under the jurisdiction of the Federal Endangered Species Act (USFWS 1990), five states (South Dakota, Nebraska, Iowa, Missouri, and Kansas), and two pallid sturgeon management units (CLMU and IHMU). The Middle Basin Pallid Sturgeon Workgroup {MBPSW), under the guidance of the Pallid Sturgeon Recovery Team, has brought together state and federal agencies to cooperatively manage pallid sturgeon across the lower Missouri River. This collaboration has increased the understanding of pallid sturgeon but several key components are yet to be quantified.

Understanding pallid sturgeon population characteristics is critical for assessing species recovery efforts. Many actions have been taken including, but not limited to, creation of a captive broodstock, habitat restoration, and development of an artificial propagation program while protecting the remaining wild individuals from harm, harassment, and death (Dryer and Sandvol 1993). Although hatchery supplementation is not the sole solution to species recovery, it has greatly increased the population of the lower Missouri River pallid sturgeon population. These hatchery-reared pallid sturgeon have been documented reproductively ready and have successfully spawned (DeLonay et al. 2010, DeLonay et al. 2012); however, survival and recruitment is yet to be documented. A self-sustaining population is the ultimate goal; however, understanding the effects of management actions is critical to species recovery. In addition, continued monitoring and evaluation is necessary to assess the wild and hatchery-reared populations and to evaluate the effects of the stocking program to ensure proper management.

The objective of my thesis was to characterize the pallid sturgeon population, predict the current and future wild and hatchery-reared pallid sturgeon populations, and examine the catch dynamics of pallid sturgeon in the lower Missouri River. Specifically, I evaluated the following objectives and conclude the following results.

(1) Determine the population characteristics of the pallid sturgeon population in the lower Missouri River (Chapter 2).

   a. Catch rates of wild pallid sturgeon with gill nets did not change ($P = 0.8991$) during this study while catch rates using trot lines declined ($P = 0.0001$). Comparatively, catch rates of hatchery-reared pallid sturgeon with gill nets ($P = 0.2290$) and trot lines ($P = 0.0610$) were variable but did not differ among years.

   b. The ratio for reproductively ready to non-reproductively ready females was 1:2.0 while the ratio for males was 1:0.9, resulting an overall ratio of reproductively ready fish of 1 female to 2.9 males.

   c. Minimum length-at-maturity was 788 mm for females and 798 mm for males while minimum age-at-maturity, using tag information from known-aged hatchery-reared fish, was age-9 for females and age-7 for males.
   d. Relative condition factor for females was significantly different by reproductive condition (P = 0.0014). The mean for reproductively ready females was 0.97 (SE = 0.02) compared to non-reproductively ready fish (Mean Kn = 0.90, SE = 0.01). Conversely, males did not display a similar trend (P = 0.2634).
   e. Absolute fecundity varied from 12,220 to 54,705 with a mean relative fecundity of 7% (SD = 1.5%).
   f. Egg size was not correlated with fork length (P = 0.1987) or weight (P = 0.2848); however, fork length (P = 0.0114) and weight (P = 0.0042) were correlated with the number of eggs released.
   g. The mean survival rate from egg to stock sized fish was 15.1% (SD = 14.7%) but was highly variable (1.9% to 42.8%).

(2) Use data from Objective #1, along with existing known population information (i.e., survival estimate and population estimate), to develop a population viability model for the lower Missouri River (Chapter 3).

   a. My model estimates the wild population size at 5,991 (± 499) in 2012 and predicts the wild pallid sturgeon population will decline to 2,659 (± 222) individuals in ten years, 1,181 (± 98) in twenty years, and 524 (± 44) in thirty years.

b. My model predicted 42,343 (± 4,570) hatchery-reared pallid sturgeon with an estimated 13,867 (age-9 females = 3,537 [± 864]; age-7 males = 10,330 [± 1,787]) reproductively aged fish were in the lower Missouri River in 2012.
c. The overall pallid sturgeon population is estimated at 48,334 fish with 659 wild and 989 hatchery-reared reproductively ready female pallid sturgeon.
d. If hatchery supplementation ceased and assuming no natural recruitment occurred, the population would decline at approximately 8% annually with only 3,801 pallid sturgeon remaining in 30 years. If naturally produced pallid sturgeon survival rate is 0.00001 from egg to age-1 then the rates of decline would be 7% and the population size in 30 years would be 5,854 fish. A fivefold increase in the egg to age-1 survival rate (Ø = 0.00005) means 2,151 pallid sturgeon would recruit to age-1 in 2012 and the projected 30 year population size would increase to 20,621 fish. If an egg to age-1 survival rate of 0.00010 occurred then 5,543 pallid sturgeon would recruit to the age-1 in 2012 and the population size would be 62,831 in 2042.
e. An annual egg to age-1 survival rates of 0.00011 is predicted to maintain a stable population over the next 30 years.

f. Our model simulations of the overall change in the pallid sturgeon population were most sensitive to ≥ age-1 survival rates. Changing the age-1 survival estimate by ±5% caused a ± 2.8% change in the population of pallid sturgeon. The population change was less sensitive to age-0 survival rates from stocked hatchery-reared fish, survival rates for natural production, and fecundity.

g. Changing the spawning frequency from every three years to every other year would affect the overall population growth by 2.7%. Underestimation of this parameter with a spawning frequency of 4 to 5 years would predict a population decrease of 1.3% for 4 years and 2.0% for 5 years.

h. Age-at-maturity is a less sensitive parameter than spawning frequency. Increasing female's age-at-maturity by one year (age-8) changed λ by 0.4%, while maturing at age-7 would result in a 1% overall population change. A decrease in age-at-maturity to age-10 or 11 only changes λ by 0.3% and 0.6%.

(3) Examine trot line catch dynamics in a large river system by using information gathered from LP Hook Timers (Chapter 4).

a. Shovelnose sturgeon were the most frequently collected species (N = 1,308) and activated hook timers 58% of the time, followed by pallid sturgeon (N = 58; 53% activation rate) and channel catfish (N = 29; 14% activation rate).

b. The size of pallid sturgeon that successfully activated hook timers (mean FL = 750 mm; SE = 175) versus those that did not (mean FL = 447 mm; SE 72) was different (P < 0.001). However, the size of shovelnose sturgeon (P = 0.191) and channel catfish (P = 0.175) that activated the timers were not different.
c. Mean catch per unit effort for trotlines rigged with hook timers was 14.6 fish (SE = 1.5) per line, adjusting for the lost fish resulted in a CPUE of 17.7 (SE = 1.3) fish per line.
d. Overall, 20% of the hook timer activations occurred within 1 h of deployment with over half (55%) collected within 4 h of deployment.
e. Of the 1,423 fish collected, six fish (one pallid sturgeon and five shovelnose sturgeon) were visually stressed upon trotline retrieval while 46 sturgeon (5 pallid sturgeon and 41 shovelnose sturgeon) had distended mouth syndrome. Hook duration for fish with distended mouth syndrome was highly variable.
f. One mortality occurred during this study; however, the fish did not activate the hook timer so hook time duration could not be determined.

Management and Research Recommendations

As part of the results of this study, more information and research is required to continue the species recovery efforts; therefore, I present the following management considerations and recommendations:

1. Continuation of the intensive broodstock collection efforts led by the Nebraska Game and Parks Commission (NGPC) is a vital part to local species recovery and acquiring important life history data. Besides the capture of adult fish for the propagation and artificial supplementation program, the associated data being collected have contributed to a preliminary survival estimate (Steffensen et al. 2010), a population estimate (Steffensen et al. 2012), and defining the population structure and characteristics (Chapter 1), which are critical input parameters in the population viability model (Chapter 2). Also, since the Pallid Sturgeon Recovery Team placed a moratorium on stocking Upper Basin origin fish in the lower Missouri River and the need for local broodstock became the priority, the majority of broodfish have been collected by NGPC, primarily around the Platte River, NE.

2. My model simulations of the overall change in the pallid sturgeon population were most sensitive to ≥ age-1 survival rates. Validating Steffensen et al. (2010) estimates and expanding the age specific survival rates would greatly benefit the

population viability model's accuracy and predictions. Steffensen at al. (2010) estimates only provided survival estimates for three age classes (age-0, age-1, and ≥ age-2) because of limited pallid sturgeon stock / recapture data when the analysis was completed. Expanding the age-specific survival rates may provide insights into critical life history events (i.e., ontogenetic diet changes).

3. The wild population estimates used in our population viability model was derived from Steffensen et al. (2012) estimate of wild and hatchery-reared populations in an 80.5 rkm reach in the lower Missouri River. The Steffensen's estimate is based on fish collected during Nebraska Game and Parks Commission's annual broodstock collection effort below the confluence of the Missouri and Platte rivers (rkm 957.5), a known pallid sturgeon "hot spot". The wild pallid sturgeon population estimate in this paper assumes equal distribution throughout the lower Missouri River as the data is extrapolated from the 80.5 rkm reach. This extrapolation may overestimate the real population size in the lower Missouri River as more adult pallid sturgeon are captured in the upper reach of the lower Missouri River (Huenemann 2012). Completion of a river wide population estimate would provide real estimates rather than the basic extrapolation methods currently being used.

4. Quantifying the age structure of the wild pallid sturgeon population was not possible as an age / length key is not available in this reach of the Missouri River.

Therefore, quantifying local extirpation of the wild pallid sturgeon population is difficult since the age structure of the wild population and the maximum age remains unknown in this reach. Several validation studies for aging sturgeon have concluded that fin rays are not a reliable method and the results should be viewed with caution (Hurley et al. 2004; Whiteman et al. 2004; Koch et al. 2011). However, I would recommend removing fin rays from the broodfish collected and known aged hatchery-reared fish during future efforts to attempt to provide some age and growth information while using the known aged fish to validate and refine readers' abilities. Even if the age estimates are not precise, gaining information on the age structure would provide an estimated maximum age of pallid sturgeon in the lower Missouri River.

5. Increasing the stocked hatchery-reared pallid sturgeon likelihood of survival should be a priority. Age-1 survival was the most sensitive parameter in the population viability model followed closely by age-2, age-3, and so on. For example, stocking 10,000 age-0 hatchery-reared fish, only 221 (age-7 males = 156; age-9 females = 65) reach age-of-maturity compared to stocking 10,000 age-1 hatchery-reared fish when 4,304 (age-7 males = 3,020; age-9 females = 1,284) reach age-of maturity. Under the current survival estimates and the importance of survival of younger individuals in our model, we would recommend maximizing the number of age-1 + fish stocked and only stocking age-0 fish when necessary (i.e., to reduce number to meet hatchery capacities).

Also, we recommend determining the cost difference associated with rearing age-0 fish compared to age-1 fish and determine the hatcheries capacities for each age class. To achieve the similar numbers of fish that reach maturity, age-0 fish would need to be stocked at a frequency of approximately 20 times that of age-1 fish. It is unlikely that field crews can collect enough reproductively ready female pallid sturgeon annually to rely solely on age-0 stocking.

6. The overall population objective is to reach an estimated 30,000 spawning-aged adults in the lower Missouri River (USFWS 2008). To achieve this goal, the Pallid Sturgeon Range-Wide Stocking and Augmentation Plan (2008) recommends an annual stocking effort of 33,560 age-1 pallid sturgeon in the Missouri River below Gavins Point Dam (rkm 1,305) for the next eight years. Since this recommendation was published in 2008, a total of 49,410 hatchery-reared pallid sturgeon have been stocked resulting in a deficit. Continuation of the stocking program for the next 10 years (i.e., stocking 10,000 age-1 hatchery-reared pallid sturgeon) would result in greater than 30,000 spawning aged adults in the lower Missouri River. At that point, reassessment of natural recruitment and mortality would be needed to evaluate artificial propagation.

7. Trot line catch rates are affected by the number of baited hooks available because the probability of capturing a fish on a hook without bait is likely zero. During retrieval of the gear, that the majority of hooks no longer had bait and had likely been unable to attract fish for at least some portion of the soak time.

Therefore, future studies should quantify the rate bait loss occurs to assess when hooks become unavailable to capture fish.

8. Further investigation using hook timers may determine the optimal time to deploy gear to better improve catch rates. Determining optimal deployment time was not part of my study design; rather, sampling crews pulled trotlines in the morning and depending on crew size, experience, and number of fish collected, redeployment generally occurred in early afternoon. Future studies should include deploying gear at other times of the day to evaluate deployment times and the influence on catch rates.

9. Finally, I recommend experimenting with short duration trot line deployments (i.e., 4-h). Hook timers showed more than half of all fish were caught within the first four hours of deployment. Therefore, short duration trotline deployments would collect approximately 50% of the fish and may reduce escapement rates. Multiple short duration sets per day could also keep bait on the hooks, potentially improve catch and retention rates, and reduce stress and possible mortalities.

References

Dryer, M. P., and A. J. Sandvol. 1993. Pallid sturgeon recovery plan. U.S. Fish and Wildlife Service, Bismarck, North Dakota.

DeLonay, A. J., R. B. Jacobson, D. M. Papoulias, M. L. Wildhaber, K. A. Chojnacki, E. K. Pherigo, C. L. Bergthold, and G. E. Mestl. 2010. Ecological requirements for pallid sturgeon reproduction and recruitment in the lower Missouri River: annual report 2009. U.S. Geological Survey Open-File Report 2010-1215. 64 p.

DeLonay, A. J., Jacobson, R. B., Papoulias, D. M., Wildhaber M. L., Chojnacki, K. A., Pherigo, E. K., Haas, J. D., and Mestl, G. E. 2012. Ecological requirements for pallid sturgeon reproduction and recruitment in the Lower Missouri River: Annual report 2010. U.S. Geological Survey, Columbia, Missouri.

Huenemann, T. W. 2012. Central lowlands and interior highlands pallid sturgeon spawning and stocking summary. Nebraska Game and Parks Commission, Lincoln, Nebraska.

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

Koch, J. D., K. D. Steffensen, and M. A. Pegg. 2011. Validation of age estimates obtained from juvenile pallid sturgeon *Scaphirhynchus albus* pectoral fin spines. Journal of Applied Ichthyology 27:209-212.

Steffensen, K. D., L. A. Powell, and J. D. Koch. 2010. Assessment of hatchery-reared pallid sturgeon survival in the lower Missouri River. North American Journal of Fisheries Management 30:671-678.

Steffensen, K.D. , L. A. Powell, and M. A. Pegg. 2012. Population size of hatchery-reared and wild pallid sturgeon in the lower Missouri River. North American Journal of Fisheries Management 32:159-166.

U.S. Fish and Wildlife Service. 1990. Endangered and threatened wildlife and plants; determinations of endangered status for the pallid sturgeon. Federal Register 55(173):36641-36647.

U.S. Fish and Wildlife Service. 2008. Pallid sturgeon (*Scaphirhynchus albus*) range-wide stocking and augmentation plan. U.S. Fish and Wildlife Service, Billings, Montana.

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

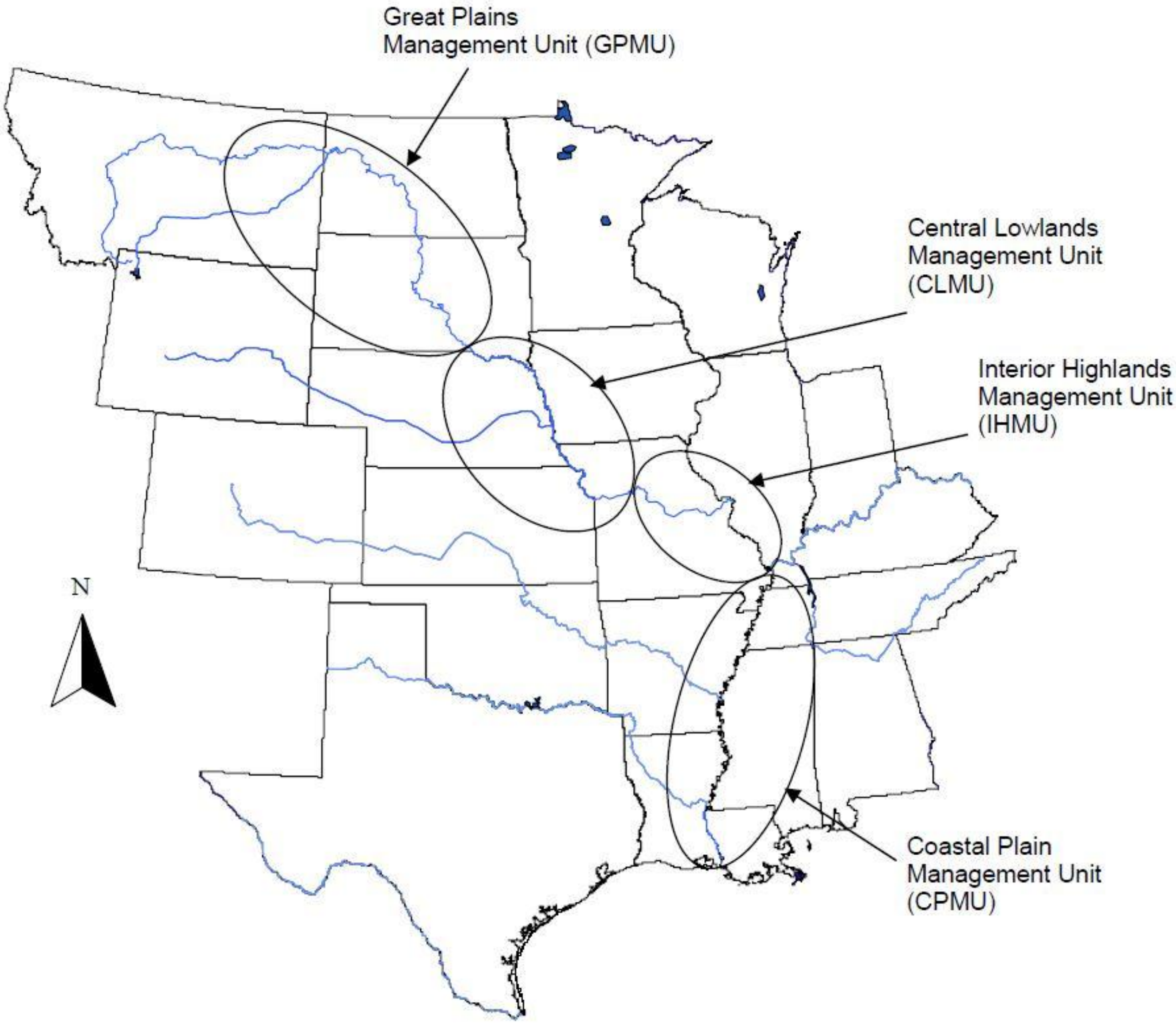

Figure 5-1. An outline of the current pallid sturgeon management units. Management units were defined by the Pallid Sturgeon Recovery Team and are based on reproduction isolation and genetic and morphometric difference with the species range.