IMPROVING SAMPLING AND MONITORING OF SHOVELNOSE STURGEON *SCAPHIRHYNCHUS PLATORYNCHUS* IN THE GREAT PLAINS

By

JOSH JOHNSTON

Bachelor of Science in Biology

Northeastern State University

Tahlequah, Oklahoma

2003

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2017

IMPROVING SAMPLING AND MONITORING OF

SHOVELNOSE STURGEON *SCAPHIRHYNCHUS*

PLATORYNCHUS IN THE GREAT PLAINS

Thesis Approved:

Dr. Shannon Brewer

Thesis Adviser

Dr. Daniel Shoup

Dr. James Long

ACKNOWLEDGEMENTS

I will forever be grateful for this opportunity to further my education, and for all of those who helped me along the way. First, I would like to thank my adviser, Dr. Shannon Brewer, for her patience and guidance throughout this process. She pushed me further than I would have pushed myself, and for that I am grateful. I thank my committee members, Dr. Daniel Shoup and Dr. Jim Long, for their insight and support. None of this would have been possible without the funding and support from the Oklahoma Department of Wildlife Conservation. I would like to thank Ian Campbell, Brandon Brown, and Jim Burroughs for starting this research with me. I sincerely thank Eric Brennan, Brad Johnston, Kendall Robbins, Chris Whisenhunt, and Jason Schooley for their tireless field work during the project. Without them, I would have never captured Shovelnose Sturgeon. Most importantly, I would like to thank my wife, Lisa, and my daughter, Charlotte. They supported me throughout this entire process, and when times were tough, they picked me up. I am very fortunate to have the support that I do in school, work, and life. I thank you all.

Name: JOSH JOHNSTON

Date of Degree: MAY, 2017

Title of Study: IMPROVING SAMPLING AND MONITORING OF SHOVELNOSE STURGEON *SCAPHIRHYNCHUS PLATORYNCHUS* IN THE GREAT PLAINS

Major Field: NATURAL RESOURCE ECOLOGY AND MANAGEMENT

Abstract: Abstract: Shovelnose Sturgeon is the most abundant sturgeon in North America, but their abundance has declined over the past century. Extirpations have occurred in some areas, and some range-edge populations are now isolated. Isolated populations of Shovelnose Sturgeon in the Arkansas River and Red River basins of the southern Great Plains represent the southwest extent of the species current range. The conservation and management of Shovelnose Sturgeon in this region will hinge on our knowledge of the current distribution, and the development of successful sampling strategies. Therefore, our objectives were to: 1) identify factors related to the current distribution of Shovelnose Sturgeon within the Arkansas River and Red River basins, and 2) synthesize existing sampling methods and strategies for Shovelnose Sturgeon throughout the range, and then test the usefulness of several of those methods for capturing Shovelnose Sturgeon in the Arkansas River, Oklahoma. The distribution of Shovelnose Sturgeon in the Arkansas River basin was primarily related to mean annual discharge, but the Red River basin distribution was mostly related to the extent of available habitat and discharge. Both populations were negatively correlated with elevation as expected by big-river fishes. Our model results showed bias resulting from existing sampling strategies, but provided a path forward for monitoring efforts. We reviewed 100 papers that reported the capture of Shovelnose Sturgeon in 12 rivers using 12 different gears or techniques. Benthic trawls were used most often, but mean catch was highest using stationary gillnets. High uncertainty in the number of sturgeon captured among gears, and studies, and the use of multiple gears in nearly half of the studies, suggested difficulties in sampling sturgeon. We had very limited success capturing Shovelnose Sturgeon in the Arkansas River using gears and methods reported in the reviewed studies. Thus, we developed a hybrid method using trammel nets, while flows were manipulated by water-management agencies. We captured 26 Shovelnose Sturgeon in five days using our hybrid method, the most successful method used. Results from this study will be used to provide insight into future study designs, and advise future study objectives.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

CHAPTER II

Figure Page

Figure Page

Figure Page

CHAPTER I

GENERAL INTRODUCTION

Prairie rivers of the Great Plains are imperiled (Dodds et al. 2004), and the distribution and abundance of associated biota have been affected (Winston et al. 1991; Alo and Turner 2005). Prairie streams exhibit high variability in discharge, and are considered relatively harsh environments (Matthews 1988). Native species have adapted to these conditions with exaggerated life-history strategies (Lytle 2002). For example, Arkansas River Shiner *Notropis girardi* and Peppered Chub *Machrybopsis tetranema* broadcast semi-buoyant eggs during high-flow events to ensure they drift and develop in suspension (Bonner 2000). Human alterations of prairie streams and rivers have caused un-natural stability in some locations and exacerbated variability in others. These systems normally experience extreme droughts, floods, and fire (Matthews 1988). Habitat fragmentation by dams has greatly smoothed hydrologic highs and lows inherent to the systems natural flow regime (Poff et al. 1997, 2007; Lytle and Poff 2004). In other locations, streams have dried completely due to groundwater pumping (Dodds et al. 2004) and lack of downstream water release via dams (D. Martinez, United States Fish and Wildlife Service, Personal Communication).

Altered prairie rivers have created difficulties for the persistence of many prairie stream fishes adapted to these environments (Matthews 1988). Many riverine species require multiple habitats and large expanses of flowing water to complete their life cycles (e.g., pelagic spawning fishes, Dudley and Platania 2007; Worthington et al. 2014; lithophilic-spawning fishes, Grabowski and Isely 2007). Dams have fragmented the habitat and reduced the drift distances available for many fishes with pelagic ichthyoplankton that drift in suspension during development (Perkin and Gido 2011; Worthington et al. 2014). Extreme drought, combined with other human-induced stressors, has even led to extirpations in some systems (Perkin et al. 2015). The lithophilic spawning guild, including Acipenseridae (sturgeons), may be one of the most vulnerable groups of fishes to occupy prairie systems (Grabowski and Isely 2007).

Sturgeon are one of the most threatened and endangered groups of fishes (Ludwig et al. 2002; Pikitch et al. 2005). There are 25 extant species of sturgeon scattered throughout the Northern Hemisphere (Birstein 1993). Most of these species are classified as endangered, threatened, or vulnerable (Birstein 1993; Raloff 2006; Jelks et al. 2008). Nine species occur in North America, where five species are endangered, and two are threatened (USFWS Endangered Species 2016). Abundance of North American sturgeon stocks has declined (Birstein 1993) due, historically, to commercial overharvest of roe and flesh (Carlson et al. 1985; Keenlyne 1997; Quist et al. 2002; Koch et al. 2009, 2012). Currently, most North American sturgeon species are protected from commercial harvest, and recent declines are related to human landscape changes (Keenlyne 1997; Raloff 2006). The biggest threat to North American sturgeon populations is habitat fragmentation caused by dams (Koch and Quist 2010). Habitat fragmentation has truncated the home ranges of most North American sturgeon species, resulting in declines in abundance and truncated distributions (McLaughlin et al. 2006; Jager et al. 2016). However, Shovelnose Sturgeon *Scaphirhynchus platorynchus* is still relatively abundant, though its abundance is in decline (Keenlyne 1997; Koch and Quist 2010; Phelps et al. 2010).

Shovelnose Sturgeon is the smallest and most abundant sturgeon in North America (Quist et al. 2002; Kappenman et al. 2009; Tripp et al. 2009). Native to the Mississippi and Missouri rivers and tributaries (Keenlyne 1997), the species has persisted in the region for nearly 100 million years (Bailey and Cross 1954). Historically, Shovelnose Sturgeon was an economically-important species to commercial fisheries throughout much of its range (Hurley et al. 1987; Keenlyne 1997; Koch et al. 2009). Prized for its roe and flesh, the species was targeted by many commercial fishermen (Koch et al. 2009). In 2010, the United States Fish and Wildlife Service enacted a rule to treat Shovelnose Sturgeon as a threatened species under the Endangered Species Act in any area of its range that overlaps with the range of the endangered Pallid Sturgeon *Scaphirhynchus albus* (United States Fish and Wildlife Service 2010). This ruling was made due to the similarity in appearance of the two species, and has afforded protection to the Shovelnose Sturgeon. Although Shovelnose Sturgeon populations of the Mississippi and Missouri rivers appear stable (Koch and Quist 2010), the status of the species in other major tributaries is unclear (e.g., Arkansas and Red rivers). However, anecdotally, Shovelnose Sturgeon was historically considered plentiful in the Arkansas River of Oklahoma, but is now thought to have a much-restricted distribution (Koch and Quist 2010). Since Shovelnose Sturgeon became extirpated from New Mexico, Oklahoma stocks now represent populations at the southwest extent of the range.

Successful management of Shovelnose Sturgeon at the southwest extent of the range will hinge on identifying effective sampling methods. Within their southwest distribution, the abundance of the species appears to be low, although targeted sampling efforts for the species have been minimal or nonexistent in some regions. Historical accounts confirm Shovelnose Sturgeon occupied areas of the Arkansas River near Wichita, Kansas (Collins 1976), and there are also accounts in the Arkansas River of Oklahoma in 1853 (Gudger 1932). Although anecdotal, stories told by fishermen that predate the McClellan-Kerr Arkansas River Navigation System, depict Shovelnose Sturgeon as plentiful and a nuisance to catfish fishermen. The Oklahoma Department of Wildlife Conservation (ODWC) regularly conducts standardized sampling procedures (SSP) on most reservoirs within the state. Sampling is conducted using a variety of gears including electrofishing, gillnetting, trap netting, and hoop netting. Although many of the gears used have proven useful for capturing sturgeon in other areas (Phelps et al. 2009; Trested et al. 2010; Bonnot et al. 2011), the SSP is designed to target sportfish in lentic habitats. Researchers in Arkansas successfully capture Shovelnose Sturgeon with gillnets within the river-reservoirs of the McClellan-Kerr Arkansas River Navigation System (Jansen 2012), but very few incidental catches occur in Oklahoma. The ODWC receives occasional reports of incidental sturgeon catches by anglers, and recently, a report of several Shovelnose Sturgeon stranded below Kaw Dam on the Arkansas River was confirmed by ODWC biologists. Other state agencies also conduct river and stream surveys across the state, and sturgeon encounters by these agencies are rare. With the steady decline in Shovelnose Sturgeon stocks throughout their native range (Wildhaber et al. 2011), efforts to monitor and manage the species have increased. These issues may be of even greater importance in Oklahoma as populations near or at the edge of the range are the most sensitive to habitat alterations (Anderson et al. 2009).

Developing effective conservation and management strategies for sturgeons persisting at the extent of the range is ultimately a two-step process. From a broad perspective, we need to know the current distribution of the species and what landscape factors are driving that distribution. We need to particularly focus on the fringes of the species range where declines often occur first (Doherty et al. 2003; Anderson et al. 2009). This is especially important because with so many stream kilometers to sample, an accurate representation of the current distribution can assist in developing a targeted monitoring protocol, especially in an area where limited monitoring has occurred. Once the distribution is documented, we need to develop a sampling protocol that can be used in rivers of Oklahoma to target Shovelnose Sturgeon populations. The rivers of the Great Plains are dramatically different in character compared to locations where sturgeon populations have been sampled regularly (e.g., Missouri River) (Matthews 1988; Dodds et al. 2004). Thus, a survey of existing sampling strategies provides a useful starting point for developing a sampling protocol for large Great Plains rivers. Therefore, the goal of my thesis is to provide information that can be used to develop a sampling strategy for monitoring Shovelnose Sturgeon populations at the southwest extent of the species range. My first objective was to identify factors related to the current distribution of Shovelnose Sturgeon within the Arkansas and Red river basins. At a minimum, spatially projecting areas of possible suitable habitat will help target locations where Shovelnose Sturgeon is likely to occur. My second objective built on the first by synthesizing existing sampling methods and strategies for Shovelnose Sturgeon throughout the range, and then I test the usefulness of several of those methods for capturing Shovelnose Sturgeon in the Arkansas River, Oklahoma.

References

Alo, D., and T. F. Turner. 2005. Effects of habitat fragmentation on effective population size in the endangered Rio Grande Silvery Minnow. Conservation Biology 19(4):1138-1148.

Anderson, B. J., H. R. Akcakaya, M. B. Araujo, D. A. Fordham, E. Martinez-Meyer, W. Thuiller, and B. W. Brook. 2009. Dynamics of range margins for metapopulations under climate change. Proceedings of the Royal Society B 276:1415-1420.

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

Birstein, V. J. 1993. Sturgeons and Paddlefishes: threatened fishes in need of conservation. Conservation Biology 7(4):773-787.

Bonner, T. M. 2000. Life history and reproductive ecology of the Arkansas River Shiner and Peppered Chub in the Canadian River, Texas and New Mexico. Ph. D. Dissertation. Texas Tech University, Lubbock.

Bonnot, T. W., M. L. Wildhaber, J. J. Millspaugh, A. J. DeLonay, R. B. Jacobson, and J. L. Bryan. 2011. Discrete choice modeling of Shovelnose Sturgeon habitat selection in the Lower Missouri River. Journal of Applied Ichthyology 27(2):291-300.

Carlson, D. M., W. L. Pflieger, L. Trial, and P. S. Haverland. 1985. Distribution, biology and hybridization of *Scaphirhynchus albus* and *S. platorynchus* in the Missouri and Mississippi rivers. Environmental Biology of Fishes 14(1):51–59.

Collins, J. T. 1976. Rediscovery of the Shovelnose Sturgeon in the Arkansas River of Kansas. Transactions of the Kansas Academy of Science 79(3–4):159-160.

Dodds, W. K., K. Gido, M. R. Whiles, K. M. Fritz, and W. J. Matthews. 2004. Life on the edge: the ecology of Great Plains prairie streams. BioScience 54(3):205-216.

Doherty, P. F., T. Boulinier, and J. D. Nichols. 2003. Local extinction and turnover rates at the edge and interior of species' ranges. Annales Zoologici Fennici 40(2):145-153.

Dudley, R. K., and S. P. Platania. 2007. Flow regulation and fragmentation imperil pelagic-spawning riverine fishes. Ecological Applications 17(7):2074–2086.

Grabowski, T. B., and J. J. Isely. 2007. Effects of flow fluctuations on the spawning habitat of a riverine fish. Southeastern Naturalist 6(3):471–478.

Gudger, E. W. 1932. The Shovelnosed Sturgeon in the Arkansas River. Science 76:323- 324.

Hurley, S. T., W. A. Hubert, and J. G. Nickum. 1987. Habitats and movements of Shovelnose Sturgeons in the Upper Mississippi River. Transactions of the American Fisheries Society 116(4):655-662.

Jager, H. I., M. J. Parsley, J. J. Cech Jr., R. L. McLaughlin, P. S. Forsythe, R. F. Elliott, and B. M. Pracheil. 2016. Reconnecting fragmented sturgeon populations in North American rivers. Fisheries 41(3):140-148.

Jansen, C. R. 2012. Population characteristics and capture techniques for Shovelnose Sturgeon *Scaphyrhynchus platorynchus* in the Arkansas River. Master's Thesis. Arkansas Tech University, Russellville.

Jelks, H. L., S. J. Walsh, N. M. Burkhead, S. Contreras-Balderas, E. Diaz-Pardo, D. A. Hendrickson, J. Lyons, N. E. Mandrak, F. McCormick, J. S. Nelson, S. P. Platania, B. A. Porter, C. B. Renaud, J. J. Schmitter-Soto, E. B. Taylor, and M. L. Warren Jr. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries 33(8):372-407.

Kappenman, K. M., W. C. Fraser, M. Toner, J. Dean, and M. A. H. Webb. 2009. Effect of temperature on growth, condition, and survival of juvenile Shovelnose Sturgeon. Transactions of the American Fisheries Society 138(4):927-937.

Keenlyne, K. D. 1997. Life history and status of the Shovelnose Sturgeon, *Scaphirhynchus platorynchus*. Environmental Biology of Fishes 48(1–4):291-298.

Koch, B., R. C. Brooks, A. Oliver, D. Herzog, J. E. Garvey, R. Hrabik, R. Colombo, Q. Phelps, and T. Spier. 2012. Habitat selection and movement of naturally occurring Pallid Sturgeon in the Mississippi River. Transactions of the American Fisheries Society 141:112-120.

Koch, J. D., and M. C. Quist. 2010. Current status and trends in Shovelnose Sturgeon *Scaphirhynchus platorynchus* management and conservation. Journal of Applied Ichthyology 26(4):491-498.

Koch, J. D., M. C. Quist, C. L. Pierce, K. A. Hansen, and M. J. Steuck. 2009. Effects of commercial harvest on Shovelnose Sturgeon populations in the Upper Mississippi River. North American Journal of Fisheries Management 29(1):84-100.

Ludwig, A., L. Debus, and I. Jenneckens. 2002. A molecular approach to control the international trade in black caviar. International Review of Hydrobiology 87(5-6):661-674.

Lytle D. A. 2002. Flash floods and aquatic insect life-history evolution: evaluation of multiple models. Ecology 83:370-385.

Lytle, D. A., and N. L. Poff. 2004. Adaptation to natural flow regimes. Trends in Ecology and Evolution 19(2):94-100.

Matthews, W. J. 1988. North American prairie streams as systems for ecological study. Journal of the North American Benthological Society 7:387-409.

McLaughlin, R. L., L. Porto, D. L. Noakes, J. R. Baylis, L. M. Carl, H. R. Dodd, J. D. Goldstein, D. B. Hayes, and R. G. Randall. 2006. Effects of low-head barriers on stream fishes: taxonomic affiliations and morphological correlates of sensitive species. Canadian Journal of Fisheries and Aquatic Sciences 63(4):766-779.

Perkin, J. S., and K. B. Gido. 2011. Stream fragmentation thresholds for a reproductive guild of Great Plains fishes. Fisheries 36(8):371-383.

Perkin, J. S., K. B. Gido, K. H. Costigan, M. D. Daniels, and E. R. Johnson. 2015. Fragmentation and drying ratchet down Great Plains stream fish diversity. Aquatic Conservation: Marine and Freshwater Ecosystems 25:639-655.

Phelps, Q. E., D. P. Herzog, R. C. Brooks, V. A. Barko, D. E. Ostendorf, J. W. Ridings, S. J. Tripp, R. E. Colombo, J. E. Garvey, and R. A. Hrabik. 2009. Seasonal comparison of catch rates and size structure using three gear types to sample sturgeon in the Middle Mississippi River. North American Journal of Fisheries Management 29(5):1487-1495.

Phelps, Q. E., S. J. Tripp, J. E. Garvey, D. P. Herzog, D. E. Ostendorf, J. W. Ridings, J. W. Crites, and R. A. Hrabik. 2010. Habitat use during early life history infers recovery needs for Shovelnose Sturgeon and Pallid Sturgeon in the Middle Mississippi River. Transactions of the American Fisheries Society 139(4):1060-1068.

Pikitch, E.K., P. Doukakis, L. Lauck, P. Charkrabarty, and D. L. Erickson. 2005. Status, trends and management of sturgeon and paddlefish fisheries. Fish and Fisheries 6:233-265.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. BioScience 47(11):769-784.

Poff, N. L., J. D. Olden, D. M. Merritt, and D. M. Pepin. 2007. Homogenization of regional river dynamics by dams and global biodiversity implications. Proceedings of the National Academy of Sciences 104(14):5732–5737.

Quist, M. C., C. S. Guy, M. A. Pegg, P. J. Braaten, C. L. Pierce, and V. H. Travnichek. 2002. Potential influence of harvest on Shovelnose Sturgeon populations in the Missouri River system. North American Journal of Fisheries Management 22(2):537-549.

Raloff, J. 2006. Saving sturgeon. Science News 169(9):138-140.

Trested, D. G., R. Goforth, J. P. Kirk, and J. J. Isely. 2010. Survival of Shovelnose Sturgeon after abdominally invasive endoscopic evaluation. North American Journal of Fisheries Management 30(1):121-125.

Tripp, S. J., Q. E. Phelps, R. E. Colombo, J. E. Garvey, B. M. Burr, D. P. Herzog, and R. A. Hrabik. 2009. Maturation and reproduction of Shovelnose Sturgeon in the Middle Mississippi River. North American Journal of Fisheries Management 29(3):730-738.

United States 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):53598-53606.

USFWS Endangered Species. ECOS Environmental Conservation Online System, U. S. Fish and Wildlife Service. Retrieved from http://ecos.fws.gov/ecp0/pub/SpeciesReport.do?groups=E&listingType=L&mapstatus=1. Accessed 2016.

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. 2011. Identifying structural elements needed for development of a predictive life-history model for Pallid and Shovelnose Sturgeons. Journal of Applied Ichthyology 27(2):462-469.

Winston, M. R., C. M. Taylor, and J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. Transactions of the American Fisheries Society 120(1):98-105.

Worthington, T. A., S. K. Brewer, N. Farless, T. B. Grabowski, and M. S. Gregory. 2014. Interacting effects of discharge and channel morphology on transport of semibuoyant fish eggs in large, altered river systems. PloS ONE 9(5):1-9.

CHAPTER II

FACTORS RELATED TO THE CURRENT DISTRIBUTION OF SHOVELNOSE STURGEON *SCAPHIRHYNCHUS PLATORYNCHUS* IN THE ARKANSAS RIVER AND RED RIVER BASINS

Abstract- Shovelnose Sturgeon once persisted throughout the Mississippi River basin, but now segregated populations exist only in areas of remaining suitable habitat, including portions of the Arkansas River and Red River basins. The Arkansas and Red rivers are highly fragmented by impoundments resulting in two isolated populations which may show different responses to the physicochemical conditions where they reside. Accordingly, the objectives of this study were to determine the current distribution of Shovelnose Sturgeon within these basins, and identify the factors related to each population's distribution. We compiled available occurrence records for Shovelnose Sturgeon from 1996 - 2016. Using a vector-based species distribution modeling approach, we developed three models: 1) a combined Arkansas River and Red River basins model (CBM), 2) Arkansas River basin model (ABM), and 3) Red River basin model (RBM). The primary factor related to the probability of Shovelnose Sturgeon presence was discharge in the CBM and ABM, but extent of available habitat was the primary factor in the RBM. The probability of Shovelnose Sturgeon presence was positively correlated with an increase in impervious surfaces in the CBM and ABM, suggesting sampling location bias. Climate variables contributed little to any of the models. The Red River basin population was related to the

Woodbine and Tuscaloosa groups of geological formations, but the Arkansas River basin population showed no relation to a specific dominant geology. Both populations were negatively correlated with elevation and slope. Modeling the populations separately allowed us to tease apart patterns that would have been masked by sampling prevalence in one basin. Although the models are biased by existing sampling strategies, the results offer guide posts for improving future sampling efforts, developing questions about Shovelnose Sturgeon ecology, and promoting better management strategies given the different threats that are present in these two basins.

Introduction

Isolated fish populations occur naturally, and in response to human activities and landscape changes. Natural isolation generally happens over long time periods, and is caused by geologic or climatic events, such as glaciation, or wet and dry periods (Meffe and Vrijenhoek 1988). For example, during the Pleistocene Epoch, North America experienced an elongated wet period with alternating warm and cold climates, and the landscape was strewn with large lakes and rivers (Schlee 2017). Following that wet period, basins slowly dried, isolating the waterbodies within the different basins. As a result, fish populations were isolated geographically, and eventually genetically. Evidence of naturally-isolated populations includes the distribution of Southern Redbelly Dace *Phoxinus erythrogaster*, widespread throughout the upper Mississippi River Valley and south to the Ozark Highlands, but with disjunct populations occurring in western Mississippi and southwest Oklahoma (Slack et al. 1997; Miller and Robison 2004). The current distribution of Southern Redbelly Dace is related to their habitat requirements (Slack et al. 1997), and potential reconnection of isolated populations is not feasible or desired due to the distance between suitable habitat patches. Isolated fish populations also result from anthropogenic activities that cause habitat fragmentation or degradation (Warren et al. 2000). Such unnatural population isolation typically occurs on a much finer temporal scale, and populations are sometimes forced to quickly adapt to the changes. In some cases, adaptive traits can evolve rapidly in fish (Hendry et al. 2000), eventually leading to reproductive isolation, genetic isolation, and speciation. When reconnecting isolated populations is neither feasible nor desirable, knowledge of the responses of isolated populations to catchment and in-channel characteristics can inform future conservation and management actions.

Isolated populations may respond differently to physicochemical conditions and thus, identifying population boundaries or locations likely to support the species within different basins may be difficult. With little or no gene dispersal between isolated populations, population-level adaptations to the local environment may result in divergence of the populations caused by local selection pressure (Meffe and Vrijenhoek 1988). This presents a challenge to managers attempting to monitor multiple isolated populations, as each population may relate differently to environmental factors. Even at fine spatial scales, species requirements and tolerances can differ between populations. For example, Strange et al. (2002) found that populations of Orangethroat Darter *Etheostoma spectabile* from two adjoining streams within the same drainage exhibited differences in maximum thermal tolerances based on the variability of water temperature in their local environment. In some instances, dispersal between isolated populations is feasible, but limited due to inadequate habitat along the dispersal route. Such population-level adaptations, or physicochemical differences, shape population boundaries that are not always evident and may also result in population hotspots that are based on different environmental factors. Therefore, understanding the factors that relate to different population distributions serves as an important foundation for developing catchment-specific monitoring programs and management strategies.

Knowledge of a species distribution is essential to ecological research and conservation (Guisan and Thuiller 2005; Elith et al. 2006). Although species presence is generally well known at the core of the range, extirpations, and immigration to new areas at range edges often go unnoticed (Simon-Bouhet et al. 2006; Neiva et al. 2015). Many species persisting at the edge of their range are currently in peril, due in part to climate change, habitat fragmentation, and anthropogenic land-use changes (Hansen et al. 2001; Laurance and Useche 2009). This is particularly concerning as range-edge populations are often sources of genetic diversity, and help to ensure species viability in an ever-changing environment (Neiva et al. 2015). The anthropogenic factors affecting species distribution in aquatic systems are well documented (i.e., habitat fragmentation, habitat degradation, and pollution), particularly in the prairie streams of the Great Plains, where anthropogenic landscape and riverscape changes have been among the most detrimental (Samson and Knopf 1994; Dodds et al. 2004). Habitat fragmentation modifies species distributions (Fahrig 2003), particularly those of highly-migratory species (e.g., Arkansas River Shiner *Notropis girardi*, Dudley and Platania 2007; Worthington et al. 2014; Alligator Gar *Atractosteus spatula*, Ferrara 2001). Migratory species, such as Shovelnose Sturgeon, persisting in highly fragmented areas at range edges, are of particular research and conservation interest; however, their distribution is not well known (Koch and Quist 2010).

Shovelnose Sturgeon was once common throughout much of the Mississippi and Missouri river drainages, but recent extirpations have truncated the range (Keenlyne 1997; Koch and Quist 2010). In fact, the species is now considered extirpated from the Alabama-Mobile River basin, the Rio Grande and Pecos rivers, and from the states of Alabama, New Mexico, Pennsylvania, and West Virginia (Koch and Quist 2010). Although historic distribution data are limited, states on the western edge of the historic range have reported the greatest losses: Wyoming reporting a ≈ 75% loss of historic Shovelnose Sturgeon habitat, and Oklahoma reporting a substantial reduction in the potential distribution (Koch and Quist 2010). Extant populations of Shovelnose Sturgeon still exist in the highly-fragmented Arkansas and Red river systems as far west as Oklahoma and Texas, but these populations are no longer connected with those of the Mississippi River, or each other. These isolated populations now make up the southwest extent of the species range and face increasing threats of prolonged droughts, and major limitations to dispersal.

Although the Arkansas River and Red River basins are close in geographic proximity, Shovelnose Sturgeon populations within each basin are separated by fragmented habitat and may respond differently to environmental stressors. We used a species distribution modeling approach to estimate the current distribution of Shovelnose Sturgeon within the two basins, and identify the factors related to each population's distribution.

Study Area

We predicted the distribution of Shovelnose Sturgeon populations of the Arkansas River and Red River basins (Figure 1). The Arkansas River and Red River basins cover several ecoregions of the Southern Great Plains. The Arkansas River basin originates in the Southern Rocky Mountains ecoregion of Colorado, and extends east to the Mississippi Alluvial Plain ecoregion of Arkansas (Woods et al. 2005), encompassing an extreme precipitation gradient (annual rainfall averages 43 - 139 cm, Wiken et al. 2011). The Red River basin originates in the Southwestern Tablelands of New Mexico, and extends east to the South Central Plains of Louisiana (Woods et al. 2005), also encompassing a major precipitation gradient (annual rainfall averages 44 - 128 cm, Wiken et al. 2011). From west to east, the basins transcend rugged rangeland, prairie grassland, and forested plain (Woods et al. 2005). Both river systems are within the historic native range of Shovelnose Sturgeon, and each basin has been affected by a substantial amount of fragmentation and human-induced changes. Both the Arkansas and Red rivers are currently used as navigation systems, where many kilometers of each river have been impounded, dredged, and channelized to accommodate barge traffic. Although the Arkansas River and Red River basins exhibit different habitat types and general characteristics, due to their proximity, they are often combined for strategic planning projects (e.g., America's Watershed Initiative- Arkansas & Red river basins watershed report card, http://www.swl.usace.army.mil/Portals/50/docs/Arkansas%20newsletter%20V4[1].pdf).

Methods

<u>Data collection</u>

Species occurrences

We compiled sampling records from existing literature and our own sampling efforts. We attempted to gather all available occurrence records for Shovelnose Sturgeon within the Arkansas River and Red River basins (Appendix A, Table 1) from museum and university collections, species databases, state and federal agencies, published literature, university theses, gray literature, and angler reports. We also recently sampled the Arkansas River, Oklahoma in 2012 - 2014 and included those occurrence points (Oklahoma Department of Wildlife Conservation, unpublished data). Each occurrence record used for distribution modelling included the location and date of capture. We georeferenced the records that only provided written descriptions of the sampling location to the nearest stream segment using a map. We omitted two occurrence points that fell outside of the basins' boundaries. We did not use records that were collected prior to 1997 (N = 10) because of differences in the temporal scale of observation and land-use data (1996 - 2016). Of the 88 remaining occurrence records, 48 were removed because they were in extremely close proximity to one another, leaving a total of 40 Shovelnose Sturgeon occurrence points (Arkansas River basin = 27, and Red River basin = 13, Figure 1) to be used in our species distribution models (SDMs).

Environmental variables

Species distribution models use environmental variables as predictors of theoretical species occurrence (Elith et al. 2006), leaving the selection of environmental variables dependent upon their relevance to the species (Mac Nally 2000; Austin 2007). We gathered data on 28 environmental variables from existing geospatial data sources to use as predictors for our SDMs (Table 1). Climate was represented by Bioclim data because it is a major driver of species distributions worldwide (Rahel 2002; Dyer et al. 2013; Arkle and Pilliod 2015). We included geology because it describes the physicochemical characteristics (e.g., pH) of a stream and is important in describing fish distributions (Hynes 1975). Discharge was chosen because it affects all stages of Shovelnose Sturgeon life history. Land use and land-use change were incorporated because of Shovelnose Sturgeon's sensitivity to anthropogenic activities (Murphy et al. 2007; Phelps et al. 2010a, 2010b). Likewise, the percentage of impervious surfaces can indicate the level of urbanization in an area, so it was also chosen as a model variable (Poff et al. 1997; Brown et al. 2005). Maximum elevation influences climate, and slope influences velocity and depth, so maximum elevation and slope were also included.

Two variables, drift and extent, were calculated using GIS tools in ArcGIS (Version 10.1) to consider the need for large expanses of unobstructed flowing water for Shovelnose Sturgeon reproduction and recruitment (Keenlyne 1997; Braaten et al. 2008). Drift was calculated as the distance (km) from each stream segment to the nearest downstream barrier, and represents the available distance for drifting eggs or larvae to develop. Extent was calculated as the total distance (km) available between two barriers to describe the total space available for Shovelnose Sturgeon to complete their life history. All barrier locations within the Arkansas River and Red River basins were obtained from the National Inventory of Dams (NID).

Variable removal

Species distribution models use independent variables (environmental variables) to predict the distribution of dependent variables (species); however, when highly correlated independent variables are used, predictive accuracy decreases, thus, fewer independent variables generally result in a more reliable model (Mac Nally 2000; Warren and Seifert 2010). We used a Spearman Rank correlation test in the program RStudio (stats, RStudio, 1.0.44, Boston, MA) to identify multicollinearity between our environmental variables. All variable pairs having a rho value > |0.70| were considered highly correlated. We selected one variable from each correlated pair based on its relevance to Shovelnose Sturgeon ecology, until few highly correlated variable pairs existed. Although drift and extent were highly correlated in all models, we retained them due to their importance to Shovelnose Sturgeon life history, their differing explanatory functionality, and because habitat fragmentation is a leading cause in the decline of Shovelnose Sturgeon populations (Keenlyne 1997; Koch and Quist 2010).

Species distribution models

Because we were interested in examining isolated populations at the southwest extent of their range, we constructed SDMs for two isolated basins and the drainages combined. The three SDMs constructed were: 1) an Arkansas River and Red River basins combined model (CBM), 2) Arkansas River basin model (ABM), and 3) Red River basin model (RBM). All three models were held to the same temporal range constraints.

We used MaxEnt (MaxEnt 3.3.3k; Phillips et al. 2004, Phillips and Dudík 2007) in samples-with-data format (Elith et al. 2011) to construct our SDMs. MaxEnt, a maximum entropy modelling software, is very accessible and out-performs most other presence-only modelling platforms for predicting species distribution (Elith et al. 2006; Townsend Peterson et al. 2007). MaxEnt is a machine learning model and is not a pure presence-only platform, as it uses background data to assign pseudoabsences (Barbet-Massin et al. 2012), giving it an edge in predictive performance when compared to true presence-only models (Elith et al. 2006). Furthermore, MaxEnt maintains high predictive performance at low sample sizes (de Siqueira et al. 2009). The major shortcoming of MaxEnt is its inability to account for imperfect species detection, leading to the omission of presences, and resulting in conservative predictions of distributions (Yackulic et al. 2013; Lahoz-Monfort et al. 2014). However, sampling is limited for Shovelnose Sturgeon in these expansive basins making this the most reasonable approach. The foundation of our SDMs was a vector-based network of stream segments within the Arkansas River and Red River basins, that we downloaded from NHDPlus version 2 (http://www.horizonsystems.com/nhdplus/NHDplusV2_data.php). Shovelnose Sturgeon inhabits large rivers (Keenlyne 1997), so we omitted third order and smaller streams to reduce the number of stream segments, and improve model processing time. Following the MaxEnt samples-with-data format, species occurrences and environmental variables were attached to the stream segments in ArcGIS (Version 10.1). We visualized the model predictions by projecting them to the corresponding stream segments in ArcGIS (Version 10.1).

We ran our models using two levels of regularization, and adjusted the number of background points available for modeling. Merow et al. (2013) suggested tuning MaxEnt regularization parameters to simplify models and improve interpretability. We ran each of our models at the MaxEnt default regularization ($\beta = 1$), and an increased regularization ($\beta = 5$), as recommended by Worthington et al. (2016) for optimized model transferability and fit. Phillips and Dudík (2007) tested MaxEnt model performance at 13 different background sizes ranging from 63 to 256,000 points, and determined that performance plateaus after 8000 background points are used, allowing users to significantly reduce processing time on large datasets. The default MaxEnt setting for maximum background points is 10,000, but because our datasets were relatively small ($\leq$ 27,723), we chose to set the maximum background at the total amount of available points (CBM = 27,723, ABM = 19,610, and RBM = 8,113), as this would not greatly affect processing time.

Model validation and evaluation of model fit were both done within the MaxEnt program. For model validation, we used a 10-fold cross validation by increasing the model settings to 10 replicates and choosing “crossvalidate” as the “replicated run type”. To evaluate model fit, we used mean area under the curve (AUC). AUC scores can range from zero to one, with 0.5 indicating model prediction equivalent to a random guess, and > 0.75 indicating a useful prediction (Elith et al. 2006). We chose to use the AUC of the test data (AUC_{Test}), rather than the AUC of the training data (AUC_{Train}), as AUC_{Test} is a measure of how well MaxEnt predicts independent data (i.e., predictive power, Phillips 2009). We also calculated differences between the mean AUC_{Train} and AUC_{Test} scores (AUC_{Diff}) for each model to provide insight to possible model over-fitting.

Results

Variable Multicollinearity

Our Spearman Rank correlation test indicated several highly correlated variable pairs in each model (Appendix B, Tables 1 - 3). As expected, several correlations were evident among the Bioclim variables so we retained three that we hypothesized to relate to sturgeon life history: BIO8- mean temperature of wettest quarter, BIO10- mean temperature of warmest quarter, and BIO3- isothermality (see Appendix C, Table 1 for Bioclim variable descriptions). Shovelnose Sturgeon spawn at a temperature range between 17 and 21°C accompanied by rising river stages (Keenlyne 1997; Tripp et al. 2009), and this typically coincides with spring and autumn throughout the Arkansas River and Red River basins. Therefore, BIO8 (mean temperature of wettest quarter) was retained for its importance to Shovelnose Sturgeon reproduction. BIO10 (mean temperature of warmest quarter) was retained due to the significant differences in Shovelnose Sturgeon mortality observed at 28°C and 30°C in laboratory studies (Kappenman et al. 2009). BIO3 (isothermality) was retained due to its low level of correlation with other variables. Maximum elevation was highly correlated with many variables in each model (CBM = 12, ABM = 13, and RBM = 16), particularly Bioclim variables. Elevation influences more than just climate (e.g., slope, water velocity), so we retained elevation in all three models and we reduced the number of Bioclim variables. We retained land-use change in the RBM rather than highly correlated Bioclim variables. As a result of our variable removal method, we retained a reduced variable set specific to each model: CBM=13, ABM=14, RBM=13.

Variable contributions and distribution predictions

Variable contributions and response curves differed among models and levels of regularization. Over 90% of the total percent contribution in all of the models was explained by three to four variables (Table 2). For three of the four CBM and ABM models, discharge, impervious surfaces, and drift were primary contributors, but at $\beta = 5$ model, discharge alone contributed > 90% in both models. In all cases, there was a positive relationship between probability of occurrence and discharge (Figure 2). Drift contributed ≤ 5% to the CBM and ABM. Impervious surfaces contributed at a similar level except in the ABM $\beta = 1$ model where the percent contribution was 12%, and the habitat appeared to be suitable (> 0.6 probability of occurrence) at 20 - 60% impervious surfaces (Figure 3). Alternatively, in the RBM models, four variables contributed > 10%: At $\beta = 1$, discharge (41%), geology (25%), extent (21%), and drift (10%) whereas primary contributors to $\beta = 5$ were extent (36%), discharge (28%), maximum elevation (17%) and geology (10%). The relationship between discharge and occurrence probability was similar to the other models, except the mean annual discharge threshold for probability of presence was lower until probability of presence was ≥ 0.45 (Figure 2). High probability of Shovelnose Sturgeon presence (> 0.7) was primarily associated with the Woodbine and Tuscaloosa groups of geological formations. The response curve indicated low-elevation areas were most suitable for Shovelnose Sturgeon. The probability of Shovelnose Sturgeon presence was positively correlated with extent, requiring ≈7,000 km to achieve 0.5 probability of presence (Figure 4). Although it contributed to the model, there was no correlation between drift and probability of occurrence; however, when drift was the only variable used in the models, response curves indicated a negative correlation between probability of occurrence and drift (Figure 5). Land use, land-use change, slope, and climate variables all contributed < 3% to any model.

Increasing regularization simplified all of the models by reducing the number of covariates, and in most cases, the percent contribution from any one variable also decreased. The CBM framework included 11 covariates contributing to the model at $\beta = 1$, but this was reduced to seven at β = 5 (Table 2, CBM). Likewise, nine covariates contributed to the RBM at β = 1, but were reduced to five when regularization was increased to β = 5 (Table 2, RBM). The ABM was affected the least by increasing regularization. Ten of 14 covariates contributed to the ABM at β = 1, and eight contributed at β = 5 (Table 2, ABM), a reduction of only 14%. In most cases, variable contribution from the same covariate decreased when β was increased to 5, with the following exceptions: discharge in the CBM; discharge and maximum elevation in the ABM; extent and maximum elevation in the RBM (Table 2).

The CBM, ABM, and RBM, at β = 1 regularization, provided similar predictions of Shovelnose Sturgeon presence with the exception of one major difference between the CBM and RBM (Figure 6). All three models placed all probability of Shovelnose Sturgeon presence > 0.4 within the mainstems of the Arkansas and Red rivers. There was a small probability of disconnected populations in three large tributaries to the Arkansas River (the Canadian, Grand, and Cimarron rivers). For the most part, high probability of presence (> 0.6) was predicted in stream segments with recorded occurrences. One substantial difference in predictions occurred between the CBM and RBM in the lower portion of the Red River. The CBM results indicated a probability of Shovelnose Sturgeon presence (range: 0.2 - 0.6) throughout the entirety of the Red River Navigation System (Figure 6, i), a series of five locks and dams 50 - 80 river km apart. Alternatively, the RBM predicted < 0.2 probability of presence within the Red River Navigation System.

Running the models at a higher level of regularization resulted in less conservative predictions of the possible Shovelnose Sturgeon distribution. Predictions made at β = 5 regularization were less patchy than those made at β = 1 (Figures 6 and 7). Also, β = 5 models predicted a higher probability of Shovelnose Sturgeon presence in large tributaries of the Arkansas and Red rivers. For instance, neither the CBM nor ABM predicted a probability of presence > 0.2 in the Verdigris River at β = 1 regularization (Figure 6, ii and iii), though we recorded an occurrence there in 2015. The same models ran at $\beta = 5$ regularization predicted a 0.4 – 0.6 probability of Shovelnose Sturgeon presence in the Verdigris River, from Oolagah Dam downstream to its confluence with the Arkansas River (Figure 7, i). Lastly, models ran at $\beta = 5$ predicted a higher probability of Shovelnose Sturgeon presence above migration barriers. For example, the CBM and ABM at $\beta = 5$, predicted the distribution of Shovelnose Sturgeon extending up the Grand River through three large reservoirs, and into the Neosho River north of the Kansas border (Figure 7, ii). Other examples are the RBM and CBM predictions of Shovelnose Sturgeon distribution extending upstream of Denison Dam into the Red and Washita rivers (Figure 7, iii).

The CBM predictions were very similar to those of the ABM, but not the RBM (Figure 8). The CBM indicated a low probability (0.2 - 0.4) of Shovelnose Sturgeon presence in the Little River (Figure 8, i), but the RBM indicated < 0.2 probability of presence. Unlike the RBM, the CBM also predicted a higher probability (0.4 - 0.8) that habitat may be suitable for Shovelnose Sturgeon throughout the Red River Navigation System (Figure 8, ii). Lastly, the RBM predicted a 0.2 - 0.4 probability of Shovelnose Sturgeon presence in Muddy Boggy Creek, Clear Boggy Creek, the Blue River, and the Washita and Red rivers upstream of Denison Dam (Figure 8, iii). The CBM predicted a very low probability (< 0.2) that sturgeon occur in the Blue and Washita rivers, Muddy Boggy and Clear Boggy creeks, and the Red River upstream of Denison Dam (probability 0.2 - 0.4).

Model evaluation

AUC scores were high for all models and AUC_{Diff} was minimal. The highest AUC occurred at $\beta = 5$ across all models. AUC_{Test} scores ranged from 0.98 to 0.99, indicating that all models had high discriminatory power (i.e., with available occurrence data). The lowest AUC_{Diff} values resulted from the CBM and ABM models (Table 3). The lowest AUC_{Diff} values were observed at

$\beta = 5$ regularization in the CBM and ABM ($\beta = 5$ AUC_{Diff} range: 0.003 - 0.005; $\beta = 1$ AUC_{Diff} range: 0.011 - 0.016). Although we observed the opposite pattern with AUC_{Diff} values via the RBM models, values were low for both levels of regularization (Table 3).

Discussion

We show that modeling different spatial extents using MaxEnt is informative, and allows for comparison of species-environment relationships. SDMs can be constructed either holistically, with all of the available data across a species range (Kumar and Stohlgren 2009), or regionally, observing population or political boundaries (Warren and Seifert 2010; Gogol-Prokurat 2011). The holistic approach may be the best practice when seeking to identify a species realized niche (Austin et al. 1990), because a truncated sample set results in truncated model predictions, and a limited range of values for environmental variables (Austin 2007). We show this with our RBM, where the probability of Shovelnose Sturgeon presence was strongly related to the area available for sturgeon to complete their life history (i.e., extent). Unfortunately, all occurrence points from the Red River basin were associated with a segment containing 7,369 km of available habitat or ‘extent’. Shovelnose Sturgeon require a certain amount of free-flowing water to complete their life history (Braaten et al. 2008), but it may be less than our model predicted based on available data. We constrained predictions to a limited amount of occurrence data over an important environmental gradient (Van Horne 2002). However, we were interested in identifying differences between two populations, and when the purpose of predictions is regionally specific (i.e., isolated populations), reduced datasets may be more appropriate for identifying subtle differences in a species response to environmental variables (VanDerWal et al. 2009). In our CBM, the Arkansas River basin species-environment relationships masked those of the Red River basin, because Arkansas River basin occurrence records made up 68% of the model training data. This was apparent in the similarities between the CBM and the ABM, and the differences between the CBM and the RBM. For example, the prediction of Shovelnose Sturgeon distribution throughout the Red River Navigation System in the CBM was probably due to the low contribution extent made to the CBM. In another example, the CBM placed discharge constraints on Shovelnose Sturgeon presence in the Red River basin due to the positive correlation between probability of presence and mean annual discharge in the ABM. The RBM's higher probability of presence in smaller rivers of the Red River basin is more likely given recent reports (Brewer, Unpublished data) and historical accounts in Muddy Boggy Creek (Pigg 1977). The benefit of having multiple models allowed us to contrast the results among models, and tease out factors driving predictions in each basin. We believe modeling our populations at different spatial scales was more informative for our purposes (i.e., moving forward with a monitoring plan); however, thorough sampling across the basins would have improved our results (Austin 2007).

The patterns observed in some of our response curves suggest that improved sampling in this region will be necessary to make strong ecological inferences about Shovelnose Sturgeon. Our models predicted unrealistic correlations between the probability of Shovelnose Sturgeon presence and multiple variables due to limited data produced via biased sampling. A large portion of our occurrence records came from studies that conducted a disproportionate amount of sampling in targeted locations, which is a documented source of bias in SDMs (Austin 2007; Yackulic et al. 2013). Most of the occurrence points used in the ABM came from the Arkansas River in Tulsa, Oklahoma, due to sampling access and logistics (see Chapter 3). This may have skewed the ABM by creating a positive correlation between Shovelnose Sturgeon presence and an increase in impervious surfaces. This response seems unlikely, as impervious surfaces relate to urbanization, which is known to reduce water quality, alter hydrology (Leonard et al. 2004; Brown et al. 2005), and negatively affect stream biota (Allan 2004; Paukert et al. 2008). Likewise, the highest probability of Shovelnose Sturgeon presence in the CBM and ABM was associated with developed land. Lastly, when the models were run with only the drift variable, Shovelnose Sturgeon responded negatively to increasing drift in all three models. This finding is in contrast to our current understanding of the effects of fragmentation on Shovelnose Sturgeon distribution and abundance (Keenlyne 1997; Koch and Quist 2010; Phelps et al. 2016). Range of available drift within the basins was 0 - 1,634 km, but drift only ranged 12.5 - 680 km across our 40 occurrence points, resulting in a correlation between decreasing drift and Shovelnose Sturgeon presence. One assumption of presence-only modeling is that all sites within the extent of the study area have an equal probability of being sampled (Yackulic et al. 2013). This assumption is frequently violated (Yackulic et al. 2013), as it certainly was in the case of our models. We recommend that future efforts include more thorough Shovelnose Sturgeon sampling at this extent of the range. It would be beneficial to include the underrepresented areas and smaller tributaries of the mainstems to fill the gaps in our current occurrence data.

Presumed low and variable Shovelnose Sturgeon detection within our study area likely affected the predictive accuracy of our models. Another commonly-violated assumption of presence-only modeling is that the probability of species detection remains constant across the environmental gradients of the study area (Yackulic et al. 2013). Variable detection results in under-predictions of suitable locations (i.e., true positives), as the model equates lack of species detection to lack of presence (Lahoz-Monfort et al. 2014). We could not consider the issue of detection in this study, due to the nature of our data, and the lack of repeated sampling events within the basins. However, sampling Shovelnose Sturgeon is difficult (Phelps et al. 2016; Chapter 3), especially because they are presumed relatively rare (Robison et al. 1974). Difficulty sampling rare species negatively affects detection (Peoples and Frimpong 2011); thus, our models probably under predicted the distribution of Shovelnose Sturgeon. We recommend that future Shovelnose Sturgeon studies in this region address the issue of detection by conducting capture-recapture studies in multiple habitat types (Pollock et al. 1990). In areas with adequate water clarity, multiple-observer point counts (Nichols et al. 2000) followed by traditional sampling approaches, could be conducted as an alternative to capture-recapture studies. These efforts would improve our understanding of the distribution and abundance of the species, and establish a foundation necessary for developing ecological hypotheses.

Our results suggest discharge to be important to the distribution of a large-river, migratory fish, but also suggest we need the benefit of more comprehensive flow data. Not surprisingly, discharge was the most important factor in predicting the distribution of Shovelnose Sturgeon in the Arkansas-Red River basin. Shovelnose Sturgeon tolerates a large range of discharges throughout its distribution; however, habitat connectivity within the system is integral to Shovelnose Sturgeon persistence (Braaten et al. 2008), and discharge controls habitat connectivity (Poff et al. 1997). At this extent of the species range, stream discharge is highly variable (Matthews 1988; Dodds et al. 2004), and stream drying is frequent (Dodds et al. 2004). In addition to anthropogenic habitat fragmentation resulting from dams (Koch and Quist 2010) and stream dewatering (Gido et al. 2010), climate-driven stream drying may also be a limiting factor to Shovelnose Sturgeon distribution in the Great Plains. Unfortunately, it is difficult to assess this given the quality of flow data currently available. We used mean annual discharge (20-yr average) from the NHDPlus Version 2 Enhanced Unit Runoff Method (EROM) for flow estimation in our models. Mean annual discharge does not account for the important dynamics of stream flow (e.g. frequency, timing, duration, Poff et al. 1997), particularly as related to completion of Shovelnose Sturgeon life history. These flow events are especially important to isolated populations lacking dispersal routes (Labbe and Fausch 2000). Little is known about the location, or water conditions necessary for successful spawning of Shovelnose Sturgeon (DeLonay et al. 2007); however, they appear to spawn during higher flows in spring (Keenlyne 1997; Simpkins and LaBay 2007; Tripp et al. 2009), and sometimes autumn (Tripp et al. 2009). The timing of those higher flows is thought to coincide with suitable water temperatures ranging 17 - 21 °C (Keenlyne 1997; Simpkins and LaBay 2007). The drift dynamics of larval Shovelnose

Sturgeon have been documented (Braaten et al. 2008), and because the larvae require six days of drift before becoming free-swimming, it is likely that the duration of flow plays a major role in Shovelnose Sturgeon recruitment. Until better flow data are available, it is difficult to model specific relationships with discharge that would improve conservation and management for the species.

Our results suggest that altering regularization parameters may be beneficial when using limited occurrence records to predict species distribution. Our simplified models ($\beta = 5$ regularization) performed the best, based on the AUC scores, and our interpretation of the predictions. This is not surprising, as Phillips and Dudík (2007) suggests that tuning regularization parameters in MaxEnt can prevent over fitting and improve predictive performance, especially when using a small number of occurrence records. Our $\beta = 5$ models were less conservative, predicting suitable habitat in many tributaries of the Arkansas and Red rivers. Therefore, the results of our $\beta = 5$ models will be more useful than those of the MaxEnt default ($\beta = 1$) models for planning future sampling events. Given our results after increasing regularization, it appears that simplified models perform better; however, care should be taken not to over-simplify models as that can also affect predictive performance (Warren and Seifert 2010). Although MaxEnt's default regularization may perform best in some cases, all attempts to achieve parsimony in model complexity should be made if accurate predictions are desired (Warren and Seifert 2010).

We found drift to be of little importance in the prediction of Shovelnose Sturgeon presence; however, drift changes depending on the location of occurrence within a fragment, whereas extent is static within a fragment. Drift is an important factor related to the persistence of many riverine fish species (e.g., Arkansas River Shiner, Worthington et al. 2016; Pallid Sturgeon *Scaphirhynchus albus*, Braaten et al. 2011), but it does not necessarily lend value to a model unless sampling corresponds to spawning. Our definition of drift related to spawning habitat, which is only used by certain life stages at particular times (Boyce et al. 2002). For example, Paddlefish *Polyodon spathula* require large, free-flowing rivers for successful spawning (Pflieger 1997), but spend most of their life foraging in slow-moving or lentic habitat (Paukert and Fisher 2001). Extent, however, facilitates drift and is independent of the occurrence location within a fragment. We cannot fully infer persistence by a long-lived species using extent in fragmented landscapes unless fragmentation exceeds the longevity of the species (i.e., there has been reproduction since the fragmentation occurred). For these reasons, we recommend that SDMs use extent to represent available habitat in fragmented segments, and drift be restricted to models focused on spawning fishes.

This study represents the first step towards improving the conservation and management of Shovelnose Sturgeon at the southwest extent of the species range. We recognize the limitations of our models, but we see value in how they might move sampling efforts forward. Our findings suggest that the populations of Shovelnose Sturgeon in the Arkansas River and Red River basins may respond differently to some abiotic factors; however, we realize more targeted sampling efforts are needed to further explore these relationships. At the current resolution, we cannot assess possible biotic limitations, or fine-grain habitat limitations that commonly shape species distribution at range edges (i.e., interspecific competition or habitat patchiness, Arkle and Pilliod 2015). Our knowledge of Shovelnose Sturgeon in these basins will continue to grow as the data improve. Future studies should attempt to resolve the issues of sampling-location bias by taking a spatially representative approach to sampling the region. First, we suggest stratifying sample sites by the amount of available habitat between barriers, and average discharge. Then, sample sites could be randomly selected from the resultant pool of suitable sites and replaced if access or lack of water renders the site unavailable for sampling. This design should include the tributaries of the mainstems as our models predicted suitable habitat in these locations. Next, we suggest sampling should be conducted to account for the variable detection inherent across the heterogeneous landscape. Lastly, improvements in the resolution of flow and other environmental data (i.e., water quality) would benefit inferences of species-environment relationships.

References

Allan, J. D. 2004. Landscapes and riverscapes: The influence of land use on stream ecosystems. Annual Review of Ecology, Evolution, and Systematics 35(1):257-284.

Arkle, R. S., and D. S. Pilliod. 2015. Persistence at distributional edges: Columbia Spotted Frog habitat in the arid Great Basin, USA. Ecology and Evolution 5(17):3704-3724.

Austin, M. P. 2007. Species distribution models and ecological theory: a critical assessment and some possible new approaches. Ecological Modelling 200(1–2):1-19.

Austin, M. P., A. O. Nicholls, and C. R. Margules. 1990. Measurement of the realized qualitative niche: environmental niches of five eucalyptus species. Ecological Monographs 60(2):161-177.

Barbet-Massin, M., F. Jiguet, C. H. Albert, and W. Thuiller. 2012. Selecting pseudo-absences for species distribution models: how, where and how many? Methods in Ecology and Evolution 3:327-338.

Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157(2–3):281-300.

Braaten, P. J., D. B. Fuller, L. D. Holte, R. D. Lott, W. Viste, T. F. Brandt, and R. G. Legare. 2008. Drift dynamics of larval Pallid Sturgeon and Shovelnose Sturgeon in a natural side channel of the Upper Missouri River, Montana. North American Journal of Fisheries Management 28(3):808-826.

Braaten, P. J., D. B. Fuller, R. D. Lott, M. P. Ruggles, T. F. Brandt, R. G. Legare, and R. J. Holm. 2011. An experimental test and models of drift and dispersal processes of Pallid Sturgeon *Scaphirhynchus albus* free embryos in the Missouri River. Environmental Biology of Fishes 93(3):377-392.

Brown, L. R., R. H. Gray, R. M. Hughes, and M. R. Meador. 2005. Introduction to effects of urbanization on stream ecosystems. American Fisheries Society Symposium 47:1-8.

Delonay, A. J., D. M. Papoulias, R. B. Jacobson, M. L. Wildhaber, D. G. Simpkins, and C. E. Korschgen. 2007. Project Overview. In C. E. Korschgen Editor, Factors affecting the reproduction, recruitment, habitat, and population dynamics of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River. Open-File Report 2007-1262. U. S. Geological Survey, Reston, VA.

de Siqueira, M. F., G. Durigan, P. de Marco Jr., and A. T. Peterson. 2009. Something from nothing: Using landscape similarity and ecological niche modeling to find rare plant species. Journal for Nature Conservation 17(1):25-32.

Dodds, W. K., K. Gido, M. R. Whiles, K. M. Fritz, and W. J. Matthews. 2004. Life on the edge: the ecology of Great Plains prairie streams. BioScience 54(3):205-216.

Dudley, R. K., and S. P. Platania. 2007. Flow regulation and fragmentation imperil pelagic-spawning riverine fishes. Ecological Applications 17(7):2074-2086.

Dyer, J. J., S. K. Brewer, T. A. Worthington, and E. A. Bergey. 2013. The influence of coarse-scale environmental features on current and predicted future distributions of narrow-range endemic crayfish populations. Freshwater Biology 58(6):1071-1088.

Elith, J., C. H. Graham, R. P. Anderson, M. Dudík, S. Ferrier, A. Guisan, R. J. Hijmans, F. Huettmann, J. R. Leathwick, A. Lehmann, J. Li, L. G. Lohmann, B. A. Loiselle, G. Manion, C. Moritz, M. Nakamura, Y. Nakazawa, J. McC. M. Overton, A. Townsend Peterson, S. J. Phillips, K. Richardson, R. Scachetti-Pereira, R. E. Schapire, J. Soberón, S. Williams, M. S. Wisz, and N. E. Zimmermann. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography 29(2):129-151.

Elith, J., S. J. Phillips, T. Hastie, M. Dudík, Y. E. Chee, and C. J. Yates. 2011. A statistical explanation of MaxEnt for ecologists. Diversity and Distributions 17(1):43-57.

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. Annual Review of Ecology and Systematics 34:487-515.

Ferrara, A. M. 2001. Life-history Strategy of Lepisosteidae: Implications for the conservation and management of Alligator Gar. Ph. D. Dissertation. Auburn University, Auburn, AL.

Gido, K. B., W. K. Dodds, and M. E. Eberle. 2010. Retrospective analysis of fish community change during a half-century of landuse and streamflow changes. Journal of the North American Benthological Society 29(3):970-987.

Gogol-Prokurat, M. 2011. Predicting habitat suitability for rare plants at local spatial scales using a species distribution model. Ecological applications 21(1):33-47.

Guisan, A., and W. Thuiller. 2005. Predicting species distribution: offering more than simple habitat models. Ecology Letters 8(9):993-1009.

Hansen, A. J., R. P. Neilson, V. H. Dale, C. H. Flather, L. R. Iverson, D. J. Currie, S. Shafer, R. Cook, and P. J. Bartlein. 2001. Global change in forests: responses of species, communities, and biomes. BioScience 51(9):765-779.

Hendry, A. P., J. K. Wenburg, P. Bentzen, E. C. Volk, and T. P. Quinn. 2000. Rapid evolution of reproductive isolation in the wild: evidence from introduced salmon. Science 290:516-518.

Hijmans, R. J., S. Phillips, J. Leathwick, and J. Elith. 2011. Species Distribution Modeling, Package 'dismo'. Available at: http://cran.r-project.org/web/packages/dismo/index.html.

Homer, C. G., J. A. Dewitz, L. Yang, S. Jin, P. Danielson, G. Xian, J. Coulston, N. Herold, J. Wickham, and K. Megown. 2015. Completion of the 2011 National Land Cover Database for the conterminous United States-representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing, 81(5):345-354.

Hynes, H. B. N. 1975. The stream and its valley. Verh. Int. Ver. Theor. Ang. Limnol. 19(1):1-15.

Kappenman, K. M., W. C. Fraser, M. Toner, J. Dean, and M. A. H. Webb. 2009. Effect of temperature on growth, condition, and survival of juvenile Shovelnose Sturgeon. Transactions of the American Fisheries Society 138(4):927-937.

Keenlyne, K. D. 1997. Life history and status of the Shovelnose Sturgeon, *Scaphirhynchus platorynchus*. Environmental Biology of Fishes 48(1–4):291-298.

Koch, J. D., and M. C. Quist. 2010. Current status and trends in Shovelnose Sturgeon *Scaphirhynchus platorynchus* management and conservation. Journal of Applied Ichthyology 26(4):491-498.

Kumar, S., and T. J. Stohlgren. 2009. Maxent modeling for predicting suitable habitat for threatened and endangered tree *Canacomyrica monticola* in New Caledonia. Journal of Ecology and Natural Science 1(4):94-98.

Labbe, T. R., and K. D. Fausch. 2000. Dynamics of intermittent stream habitat regulate persistence of a threatened fish at multiple scales. Ecological Applications 10(6):1774-1791.

Lahoz-Monfort, J. J., G. Guillera-Arroita, and B. A. Wintle. 2014. Imperfect detection impacts the performance of species distribution models. Global Ecology and Biogeography 23(4):504-515.

Laurance, W. F., and D. C. Useche. 2009. Environmental synergisms and extinctions of tropical species. Conservation Biology 23(6):1427-1437.

Leonard, N. J., W. W. Taylor, and C. Goddard. 2004. Multijurisdictional management of Lake Sturgeon in the Great Lakes and St. Lawrence River. In G. T. O., LeBreton, F. W. H. Beamish, and R. S. McKinley Eds., Sturgeons and paddlefish of North America pp. 231-251. Kluwer Academic Publishers, Dordrecht.

Mac Nally, R. 2000. Regression and model-building in conservation biology, biogeography and ecology: the distinction between and reconciliation of “predictive” and “explanatory” models. Biodiversity and Conservation 9:655-671.

Matthews, W. J. 1988. North American prairie streams as systems for ecological study. Journal of the North American Benthological Society 7:387-409.

Meffe, G. K., and R. C. Vrijenhoek. 1988. Conservation genetics in the management of desert fishes. Society for Conservation Biology 2(2):157-169.

Merow, C., M. J. Smith, and J. A. Silander. 2013. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. Ecography 36(10):1058-1069.

Miller, R. J., and H. W. Robison. 2004. Fishes of Oklahoma. University of Oklahoma Press, Norman, OK.

Murphy, C. E., J. J. Hoover, S. G. George, and K. J. Killgore. 2007. Morphometric variation among river sturgeons *Scaphirhynchus spp.* of the Middle and Lower Mississippi River. Journal of Applied Ichthyology 23:313-323.

Neiva, J., J. Assis, N. C. Coelho, F. Fernandes, G. A. Pearson, and E. A. Serrão. 2015. Genes left behind: Climate change threatens cryptic genetic diversity in the canopy-forming seaweed *Bifurcaria bifurcata*. PLoS ONE 10(7):1-21.

Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon, J. E. Fallon, and P. J. Heglund. 2000. A double-observer approach for estimating detection probability and abundance from point counts. The Auk 117(2):393-408.

Paukert, C. P., and W. L. Fisher. 2001. Spring movements of Paddlefish in a prairie reservoir system. Journal of Freshwater Ecology 16(1):113-124.

Paukert, C., J. Schloesser, J. Fischer, J. Eitzmann, K. Pitts, and D. Thornbrugh. 2008. Effect of instream sand dredging on fish communities in the Kansas River USA: current and historical perspectives. Journal of Freshwater Ecology 23(4):623-633.

Peoples, B. K., and E. A. Frimpong. 2011. Among-pass, interregional, and single-versus multiple-season comparisons of detection probabilities of stream fishes. Tansactions of the American Fisheries Society 140(1):67-83.

Pflieger, W. L. 1997. The fishes of Missouri Revised Edition. Missouri Department of Conservation, Jefferson City.

Phelps, Q. E., S. J. Tripp, J. E. Garvey, D. P. Herzog, D. E. Ostendorf, J. W. Ridings, J. W. Crites, and R. A. Hrabik. 2010a. Habitat use during early life history infers recovery needs for Shovelnose Sturgeon and Pallid Sturgeon in the Middle Mississippi River. Transactions of the American Fisheries Society 139(4):1060-1068.

Phelps, Q. E., S. J. Tripp, M. J. Hamel, J. Koch, E. J. Heist, J. E. Garvey, K. M. Kappenman, and M. A. H. Webb. 2016. Status of knowledge of the Shovelnose Sturgeon (*Scaphirhynchus platorynchus*, Rafinesque, 1820). Journal of Applied Ichthyology 32(Sup. 1):249-260.

Phelps, Q. E., S. J. Tripp, W. D. Hintz, J. E. Garvey, D. P. Herzog, D. E. Ostendorf, J. W. Ridings, J. W. Crites, and R. A. Hrabik. 2010b. Water temperature and river stage influence mortality and abundance of naturally occurring Mississippi River Scaphirhynchus Sturgeon. North American Journal of Fisheries Management 30(3):767-775.

Phillips, S. J. 2009. A brief tutorial on Maxent. AT&T Research, Florham Park, NJ.

Phillips, S. J., M. Dudík, and R. Schapire. 2004. A maximum entropy approach to species distribution modeling. Proceedings of the twenty-first International Conference on Machine Learning pp. 655-662.

Phillips, S. J., and M. Dudík. 2007. Modeling of species distribution with Maxent: new extensions and a comprehensive evalutation. Ecograpy 31:161-175.

Pigg, J. 1977. A survey of the fishes of the Muddy Boggy River in south central Oklahoma. Proceedings of the Oklahoma Academy of Sciences 57:68-82.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. BioScience 47(11):769-784.

Pollock, K. H., J. D. Nichols, C. Brownie, and J. E. Hines. 1990. Statistical inference for capture-recapture experiments. Wildlife Monographs 107:3-97.

Rahel, F. J. 2002. Using current biogeographic limits to predict fish distributions following climate change. American Fisheries Society Symposium 32:99-110.

Robison, H. W., G. A. Moore, and R. J. Miller. 1974. Threatened fishes of Oklahoma. Proceedings of the Oklahoma Academy of Sciences 54:139-146.

RStudio Team. 2016. RStudio: Integrated Development for R. RStudio Inc., Boston, MA. Available at: http://www.rstudio.com/.

Samson, F., and F. Knopf. 1994. Prairie conservation in North America. BioScience 44(6):418-421.

Schlee, J. S. 2017. Our changing continent. USGS General Interest Publications, U. S. Geological Survey. Retrieved from https://pubs.usgs.gov/gip/continents/. Accessed 2016.

Schruben, P. G., R. E. Arndt, W. J. Bawiec, P. B. King, and H. M. Beikman. 1994. Geology of the Conterminous United States at 1:2,500,000 Scale - A Digital Representation of the 1974 P.B. King and H.M. Beikman Map. USGS Digital Data Series 11. U. S. Geological Survey, Reston, VA. Available at: http://pubs.usgs.gov/dds/dds11/.

Simon-Bouhet, B., P. Garcia-Meunier, and F. Viard. 2006. Multiple introductions promote range expansion of the mollusc *Cyclope neritea* (Nassariidae) in France: evidence from mitochondrial sequence data. Molecular Ecology 15(6):1699-1711.

Simpkins, D. G., and S. R. LaBay. 2007. Site-specific assessment of spawning behavior and habitat use. In C. E. Korschgen Editor, Factors affecting the reproduction, recruitment, habitat, and population dynamics of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River. Open-File Report 2007-1262. U. S. Geological Survey, Reston, VA.

Slack, W. T., M. T. O. Connell, T. L. Peterson, J. A. E. Iii, and S. T. Ross. 1997. Ichthyofaunal and habitat associations of disjunct populations of Southern Redbelly Dace *Phoxinus erythrogaster* (Teleostei: Cyprinidae) in Mississippi. The American Midland Naturalist 137(2):251-265.

Strange, K. T., J. C. Vokoun, and D. B. Noltie. 2002. Thermal tolerance and growth differences in Orangethroat Darter *Etheostoma Spectabile* from thermally contrasting adjoining streams. American Midland Naturalist 148(1):120-128.

Townsend Peterson, A., M. Papeş, and M. Eaton. 2007. Transferability and model evaluation in ecological niche modeling: a comparison of GARP and Maxent. Ecography 30(4):550-560.

Tripp, S. J., Q. E. Phelps, R. E. Colombo, J. E. Garvey, B. M. Burr, D. P. Herzog, and R. A. Hrabik. 2009. Maturation and reproduction of Shovelnose Sturgeon in the Middle Mississippi River. North American Journal of Fisheries Management 29(3):730-738.

US Army Corps of Engineers. 2010. National Inventory of Dams. US Army Topographic Engineering Center, Alexandria, Virginia. Available at: http://nid.usace.army.mil. Accessed: November, 2016.

USEPA, USGS. 2012. National Hydrography Dataset Plus – NHDPlus, Edition 2.10. U.S. Environmental Protection Agency, Washington, DC and the U.S. Geological Survey, Reston, VA. Available at: http://www.horizonsystems.com/NHDPlus/NHDPlusV2_home.php.

VanDerWal, J., L. P. Shoo, C. Graham, and S. E. Williams. 2009. Selecting pseudo-absence data for presence-only distribution modeling: How far should you stray from what you know? Ecological Modelling 220(4):589-594.

Van Horne, B. 2002. Approaches to habitat modeling: The tensions between pattern and process and between specificity and generality. In M. J. Scott, P. J. Heglund, M. L. Morrison, J. B. Haufler, M. G. Raphael, W. A. Wall, and F. B. Samson Eds., Predicting Species Occurrences: Issues of Accuracy and Scale pp. 63-72. Island Press, Washington, DC.

Warren, D. L., and S. N. Seifert. 2010. Ecological niche modeling in Maxent: the importance of model complexity and the performance of model selection criteria. Ecological Applications 21(2):335-342.

Warren, M. L. J., B. M. Burr, S. J. Walsh, H. L. J. Bart, R. C. Cashner, D. A. Etnier, B. J. Freeman, B. R. Kuhajda, R. L. Mayden, H. W. Robison, S. T. Ross, and W. C. Starnes. 2000. Diversity, distribution, and conservation status of the native freshwater fishes of the southern United States. Fisheries 25(10):7-31.

Wiken, E., F. J. Nava, and G. Griffith. 2011. North American Terrestrial Ecoregions—Level III. Commission for Environmental Cooperation, Montreal, Canada.

Woods, A. J., J. M. Omernik, D. R. Butler, J. G. Ford, J. E. Henley, B. W. Hoagland, D. S. Arndt, and B. C. Moran. 2005. Ecoregions of Oklahoma (color poster with map, descriptive text, summary tables, and photographs) (map scale 1:1,250,000). U. S. Geological Survey, Reston, Virginia.

Worthington, T. A., S. K. Brewer, T. B. Grabowski, and J. Mueller. 2014. Backcasting the decline of a vulnerable Great Plains reproductive ecotype: identifying threats and conservation priorities. Global Change Biology 20(1):89-102.

Worthington, T. A., T. Zhang, D. R. Logue, A. R. Mittelstet, and S. K. Brewer. 2016. Landscape and flow metrics affecting the distribution of a federally-threatened fish: Improving management, model fit, and model transferability. Ecological Modelling 342:1-18.

Yackulic, C. B., R. Chandler, E. F. Zipkin, J. A. Royle, J. D. Nichols, E. H. Campbell Grant, and S. Veran. 2013. Presence-only modelling using MAXENT: When can we trust the inferences? Methods in Ecology and Evolution 4(3):236-243.

Table 1. Description, resolution, and source of environmental variables chosen for MaxEnt model framework. We used MaxEnt to model the distribution of Shovelnose Sturgeon populations of the Arkansas River and Red River basins. Specific Bioclim variables associated with climate are described in Appendix C, Table 1. Geology and land use types are provided in Appendix C, Tables 2 and 3.

Environmental Variables	Description	Resolution	Source
Climate	19 Bioclim variables describing trends in temperature and precipitation.	4 km	Hijmans et al. (2011)
Discharge	Mean annual discharge (cfs) of stream segment	1:100,000	USEPA, USGS (2012)
Slope	Slope (m/m) of stream segment	1:100,000	USEPA, USGS (2012)
Elevation	Maximum elevation (cm) of stream segment	30 m	USEPA, USGS (2012)
Geology	Dominant geology type within stream segment	1:2,500,000	Schruben et al. (1994)
Land use	Dominant land-use category within stream segment	30 m	Homer et al. (2015)
Land-use change	Pixels changing land-use category (%) between 2001 and 2011 within stream segment	30 m	Homer et al. (2015)
Impervious	Impervious surfaces (%) within stream segment	30 m	Homer et al. (2015)
Drift	Distance (km) from stream segment to nearest downstream barrier		Drift was calculated using data from the National Inventory of Dams, US Army Corps of Engineers (2010)
Extent	Total stream segment distance (km) from nearest upstream to nearest downstream barrier		Extent was calculated using data from the National Inventory of Dams, US Army Corps of Engineers (2010)

Table 2. Percent contribution of each variable associated with three MaxEnt models, at two levels of regularization (β = 1, and β = 5). Some variables were not included in all models as indicated by dashes (--). Zero indicates that the variable did not contribute to the model. The three model names are represented as: CBM = Arkansas River and Red River basins combined model; ABM = Arkansas River basin model; RBM = Red River basin model. The model boundaries are shown in Figure 1. Variable definitions were provided in Table 1. Specific Bioclim variables associated with climate are described in Appendix C, Table 1. Geology and land use types are provided in Appendix C, Tables 2 and 3.

	CBM		**ABM**		**RBM**	
Variable	**β = 1**	**β = 5**	**β = 1**	**β = 5**	**β = 1**	**β = 5**
Discharge	82	92	76	92	41	28
Impervious	6	5	12	3	< 1	0
Drift	5	2	5	1	10	9
Land use	3	< 1	1	1	< 1	0
Geology	2	0	2	< 1	25	10
Slope	< 1	0	< 1	0	< 1	0
Elevation	< 1	< 1	< 1	2	2	17
Land-use change	< 1	< 1	1	1	< 1	0
Extent	< 1	0	< 1	0	21	36
BIO8	< 1	0	0	0	< 1	0
BIO10	< 1	< 1	< 1	< 1	0	0
BIO3	0	0	0	0	0	0
BIO4	0	0	0	0	--	--
BIO1	--	--	--	--	0	0
BIO5	--	--	0	0	--	--

Table 3. Mean AUC scores of the test data (AUC_{Test}), training data (AUC_{Train}), and differences (AUC_{Diff}) between AUC_{Test} and AUC_{Train} for all models. Higher AUC_{Test} scores indicate higher discriminatory power. Greater AUC_{Diff} values indicate greater potential of model over fit. Model names are represented as: CBM = Arkansas River and Red River basins combined model; ABM = Arkansas River basin model; RBM = Red River basin model.

	CBM		**ABM**		**RBM**	
	β = 1	**β = 5**	**β = 1**	**β = 5**	**β = 1**	**β = 5**
AUC_{Test}	0.982	0.985	0.979	0.985	0.989	0.990
AUC_{Train}	0.993	0.988	0.995	0.989	0.992	0.986
AUC_{Diff}	0.011	0.003	0.016	0.005	0.003	0.005

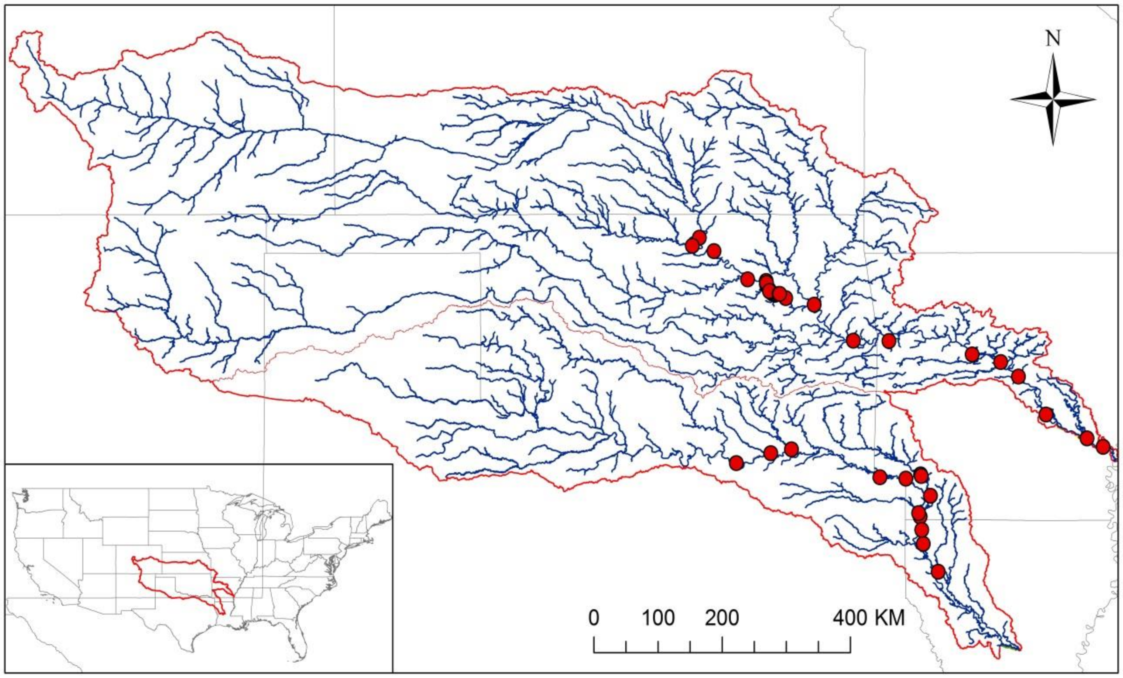

Figure 1. Map of the stream networks and Shovelnose Sturgeon occurrence records within the Arkansas River and Red River basins used to develop our SDMs. The dark red outline indicates the spatial extent of the combined basins, and the lighter red line indicates the border between the two basins. Blue lines indicate fourth order and larger streams within the basins. The red circles indicate Shovelnose Sturgeon occurrences gathered from museum and university collections, species databases, state and federal agencies, published literature, university theses, gray literature, angler reports, and recent field sampling conducted by the Oklahoma Department of Wildlife Conservation.

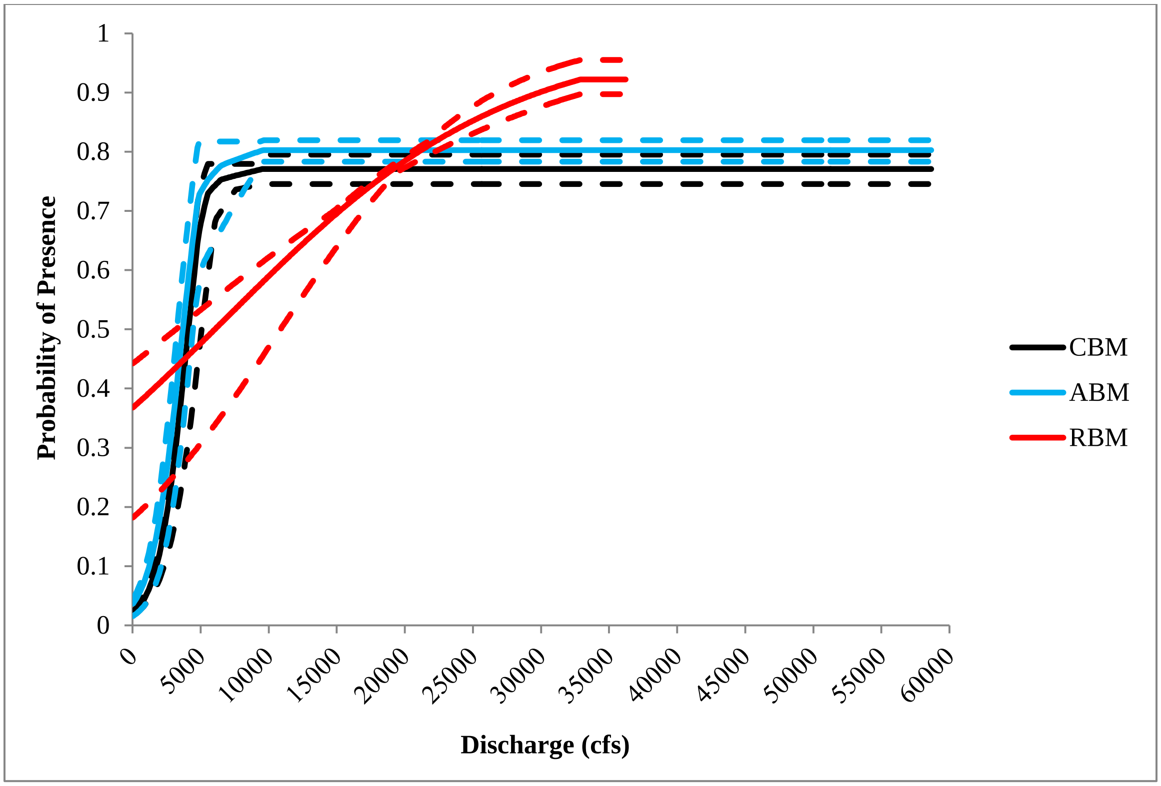

Figure 2. Response curves showing the relationship between Shovelnose Sturgeon probability of presence and mean annual discharge in three MaxEnt models, at β = 5 regularization. The solid lines show the mean probabilities of presence from 10 replicate model runs, and dashed lines show the range in probability values observed throughout the 10 runs. Models were used to predict the distribution of isolated Shovelnose Sturgeon populations within the Arkansas River and Red River basins. Model names are represented by: CBM = Arkansas River and Red River basins combined model; ABM = Arkansas River basin model; RBM = Red River basin model.

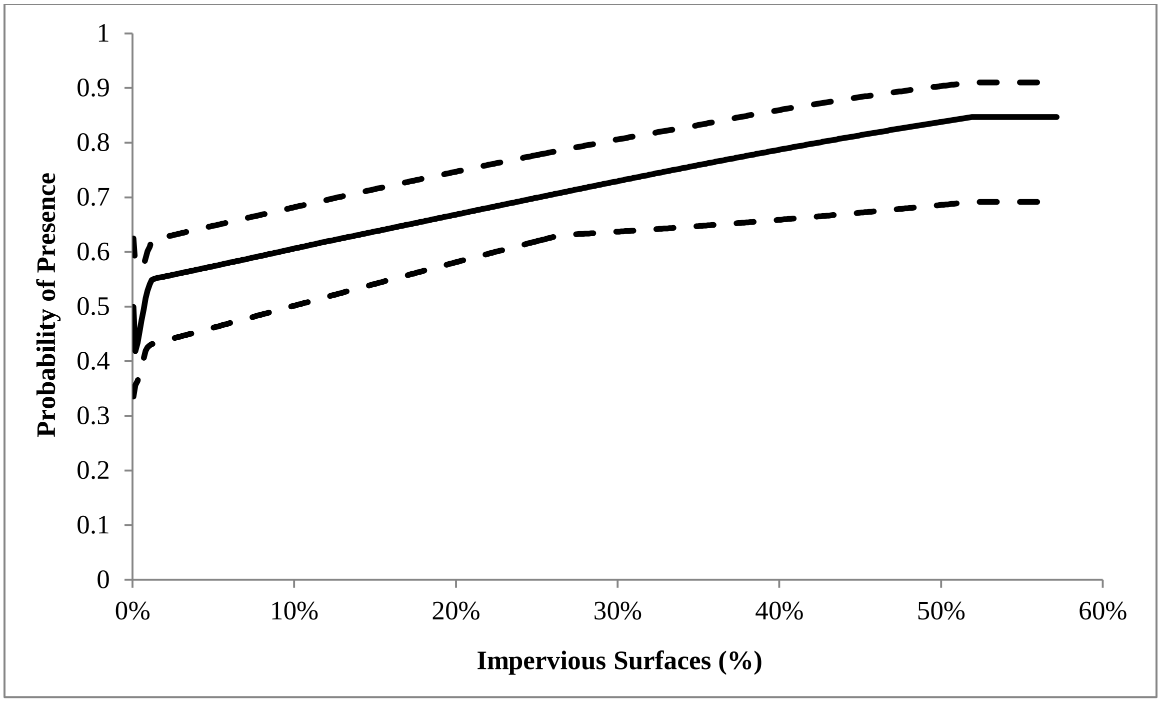

Figure 3. Response curve showing the relationship between Shovelnose Sturgeon probability of presence and the percentage impervious surfaces in the MaxEnt Arkansas River basin model, at β = 1 regularization. The solid line shows the mean probability of presence from 10 replicate model runs, and dashed lines show the range in probability values observed throughout the 10 runs. Models were used to predict the distribution of isolated Shovelnose Sturgeon populations within the Arkansas River and Red River basins.

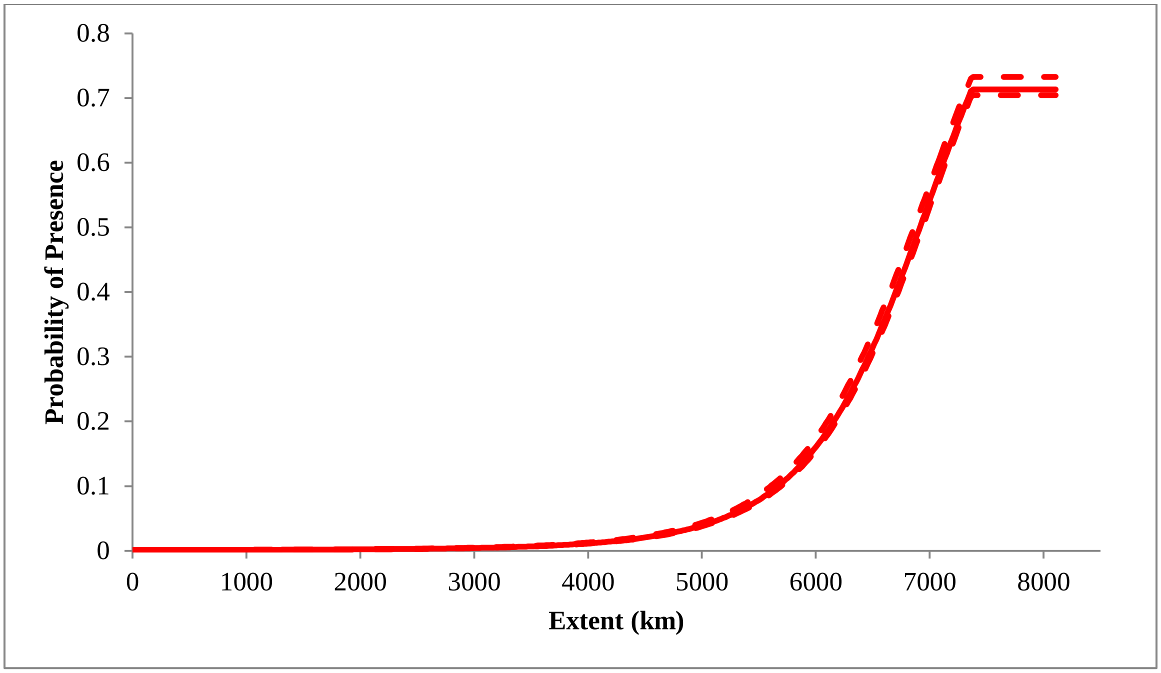

Figure 4. Response curve showing the relationship between Shovelnose Sturgeon probability of presence and the habitat available upstream of a barrier (extent) in the MaxEnt Red River basin model, at β = 5 regularization. The solid line shows the mean probability of presence from 10 replicate model runs, and dashed lines show the range in probability values observed throughout the 10 runs. Models were used to predict the distribution of isolated Shovelnose Sturgeon populations within the Arkansas River and Red River basins.

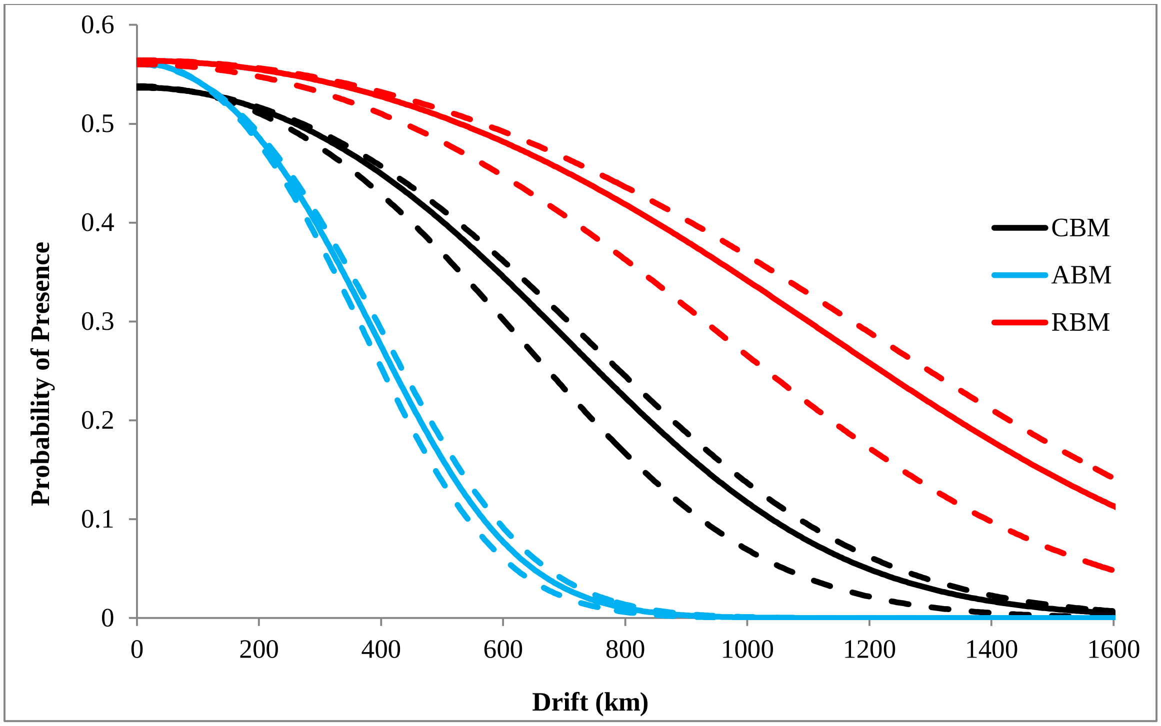

Figure 5. Response curves showing the relationship between Shovelnose Sturgeon probability of presence and the distance to a downstream barrier (drift) when drift was the only variable used in three MaxEnt models, at β = 5 regularization. The solid lines show the mean probabilities of presence from 10 replicate model runs, and dashed lines show the range in probability values observed throughout the 10 runs. Models were used to predict the distribution of isolated Shovelnose Sturgeon populations within the Arkansas River and Red River basins. Model names are represented by: CBM = Arkansas River and Red River basins combined model; ABM = Arkansas River basin model; RBM = Red River basin model.

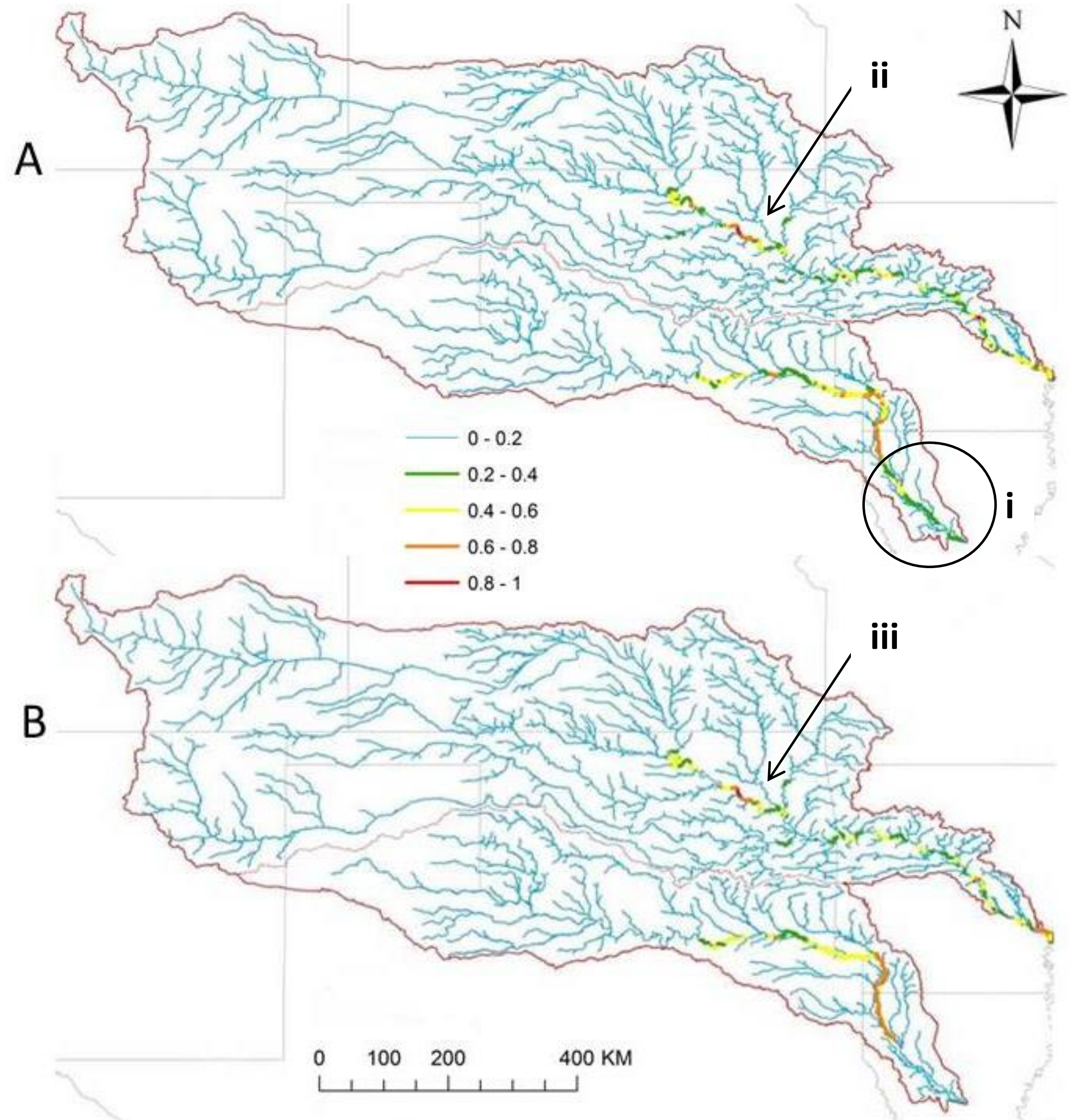

Figure 6. Probability of Shovelnose sturgeon presence predicted by the Arkansas River and Red River basins combined model (CBM) (A), and the Arkansas River basin model (ABM) and Red River basin model (RBM) (B), at β = 1 regularization. A color-coded legend, located in the center of the figure, shows the range of probability of occurrence by stream segment. The CBM predicts a 0.2 - 0.6 probability of presence within the Red River Navigation System (i), but the RBM predicts < 0.2 probability within the same area. The CBM and ABM predicted < 0.2 probability of presence in the Verdigris River (ii, and iii).

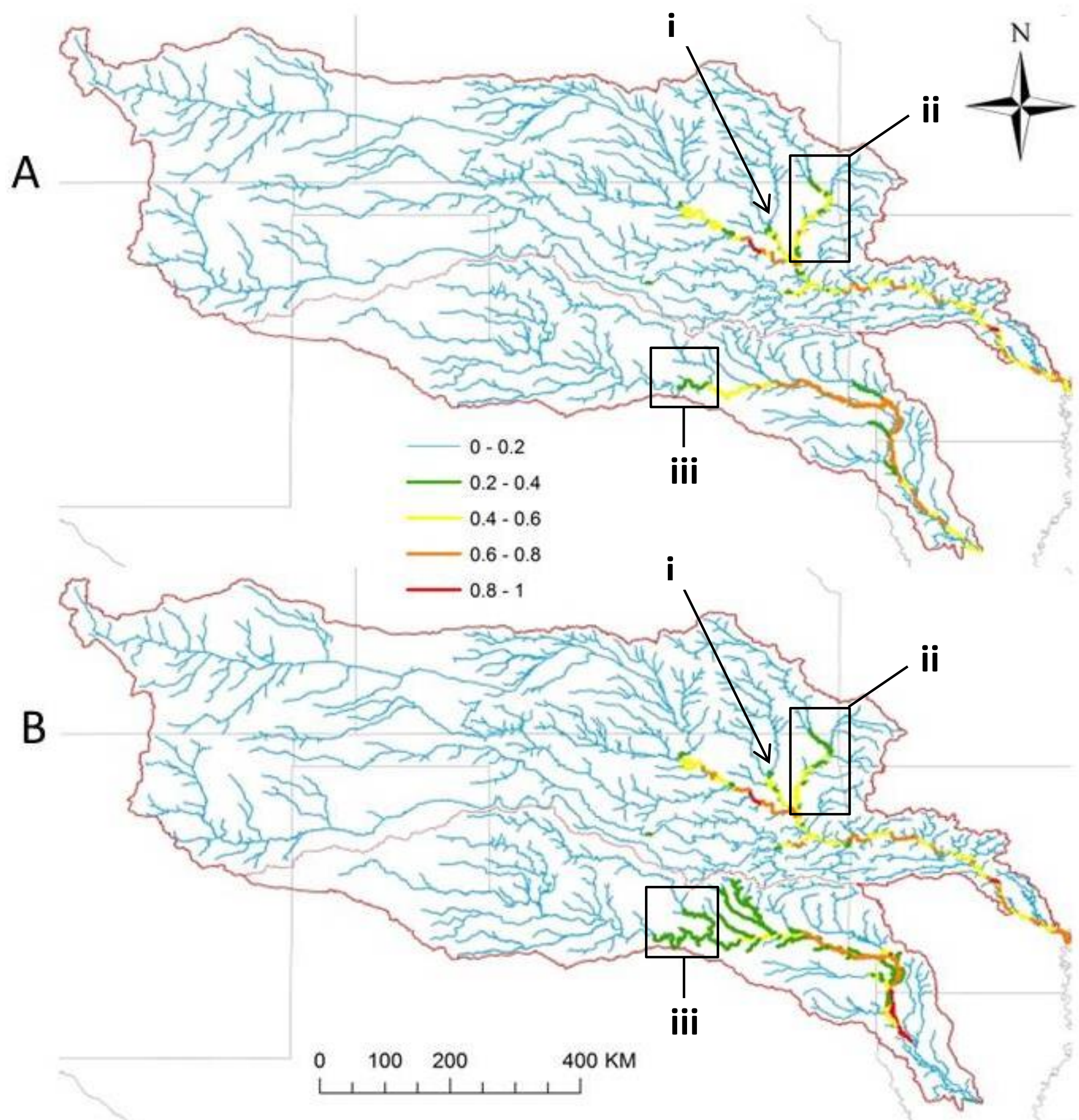

Figure 7. Probability of Shovelnose Sturgeon presence predicted by the Arkansas River and Red River basins combined model (CBM) (A), and the Arkansas River basin model (ABM) and Red River basin model (RBM) (B), at β = 5 regularization. A color-coded legend, located in the center of the figure, shows the range of probability of occurrence by stream segment. The CBM and ABM predicted Shovelnose Sturgeon distribution extending into the Verdigris River, upstream to Oolagah Dam (i), and throughout the Grand-Neosho River system (ii). The CBM and RBM predict a 0.2 - 0.4 probability of Shovelnose Sturgeon presence upstream of Denison Dam (iii).

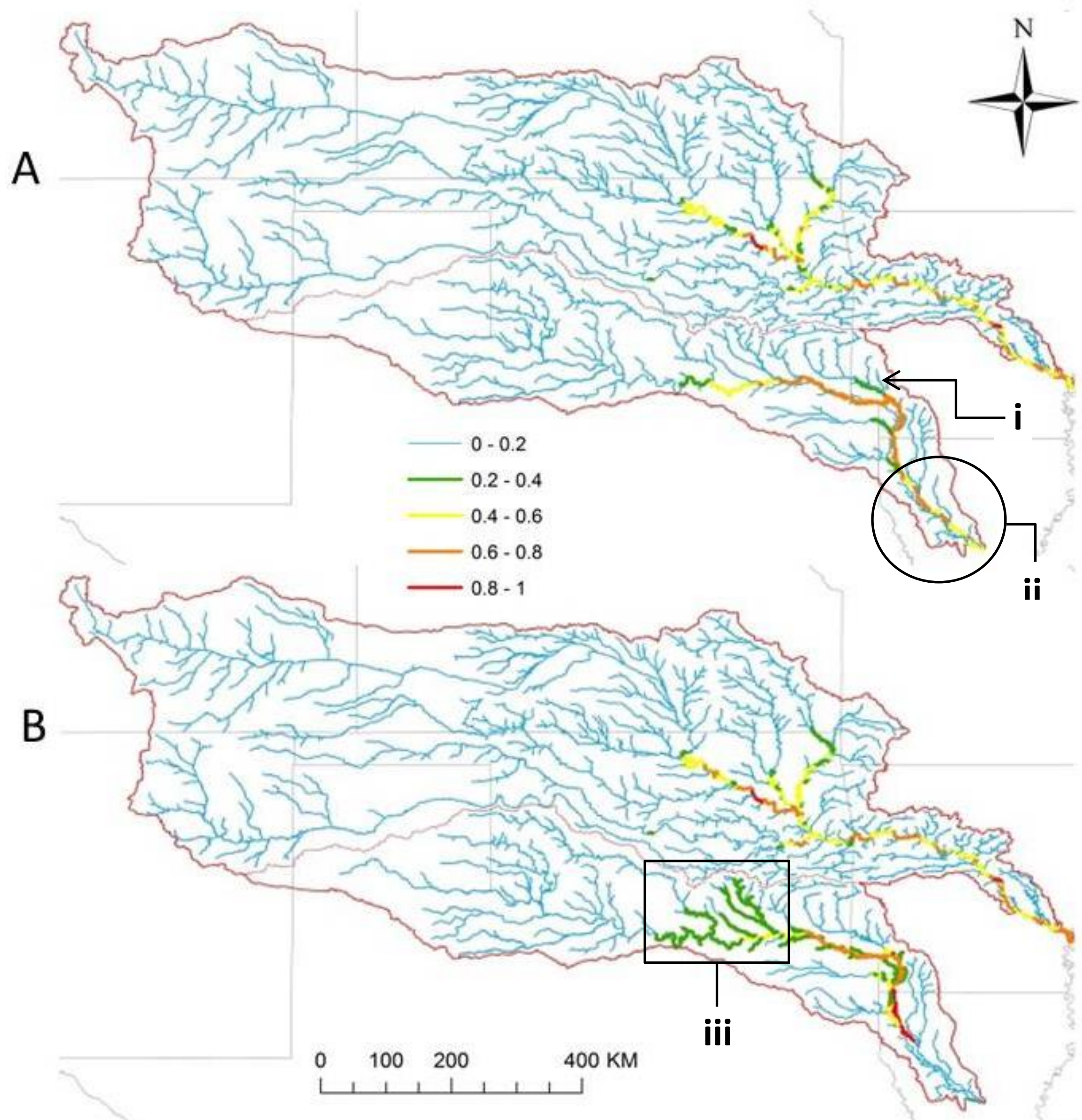

Figure 8. Probability of Shovelnose sturgeon presence predicted by the Arkansas River and Red River basins combined model (CBM) (A), and the Arkansas River basin model (ABM) and Red River basin model (RBM) (B), at β = 5 regularization. A color-coded legend, located in the center of the figure, shows the range of probability of occurrence by stream segment. The CBM predicted a 0.2 - 0.4 probability of presence in the Little River (i), and a 0.4 - 0.8 probability of presence throughout the Red River Navigation System (ii). The RBM predicted distribution extending into the Blue River, Muddy Boggy and Clear Boggy creeks, and the Washita and Red rivers upstream of Denison Dam (iii).

Appendix A

Table 1. List of Arkansas River and Red River basins Shovelnose Sturgeon occurrence records gathered for our models. Latitude and longitude is in decimal degrees. These data were retrieved from the sources listed.

Latitude	Longitude	Collection date	Water body	Source
34.860000	-99.190000	1921	North Fork of Red River	Sam Noble Museum
35.241110	-94.619720	1949	Arkansas River	Oklahoma State University
36.205000	-94.797500	1950	Arkansas River	Oklahoma State University
34.780000	-99.170000	1951	North Fork of Red River	Sam Noble Museum
33.911670	-96.577780	1951	Washita River	Oklahoma State University
33.886480	-95.946649	1953	Blue River	Oklahoma State University
36.968341	-95.354143	1958	Big Creek	Sam Noble Museum
34.214330	-99.101292	1961	Salt Fork of Red River	Oklahoma State University
34.606266	-95.178610	1977	Red River	Oklahoma State University
33.569139	-94.408058	1997	Red River	Arkansas Game and Fish Commission
33.553556	-94.046369	1997	Red River	Arkansas Game and Fish Commission
33.609514	-93.823911	1997	Red River	Arkansas Game and Fish Commission
33.360883	-93.702378	1997	Red River	Arkansas Game and Fish Commission
33.091497	-93.859164	1997	Red River	Arkansas Game and Fish Commission
33.609514	-93.823911	1998	Red River	Arkansas Game and Fish Commission
33.360883	-93.702378	1998	Red River	Arkansas Game and Fish Commission
33.091497	-93.859164	1998	Red River	Arkansas Game and Fish Commission
33.974720	-91.281736	1999	Arkansas River	Arkansas Game and Fish Commission
32.350028	-93.607875	2000	Red River	Arkansas Game and Fish Commission
32.859735	-93.792348	2000	Red River	Arkansas Game and Fish Commission
35.345650	-94.774272	2007	Arkansas River	Angler report
33.368861	-93.702256	2007	Red River	Arkansas Game and Fish Commission
33.593846	-93.813605	2007	Red River	Arkansas Game and Fish Commission

34.384722	-92.066277	2007	Arkansas River	Arkansas Game and Fish Commission
34.880073	-92.459083	2007	Arkansas River	Arkansas Game and Fish Commission
35.344224	-94.273056	2007	Arkansas River	Arkansas Game and Fish Commission
33.884574	-95.924000	2011	Red River	OWRB
36.149782	-96.252428	2011	Arkansas River	Oklahoma Department of Wildlife Conservation
34.880073	-92.459083	2011	Arkansas River	Arkansas Game and Fish Commission
36.696579	-96.927639	2012	Arkansas River	Oklahoma Department of Wildlife Conservation
36.090204	-95.988915	2012	Arkansas River	Oklahoma Department of Wildlife Conservation
33.974720	-91.281736	2012	Arkansas River	Arkansas Game and Fish Commission
34.073619	-91.504221	2012	Arkansas River	Arkansas Game and Fish Commission
35.072615	-92.703776	2012	Arkansas River	Arkansas Game and Fish Commission
35.172396	-93.099110	2012	Arkansas River	Arkansas Game and Fish Commission
35.344224	-94.273056	2012	Arkansas River	Arkansas Game and Fish Commission
36.585768	-97.033902	2013	Arkansas River	OWRB
34.073619	-91.504221	2013	Arkansas River	Arkansas Game and Fish Commission
33.106690	-93.861200	2013	Red River	Arkansas Game and Fish Commission
33.109300	-93.861800	2013	Red River	Arkansas Game and Fish Commission
33.088450	-93.858600	2013	Red River	Arkansas Game and Fish Commission
33.109470	-93.862800	2013	Red River	Arkansas Game and Fish Commission
33.091164	-93.859609	2013	Red River	Arkansas Game and Fish Commission
36.089420	-95.989270	2014	Arkansas River	Oklahoma Department of Wildlife Conservation
36.089240	-95.989200	2014	Arkansas River	Oklahoma Department of Wildlife Conservation
36.110880	-95.989270	2014	Arkansas River	Oklahoma Department of Wildlife Conservation
36.068930	-95.984250	2014	Arkansas River	Oklahoma Department of Wildlife Conservation
36.088380	-95.989640	2014	Arkansas River	Oklahoma Department of Wildlife Conservation
36.089050	-95.989050	2014	Arkansas River	Oklahoma Department of Wildlife Conservation
36.088040	-95.989130	2014	Arkansas River	Oklahoma Department of Wildlife Conservation
35.962090	-95.806100	2014	Arkansas River	Oklahoma Department of Wildlife Conservation

35.962170	-95.803900	2014	Arkansas River	Oklahoma Department of Wildlife Conservation
35.962080	-95.806140	2014	Arkansas River	Oklahoma Department of Wildlife Conservation
33.755370	-96.411008	2014	Red River	Angler report
35.961902	-95.805478	2014	Arkansas River	Oklahoma Department of Wildlife Conservation
36.088472	-95.988932	2014	Arkansas River	Oklahoma Department of Wildlife Conservation
36.070433	-95.985732	2014	Arkansas River	Oklahoma Department of Wildlife Conservation
36.089126	-95.989064	2014	Arkansas River	Oklahoma Department of Wildlife Conservation
36.121018	-95.986985	2014	Arkansas River	Angler report
36.071070	-95.986290	2015	Red River	Oklahoma Department of Wildlife Conservation
35.961820	-95.805630	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
35.961820	-95.805630	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
35.961820	-95.805630	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.053570	-95.976360	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.053950	-95.976270	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.053780	-95.976300	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.111020	-95.989330	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.054000	-95.976260	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.069310	-95.984570	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.089140	-95.989050	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.076100	-95.987850	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.070150	-95.985120	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.055650	-95.976710	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.068810	-95.984110	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.089100	-95.989230	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.069480	-95.984560	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
35.961900	-95.804410	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
35.994170	-95.944470	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
35.997010	-95.945530	2015	Arkansas River	Oklahoma Department of Wildlife Conservation

35.996130	-95.943470	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
35.993640	-95.943410	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.004310	-95.948040	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
35.952500	-95.869030	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
35.947480	-95.860140	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
35.961750	-95.805180	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
35.957050	-95.812590	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.110710	-95.989400	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
36.069690	-95.984530	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
35.976710	-95.924380	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
35.974440	-95.921080	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
35.906230	-95.717650	2015	Arkansas River	Oklahoma Department of Wildlife Conservation
35.965411	-95.902356	2015	Arkansas River	Angler report
36.507437	-96.724671	2015	Arkansas River	Angler report
35.815620	-95.324166	2015	Verdigris River	Oklahoma Department of Wildlife Conservation
33.924880	-95.654710	2016	Red River	Oklahoma State University

Appendix B

Table 1. Spearman's Rank correlations matrix of rho values between variable pairs in the Arkansas River and Red River basins combined model (CBM). Highlighted values indicated multicollinearity ($\geq |0.70|$).

	Landuse change	Impervious	Extent	Max elevation	Slope	Drift	Discharge	bio1	bio2	bio3	bio4	bio5	bio6	bio7	bio8	bio9	bio10	bio11	bio12	bio13	bio14	bio15	bio16	bio17	bio18	bio19
Landuse change	1																									
Impervious	0.379	1																								
Extent	-0.216	-0.272	1																							
Max elevation	-0.555	-0.419	0.372	1																						
Slope	-0.216	-0.216	0.078	0.422	1																					
Drift	-0.299	-0.354	0.825	0.515	0.194	1																				
Discharge	0.261	0.272	-0.184	-0.420	-0.223	-0.294	1																			
bio1	0.510	0.072	0.037	-0.703	-0.294	-0.070	0.219	1																		
bio2	-0.395	-0.448	0.384	0.841	0.344	0.523	-0.395	-0.457	1																	
bio3	-0.047	-0.396	0.291	0.594	0.292	0.443	-0.278	-0.103	0.83	1																
bio4	-0.594	-0.059	0.213	0.449	0.052	0.204	-0.239	-0.599	0.26	-0.240	1															
bio5	0.056	-0.251	0.391	-0.101	-0.111	0.341	-0.092	0.636	0.18	0.239	-0.048	1														
bio6	0.603	0.158	-0.127	-0.809	-0.306	-0.236	0.298	0.953	-0.61	-0.215	-0.702	0.432	1													
bio7	-0.646	-0.281	0.315	0.806	0.249	0.396	-0.373	-0.740	0.73	0.297	0.822	-0.028	-0.879	1												
bio8	-0.512	-0.331	0.475	0.633	0.137	0.470	-0.324	-0.310	0.54	0.269	0.582	0.252	-0.486	0.670	1											
bio9	0.617	0.120	-0.152	-0.749	-0.270	-0.217	0.275	0.913	-0.49	-0.072	-0.752	0.430	0.960	-0.846	-0.516	1										
bio10	0.333	0.029	0.188	-0.565	-0.274	0.062	0.134	0.928	-0.34	-0.124	-0.346	0.794	0.808	-0.514	-0.103	0.749	1									
bio11	0.555	0.048	-0.022	-0.688	-0.260	-0.102	0.229	0.979	-0.44	-0.028	-0.719	0.554	0.970	-0.799	-0.369	0.952	0.850	1								
bio12	0.541	0.414	-0.456	-0.948	-0.357	-0.553	0.387	0.583	-0.86	-0.632	-0.444	-0.048	0.736	-0.804	-0.685	0.683	0.406	0.596	1							
bio13	0.505	0.401	-0.453	-0.921	-0.350	-0.544	0.375	0.560	-0.85	-0.644	-0.407	-0.046	0.707	-0.767	-0.662	0.642	0.394	0.569	0.979	1						
bio14	0.550	0.455	-0.512	-0.901	-0.312	-0.607	0.420	0.478	-0.82	-0.597	-0.491	-0.162	0.657	-0.794	-0.768	0.622	0.296	0.502	0.943	0.910	1					
bio15	-0.544	-0.443	0.467	0.902	0.316	0.577	-0.417	-0.499	0.82	0.588	0.493	0.146	-0.668	0.801	0.750	-0.627	-0.316	-0.520	-0.932	-0.877	-0.971	1				
bio16	0.497	0.415	-0.459	-0.916	-0.350	-0.547	0.380	0.529	-0.86	-0.661	-0.389	-0.087	0.681	-0.759	-0.654	0.613	0.358	0.539	0.985	0.986	0.916	-0.893	1			
bio17	0.566	0.406	-0.444	-0.946	-0.340	-0.543	0.400	0.633	-0.86	-0.601	-0.517	-0.021	0.779	-0.855	-0.714	0.731	0.458	0.646	0.980	0.952	0.957	-0.952	0.952	1		
bio18	0.055	0.391	-0.382	-0.556	-0.255	-0.486	0.243	0.013	-0.71	-0.824	0.177	-0.321	0.133	-0.262	-0.207	0.007	-0.018	-0.026	0.664	0.687	0.597	-0.573	0.717	0.588	1	
bio19	0.577	0.408	-0.417	-0.972	-0.369	-0.527	0.407	0.681	-0.85	-0.577	-0.525	0.044	0.813	-0.858	-0.706	0.765	0.513	0.688	0.978	0.948	0.943	-0.941	0.947	0.983	0.563	1

Table 2. Spearman's Rank correlations matrix of rho values between variable pairs in the Arkansas River basin model (ABM). Highlighted values indicated multicollinearity ($\geq$|0.70|).

	Landuse change	Impervious	Extent	Max elevation	Slope	Drift	Discharge	bio1	bio2	bio3	bio4	bio5	bio6	bio7	bio8	bio9	bio10	bio11	bio12	bio13	bio14	bio15	bio16	bio17	bio18	bio19
Landuse change	1																									
Impervious	0.418	1																								
Extent	-0.197	-0.162	1																							
Max elevation	-0.440	-0.358	0.443	1																						
Slope	-0.177	-0.184	0.035	0.409	1																					
Drift	-0.313	-0.255	0.736	0.588	0.172	1																				
Discharge	0.245	0.240	-0.189	-0.396	-0.197	-0.298	1																			
bio1	0.445	0.164	-0.261	-0.825	-0.371	-0.413	0.323	1																		
bio2	-0.350	-0.409	0.405	0.862	0.340	0.551	-0.379	-0.637	1																	
bio3	-0.098	-0.423	0.261	0.696	0.326	0.447	-0.270	-0.374	0.881	1																
bio4	-0.473	-0.003	0.369	0.267	-0.046	0.295	-0.250	-0.435	0.185	-0.228	1															
bio5	-0.009	-0.171	0.212	-0.133	-0.186	0.115	-0.064	0.489	0.144	0.169	0.180	1														
bio6	0.485	0.205	-0.339	-0.845	-0.334	-0.481	0.358	0.966	-0.721	-0.431	-0.537	0.303	1													
bio7	-0.530	-0.275	0.464	0.749	0.208	0.540	-0.401	-0.725	0.759	0.432	0.742	0.165	-0.846	1												
bio8	-0.404	-0.258	0.537	0.505	0.037	0.475	-0.267	-0.278	0.477	0.265	0.516	0.352	-0.384	0.607	1											
bio9	0.498	0.100	-0.327	-0.699	-0.256	-0.379	0.294	0.909	-0.507	-0.151	-0.643	0.361	0.926	-0.763	-0.359	1										
bio10	0.290	0.167	-0.104	-0.722	-0.381	-0.295	0.237	0.910	-0.537	-0.402	-0.145	0.669	0.812	-0.482	-0.093	0.729	1									
bio11	0.469	0.096	-0.305	-0.749	-0.298	-0.404	0.319	0.963	-0.563	-0.232	-0.609	0.396	0.968	-0.780	-0.313	0.964	0.799	1								
bio12	0.424	0.344	-0.484	-0.957	-0.346	-0.591	0.375	0.752	-0.892	-0.717	-0.309	-0.004	0.819	-0.795	-0.579	0.666	0.596	0.705	1							
bio13	0.380	0.340	-0.468	-0.933	-0.345	-0.577	0.355	0.717	-0.871	-0.731	-0.255	0.003	0.777	-0.742	-0.552	0.607	0.579	0.661	0.977	1						
bio14	0.471	0.395	-0.529	-0.912	-0.280	-0.626	0.404	0.690	-0.858	-0.652	-0.425	-0.097	0.770	-0.839	-0.688	0.634	0.538	0.656	0.946	0.907	1					
bio15	-0.453	-0.380	0.500	0.899	0.280	0.605	-0.416	-0.679	0.850	0.643	0.416	0.106	-0.758	0.830	0.677	-0.624	-0.521	-0.644	-0.927	-0.869	-0.978	1				
bio16	0.374	0.346	-0.469	-0.924	-0.342	-0.572	0.365	0.688	-0.889	-0.754	-0.246	-0.049	0.761	-0.747	-0.549	0.583	0.542	0.636	0.982	0.985	0.912	-0.881	1			
bio17	0.447	0.364	-0.507	-0.947	-0.319	-0.612	0.400	0.768	-0.880	-0.675	-0.396	-0.005	0.836	-0.844	-0.630	0.698	0.618	0.728	0.978	0.943	0.979	-0.970	0.944	1		
bio18	-0.024	0.328	-0.225	-0.603	-0.273	-0.388	0.228	0.294	-0.722	-0.875	0.270	-0.115	0.337	-0.333	-0.120	0.067	0.318	0.168	0.665	0.705	0.578	-0.551	0.730	0.609	1	
bio19	0.447	0.345	-0.486	-0.964	-0.344	-0.598	0.395	0.806	-0.880	-0.673	-0.379	0.050	0.860	-0.835	-0.605	0.727	0.666	0.759	0.981	0.946	0.964	-0.955	0.944	0.993	0.595	1

Table 3. Spearman's Rank correlations matrix of rho values between variable pairs in the Red River basin model (RBM). Highlighted values indicated multicollinearity (≥|0.70|).

	Landuse change	Impervious	Extent	Max elevation	Slope	Drift	Discharge	bio1	bio2	bio3	bio4	bio5	bio6	bio7	bio8	bio9	bio10	bio11	bio12	bio13	bio14	bio15	bio16	bio17	bio18	bio19
Landuse change	1																									
Impervious	0.489	1																								
Extent	-0.512	-0.388	1																							
Max elevation	-0.688	-0.696	0.466	1																						
Slope	-0.289	-0.317	0.172	0.471	1																					
Drift	-1.250	-0.554	0.843	0.730	0.346	1																				
Discharge	0.336	0.358	-0.570	-0.502	-0.282	-0.386	1																			
bio1	0.362	0.455	-0.129	-0.681	-0.346	-0.372	0.292	1																		
bio2	-0.594	-0.603	0.487	0.853	0.384	0.683	-0.486	-0.480	1																	
bio3	-0.213	-0.311	0.255	0.470	0.264	0.450	-0.391	-0.020	0.696	1																
bio4	-0.726	-0.544	0.482	0.790	0.306	0.590	-0.363	-0.590	0.706	0.105	1															
bio5	-0.634	-0.447	0.556	0.543	0.166	0.547	-0.286	0.033	0.636	0.294	0.692	1														
bio6	0.612	0.551	-0.374	-0.870	-0.395	-0.599	0.422	0.845	-0.768	-0.267	-0.872	-0.409	1													
bio7	-0.711	-0.598	0.509	0.857	0.346	0.657	-0.419	-0.608	0.845	0.326	0.955	0.706	-0.910	1												
bio8	-0.684	-0.567	0.560	0.783	0.334	0.683	-0.450	-0.242	0.775	0.538	0.701	0.757	-0.597	0.748	1											
bio9	0.667	0.609	-0.442	-0.934	-0.436	-0.697	0.476	0.758	-0.805	-0.368	-0.841	-0.472	0.925	-0.874	-0.722	1										
bio10	-0.259	0.013	0.271	-0.050	-0.105	0.118	-0.008	0.605	0.078	0.095	0.208	0.705	0.172	0.164	0.401	0.111	1									
bio11	0.550	0.496	-0.261	-0.775	-0.358	-0.477	0.343	0.917	-0.589	-0.033	-0.828	-0.258	0.955	-0.815	-0.440	0.858	0.288	1								
bio12	0.711	0.642	-0.601	-0.870	-0.359	-0.733	0.443	0.348	-0.850	-0.536	-0.748	-0.767	0.680	-0.822	-0.879	0.778	-0.296	0.520	1							
bio13	0.685	0.604	-0.620	-0.828	-0.335	-0.721	0.437	0.296	-0.836	-0.531	-0.746	-0.786	0.659	-0.817	-0.871	0.745	-0.342	0.489	0.969	1						
bio14	0.720	0.595	-0.569	-0.865	-0.377	-0.731	0.448	0.388	-0.806	-0.532	-0.748	-0.677	0.698	-0.801	-0.844	0.804	-0.222	0.549	0.926	0.887	1					
bio15	-0.739	-0.622	0.496	0.882	0.397	0.706	-0.429	-0.439	0.793	0.508	0.755	0.651	-0.726	0.805	0.817	-0.815	0.216	-0.601	-0.893	-0.811	-0.935	1				
bio16	0.691	0.616	-0.606	-0.837	-0.342	-0.712	0.439	0.298	-0.838	-0.533	-0.746	-0.778	0.656	-0.813	-0.870	0.751	-0.335	0.489	0.985	0.984	0.898	-0.844	1			
bio17	0.732	0.624	-0.581	-0.893	-0.389	-0.735	0.437	0.428	-0.837	-0.522	-0.761	-0.685	0.724	-0.821	-0.834	0.819	-0.173	0.578	0.950	0.904	0.963	-0.937	0.921	1		
bio18	0.672	0.557	-0.570	-0.748	-0.271	-0.640	0.354	0.181	-0.761	-0.429	-0.739	-0.848	0.571	-0.788	-0.790	0.644	-0.441	0.407	0.912	0.927	0.834	-0.775	0.925	0.853	1	
bio19	0.734	0.688	-0.564	-0.951	-0.410	-0.754	0.463	0.552	-0.869	-0.491	-0.799	-0.669	0.804	-0.867	-0.839	0.877	-0.108	0.680	0.943	0.892	0.929	-0.927	0.906	0.958	0.826	1

Appendix C

Table 1. Bioclim codes for bioclimatic variables, and a description of each variable. Most of the Bioclim variables were not used in our models, due to multicollinearity with other variables. These descriptions are available at: http://www.worldclim.org/bioclim.

Bioclim codes	Variable description
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

Table 2. Geological formations found within our study area, and codes for use in our MaxEnt models. These data are available at: http://pubs.usgs.gov/dds/dds11/.

Code	Geological Formation	Code	Geological Formation
1	Atokan and Morrowan Series	26	Navarro Group
2	Atokan and Morrowan Series, Jackfork SS	27	Ochoan Series
3	Austin and Eagle Ford Groups	28	Older Y granitic rocks
4	Cambrian granitic rocks	29	Orthogneiss and paragneiss
5	Chesterian Series	30	Osagean and Kinderhookian Series
6	Des Moinesian Series	31	Paleocene
7	Devonian	32	Paleocene continental
8	Devonian and Silurian	33	Pleistocene
9	Early Leonardian continental	34	Pliocene continental
10	Eocene Claiborne Group	35	Pliocene volcanic rocks
11	Eocene continental	36	Quaternary
12	Eocene Wilcox Group	37	Quaternary volcanic rocks
13	Fredericksburg Group	38	Taylor Group
14	Holocene	39	Triassic
15	Jurassic	40	Trinity group
16	Lower Cretaceous	41	Upper Paleozoic
17	Lower Paleozoic	42	Upper part of Guadalupian Series
18	Lower part of Guadalupian Series	43	Upper part of Leonardian Series
19	Lower part of Leonardian Series	44	Virgilian Series
20	Lower Tertiary volcanic rocks	45	Washita Group
21	Meramecian Series	46	Wolfcampian Series
22	Middle Ordovician (Mohawkian)	47	Wolfcampian Series continental
23	Miocene	48	Woodbine and Tuscaloosa groups
24	Mississippian	49	X granitic rocks
25	Missourian Series	50	Younger Y granitic rocks

Table 3**.** Classes, codes, and descriptions of land classifications used by the National Land Cover Database 2011 (NLCD 2011). These descriptions are available at: https://www.mrlc.gov/nlcd2011.php.

Class	Code	Classification Description
Water	11	**Open Water -** areas of open water, generally with less than 25% cover of vegetation or soil.
	12	**Perennial Ice/Snow -** areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed	21	**Developed, Open Space -** areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
	22	**Developed, Low Intensity -** areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
	23	**Developed, Medium Intensity -** areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
	24	**Developed High Intensity -**highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
Barren	31	**Barren Land (Rock/Sand/Clay) -** areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Forest	41	**Deciduous Forest -** areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
	42	**Evergreen Forest -** areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
	43	**Mixed Forest -** areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrubland	51	**Dwarf Scrub -** Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.

	52	**Shrub/Scrub -** areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Herbaceous	71	**Grassland/Herbaceous -** areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
	72	**Sedge/Herbaceous -** Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.
	73	**Lichens -** Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.
	74	**Moss -** Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.
Planted/Cultivated	81	**Pasture/Hay -** areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
	82	**Cultivated Crops -** areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
Wetlands	90	**Woody Wetlands -** areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
	95	**Emergent Herbaceous Wetlands -** Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

CHAPTER III

SYNTHESIZING SAMPLING APPROACHES FOR SHOVELNOSE STURGEON: APPLICATION OF THESE APPROACHES IN A LARGE RIVER OF THE GREAT PLAINS

Abstract- Sampling rare fish in extreme environments presents fisheries managers and researchers with multiple challenges. The development of a gear-use guide for sampling Shovelnose Sturgeon in different locations would be beneficial to monitoring programs and associated management plans. Our objectives were to complete a systematic review of the available literature on Shovelnose Sturgeon sampling, and conduct field sampling in a large southern Great Plains river to test some of the commonly-used gears. We systematically searched four large databases targeting publications reporting capture of Shovelnose Sturgeon via specific search terms. We reviewed the 100 publications (1953 - 2015) that met our search criteria. We also tested eight of the approaches reported for capturing Shovelnose Sturgeon in the Arkansas River, Oklahoma. Shovelnose Sturgeon capture was reported in 12 rivers, and 12 different capture gears were used. Benthic trawls were used in more studies than any other gear (39 of 100), but stationary gillnets captured more Shovelnose Sturgeon, on average, than any other gear. Nearly half of the studies (46 of 100) reported the use of multiple gears. Uncertainty in the number of fish captured among gears, and studies, was high. The level of reporting varied among publications reviewed (100): only 11 publications reported the dominant substrate, seven reported catch-per-unit-effort (CPUE), and five reported discharge while sampling. The eight gears

tested in the Arkansas River captured few Shovelnose Sturgeon. Thus, we developed a hybrid method that used both drifting trammel nets and cooperation from water-management agencies to maintain environmental conditions more conducive to sampling. We successfully captured 26 Shovelnose Sturgeon in five days of sampling using our approach. Our results suggest that more thorough reporting in publications is needed for a reliable gear-use guide to be developed. Our systematic review and field efforts both suggest that sampling Shovelnose Sturgeon is difficult, resulting in high variability in the number of sturgeon captured among gears and sampling locations. Therefore, non-standard use of existing gears, or the development of novel gears, may be more applicable to Shovelnose Sturgeon sampling in highly variable and dynamic environments.

Introduction

Traditional aquatic species sampling techniques exhibit variable detection and efficiency is often unknown (Peterson and Paukert 2009), and this becomes more readily apparent when sampling harsh or capricious environments. Lotic systems, in general, are dynamic, and the prairie streams of the Great Plains exemplify this characteristic. Prairie streams are characterized as harsh environments, with large fluctuations in water temperature and discharge, as well as a high frequency of fire, flood, and drought (Matthews 1988; Dodds et al. 2004). This extreme environment has resulted in diverse species assemblages with specific adaptations to persist (Lytle and Poff 2004), but also presents several challenges to researchers attempting to sample those species. There is a plethora of available gears to sample rivers (Bonar et al. 2009); however, gear performance is variable due to the different physicochemical characteristics of each system (Pierce et al. 1990; Stoner 2004), species behavior (Fréon et al. 1993; Graham et al. 2004), and the differences in species anatomy and physiology (Winger et al. 1999; Bayley and Austen 2002; Hubert et al. 2012). For example, Milewski et al. (2001) found that gillnets captured few fish in South Dakota prairie streams, and Utrup and Fisher (2006) described electrofishing as inadequate for sampling prairie rivers of the southern Great Plains due to high conductivity and turbidity. Electrofishing, the most commonly used gear type, is problematic for estimating stream-fish abundances due to habitat complexity (Larimore 1961) and changes in channel morphology (Mollenhauer and Brewer 2017).

Standardized sampling helps control for some factors that influence catchability; however, it is still challenging to design sampling strategies that can reliably estimate or index abundance under naturally-occurring physicochemical extremes (e.g., conductivity). For instance, boat electrofishing may not be a useful approach on prairie streams because of difficult navigation, extensive regions of extremely shallow water, and limited access related to private ownership. An electric seine (Braaten and Berry 1997) and electric grids (Bain et al. 1985) were designed to facilitate sampling in shallow prairie stream habitats to avoid the logistical constraints of boat sampling. Further, Killgore et al. (1989) used non-traditional pop nets to sample fish in dense vegetation where electrofishing efficiency was low. Quantitative approaches are increasingly common to adjust catch data via variable detection (e.g., Mackenzie and Royle 2005, Royle et al. 2013), but this requires extensive data to produce adjustment values. Knowing how to reasonably sample an environment is the first step in moving toward improved estimates (i.e., your efficiency has to be adequate for repeat sampling events where you capture fish).

Expanses of prairie streams have been lost due to human-induced landscape changes, placing the persistence of many species at risk. Agriculture and urbanization have fragmented the once continuous prairie of the Great Plains, and most of the remaining fragments are too small to support a functional watershed (Samson and Knopf 1994; Dodds et al. 2004). Approximately 99% of the tallgrass prairie has been lost since the early 1800s, more than any other major ecosystem in North America (Samson and Knopf 1994). Human alteration has affected the natural variability of prairie streams. For example, the Arkansas River through Kansas is mostly a dry channel, with sewage effluent now forming the headwaters of the lower Arkansas River for much of the year (Dodds et al. 2004). In turn, these drastic changes have placed much of the native fauna in peril, and many prairie stream fishes are now federally listed as threatened or endangered (e.g., Topeka Shiner *Notropis topeka*, Rio Grande Silvery Minnow *Hybognathus amarus*, and Neosho Madtom *Noturus placidus,* USFWS Endangered Species 2016). Many relict species still occupy these extreme environments and are the focus of many studies across North America (Scarnecchia et al. 2007; Worthington et al. 2014; Hamel et al. 2015).

Many sturgeon are the focus of research and management efforts because of both their imperiled status (Pikitch et al. 2006) and current threats. Many states are creating sturgeon management plans for the first time (e.g., Oklahoma and Arkansas), and one goal is to better understand abundance trends where sturgeon persist. Twenty-six extant sturgeon species exist throughout the Northern Hemisphere and 16 are critically endangered, two are endangered, two are near threatened, and three are vulnerable (The IUCN Red List of Threatened Species 2016). Of the nine species of sturgeon that persist in North America, five are federally endangered, and two are federally threatened (USFWS Endangered Species 2016). Pallid Sturgeon was listed as federally endangered in 1990 (United States Fish and Wildlife Service 1990) due to a sharp decline in species abundance related to habitat loss, habitat fragmentation, commercial overharvest, and flow alteration of the Mississippi and Missouri rivers (Dryer and Sandvol 1993; Shuman et al. 2011). The co-occurring Shovelnose Sturgeon appears stable at the center of their range, but edge-of-range abundances are presumed low and declining, and some states (e.g., Alabama, New Mexico, Pennsylvania, and West Virginia) have reported extirpations (Quist et al. 2002; Koch and Quist 2010), primarily due to habitat fragmentation (Wildhaber et al. 2007). Extant populations of Shovelnose Sturgeon still exist in the Red River of Oklahoma and Texas, and the Arkansas River of Oklahoma and possibly as far north as Wichita, Kansas (Collins 1976). These river systems are highly fragmented by dams, and Shovelnose Sturgeon populations persisting within them are no longer connected to those of the Mississippi River. There is also at least one mainstem dam recently proposed on the Arkansas River near Tulsa, Oklahoma (http://vision2025.info/index.php/archives/350). The increasing water use, along with the threat of additional habitat fragmentation, places Shovelnose Sturgeon persistence at risk in this region.

The continued threats to Shovelnose Sturgeon have made them a species of interest within the southern Great Plains, but their capture for population assessment has been challenging. Although many gears have been used to successfully capture Shovelnose Sturgeon across the United States (Table 1), efforts have been lacking at the southwest extent of the species range where they inhabit some of the most extreme environments within their distribution (Matthews 1988; Dodds et al. 2004).

In an effort to better understand how different gears would be useful in these environments, we documented possible gear choices and then tested the usefulness of select approaches. Our objectives were to both systematically review existing approaches used for sampling Shovelnose Sturgeon, and conduct preliminary sampling in a large southern Great Plains river to test some of the commonly-used gears.

Study Area

We tested commonly-used gears in the Arkansas River, Oklahoma. The Arkansas River is a braided Great Plains prairie stream that originates in the southern Rocky Mountains ecoregion of Colorado. The river flows from west to east from the Southwestern Tablelands, to the Arkansas Valley and Mississippi Alluvial Plain ecoregions (Woods et al. 2005) crossing a major precipitation gradient (annual rainfall averages 43.3 - 139.5 cm, Wiken et al. 2011). The river exhibits extremely variable diel and seasonal water temperatures, fluctuating discharge, flooding, and seasonal drying throughout much of its range (Dodds et al. 2004). The Arkansas River flows through four medium to large impoundments (i.e., 10,000 - 24,000 surface acres) and a series of sixteen lock and dam structures before it reaches the Mississippi River, Desha County, Arkansas.

Our sampling reach was located in the highly-fragmented section of Oklahoma (Figure 1). Within Oklahoma, the Arkansas River is impounded six times (two large reservoirs, three navigation system locks and dams, and one low-head dam). The free-flowing river sections resemble a typical prairie stream, with shallow, meandering braided channels, dominated by sand substrate. The water in this area is relatively clear (secchi depth: 45 - 125 cm), but contains high levels of algae and other organic materials. Downstream of Muskogee, the Arkansas River approximates a lentic environment, channelized and impounded by the McClellan-Kerr Navigation System. This area is turbid and relatively deep (minimum depth of 3 m). Despite the current level of river fragmentation, documented and anecdotal Shovelnose Sturgeon encounters have been reported (Smith 1974 unpublished; Morrison 1996).

Methods

Systematic Review

We conducted an extensive literature review to identify papers related to Shovelnose Sturgeon sampling from four scientific databases: Agricola, Web of Science, JSTOR, and Taylor and Francis. Google Scholar was not used because it searches the body of the text in addition to title, abstract, and keywords; thus, it provided an abundance of irrelevant articles. We used twenty search strings to identify papers of interest. The general form of the search string consisted of terms related to the common name, the scientific name (genus and species), and terms associated with fish capture including the common names of sampling gears (Table 2). Each search term was placed in double quotation marks and separated by the Boolean operator 'AND'. We placed no limit on publication dates, but we retrieved all of our papers by December 2015.

We retrieved relevant information about sampling Shovelnose Sturgeon from each article. We recorded bibliographic information (title, authors, publication year) to capture trends in sampling through time. We also recorded information about the sampling time frame and location. We retrieved information useful to understanding the general characteristics of the river sampled (subcategories: stream order, drainage area, dominant substrate) and conditions specific to a sample event (i.e., discharge). Finally, we extracted information related to the study objective(s), gear used, technique employed (i.e., standard use of gear), whether the gear used was active or passive, sample size by gear, time of collection (day, night, or 24-hour), and resulting catch-per-unit effort (CPUE). When sample size was reported, we calculated catch by gear across all studies to compare catch among gears.

Field Sampling

Two years of preliminary field sampling were conducted across all seasons from winter 2012 to autumn 2014. We applied eight commonly-used gears or techniques for capturing Shovelnose Sturgeon: stationary gill net, drifting gill net, hoop net, drifting trammel net, trot line, benthic trawl, rod and reel, and hand fishing. We also used a hybrid method in cooperation with water-management agencies in an attempt to capture Shovelnose Sturgeon.

Stationary gill nets

We used two sizes of gill nets for approximately 40 net nights across a variety of macrohabitat types during autumn, winter, and spring (2013 - 2014). The larger gill nets were monofilament nets having 5.08 cm bar mesh, constructed of one panel spanning 47.7 meters in length and free hanging, unhobbled 1.8 m in depth. The top line was a floating 9.5 mm diameter polypropylene fiber (prolene) rope having a buoyant foam center and the bottom line was a lead core rope. The smaller nets were of the same dimensions, but only hanging 1.2 m in depth. Both net specifications were derived from the nets found to have the highest success in capturing Shovelnose Sturgeon by (Phelps et al. 2009). Gillnets were deployed following methods of Hubert et al. (2012), mainly perpendicular to the channel in main channel habitats, channel borders, island tips, and the backs of wing-dams. Gillnets were set overnight and allowed to fish for 18 to 24 h to include crepuscular and nocturnal movement. We avoided the use of stationary gillnets during extreme high discharge events. Stationary gill nets were not used during summer to avoid excess fish stress or mortality due to high water temperature.

Drifting gill nets

We used drifting gill nets exclusively in the main channel and side channel habitats during spring 2014. Our drifting gill nets were constructed under the same specifications as the stationary gill nets used in this study. We deployed the nets perpendicular to the channel and followed them on foot, or motorized kayak. Gill nets were retrieved upon traveling an adequate distance, or encountering a snag. When discharge was < 2.85 m^3/s, drifting gill nets were manually pulled downstream.

Drifting trammel nets

We used drifting trammel nets during summer and autumn 2014 in main channel, side channel, tributary, and wing dike habitats and under a wide range of discharge conditions (1.5 - 440 m^3/s). Trammel nets were 15.24 m in length, and hung 1.80 m in depth, with a 9.5 mm foam-core float line, and #50 lead-core bottom line. Brails were 30.48 mm bar mesh constructed of multifilament twine, and housed either 3.81 mm or 5.08 mm monofilament bar mesh. Trammel nets were drifted in a variety of depths ranging from 0.5 to 3.5 m. We deployed the nets perpendicular to the channel and followed them on foot, or motorized kayak. Trammel nets were retrieved upon traveling an adequate distance, or encountering a snag. When discharge was < 2.85 m^3/s, trammel nets were manually pulled downstream.

Hoop nets

We used unbaited hoop nets for approximately 100 net nights to sample in-channel habitats across all seasons (2013 - 2014). Hoop nets were approximately 3.35 m in length and 0.76 m in diameter with 7 hoops and 2.54 cm bar mesh. Hoop nets were set in accordance with methods described by Doyle et al. (2008); parallel with the channel and oriented so that the opening faced downstream. Each end was connected to approximately 10 m of nylon rope with an anchor at the end. The rope was pulled tight, and anchors were firmly embedded into the substrate to ensure the net remained open and fishing. Hoop nets were set overnight in depths from 0.75 – 4.00 m and allowed to fish for 18 to 24 hours to include crepuscular and nocturnal movement.

Trotlines

We used trotlines baited with night crawlers for approximately 5,000 hook nights across all seasons (2012 - 2014) and a variety of macrohabitat types. Trotlines were constructed of 6.35 mm lead-core rope, 61 m in length, and having 1/0, 2/0 or 3/0 hook droppers attached every 3.0 m. Trotlines were set both parallel and perpendicular to the channel, in main channel habitats, side channel habitats, channel borders, island tips, tributaries, and on all sides of wing-dams. An anchor was attached to each end and the trotline was stretched tight, with a buoy attached on one end for easy location and retrieval. The use of lead-core rope ensured that trotlines were fishing in the benthic zone at all times. Trotlines were set overnight and allowed to fish for 18 to 24 h to include crepuscular and nocturnal feeding activity.

Benthic Trawl

We used a bow-mounted benthic trawl (Innovative Net Systems SKT model 38) for approximately 20 trawl hours to sample across all seasons (2013 and 2014). The trawl was equipped with a chain-weighted bottom rope, two otter doors, and two 30.48 m tow ropes. The throat measured 4.87-m wide, and the cod end was constructed of dual mesh, with a fine mesh inner bag. Trawling was used primarily to sample water depths ranging from 1.5 - 6.0 m at speeds of 1.6 – 4.8 km/h, and covered several habitats: main channel, side channels, tributaries, and wing dike tips. Trawl hauls were made primarily parallel to the channel, and followed the methods described by Herzog et al. (2005).

Rod and reel

We conducted rod and reel sampling for approximately 200 angler hours during spring and summer 2014 at two locations near Tulsa, Oklahoma, where anglers have historically reported Shovelnose Sturgeon catches. Lines were rigged with 1/0 circle hooks and baited with night crawlers. Ample weight was used to ensure bait remained in the benthic zone, which required variable weight sizes (14 – 140 g) due to variable rates of discharge (1.5 - 350 m^3/s). Sampling locations were within the main channel, ranged in depth from ≈0.5 - 3.0 m, and had a mixture of sand and cobble substrates. One of the sampling locations had a rock jetty ≈30 m in length, perpendicular to the channel.

Hand fishing

Hand fishing was conducted in all available habitat types when discharge was low (< 5.5 m^3/s) (2012 - 2014), and water clarity was good (> 1.5 m). We visually located sturgeon using snorkeling, or above-water observation. When a sturgeon was located, we attempted to capture it by hand.

Non-traditional hybridized method

We used a non-standard gear, and combined those efforts with cooperation of water-management agencies. We worked with the United States Army Corps of Engineers (USACE) and Southwestern Power Administration (SWPA) to prevent water releases from Keystone Dam for 72 h on three occasions in autumn 2014. This allowed the water level to stabilize, and for most suspended sediment to settle thereby increasing water clarity. A large field crew (8 - 12 people) spread out across the channel and walked slowly upstream. Two crew members had net baskets equipped with a 5.08 mm bar mesh trammel net (aforementioned specifications). When a crew member encountered a sturgeon, they would stop and call for the other crew members. One of the trammel nets was then fed out to encircle one crew member and the sturgeon. The fish was then guided into the net, and quickly captured.

Results

Systematic Review

Our database searches returned 2,289 articles, and many articles were omitted from further examination due to duplication or lack of relevancy. Excluded papers were: duplicates from prior searches, studies that did not report capturing Shovelnose Sturgeon, studies that did not report gear used, and studies where Shovelnose Sturgeon were not addressed at all (see Appendix A, Tables 1 - 4). The final set of relevant papers (N = 100) were systematically reviewed.

The 100 relevant publications we reviewed revealed distinct spatial and temporal patterns in Shovelnose Sturgeon research and sampling. Published Shovelnose Sturgeon studies occurred exclusively in 12 rivers, but 77% (77 of 100) of those studies were conducted in the Mississippi or Missouri rivers (Figure 2). All other sampled rivers were tributaries of the Mississippi or Missouri rivers. Reviewed papers were published from 1953 to 2015, with most of the work (63%) completed from 2000 to 2010 (Figure 3). Benthic trawls were not used as a sampling gear in studies prior to 1996, but were used in 53% (8 of 15) of the studies conducted during the 1990's, and 48% (29 of 61) of the studies conducted from 2000 to 2009. Plankton nets were not reported as a sampling gear in any reviewed studies prior to 2010; however, they were used to capture age-0 sturgeon in 20% (2 of 10) of the studies conducted from 2010 to 2015, reflecting recent interest in Shovelnose Sturgeon reproduction.

The objectives of the reviewed studies were broad, resulting in 21 categories, and many studies had multiple objectives (Table 3). The most common studies targeted species monitoring, and reproduction as study objectives (15 of 100 studies each, Figure 4). Four objectives were specific to single studies: microchemistry, entrainment, genetics, and field techniques. Thirty-two percent (32 of 100) of the studies had multiple objectives, again with species monitoring as the focus (12 of 32).

Temporal trends in research objectives were apparent. Early studies (i.e., 1950 - 1980) were largely focused on Shovelnose Sturgeon presence (3 of 8) and diet (3 of 8), laying the groundwork for species monitoring and management (i.e., is the species present, and what do they eat?). Around 2000 (i.e., 2000 - 2015), the focus of the studies shifted and considerable interest was placed on Shovelnose Sturgeon reproduction (15 of 77), suggesting a shift in research emphasis to Shovelnose Sturgeon sustainability and persistence.

Many of the reviewed studies lacked reporting of sampling effort and study area descriptions. All reviewed studies reported sample location(s) (i.e., rivers) and gear used, and most (91 of 100) reported the number of sturgeon captured; however, only 13 of the 46 studies that reported the use of multiple gears reported capture by gear. Only 11 of the studies we reviewed reported the dominate substrate of the sample site, however, 91% (10 of 11) of those studies indicated sand was the most common substrate. Only five studies reported discharge while sampling (range: 0.16 - 1.5 m^3/s).

From the 100 reviewed studies, 12 gears were used to capture Shovelnose Sturgeon. Overall, benthic trawls were used most often (39 studies), followed by stationary gillnets, drifting trammel nets, trotlines, and electrofishing (Figure 5). Hand-fishing was only used in one study. Gears were used in a traditional way in most studies (97 of 100). Active gears were used in 75% (75 of 100) of the studies. The most commonly-used active gear was a benthic trawl. Passive gears were used in 56% (56 of 100) of the studies. The most commonly-used passive gear was a stationary gillnet. Three of the gears used did not capture any Shovelnose Sturgeon: seine, trap/fyke net, and hand fishing. Forty-six percent (46 of 100) of studies reported the use of multiple gear types, and five of the 12 gears reported were used in conjunction with other gears 100% (N = 27) of the time: drifting gillnet (N = 6), trap/fyke net (N = 2), hand fishing (N = 1), hoop net (N = 10), and seine (N = 8). Interestingly, these five gears captured few Shovelnose

Sturgeon (median catch = 56). Plankton nets (N = 2) were never used with other gear combinations, but they were used specifically to capture juvenile sturgeon in both of the studies.

The use of some gears appeared to be river specific, suggesting some gears are used given the prevalence of certain physicochemical conditions. For example, almost 40% (9 of 23) of all studies using electrofishing to capture Shovelnose Sturgeon occurred in the Wabash River. The Wabash River was generally described as moderately deep, with a mixture of clay, gravel, and sand substrates (Kennedy et al. 2007). Likewise, almost 40% (3 of 8) of all studies using seines occurred on the Kansas River, described as wide and shallow, with mainly sand substrate (Fischer et al. 2012). Lastly, 50% of studies (3 of 6) where drifting gill nets were used in sampling occurred on the Platte River, described as sandy, with highly braided, wide and shallow channels (Hamel et al. 2014).

Different study objectives and approaches used to capture Shovelnose Sturgeon across our reviewed studies made it difficult to identify factors contributing to differences in number of sturgeon captured among gears. Stationary gill nets generally resulted in more sturgeon captured (N=18, median catch= 434) when compared to other commonly-used gears (benthic trawl, N=22, median catch=300; drifting trammel net, N=12, median catch=136; and electrofishing, N=12, median catch=55), suggesting they may be one of the more useful sampling gears for Shovelnose Sturgeon. Because effort was rarely reported, it was unclear how gill nets compared to the catch rates of other commonly-used gears. However, in all four studies that compared catch rates among multiple gears, stationary gill nets produced the highest CPUE when compared to drifting trammel nets, trawls, trotlines, and hoop nets (Doyle et al. 2008; Phelps et al. 2009; Wanner et al. 2010; Wildhaber et al. 2011). The number of Shovelnose Sturgeon captured was related to the study objective (Figure 6). For example, mean catch was higher in habitat studies compared to catch associated with other study objectives. Studies occurring in the center of the species distribution (i.e., Missouri and Mississippi rivers) reported more sturgeon captured on average compared to studies on other rivers.

Field Sampling

We had limited success capturing Shovelnose Sturgeon after two years of sampling using eight commonly-used methods or techniques. We captured only five Shovelnose Sturgeon using traditional gears and approaches. Our hybrid method, using a trammel net in an unorthodox way, while cooperating with water-management agencies, proved to be the most useful method for capturing Shovelnose Sturgeon in the Arkansas River, Oklahoma.

Successful capture of Shovelnose Sturgeon in the Arkansas River using standard sampling gears and methods was limited. We captured four Shovelnose Sturgeon using drifting trammel nets, and one using rod and reel. Unfortunately, we cannot report the total number of drifts, or an approximation of drift distance, because we rarely made a substantial drift before the net was caught on a snag. Our rod and reel sampling yielded only one Shovelnose Sturgeon, despite several reported captures from anglers. However, angler reports of Shovelnose Sturgeon catches are rare (i.e., 1 - 3 per year), and we lack the data to compare angler effort and catch rates to ours.

Hand fishing in winter was one of the more successful methods we used in the Arkansas River, but it only worked under specific environmental conditions. The water temperature was extremely cold (1°C) and discharge was low (< 1.42 m^3/s), resulting in clear water conditions (> 3-m visibility underwater). We captured four Shovelnose Sturgeon by hand via snorkeling. However, the sampling conditions encountered were extremely rare, and normally discharge fluctuates between 5.75 and 340 m^3/s daily and clarity ranges 0.15 - 0.6 m.

Using drifting trammel nets, combined with cooperation from water-management agencies to manipulate discharge, proved the most reliable method to capture Shovelnose

Sturgeon in the Arkansas River. Because there were no water releases, the water clarity improved to similar conditions experienced in January 2013 (≈ 3 m visual clarity). The low-flow conditions also allowed us to more readily capture the fish because they were confined to isolated pools. We successfully captured 26 Shovelnose Sturgeon in five days of sampling using this approach.

Discussion

Results from our field sampling, and review, exemplify the difficulties of sampling Shovelnose Sturgeon. In two years of sampling the Arkansas River, Oklahoma, we captured only nine Shovelnose Sturgeon using common gears and methods. Shovelnose Sturgeon are presumed to be in low abundance throughout Oklahoma (Pigg 1983; Koch and Quist 2010), which likely contributed to our limited success (Peterman and Steer 1981; Pregler et al. 2015). In addition, our sampling reach was characterized by high conductivity, variable discharge, and variable depths. These conditions are known to affect catchability (Hill and Willis 1994; McInerny and Cross 2000; Speas et al. 2004). Our hybrid method was more effective at capturing Shovelnose Sturgeon than standard gear or methods, but required control over discharge, and would not be feasible at many locations. Sampling difficulties were also apparent in the studies we reviewed. Large differences and uncertainty in the number of Shovelnose Sturgeon captured occurred among studies, regardless of gear or sampling location. Studies conducted outside of the center of Shovelnose Sturgeon's range captured few fish relative to other studies, likely due to low species abundances (Koch and Quist 2010). Despite the difficulties in sampling Shovelnose Sturgeon, there has been a clear increase in research and management efforts directed toward the species.

The spatial and temporal patterns of Shovelnose Sturgeon studies were not surprising. Many of the reviewed studies were conducted in the center of the distribution where there were historic management needs related to overfishing and an endangered species. Over 75% of the reviewed studies were conducted in the Mississippi and Missouri rivers. Although Shovelnose Sturgeon abundance has declined across their range (Keenlyne 1997; Tripp et al. 2009), the Mississippi and Missouri rivers possess a relatively high abundance of the species (Koch and Quist 2010). This is also an area where Shovelnose Sturgeon accounted for a big portion of the commercial fishery until recently (Carlson et al. 1985; Hurley et al. 1987), and management of the species has been necessary for decades due to overharvest (Funk and Robinson 1974; Moos 1978). Also, Shovelnose Sturgeon coexists with the federally-endangered Pallid Sturgeon in the Mississippi and Missouri rivers, where it received growing attention due to its morphological similarities (Bettoli et al. 2009; Boley and Heist 2011), and habitat overlap (United States Fish and Wildlife Service 1990). The increase in Shovelnose Sturgeon research in the 2000's aligns with the increased attention associated with sturgeon listing, but also a general societal shift to resource sustainability (Burrows 2010). The increased effort devoted to capturing these fish may be one reason why several studies used multiple sampling gears.

Although the reasons were rarely reported, there are several possible reasons why nearly half of the studies we reviewed used multiple gears to capture Shovelnose Sturgeon. Summerfelt (1967) reported using seines and trotlines to bolster numbers captured by electrofishing, and it is possible that others also used multiple gears to supplement their catch. Due to sampling difficulties associated with large rivers, multi-gear approaches are often encouraged for adequate fish capture (Meador et al. 1993; Utrup and Fisher 2006). It is also possible that species characteristics necessitated the use of multiple gears. Shovelnose Sturgeon is considered highly migratory (Hamel et al. 2014), yet the species is sedentary for much of the year (Hurley et al. 1987; Quist et al. 1999), and this affects the usefulness of passive gears (Phelps et al. 2009; Hubert et al. 2012). Lastly, it is likely that a single gear could not effectively sample the heterogeneous habitats of a river (Pringle et al. 1988); thus, additional gears may have been chosen because they are useful for sampling specific habitats (i.e., seines in prairie streams, Utrup and Fisher 2006).

Gear effectiveness is dependent on the physicochemical conditions of the sampling location. Shovelnose Sturgeon sampling took place across a wide range of conditions ranging from deep, wide, turbid, and high-discharge rivers (e.g., the Mississippi River, Herzog et al. 2005; Divers et al. 2009), to shallow, braided prairie rivers, with low discharge (e.g., the Kansas River, Eitzmann and Paukert 2010; Fischer et al. 2012). The physicochemical diversity among the rivers occupied by Shovelnose Sturgeon likely affects the usefulness of gears. For example, our review indicated that stationary gillnets were effective at capturing Shovelnose Sturgeon in the Missouri River; however, we had no success using stationary gillnets in the Arkansas River. Unless we were in relatively deep (> 4 m), turbid water (< 30 cm secchi depth), the nets were quickly filled with algae and other organic material, and swept downstream. It is possible that researchers in other river systems encountered a similar dilemma, as benthic trawls were used in more studies than any other gear, even though Phelps et al. (2009) found them to produce inferior catch rates compared to gillnets. Electrofishing is effective for capturing Shovelnose Sturgeon in the Wabash River (Kennedy et al. 2007; Nepal KC et al. 2015), but likely less so in the Mississippi River due to greater depth and velocity (Hayes and Baird 1994), and turbidity (Lyon et al. 2014). Boat electrofishing was unfeasible throughout much of our sampling reach, as with most prairie rivers of the southern Great Plains (Utrup and Fisher 2006), due to the presence of large areas of extremely shallow water and high conductivity. Drifting trammel nets captured many Shovelnose Sturgeon in reviewed studies conducted in the Platte River, a river with characteristics comparable to our sampling reach of the Arkansas River. However, the usefulness of drifting trammel nets in the Arkansas River was limited by the high frequency of snags we encountered.

We found reporting of capture details and study area descriptions were limited from many of the reviewed studies. Many of the studies did not report capture methods, and this created difficulty in our attempt at developing a gear-use guide. Rarely was the discharge, substrate, or depth of the sampling location reported, all major factors driving gear effectiveness (Wanner et al. 2007; Hubert et al. 2012). Some lack of detail was understandable, given the wide range of study objectives. It would be hard for a researcher studying the reproductive or feeding habits of Shovelnose Sturgeon, to see the importance in reporting sampling strategy, or minute details of the sample site. However, sampling for Shovelnose Sturgeon is difficult (Phelps et al. 2016), and could improve if refined by the details of successful strategies.

Our field sampling revealed that non-standard uses of gears may be necessary under certain physicochemical conditions. Bramblett and White (2001) used hand fishing to capture a Pallid Sturgeon below Fort Peck Dam in the Missouri River. Interestingly, hand fishing was among the most successful methods we tested in the Arkansas River, although only feasible under atypical river conditions. It is intuitive that sampling success is reliant upon species presence at the sampling location; thus, hand fishing success was likely related to the visual confirmation of Shovelnose Sturgeon presence. However, other gears failed to capture Shovelnose Sturgeon in the same location after species presence was confirmed. Visual detection approaches are not novel to fisheries sampling (e.g., streams, Slaney and Martin 1987; Hankin and Reeves 1988; coral reef, Bohnsack and Bannerot 1986; Samoilys and Carlos 2000). Due to perceived low Shovelnose Sturgeon abundance, and environmental conditions unfavorable to standard sampling approaches, visual detection was key to successful Shovelnose Sturgeon capture in the Arkansas River; however, it was limited to very controlled environmental conditions that are often not feasible. Our hybrid method was developed using information we learned via hand fishing during winter, and adjusted for use across all seasons by the incorporation of trammel nets. We will continue to expand on these techniques to refine Shovelnose Sturgeon sampling in the Great Plains.

This review highlights the need for more Shovelnose Sturgeon research and sampling at range edges, and the benefit of more detailed reporting. Although multiple studies have compared gear effectiveness for capturing Shovelnose Sturgeon in rivers at the center of the species range (i.e., the Missouri River, Arab et al. 2008; the Mississippi River, Phelps et al. 2009; and the Wabash River, Nepal KC et al. 2015), none have done so at the periphery. The areas where species monitoring is lacking are also those that might benefit from our review. We were unable to develop a gear-use guide, but our results highlight the complexity of such a task. Current gaps in our knowledge of Shovelnose Sturgeon are partially due to the difficulties in sampling the species (Phelps et al. 2016). The array of environments, and differences in population dynamics across Shovelnose Sturgeon's range, pose difficulties in applying standard sampling approaches. Therefore, we recommend that Shovelnose Sturgeon sampling strategies be flexible, and allow the situation to advise the methods. In particular, we suggest that use of novel gears may be useful, and reporting more detail in these studies may help facilitate improved sampling across the range.

References

Arab, A., M. L. Wildhaber, C. K. Wikle, and C. N. Gentry. 2008. Zero-inflated modeling of fish catch per unit area resulting from multiple gears: application to Channel Catfish and Shovelnose Sturgeon in the Missouri River. North American Journal of Fisheries Management 28(4):1044-1058.

Bain, M. B., J. T. Finn, and H. E. Booke. 1985. A quantitative method for sampling riverine microhabitats by electrofishing. North American Journal of Fisheries Management 5(3B):489-493.

Bayley, P. B., and D. J. Austen. 2002. Capture efficiency of a boat electrofisher. Transactions of the American Fisheries Society 131(3):435-451.

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

Bohnsack, J. A., and S. P. Bannerot. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Technical Report NMFS 41, National Marine Fisheries Service. Retrieved from https://docs.lib.noaa.gov/noaa_documents/NMFS/TR_NMFS/TR_NMFS_41.pdf

Boley, R. M., and E. J. Heist. 2011. Larval surveys indicate low levels of endangered Pallid Sturgeon reproduction in the Middle Mississippi River. Transactions of the American Fisheries Society 140(6):1604-1612.

Bonar, S. A., W. A. Hubert, and D. W. Willis. 2009. Standard methods for sampling North American freshwater fishes. American Fisheries Society, Bethesda, MD.

Bonnot, T. W., M. L. Wildhaber, J. J. Millspaugh, A. J. DeLonay, R. B. Jacobson, and J. L. Bryan. 2011. Discrete choice modeling of Shovelnose Sturgeon habitat selection in the Lower Missouri River. Journal of Applied Ichthyology 27(2):291-300.

Braaten, P. J., and C. R. Berry. 1997. Fish associations with four habitat types in a South Dakota prairie stream. Journal of Freshwater Ecology 12(3):477-489.

Bramblett, R. G., and R. G. White. 2001. Habitat use and movements of Pallid and Shovelnose Sturgeon in the Yellowstone and Missouri rivers in Montana and North Dakota. Transactions of the American Fisheries Society 130(6):1006-1025.

Burrows, D. 2010, June 10. Supermarkets: Leahy's exit reflects shift in retail focus. Marketing Week, p. 5. London, UK.

Carlson, D. M., W. L. Pflieger, L. Trial, and P. S. Haverland. 1985. Distribution, biology and hybridization of *Scaphirhynchus albus* and *S. platorynchus* in the Missouri and Mississippi rivers. Environmental Biology of Fishes 14(1):51-59.

Collins, J. T. 1976. Rediscovery of the Shovelnose Sturgeon in the Arkansas River of Kansas. Transactions of the Kansas Academy of Science 79(3–4):159-160.

Curtis, G. L., J. S. Ramsey, and D. L. Scarnecchia. 1997. Habitat use and movements of Shovelnose Sturgeon in Pool 13 of the Upper Mississippi River during extreme low flow conditions. Environmental Biology of Fishes 50(2):175-182.

Divers, S. J., S. S. Boone, J. J. Hoover, K. A. Boysen, K. J. Killgore, 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(Sup. 2):68-74.

Dodds, W. K., K. Gido, M. R. Whiles, K. M. Fritz, and W. J. Matthews. 2004. Life on the edge: the ecology of Great Plains prairie streams. BioScience 54(3):205-216.

Doyle, W., C. Paukert, A. Starostka, and T. Hill. 2008. A comparison of four types of sampling gear used to collect Shovelnose Sturgeon in the Lower Missouri River. Journal of Applied Ichthyology 24:637-642.

Dryer, M. P., and A. J. Sandvol. 1993. Recovery plan for the Pallid Sturgeon *Scaphirhynchus albus*. U. S. Fish and Wildlife Service, Bismarck, ND. pp. 55.

Eichelberger, J. S., P. J. Braaten, D. B. Fuller, M. S. Krampe, and E. J. Heist. 2014. Novel single-nucleotide polymorphism markers confirm successful spawning of endangered Pallid Sturgeon in the Upper Missouri River Basin. Transactions of the American Fisheries Society 143(6):1373-1385.

Eitzmann, J. L., and C. P. Paukert. 2010. Longitudinal differences in habitat complexity and fish assemblage structure of a Great Plains river. The American Midland Naturalist 163(1):14-32.

Fischer, J., C. Paukert, and M. Daniels. 2012. Fish community response to habitat alteration: impacts of sand dredging in the Kansas River. Transactions of the American Fisheries Society 141(6):1532-1544.

Fréon, P., F. Gerlotto, and O. A. Misund. 1993. Consequences of fish behaviour for stock assessment. ICES Marine Science Symposium 196:190-195.

Funk, J. L., and J. W. Robinson. 1974. Changes in the channel of the Lower Missouri River and effects on fish and wildlife. Issue 11 of Aquatic Series, Missouri Department of Conservation. pp. 52.

Gerrity, P. C., C. S. Guy, and W. M. Gardner. 2008. Habitat use of juvenile Pallid Sturgeon and Shovelnose Sturgeon with implications for water-level management in a downstream reservoir. North American Journal of Fisheries Management 28(3):832-843.

Gosch, N. J. C., M. L. Miller, T. R. Gemeinhardt, S. J. Sampson, and J. L. Bonneau. 2015. Age-0 sturgeon accessibility to constructed and modified chutes in the Lower Missouri River. North American Journal of Fisheries Management 35(1):75-85.

Graham, N., E. Jones, and D. Reid. 2004. Review of technological advances for the study of fish behaviour in relation to demersal fishing trawls. ICES Journal of Marine Science 61(7):1036-1043.

Gutreuter, S., J. M. Vallazza, and B. C. Knights. 2009. Lateral distribution of fishes in the main-channel trough of a large floodplain river: implications for restoration. River Research and Applications 26(5):619-635.

Hamel, M. J., M. A. Pegg, J. J. Hammen, and M. L. Rugg. 2014. Population characteristics of Pallid Sturgeon, *Scaphirhynchus albus* (Forbes & Richardson, 1905), in the lower Platte River, Nebraska. Journal of Applied Ichthyology 30:1362-1370.

Hamel, M. J., M. L. Rugg, M. A. Pegg, R. Patiño, and J. J. Hammen. 2015. Reproductive traits of Shovelnose Sturgeon *Scaphirhynchus platorynchus* (Rafinesque, 1820) in the lower Platte River, Nebraska. Journal of Applied Ichthyology 31(4):592-602.

Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45(5):834-844.

Hayes, J. W., and D. B. Baird. 1994. Estimating relative abundance of juvenile Brown Trout in rivers by underwater census and electrofishing. New Zealand Journal of Marine and Freshwater Research 28(3):243-253.

Herrala, J. R., P. T. Kroboth, N. M. Kuntz, and H. L. Schramm. 2014. Habitat use and selection by adult Pallid Sturgeon in the Lower Mississippi River. Transactions of the American Fisheries Society 143(1):153-163.

Herzog, D. P., V. A. Barko, J. S. Scheibe, R. A. Hrabik, and D. E. Ostendorf. 2005. Efficacy of a benthic trawl for sampling small-bodied fishes in large river systems. North American Journal of Fisheries Management 25(2):594-603.

Hill, T. D., and D. W. Willis. 1994. Influence of water conductivity on pulsed AC and pulsed DC electrofishing catch rates for Largemouth Bass. North American Journal of Fisheries Management 14(1):202-207.

Hoopes, D. T. 1960. Utilization of Mayflies and Caddis Flies by some Mississippi River fishes. Transactions of the American Fisheries Society 89(1):32-34.

Hubert, W., K. Pope, and J. Dettmers. 2012. Passive capture techniques. In A. V. Zale, D. L. Parrish, and T. M. Sutton Eds., Fisheries techniques, 3rd ed. pp 223-265. American Fisheries Society, Bethesda, MD.

Hughes, R. M., and R. F. Noss. 1992. Biological diversity and biological integrity: current concerns for lakes and streams. Fisheries 17(3):11-19.

Hurley, S. T., W. A Hubert, and J. G. Nickum. 1987. Habitats and movements of Shovelnose Sturgeons in the upper Mississippi River. Transactions of the American Fisheries Society 116(4):655-662.

Keenlyne, K. D. 1997. Life history and status of the Shovelnose Sturgeon, *Scaphirhynchus platorynchus*. Environmental Biology of Fishes 48(1–4):291-298.

Kennedy, A., D. Daugherty, T. Sutton, and B. Fisher. 2007. Population characteristics of Shovelnose Sturgeon in the Upper Wabash River, Indiana. North American Journal of Fisheries Management 27(1):52-62.

Killgore, K. J., R. P. I. Morgan, and N. B. Rybicki. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River. North American Journal of Fisheries Management 9(1):101-111.

Koch, J. D., and M. C. Quist. 2010. Current status and trends in Shovelnose Sturgeon *Scaphirhynchus platorynchus* management and conservation. Journal of Applied Ichthyology 26(4): 491-498.

Koch, J. D., M. C. Quist, C. L. Pierce, K. A. Hansen, and M. J. Steuck. 2009. Effects of commercial harvest on Shovelnose Sturgeon populations in the Upper Mississippi River. North American Journal of Fisheries Management 29(1):84-100.

Kvaloy, B., H. Finseraas, and O. Listhaug. 2012. The publics' concern for global warming: A cross-national study of 47 countries. Journal of Peace Research 49(1):11-22.

Larimore, R. W. 1961. Fish population and electrofishing success in a warm-water stream. The Journal of Wildlife Management 25(1):1-12.

Lipschutz, R. D., and J. Mayer. 1996. Global civil society and global environmental governance: the politics of nature from place to planet. Sheldon Kamieniecki, editor, pp. 365. State University of New York Press, Albany, NY.

Lyon, J. P., T. Bird, S. Nicol, J. Kearns, J. O'Mahony, C. R. Todd, I. G. Cowx, and C. J. A. Bradshaw. 2014. Efficiency of electrofishing in turbid lowland rivers: implications for measuring temporal change in fish populations. Canadian Journal of Fisheries and Aquatic Sciences 71:878-886.

Lytle, D. A., and N. L. Poff. 2004. Adaptation to natural flow regimes. Trends in Ecology & Evolution 19(2):94-100.

Mackenzie, D. I., and J. A. Royle. 2005. Designing occupancy studies: general advice and allocating survey effort. Journal of Applied Ecology 42(6):1105-1114.

Matthews, W. J. 1988. North American prairie streams as systems for ecological study. Journal of the North American Benthological Society 7:387-409.

McInerny, M. C., and T. K. Cross. 2000. Effects of sampling time, intraspecific density, and environmental variables on electrofishing catch per effort of Largemouth Bass in Minnesota lakes. North American Journal of Fisheries Management 20(2):328-336.

Meador, M. R., T. F. Cuffney, and M. E. Gurtz. 1993. Methods for sampling fish communities as part of the National Water-Quality Assessment Program. Open-File Report 93-104, U.S. Geological Survey, Reston, VA. Retrieved from https://water.usgs.gov/nawqa/protocols/OFR-93-104/fish1.html.

Milewski, C. L., C. R. Berry, and D. J. Dieterman. 2001. Use of the index of biological integrity in eastern South Dakota rivers. Prairie Naturalist 33:135-151.

Modde, T., and J. C. Schmulbach. 1977. Food and feeding behavior of the Shovelnose Sturgeon, *Scaphirhynchus platorynchus*, in the unchannelized Missouri River, South Dakota. Transactions of the American Fisheries Society 106(6):602-608.

Mollenhauer, R., and S. K. Brewer. 2017. Multinomial N -mixture models improve the applicability of electrofishing for developing population estimates of stream-dwelling Smallmouth Bass. North American Journal of Fisheries Management 37(1):211-224.

Moos, R. E. 1978. Movement and reproduction of Shovelnose Sturgeon, *Scaphirhynchus platorynchus*, in the Missouri River, South Dakota. Ph. D. Dissertation. University of South Dakota, Vermillion.

Morrison, J. 1996, May 10. Teen snags state record with ugly fish. Muskogee Phoenix & Times Democrat p. 6A. Muskogee, OK.

Morrow, J. V, J. P. Kirk, K. J. Killgore, and S. G. George. 1998. Age, growth, and mortality of Shovelnose Sturgeon in the lower Mississippi River. North American Journal of Fisheries Management 18(3):725-730.

Murphy, M., and T. J. Dowding. 2010. The coffee bean: A value chain and sustainability initiatives analysis. Final Project. University of Connecticut, Stamford.

Nepal KC, V., R. E. Colombo, and L. D. Frankland. 2015. Demographics of Shovelnose Sturgeon in the Lower Wabash River, Illinois. North American Journal of Fisheries Management 35(4):835-844.

Peterman, R. M., and G. J. Steer. 1981. Relation between sport-fishing catchability coefficients and salmon abundance. Transactions of the American Fisheries Society 110(5):585-593.

Peterson, J. T., and C. P. Paukert. 2009. Converting nonstandard fish-sampling data to standardized data. In S. A. Bonar, W. A. Hubert, and D. W. Willis Eds. Standard Methods for Sampling North American Freshwater Fishes, pp 195-215. American Fisheries Society, Bethesda, MD.

Phelps, Q. E., D. P. Herzog, R. C. Brooks, V. A. Barko, D. E. Ostendorf, J. W. Ridings, S. J. Tripp, R. E. Colombo, J. E. Garvey, and R. A. Hrabik. 2009. Seasonal comparison of catch rates and size structure using three gear types to sample sturgeon in the Middle Mississippi River. North American Journal of Fisheries Management 29(5):1487-1495.

Phelps, Q. E., S. J. Tripp, J. E. Garvey, D. P. Herzog, D. E. Ostendorf, J. W. Ridings, J. W. Crites, and R. A. Hrabik. 2010. Habitat use during early life history infers recovery needs for Shovelnose Sturgeon and Pallid Sturgeon in the Middle Mississippi River. Transactions of the American Fisheries Society 139(4):1060-1068.

Phelps, Q. E., S. J. Tripp, M. J. Hamel, J. Koch, E. J. Heist, J. E. Garvey, K. M. Kappenman, and M. A. H. Webb. 2016. Status of knowledge of the Shovelnose Sturgeon (*Scaphirhynchus platorynchus*, Rafinesque, 1820). Journal of Applied Ichthyology 32(Sup. 1):249-260.

Phelps, Q. E., I. Vining, D. P. Herzog, R. Dames, V. H. Travnichek, S. J. Tripp, and M. Boone. 2013. A comparison of methods to estimate Shovelnose Sturgeon mortality in the Mississippi River adjacent to Missouri and Illinois. North American Journal of Fisheries Management 33(4):754-761.

Pierce, C. L., J. B. Rasmussen, and W. C. Leggett. 1990. Sampling littoral fish with a seine: corrections for variable capture efficiency. Canadian Journal of Fisheries and Aquatic Sciences 47(5):1004-1010.

Pigg, J. 1983. Three additional records for fishes rare in Oklahoma. Proceedings of the Oklahoma Academy of Science 63(1979):105.

Pikitch, E. K., P. Doukakis, L. Lauck, P. Chakrabarty, and D. L. Erickson. 2005. Status, trends and management of sturgeon and paddlefish fisheries. Fish and Fisheries 6:233-265.

Pregler, K. C., J. C. Vokoun, T. Jensen, and N. Hagstrom. 2015. Using multimethod occupancy estimation models to quantify gear differences in detection probabilities: Is backpack electrofishing missing occurrences for a species of concern? Transactions of the American Fisheries Society 144(1):89-95.

Pringle, C. M., R. J. Naiman, G. Bretschko, J. R. Karr, M. W. Oswood, J. R. Webster, R. L. Welcomme, and M. J. Winterbourn. 1988. Patch dynamics in lotic systems: the stream as a mosaic. Journal of the North American Benthological Society 7(4):503-524.

Quist, M. C., J. S. Tillma, M. N. Burlingame, and C. S. Guy. 1999. Overwinter habitat use of Shovelnose Sturgeon in the Kansas River. Transactions of the American Fisheries Society 128(3):522-527.

Quist, M. C., C. S. Guy, M. A. Pegg, P. J. Braaten, C. L. Pierce, and V. H. Travnichek. 2002. Potential influence of harvest on Shovelnose Sturgeon populations in the Missouri River system. North American Journal of Fisheries Management 22(2):537-549.

Royle, J. A., R. B. Chandler, C. C. Sun, and A. K. Fuller. 2013. Integrating resource selection information with spatial capture-recapture. Methods in Ecology and Evolution 4(6):520-530.

Samoilys, M. A., and G. Carlos. 2000. Determining methods of underwater visual census for estimating the abundance of coral reef fishes. Environmental Biology of Fishes 57(3):289-304.

Samson, F., and F. Knopf. 1994. Prairie conservation in North America. BioScience 44(6):418-421.

Scarnecchia, D. L., L. F. Ryckman, Y. Lim, G. J. Power, B. J. Schmitz, and J. A. Firehammer. 2007. Life history and the costs of reproduction in northern Great Plains Paddlefish *Polyodon spathula* as a potential framework for other Acipenseriform fishes. Reviews in Fisheries Science 15(3):211-263.

Sepúlveda, M. S., T. Stefanavage, and R. Goferth. 2010. First record of a *Polypodium sp*. parasitizing eggs of Shovelnose Sturgeon from the Wabash River, Indiana. Journal of Aquatic Animal Health 22(1):36-38.

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(2):269-281.

Slaney, P. A., and A. D. Martin. 1987. Accuracy of underwater census of trout populations in a large stream in British Columbia. North American Journal of Fisheries Management 7(1):117-122.

Smith, J. 1974. Oklahoma Department of Wildlife Conservation Sampling Report. In Letter to Jim Randolph of U. S Army Corps of Engineers. Muskogee, OK.

Speas, D. W., C. J. Walters, D. L. Ward, and R. S. Rogers. 2004. Effects of intraspecific density and environmental variables on electrofishing catchability of Brown and Rainbow Trout in the Colorado River. North American Journal of Fisheries Management 24(2):586-596.

Stoner, A. W. 2004. Effects of environmental variables on fish feeding ecology: implications for the performance of baited fishing gear and stock assessment. Journal of Fish Biology 65(6):1445-1471.

Summerfelt, R. C. 1967. Fishes of the Smoky Hill River, Kansas. Transactions of the Kansas Academy of Science 70(1):102-139.

The IUCN Red List of Threatened Species. 2016. Retrieved from http://www.iucnredlist.org/search.

Trested, D. G., R. Goforth, J. P. Kirk, and J. J. Isely. 2010. Survival of Shovelnose Sturgeon after abdominally invasive endoscopic evaluation. North American Journal of Fisheries Management 30(1):121-125.

Tripp, S. J., R. E. Colombo, and J. E. Garvey. 2009. Declining recruitment and growth of Shovelnose Sturgeon in the Middle Mississippi River: implications for conservation. Transactions of the American Fisheries Society 138(2):416-422.

United States Fish and Wildlife Service. 1990. Endangered and threatened wildlife and plants; determination of endangered status for the Pallid Sturgeon. Federal Register 55(173):36641- 36647.

USFWS Endangered Species. ECOS Environmental Conservation Online System, U. S. Fish and Wildlife Service. Retrieved from http://ecos.fws.gov/ecp0/pub/SpeciesReport.do?groups=E&listingType=L&mapstatus=1. Accessed 2016.

Utrup, N. J., and W. L. Fisher. 2006. Development of a rapid bioassessment protocol for sampling fish in large prairie rivers. North American Journal of Fisheries Management 26(3):714-726.

Wanner, G. A., D. A. Shuman, M. L. Brown, and D. W. Willis. 2007. An initial assessment of sampling procedures for juvenile Pallid Sturgeon in the Missouri River downstream of Fort Randall Dam, South Dakota and Nebraska. Journal of Applied Ichthyology 23:529-538.

Wanner, G. A., R. A. Klumb, D. A. Shuman, K. Steffensen, S. Stukel, and N. J. Utrup. 2010. Comparison of green and white mesh trammel nets and gill nets to assess the fish community in a large river. North American Journal of Fisheries Management 30:12-25.

Wiken, E., F. J. Nava, and G. Griffith. 2011. North American terrestrial ecoregions—Level III. Commission for Environmental Cooperation, Montreal, Canada.

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. USGS Circular 1315, U. S. Geological Survey, Reston, VA. pp. 18.

Wildhaber, M. L., S. H. Holan, J. L. Bryan, D. W. Gladish, and M. Ellersieck. 2011. Assessing power of large river fish monitoring programs to detect population changes: the Missouri River sturgeon example. Journal of Applied Ichthyology 27:282-290.

Winger, P., P. He, and S. J. Walsh. 1999. Swimming endurance of American Plaice *Hippoglossoides platessoides* and its role in fish capture. ICES Journal of Marine Science 56(3):252-265.

Woods, A. J., J. M. Omernik, D. R. Butler, J. G. Ford, J. E. Henley, B. W. Hoagland, D. S. Arndt, and B. C. Moran. 2005. Ecoregions of Oklahoma (color poster with map, descriptive text, summary tables, and photographs) (map scale 1:1,250,000). U. S. Geological Survey, Reston, Virginia.

World Values Survey Wave 5: 2005-2009. 2014. Retrieved from http://www.worldvaluessurvey.org/WVSOnline.jsp.

Worthington, T. A., S. K. Brewer, T. B. Grabowski, and J. Mueller. 2014. Backcasting the decline of a vulnerable Great Plains reproductive ecotype: identifying threats and conservation priorities. Global Change Biology 20(1):89-102.

Zhang, Y., D. J. Jacob, H. M. Horowitz, L. Chen, H. M. Amos, D. P. Krabbenhoft, F. Slemr, V. L. St Louis, and E. M. Sunderland. 2016. Observed decrease in atmospheric mercury explained by global decline in anthropogenic emissions. Proceedings of the National Academy of Sciences of the United States of America 113(3):526-531.

Table 1. A list of gear types that have been used to successfully capture Shovelnose Sturgeon in published studies.

Gear	**Citations**
Stationary gillnet	(Modde and Schmulbach 1977, Phelps et al. 2009, 2013, Tripp et al. 2009)
Drifting gillnet	(Bramblett and White 2001, Bonnot et al. 2011)
Stationary trammel net	(Carlson et al. 1985, Curtis et al. 1997)
Drifting trammel net	(Hurley et al. 1987; Quist et al. 1999; Koch et al. 2009)
Hoop net	(Hoopes 1960; Doyle et al. 2008; Nepal KC et al. 2015)
Trotline	(Morrow et al. 1998; Gerrity et al. 2008; Herrala et al. 2014)
Benthic trawl	(Arab et al. 2008; Gutreuter et al. 2009; Phelps et al. 2010)
Electrofishing	(Kennedy et al. 2007; Sepúlveda et al. 2010; Trested et al. 2010)
Plankton net	(Eichelberger et al. 2014; Gosch et al. 2015)

Table 2. The 20 search strings used to retrieve publications related to Shovelnose Sturgeon sampling and capture. Search strings were entered into four scientific databases: Web of Science, Taylor and Francis, Agricola, and JSTOR.

Search strings
"Shovelnose Sturgeon" sampling
"Shovelnose Sturgeon" collection
"Shovelnose Sturgeon" capture
"Shovelnose Sturgeon" AND gill nets
"Shovelnose Sturgeon" AND trammel nets
"Shovelnose Sturgeon" AND trotlines
"Shovelnose Sturgeon" AND hoop nets
"Shovelnose Sturgeon" AND trap nets
"Shovelnose Sturgeon" AND fyke nets
"Scaphirhynchus platorynchus" sampling
"Scaphirhynchus platorynchus" collection
"Scaphirhynchus platorynchus" capture
"Scaphirhynchus platorynchus" AND gill nets
"Scaphirhynchus platorynchus" AND trammel nets
"Scaphirhynchus platorynchus" AND trotlines
"Scaphirhynchus platorynchus" AND hoop nets
"Scaphirhynchus platorynchus" AND trap nets
"Scaphirhynchus platorynchus" AND fyke nets
"Scaphirhynchus platorynchus" AND electrofishing

Table 3. A description of the 21 categories constructed to describe the study objectives of the 100 reviewed studies associated with Shovelnose Sturgeon sampling. Frequency refers to the number studies placed in each category. Description defines the specific parameters of each category. Many studies had multiple objectives and are represented in multiple categories.

Objective category	**Frequency**	**Description**
Gear comparison	11	Comparing multiple gears or gear sizes for Shovelnose Sturgeon capture
Age and Growth	8	Age estimation and precision using pectoral fin rays and other calcified structures, growth rates, comparison of age and growth between multiple rivers, standardized removal of fin rays for aging
Abundance	9	Relative abundance of Shovelnose Sturgeon, effects of commercial harvest on abundance, recruitment measures
Length frequency	2	Length frequency
Telemetry	6	Tagging and tracking, movement
Tag Retention	3	Retention of T-bar anchor tags, passive integrated transponder (PIT) tags, and telemetry transmitters
Fish Health	7	Blood chemistry, parasitology, liver biopsy, effects of fin ray removal, morphological anomalies
Environmental contaminants	2	Contaminants in prey items, contaminant build-up in organs
Genetics	1	Identifying single-nucleotide polymorphism markers
Stock assessment	4	Population characteristics, stock characteristics, and demographics of Shovelnose Sturgeon
Population dynamics	5	Multimetric fish indices, age, growth, and mortality indices, factors affecting mortality in Shovelnose Sturgeon
Microchemistry	1	Fin ray microchemistry to identify river of origin
Reproductive study	15	Reproduction, spawning, reproductive biology, reproductive traits, environmental cues for reproductive cycling and spawning, sexual development and maturation, hormonal examination, evaluation of spawning success (physiological indicators and larval surveys)
Habitat studies	9	Habitat use of adult and larval Shovelnose Sturgeon, seasonal habitat use of Shovelnose Sturgeons, effects of habitat type on sampling, effects of habitat alteration on Shovelnose Sturgeon
Exploitation study	3	Effects of harvest on Shovelnose Sturgeon populations
Field techniques	1	Measurement techniques for Shovelnose Sturgeon
Entrainment	1	Entrainment through boat propellers
Diet study	12	Diet composition of larval and adult Shovelnose Sturgeon (seasonal, and by river stage), feeding habits of Shovelnose Sturgeon

Species monitoring	15	Monitoring Shovelnose Sturgeon response to various disturbances (habitat alteration, pollution, and disease), assessment of large river monitoring programs, Monitoring effects of commercial harvest on Shovelnose Sturgeon
Species distribution	7	Distribution of Shovelnose Sturgeon, effects of geology and habitat alteration on the distribution of Shovelnose Sturgeon
Presence/Absence	13	Attempts to confirm presence or absence of Shovelnose Sturgeon

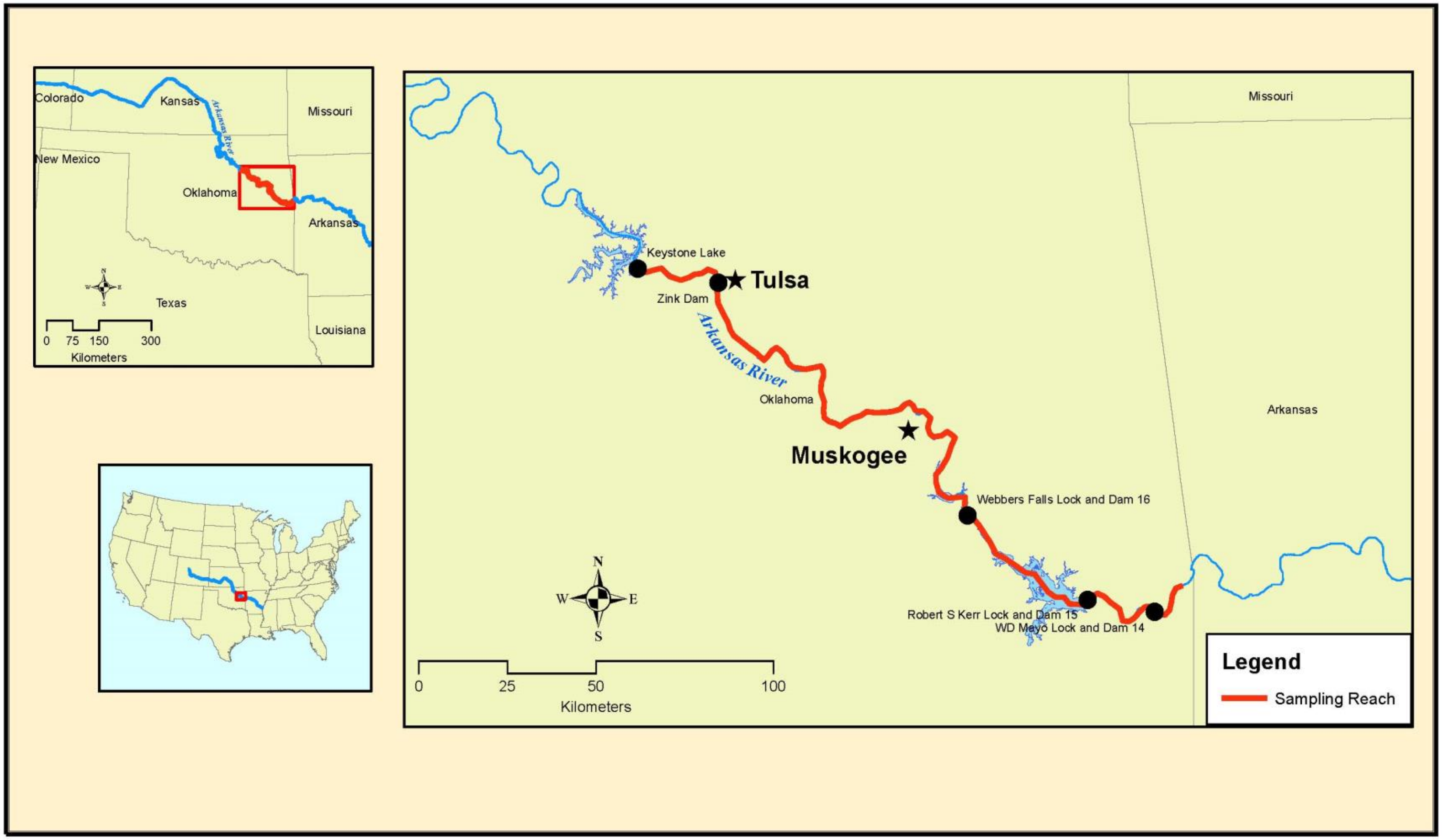

Figure 1. Our Shovelnose Sturgeon sampling reach on the Arkansas River, Oklahoma. We sampled Shovelnose Sturgeon across all seasons, with multiple gears, at various locations throughout this reach from winter 2013 through autumn 2015.

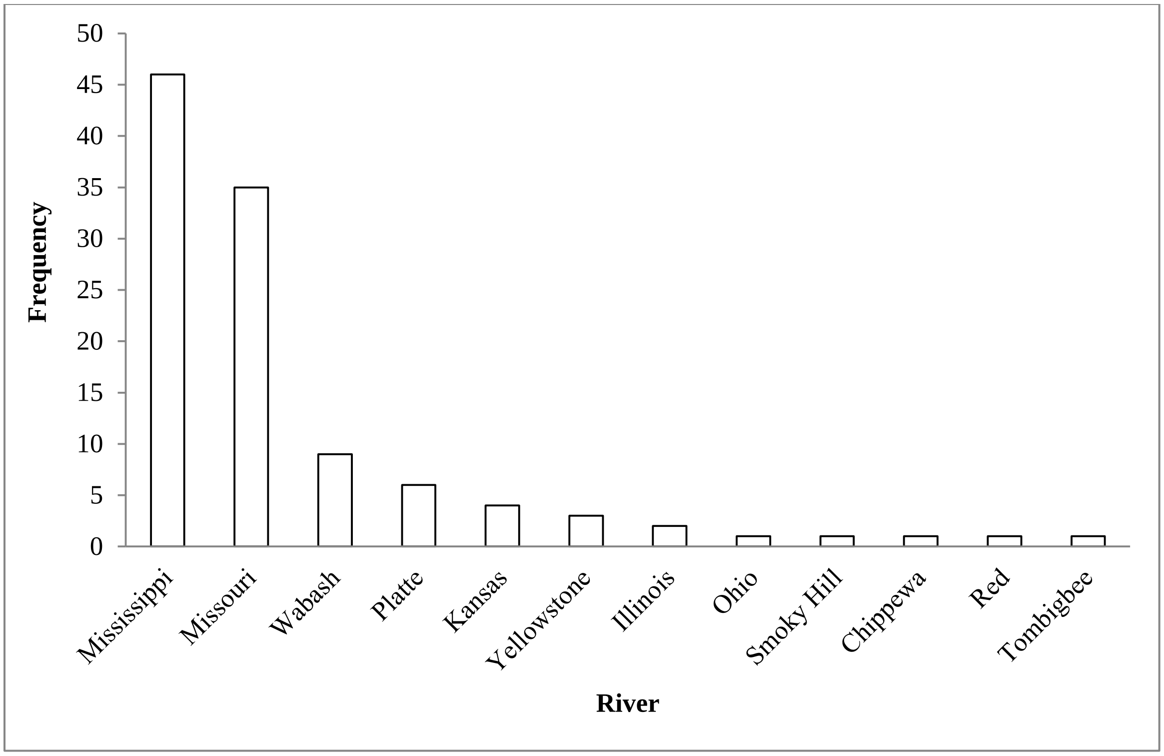

Figure 2. The frequency of Shovelnose Sturgeon studies by river. These studies were part of a systematic review we conducted on Shovelnose Sturgeon sampling. The specific search strings used were reported in Table 2. Databases searched were: Agricola, Web of Science, JSTOR, and Taylor and Francis. Nine studies were conducted on multiple rivers, thus, they were placed in multiple categories for this figure.

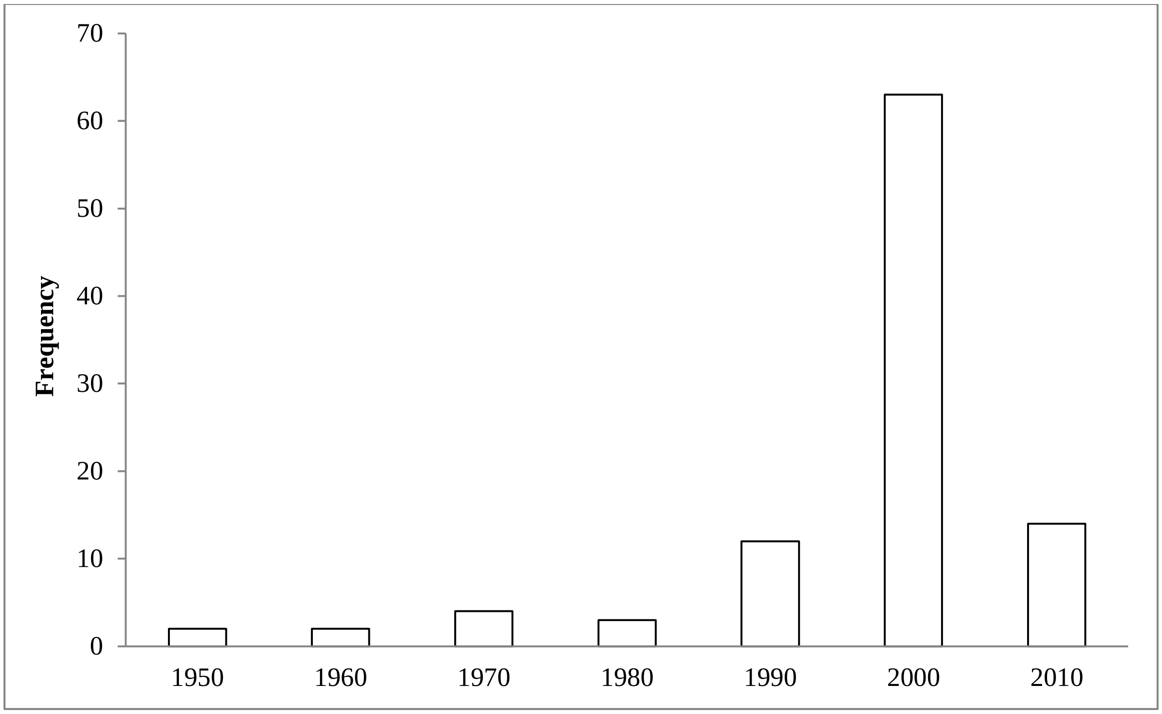

Figure 3. The temporal frequency of published studies related to Shovelnose Sturgeon sampling retrieved via searching four scientific databases: Agricola, Web of Science, JSTOR, and Taylor and Francis. The search strings used in our database review were reported in Table 2.

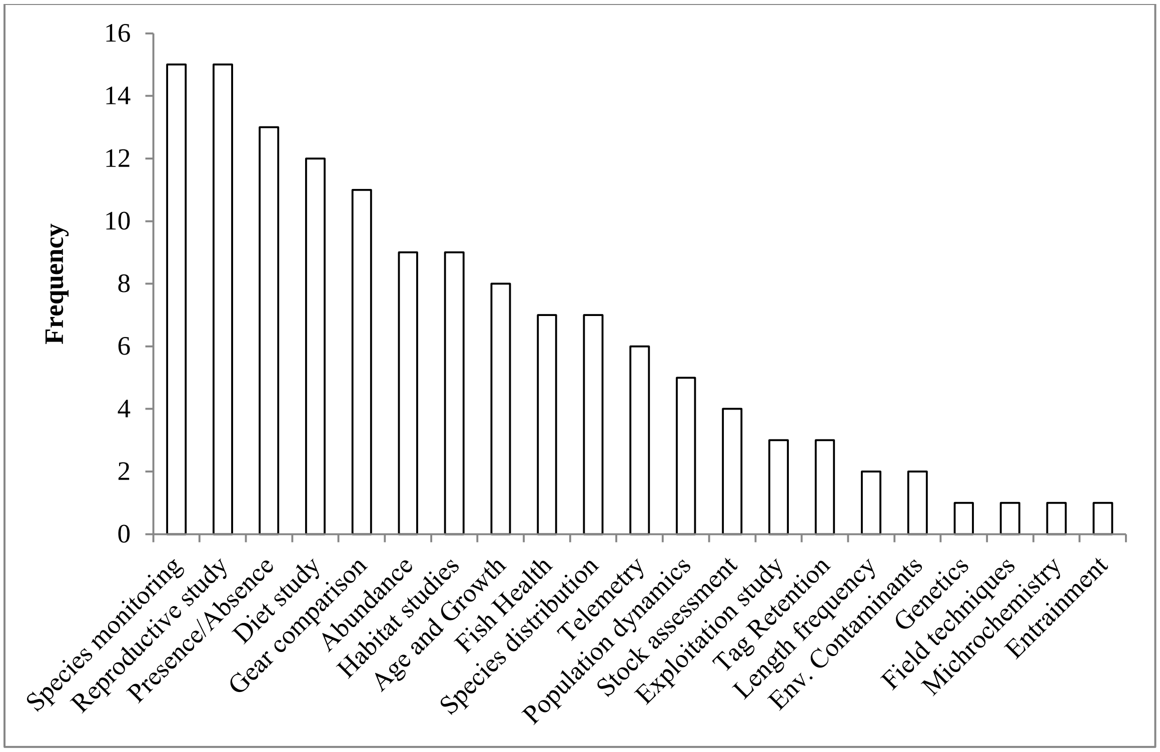

Figure 4. The frequency of study objective(s) found in the 100 published studies we reviewed as part of a systematic review we conducted on Shovelnose Sturgeon sampling. Published studies were retrieved via searching four scientific databases: Agricola, Web of Science, JSTOR, and Taylor and Francis. The search strings used in our database review were reported in Table 2. Study objective definitions are provided in Table 3. Thirty-two of the reviewed studies had multiple objectives and were placed in multiple categories for this figure.

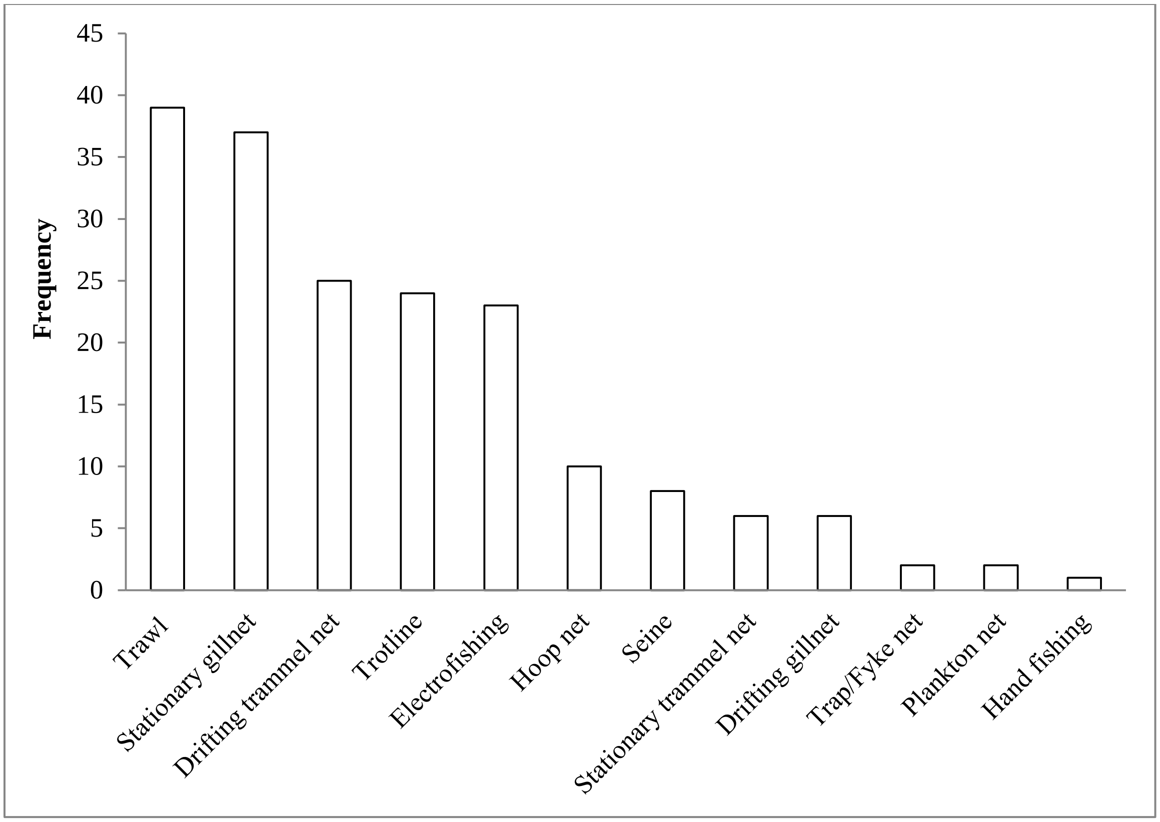

Figure 5. The frequency of twelve different gears used in the 100 published studies we reviewed as part of a systematic review we conducted on Shovelnose Sturgeon sampling. Published studies were retrieved via searching four scientific databases: Agricola, Web of Science, JSTOR, and Taylor and Francis. The search strings used in our database review were reported in Table 2. Multiple gears were used in 46 studies and are duplicated in this figure to account for all gear use.

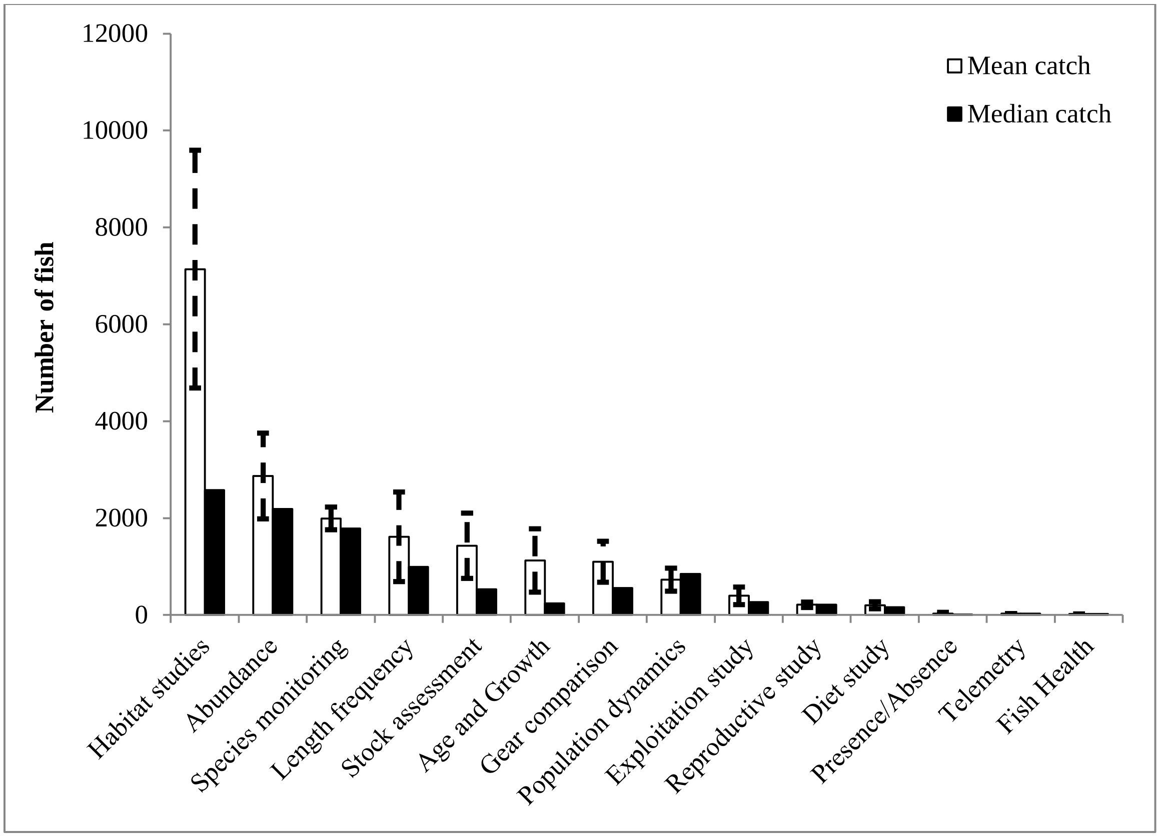

Figure 6. Mean and median catch (with standard error around the mean) of Shovelnose Sturgeon associated with different study objectives. Fish capture was systematically reviewed from 100 studies in four databases: Agricola, Web of Science, JSTOR, and Taylor and Francis. Study objectives were defined in Table 3. Means and medians were calculated using data associated with the five most common gears used to sample Shovelnose Sturgeon in the reviewed studies: stationary gillnets, drifting trammel nets, benthic trawls, trotlines, and electrofishing. Catch data were only used from reviewed studies where sample size was reported.

Appendix A

Table 1. A summary of the total number of articles returned from the Agricola database, sorted by search string. We removed duplicate articles from previous searches within this database (Duplicates), and reviewed all relevant articles returned (Used). Articles not relevant to our study objective were not reviewed (Dismissed).

Search string	Returned	Duplicates	Used	Dismissed
"Shovelnose Sturgeon" sampling	3	0	3	0
"Scaphirhynchus platorynchus" sampling	37	3	19	15
"Shovelnose Sturgeon" collection	50	36	4	10
"Scaphirhynchus platorynchus" collection	37	37	0	0
"Shovelnose Sturgeon" capture	51	50	0	1
"Scaphirhynchus platorynchus" capture	37	37	0	0
"Shovelnose Sturgeon" AND gill nets	3	3	0	0
"Scaphirhynchus platorynchus" AND gill nets	3	3	0	0
"Shovelnose Sturgeon" AND trammel nets	2	2	0	0
"Scaphirhynchus trammel nets	2	2	0	0
"Shovelnose Sturgeon" AND trotlines	3	3	0	0
"Scaphirhynchus platorynchus" AND trotlines	1	1	0	0
"Shovelnose Sturgeon" AND hoop nets	1	1	0	0
"Scaphirhynchus platorynchus" AND hoop nets	1	1	0	0
"Shovelnose Sturgeon" AND trap nets	50	50	0	0
"Scaphirhynchus platorynchus" AND trap nets	37	37	0	0
"Shovelnose Sturgeon" AND fyke nets	22	0	1	21
"Scaphirhynchus platorynchus" AND fyke nets	22	22	0	0
"Shovelnose Sturgeon" AND electrofishing	50	50	0	0
"Scaphirhynchus platorynchus" AND electrofishing	37	37	0	0
Total	**449**	**375**	**27**	**47**

Table 2. A summary of the total number of articles returned from the Web of Science database, sorted by search string. We removed duplicate articles from previous searches within this database and the Agricola database (Duplicates), and reviewed all relevant articles returned (Used). Articles not relevant to our study objective were not reviewed (Dismissed).

Search string	**Returned**	**Duplicates**	**Used**	**Dismissed**
"Shovelnose Sturgeon" sampling	69	19	21	29
"Scaphirhynchus platorynchus" sampling	31	31	0	0
"Shovelnose Sturgeon" collection	14	9	2	3
"Scaphirhynchus platorynchus" collection	3	3	0	0
"Shovelnose Sturgeon" capture	42	20	10	12
"Scaphirhynchus platorynchus" capture	15	14	1	0
"Shovelnose Sturgeon" AND gill nets	15	11	1	3
"Scaphirhynchus platorynchus" AND gill nets	10	10	0	0
"Shovelnose Sturgeon" AND trammel nets	6	5	1	0
"Scaphirhynchus platorynchus" AND trammel nets	3	3	0	0
"Shovelnose Sturgeon" AND trotlines	8	8	0	0
"Scaphirhynchus platorynchus" AND trotlines	3	3	0	0
"Shovelnose Sturgeon" AND hoop nets	3	3	0	0
"Scaphirhynchus platorynchus" AND hoop nets	2	2	0	0
"Shovelnose Sturgeon" AND trap nets	0	0	0	0
"Scaphirhynchus platorynchus" AND trap nets	0	0	0	0
"Shovelnose Sturgeon" AND fyke nets	0	0	0	0
"Scaphirhynchus platorynchus" AND fyke nets	0	0	0	0
"Shovelnose Sturgeon" AND electrofishing	6	6	0	0
"Scaphirhynchus platorynchus" AND electrofishing	5	5	0	0
Total	**235**	**152**	**36**	**47**

Table 3. A summary of the total number of articles returned from the JSTOR database, sorted by search string. We removed duplicate articles from previous searches within this database and the Agricola, and Web of Science databases (Duplicates). We reviewed all relevant articles returned (Used), and articles not relevant to our study objective were not reviewed (Dismissed).

Search string	**Returned**	**Duplicates**	**Used**	**Dismissed**
"Shovelnose Sturgeon" sampling	34	2	3	29
"Scaphirhynchus platorynchus" sampling	27	21	0	6
"Shovelnose Sturgeon" collection	47	25	2	19
"Scaphirhynchus platorynchus" collection	47	36	0	11
"Shovelnose Sturgeon" capture	33	27	0	6
"Scaphirhynchus platorynchus" capture	21	20	0	1
"Shovelnose Sturgeon" AND gill nets	12	10	0	2
"Scaphirhynchus platorynchus" AND gill nets	8	8	0	0
"Shovelnose Sturgeon" AND trammel nets	3	3	0	0
"Scaphirhynchus platorynchus" AND trammel nets	2	2	0	0
"Shovelnose Sturgeon" AND trotlines	2	2	0	0
"Scaphirhynchus platorynchus" AND trotlines	2	2	0	0
"Shovelnose Sturgeon" AND hoop nets	4	4	0	0
"Scaphirhynchus platorynchus" AND hoop nets	3	3	0	0
"Shovelnose Sturgeon" AND trap nets	4	4	0	0
"Scaphirhynchus platorynchus" AND trap nets	4	4	0	0
"Shovelnose Sturgeon" AND fyke nets	1	1	0	0
"Scaphirhynchus platorynchus" AND fyke nets	1	1	0	0
"Shovelnose Sturgeon" AND electrofishing	6	6	0	0
"Scaphirhynchus platorynchus" AND electrofishing	4	4	0	0
Total	**265**	**185**	**5**	**74**

Table 4. A summary of the total number of articles returned from the Taylor and Francis database, sorted by search string. We removed duplicate articles from previous searches within this database and the Agricola, Web of Science, and JSTOR databases (Duplicates). We reviewed all relevant articles returned (Used), and articles not relevant to our study objective were not reviewed (Dismissed).

Search string	**Returned**	**Duplicates**	**Used**	**Dismissed**
"Shovelnose Sturgeon" sampling	197	36	31	130
"Scaphirhynchus platorynchus" sampling	118	110	0	8
"Shovelnose Sturgeon" collection	193	184	0	9
"Scaphirhynchus platorynchus" collection	118	114	1	3
"Shovelnose Sturgeon" capture	155	155	0	0
"Scaphirhynchus platorynchus" capture	95	95	0	0
"Shovelnose Sturgeon" AND gill nets	94	94	0	0
"Scaphirhynchus platorynchus" AND gill nets	55	55	0	0
"Shovelnose Sturgeon" AND trammel nets	46	46	0	0
"Scaphirhynchus platorynchus" AND trammel nets	26	26	0	0
"Shovelnose Sturgeon" AND trotlines	13	13	0	0
"Scaphirhynchus platorynchus" AND trotlines	9	9	0	0
"Shovelnose Sturgeon" AND hoop nets	21	21	0	0
"Scaphirhynchus platorynchus" AND hoop nets	12	12	0	0
"Shovelnose Sturgeon" AND trap nets	50	50	0	0
"Scaphirhynchus platorynchus" AND trap nets	18	18	0	0
"Shovelnose Sturgeon" AND fyke nets	13	13	0	0
"Scaphirhynchus platorynchus" AND fyke nets	4	4	0	0
"Shovelnose Sturgeon" AND electrofishing	68	68	0	0
"Scaphirhynchus platorynchus" AND electrofishing	35	35	0	0
Total	**1340**	**1158**	**32**	**150**

VITA

Joshua Stephen Johnston

Candidate for the Degree of

Master of Science

Thesis: IMPROVING SAMPLING AND MONITORING OF SHOVELNOSE STURGEON *SCAPHIRHYNCHUS PLATORYNCHUS* IN THE GREAT PLAINS

Major Field: Natural Resource Ecology and Management

Biographical:

Education:

Completed the requirements for the Master of Science in Natural Resource Ecology and Management at Oklahoma State University, Stillwater, Oklahoma in May, 2017.

Completed the requirements for the Bachelor of Science in Biology at Northeastern State University, Tahlequah, Oklahoma in 2003.

Experience:

Fisheries Supervisor, Northeast Region, Oklahoma Department of Wildlife Conservation, June 2013 – Present
Fisheries Biologist, East Central Region, Oklahoma Department of Wildlife Conservation, September 2010 – June 2013
Fisheries Technician, J. A. Manning Hatchery, Oklahoma Department of Wildlife Conservation, March 2004 – May 2006
Fisheries Intern, Northeast Region, Oklahoma Department of Wildlife Conservation, May 2003 – August 2003

Professional Memberships:

Oklahoma Chapter of the American Fisheries Society