Minnesota River Shovelnose Sturgeon: population dynamics and movement patterns

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Executive Summary

Activity 4A: Evaluate population dynamics, movement, and habitat use of Shovelnose Sturgeon in the Minnesota River.

Project Objectives

- Evaluate abundance, growth, mortality, and recruitment of Minnesota River Shovelnose Sturgeon.
- Quantify movement patterns of Minnesota River Shovelnose Sturgeon.

Significant Outcomes

- Shovelnose Sturgeon are abundant in the free-flowing reach of the Minnesota River with an estimated population density of approximately 100 adult fish per river kilometer.
- Shovelnose Sturgeon captured during this project varied in fork length 282–775 mm and ages 2–15 years indicating that many year classes are present and recruitment is relatively consistent.
    - However, very few young (< age-5) Shovelnose Sturgeon were captured during this project and zero ≤ age-1 Shovelnose Sturgeon have been captured during the last five years. This is a potentially concerning indication of limited recruitment success during recent years, but more likely a reflection of ineffective sampling methods for capturing small fish.
- Minnesota River Shovelnose Sturgeon growth is similar to growth in other Mississippi River basin populations with fish reaching approximately 600 mm fork length by age 8, maximum observed fork lengths around 800 mm, and maximum age of 15 years.
- Estimated annual survival of age-7 and older Shovelnose Sturgeon is 67%, which is similar to other large river Shovelnose Sturgeon populations.
- Minnesota River Shovelnose Sturgeon are most effectively sampled with fall trotline surveys, but captured fish tend to be ≥ 590 mm fork length.
    - An effective method for sampling young and juvenile Minnesota River Shovelnose Sturgeon has not been identified.
- Most acoustic tagged Shovelnose Sturgeon (17 of 30) exhibited small home ranges (< 5 km), but 7 of 30 exhibited upstream movements > 20 km and up to > 160 km.
- Large upstream movement always occurred during April-June and we hypothesize they are associated with spawning.
- Overall, most acoustic tagged Shovelnose Sturgeon exhibited very little movement, often remaining within a small reach of river for long periods of time, and exhibited site fidelity by often returning to the same reach of river (if they did exhibit any long distance movements).

Remaining Questions

- Where do Shovelnose Sturgeon spawn within the Minnesota River?
    - Do they successfully spawn in a few specific locations or at many locations throughout the river?
- Is successful Shovelnose Sturgeon spawning still frequently occurring, or do low numbers of young Shovelnose Sturgeon captured during this study indicate limited recruitment during recent years?
- Would the Shovelnose Sturgeon population be resilient to harvest mortality?
- Is immigration or emigration important for the Minnesota River Shovelnose Sturgeon population?

Abstract

Shovelnose Sturgeon *Scaphirhynchus platorynchus* is one of two species of the globally imperiled sturgeon family native to Minnesota. Sturgeons are generally long-lived, slow-growing, and late-maturing resulting in particular sensitivity to habitat alteration and over-harvest. Although perception is Shovelnose Sturgeon are relatively abundant in the Minnesota River, historically collected data are insufficient for monitoring the population. Thus, we sought to establish a baseline understanding of Minnesota Rive Shovelnose Sturgeon population dynamics and evaluate movement patterns. During August 2016–November 2018 we conducted extensive targeted sampling at four Minnesota River sites; capturing 391 Shovelnose Sturgeon varying 282–775 mm fork-length and estimated ages 2–15 years. We found fall trotlines set when water temperatures fell below 10°C as the most effective method for capturing Shovelnose Sturgeon from the Minnesota River, but similar to most evaluated methods, trotlines primarily captured fish > 570 mm fork length. Estimated Von Bertalanffy growth parameters (L_∞ = 669.7 and K = 0.323), annual mortality (A = 0.33), and population density (96 ≥ 560 mm fork length Shovelnose Sturgeon per river km) are relatively similar to estimates reported for other large river populations of Shovelnose Sturgeon, and particularly other populations in the upper Mississippi River basin. Both active and passive telemetry indicated that most Shovelnose Sturgeon surgically implanted with acoustic transmitters exhibited small home ranges of < 20 river km during a two year period, but four fish migrated > 100 river km. Our results provide evidence of an abundant Minnesota River Shovelnose Sturgeon population with typical to fast growth rates, consistent recruitment, and moderate annual adult mortality rates reflective of a healthy population. However, we captured very few young (i.e., < age 5) fish, likely resulting from size bias of sampling methods, but potentially indicating poor recruitment during recent years. The next steps for ensuring sustainability of the Minnesota River Shovelnose Sturgeon population include evaluating recruitment success, identifying critical spawning habits, and continued monitoring of population dynamics.

Introduction

Shovelnose Sturgeon *Scaphirhynchus platorynchus* are an important species because of their commercial and recreational value, unique life history characteristics, similarity to other endangered *Scaphirhynchus* species, and the imperiled status of sturgeon species globally. In general, sturgeon species are long-lived, slow-growing, and late-maturing which results in sensitivity to disturbances such as harvest, habitat alteration, and pollution (Boreman 1997). For instance, Quist et al. (2002) reported that exploitation rates of ≥ 20% could affect size structure of Shovelnose Sturgeon populations and many localized extirpations resulting from the construction of dams or other water development activities have been documented (Keenlyne 1997). Shovelnose Sturgeon are among the smallest of the North American sturgeon species generally reaching maximum lengths (fork length; FL) less than 1.0 m and although they sexually mature at an earlier age than most other sturgeon species, they may not reach maturity until around age 8, may not spawn every year, and have been reported to live > 30 years. As concerns regarding sturgeon species remain, many fisheries management agencies are taking proactive measures to monitor Shovelnose Sturgeon populations (Pikitch et al. 2005; Koch and Quist 2010).

Shovelnose Sturgeon are native throughout the Mississippi River drainage and in Minnesota they inhabit the Mississippi River and its larger tributaries such as the Minnesota River, St. Croix River, and Root River. The population of Shovelnose Sturgeon inhabiting the Minnesota River is perceived as among the most abundant in the state. Although habitat alterations and overfishing negatively affect all sturgeon species (family Acipenseridae) in North America, Shovelnose Sturgeon may be the most resilient since they sexually mature quicker (age 5-7) and have less specific spawning habitat requirements than other species. In fact, Shovelnose Sturgeon are the only one of three sturgeon species that still supports commercial fisheries in the Mississippi River. Yet, commercial fishing is outlawed in some regions because of similarity in appearance to the federally endangered Pallid Sturgeon *Scaphirhynchus albus* and is not legal in Minnesota Waters (but is legal in Wisconsin waters of the Mississippi River along the shared border).

Shovelnose Sturgeon likely inhabited the Minnesota River well before European settlement and have endured drastic changes to the river resulting from installation of complex drainage systems, row crop agriculture, introduction of non-native species, and construction of dams throughout the Mississippi River basin. Shovelnose Sturgeon were once listed as a species of conservation need in Minnesota, but the species was removed from the list in 2015 after an increasing number of fisheries surveys provided better information about their populations. Although Shovelnose Sturgeon are perceived as abundant in the Minnesota River, limited historical datasets prevent comparisons with historical populations. The primary goal of this study is to establish a baseline understanding of the Minnesota River Shovelnose Sturgeon population, evaluate population health, and provide the capability for quantifying future changes to the population. Specifically we sought to quantify relative abundance, size structure, growth, mortality, and recruitment. Our secondary goal was to evaluate movement patterns by surgically implanting individual fish with acoustic transmitters.

Study Area

The free-flowing reach of the Minnesota River extends 395 rkm from Granite Falls Dam downstream to its confluence with the Mississippi River at St. Paul, Minnesota (1,358 rkm from the confluence with the Ohio River; Figure 1). Although Shovelnose Sturgeon may have once inhabited the Minnesota River upstream of Granite Falls Dam prior to dam construction, their range is now restricted to downstream of the dam. Downstream of Granite Falls Dam the Minnesota River is a seventh- thru eight-order warmwater river flowing through the agriculturally dominated prairie region of southern Minnesota. The Minnesota River is generally low gradient, productive, and turbid. For instance, at St. Peter, Minnesota (rkm 142, approximately half way between Granite Falls Dam and the mouth) mean discharge was 178.9 m^3/s, total phosphorous was 0.25 mg/L, and total suspended solids were 127.0 mg/L during 2007–2015 (Minnesota Pollution Control Agency; www.pca.state.us/wplmn, December 2018).

We conducted Shovelnose Sturgeon assessments at four study reaches during 2016–2018 (Figure 1). Study reaches are approximately 3.0–4.0 km in length and near the communities of North Redwood (rkm 326–330), Judson (rkm 180–184), Mankato (159.5–162.5), and Chaska (rkm 46–49). Although not considered a study reach, we also conducted targeted sampling at a reach near New Ulm (rkm 213–215).

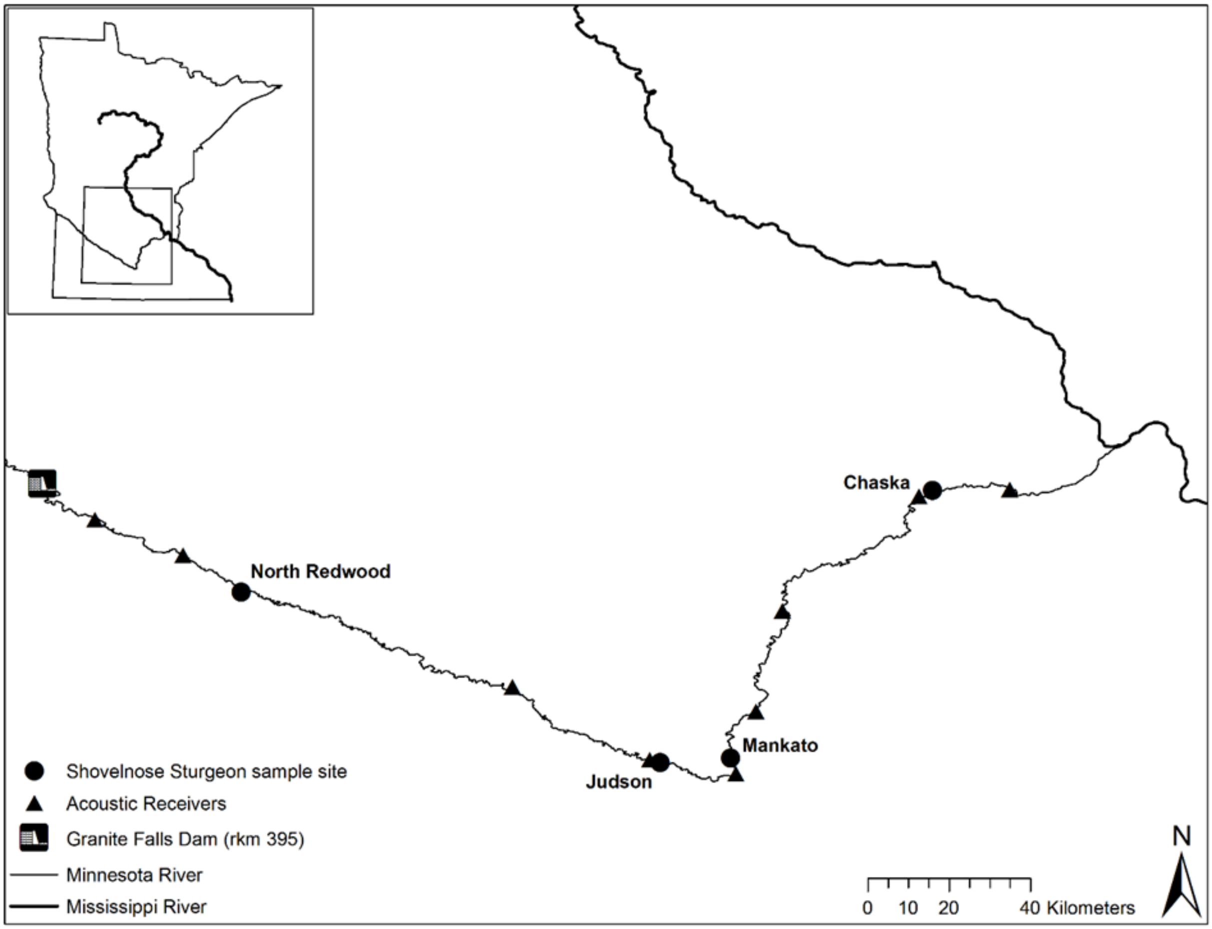

Figure 1. Location of four study reaches where targeted Shovelnose Sturgeon surveys were conducted along with the location of nine stationary acoustic receivers within the 395-km free-flowing reach of the Minnesota River downstream of Granite Falls Dam.

Methods

Shovelnose Sturgeon sampling

We conducted targeted Shovelnose Sturgeon assessments with a suite of sample gears including pulsed direct-current boat electrofishing, trammel nets, benthic trawls, angling, and 10-hook trotlines. Specifically, we conducted pulsed-DC (60 Hz frequency, 30% duty cycle) electrofishing surveys during the day from a boat equipped with an MDS-2DP-MN electrofisher (ETS Electrofishing Systems LLC, Madison, Wisconsin), two six-dropper spider array anodes, and the boat hull serving as the cathode. During each electrofishing run, we adjusted voltage for desired fish response and two netters captured fish from the bow of the boat. We actively fished 30.5-m long by 2.4-m deep trammel nets by drifting them with the current; generally through depths of 1–4 m. Trammel nets were constructed with two 35.5-cm bar mesh outer panels, a 6.4-cm bar mesh inner panel, two 1.3-cm foam core float lines, and a 9.1-kg lead core bottom line. For benthic trawls we pulled Siamese Trawls (constructed with a 2.4-m head rope and 6-mm outer mesh; Innovative Net Systems, Milton, Louisiana) with otter boards off the bow of the boat in a downstream direction. For a passive sampling method, we set 21-m long trotlines parallel to the current for approximately 24-hours. Each trotline had ten 41-cm long evenly spaced droppers attached to the main line with a stainless steel trotline clip and each dropper had a 3/0 Lazer Sharp Circle Sea Big Eye Trotline hook (Eagle Claw Fishing Tackle Co., Denver, Colorado) baited with half a nightcrawler *Lumbricus* spp. attached with a 4/0 barrel swivel.

During spring and summer 2016, we primarily conducted experimental sampling with boat electrofishing, trammel nets, and angling at the North Redwood and Judson reaches. Additionally, during fall 2016 we conducted angling assessments at the Mankato and Chaska reaches and trotline assessments at Judson. During spring 2017 we conducted boat electrofishing assessments at the shallower North Redwood and Judson reaches and angling assessments at the deeper Mankato and Chaska reaches. We also conducted boat electrofishing, trammel net, and benthic trawl assessments at all four study reaches during summer 2017. For the remainder of the study, we targeted Shovelnose Sturgeon with fall trotline assessments; sampling at North Redwood, Mankato, and Chaska during 2017 and at North Redwood, Judson, and Mankato during 2018.

We measured FL (mm), weighed (g), and examined all captured Shovelnose Sturgeon for external marks or internal tags. Excluding recaptures, we tagged each captured Shovelnose Sturgeon with a uniquely numbered 11.4 x 2.18 mm FDX-B polymer passive integrated transponder (PIT; Hallprint, Hindmarsh Valley, Australia) injected into the left operculum (see Hamel et al. 2012) and clipped the left pelvic fin as a secondary mark. We removed the anterior left pectoral fin ray from a subset of captured Shovelnose Sturgeon for age and growth analyses. We released all fish near (within 0.5 km) their capture location.

Telemetry

We selected nine Shovelnose Sturgeon captured from each study reach for the telemetry component of this study and surgically implanted a 69-kHz V9-2x acoustic transmitter (Vemco, Bedford, Nova Scotia, Canada) into their peritoneal cavity. Vemco V9-2x transmitters were programmed to emit a signal every 80–160 seconds with an approximate battery life of 802 days. We implanted transmitters through a small approximately 2.5 cm incision along the ventral side, offset from the midline, and anterior of the pelvic girdle. We closed incisions with three interrupted sutures and held fish for a short recovery period prior to release.

We detected movements of Shovelnose Sturgeon implanted with acoustic transmitters with both passive and active tracking methods. An array of stationary receivers (VR2W–69kHz, Vemco) was established in the Minnesota River by suspending receivers inside 3.5 m long 10.2 cm diameter polyvinyl chloride (PVC) pipes that were attached to bridge pilings near rkm 27, 48, 107, 141, 164, 185, 232, 346, and 371 (Figure 1). Six receivers were installed during fall of 2015 while the remaining three at rkm 141, 185, and 346 were installed during July–September 2017.

We sporadically conducted active tracking surveys at study reaches using a VR100 receiver and omni-directional hydrophone (Vemco). We drifted a boat with the current through the study reach with the hydrophone deployed in the water. If we heard transmitter signals but failed to detect transmitter information, we held the boat stationary (with either the motor or an anchor) or re-drifted through the area until we detected the transmitter information. For both passive and active tracking, we interpreted transmitter detections as the presence of the corresponding tagged fish within close proximity (likely within 1 km) of the receiver. Non-detection of a transmitter likely indicated the corresponding fish was not in close proximity, but we could not exclude the possibility of false negatives.

We summarized telemetry data by calculating linear home range and cumulative movements between the first and last detections (i.e., duration) for each fish. Linear home range is the distance in rkm between the upstream most detection and the downstream most detection. Cumulative movements is the sum of distances between each sequential detection. For example, if we first detected a fish at rkm 141, followed by a detection at rkm 107 and then back at rkm 141, the linear home range is 34 rkm and the cumulative movement is 68 rkm. Similar to Tripp et al. (2019), we also categorized movement behaviors of Shovelnose Sturgeon into three general categories: 1) resident fish with home ranges ≤ 20 rkm that exhibited little movement (i.e., mean monthly cumulative movement ≤ 5.0 rkm), 2) migratory fish that exhibited either one large migration or patterned seasonal migrations, and 3) nomadic fish that exhibited frequent, seemingly random, upstream and downstream movements.

Age estimation and analyses

We estimated age at capture of Shovelnose Sturgeon by counting annuli on sectioned pectoral fin rays with similar methods described by Koch and Quist (2007). First, we mounted fin rays in two-part epoxy (EpoxiCure 2, Buehler, Lake Bluff, IL, USA) and then cut several thin transverse (approximately 0.5–1.0 mm) sections from the proximal end of the fin ray using a Buehler Isomet low-speed saw. We examined fin ray sections under a stereo microscope (4–28 × magnification) with transmitted light. One primary reader assigned an estimated age to each Shovelnose Sturgeon based on the number of visible annuli and we used those estimated ages to describe growth of Minnesota River Shovelnose Sturgeon. We also evaluated aging bias and precision by comparing assigned ages from the primary readers to ages estimated by secondary readers. Lastly, we assigned ages to all un-aged Shovelnose Sturgeon using an age-length key (DeVries and Frie 1996) and used the resulting age-frequency data for catch-curve analyses. We pooled data among sites for both growth and catch-curve analyses.

We described growth with the Von Bertalanffy growth function:

$$FL_t = L_\infty[1 - e^{-K(t-t_0)}]$$

where FL_t is fork length (mm) at time t, L_∞ is asymptotic length, t is age (years), t_0 is hypothetical age at length zero, and K is growth coefficient. We estimated total annual mortality (A) from a catch curve that assumed equal catchability for age 7 and older Shovelnose Sturgeon since we assumed minimal sampling gear biases existed for ≥ age 7 fish. The catch curve is the linear regression of the natural log of the number of fish at each age against fish age and assumes constant mortality, recruitment, and catchability among fish ages (Allen and Hightower 2010). The slope of the regression is equal to instantaneous mortality (Z) which we used to estimate total annual mortality (A) with the equation:

$A = 1 - e^{-Z}$.

Although we violated many assumptions, we adapted the basic Lincoln-Peterson model to estimate the population size of ≥ 560 mm FL Shovelnose Sturgeon at each study reach and the corresponding mean population density (fish/rkm). We estimated population size with the formula:

$$N = \frac{Kn}{k}$$

Table 1. Shovelnose Sturgeon captured (and number of sample trips) with five sampling gears from each study reach of the Minnesota River, Minnesota during 2016–2017.

	Sampling gear						
Study reach	Trot line	Boat electrofishing	Trammel net	Trawl	Angling	Total	Recaptures
North Redwood	53 (4)	24 (5)	5 (1)	9 (2)	0 (1)	91	1
Judson	63 (4)	79 (8)	3 (1)	7 (1)	4 (1)	156	3
Mankato	48 (5)	0 (0)	8 (2)	10 (1)	13 (3)	79	0
Chaska	28 (2)	2 (2)	15 (2)	0 (1)	20 (5)	65	1
Combined	188 (15)	105 (15)	31 (6)	25 (5)	37 (10)	391	5

where, N is population size within the study reach, K is number of fish captured during the recapture event, n is the number of fish marked during previous sample events within the study reach, and k is the number of fish captured during the recapture event that are marked. However, we used active telemetry data pooled across all sites and years to adjust n for the probability of marked fish being present within the study reach based on when we initially captured and marked the fish (e.g., within the same year, during the previous year). For instance, if telemetry data indicated 50% of fish implanted with acoustic receivers during the same year were present and 25% of fish implanted with acoustic receivers during the previous year were present, we estimated population size with:

$$N = \frac{K[(n_1 \times 0.5) + (n_2 \times 0.25)]}{k}$$

where n_1 is the number of fish marked during previous sample events within the same year and study reach, and n_2 is the number of fish marked during the previous year at the same study reach. This method assumes immigration and emigration of unmarked fish is equal. We calculated population estimates for each resampling event we recaptured marked fish, and then calculated the mean of population estimates for each study reach and all study reaches combined.

Results

Shovelnose Sturgeon sampling

Targeted sampling efforts captured 391 Shovelnose Sturgeon from the four study reaches of the Minnesota River during 2016–2018 with the greatest catch at the Judson reach (156) and the lowest catch at the Chaska reach (65; Table 1). We captured nearly half (49.1%) of the Shovelnose Sturgeon with trotlines, 26.9% with boat electrofishing, and the remaining with angling (9.5%), trammel nets (7.9%), or benthic trawls (6.6%). Although effort among sampling gear types is difficult to compare, we considered fall (water temperature < 10°C) trotlines the most effective method for capturing Shovelnose Sturgeon across all sample reaches with a mean catch of 12.8/sample event and 1.3/10-hook trotline.

Mean FL of captured Shovelnose Sturgeon was 622 mm, varying from 282 to 775 mm, with 75% of captured fish between 573 and 683 mm. Length frequency distributions of captured Shovelnose Sturgeon significantly differed among study reaches (Kruskall-Wallis test: chi-square = 19.94, df = 3, P = < 0.001; Figure 2), but this may have been influenced by variable sampling gear effort among sites. The length distribution of Shovelnose Sturgeon tended to be greater at the North Redwood reach (Kruskall-Wallis test: $P \leq 0.05$) than all other reaches while lengths also tended to be greater at the Judson reach than the Chaska reach. Similarly, the

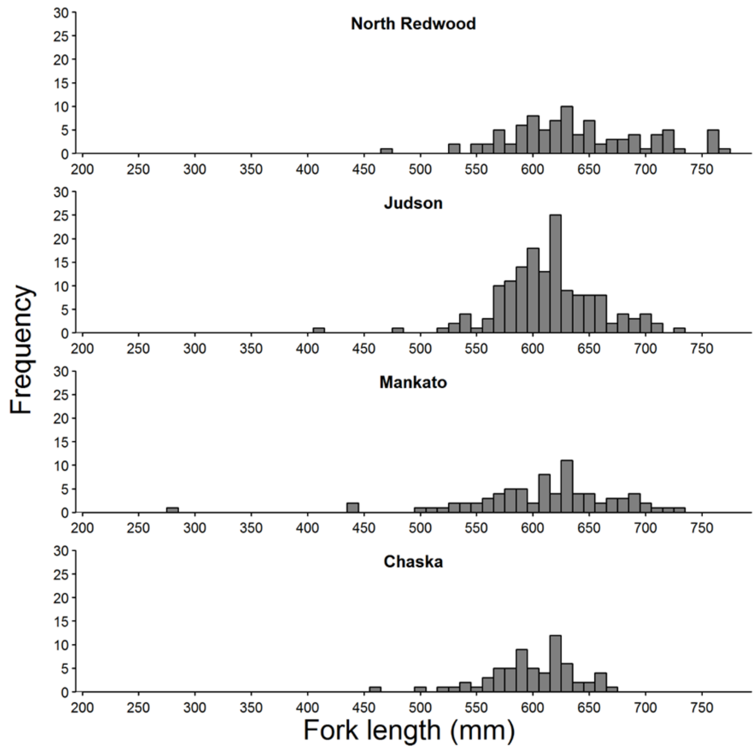

Figure 2. Length-frequency (fork length) of Shovelnose Sturgeon captured from four study reaches of the Minnesota River, Minnesota during 2016–2018.

proportion of Shovelnose Sturgeon > 700 mm was greatest at the furthest upstream reach (0.20 at North Redwood), intermediate at Judson (0.05) and Mankato (0.06), and 0.00 at the furthest downstream reach (Chaska).

Age at capture of 279 Shovelnose Sturgeon varying 282–775 mm (including 11 fish captured at New Ulm) estimated by the primary reader varied 2–15 years (Figure 3). The primary and secondary readers had exact agreement among estimated ages for 45% of fish, while age estimates were within 1-year for 87% of fish, and within 2-years for 99% of fish. Plotting estimated ages from each reader for each fish demonstrates that neither the primary nor secondary readers consistently tended to over- or under-estimate ages (Figure 4).

Von Bertalanffy growth parameters estimated from length at capture and estimated age at capture of Minnesota River Shovelnose Sturgeon are L_∞ = 669.7 and K = 0.323 (Figure 5). Growth estimated for Minnesota River Shovelnose Sturgeon is comparable to growth reported for other

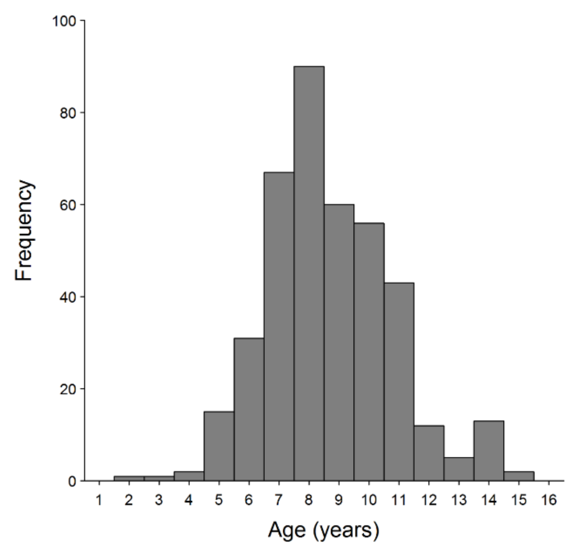

Figure 3. Estimated age frequency of Shovelnose Sturgeon captured from the Minnesota River, Minnesota during 2016–2018.

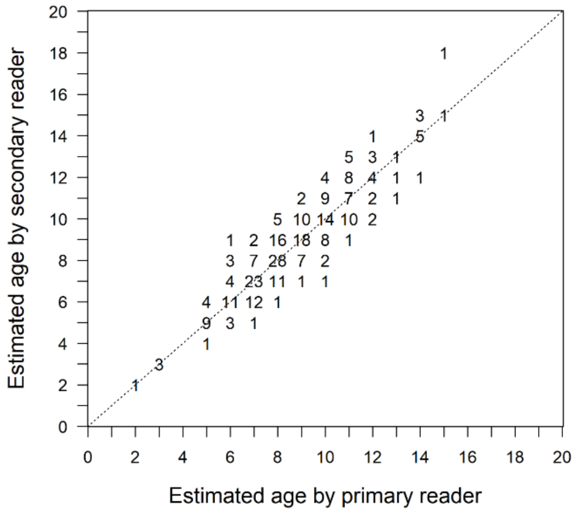

Figure 4. Estimated age at capture of 297 Shovelnose Sturgeon by the primary reader plotted against estimated ages by the secondary reader. Readers estimated ages by counting annuli on pectoral fin ray sections. A 1:1 line provided for reference.

populations (Morrow et al. 1998; Quist et al. 2002; Kennedy et al. 2007; Tripp et al. 2009)

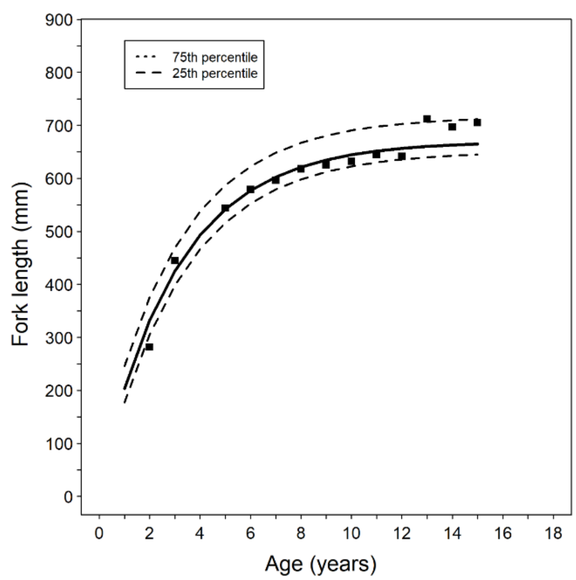

Figure 5. Von Bertalanffy growth curve derived from fork length (mm) at capture and estimated age at capture of 297 Minnesota River Shovelnose Sturgeon along with growth curves estimated for 25th percentile and 75th percentile lengths at capture for each age. Squares indicate mean length for each age.

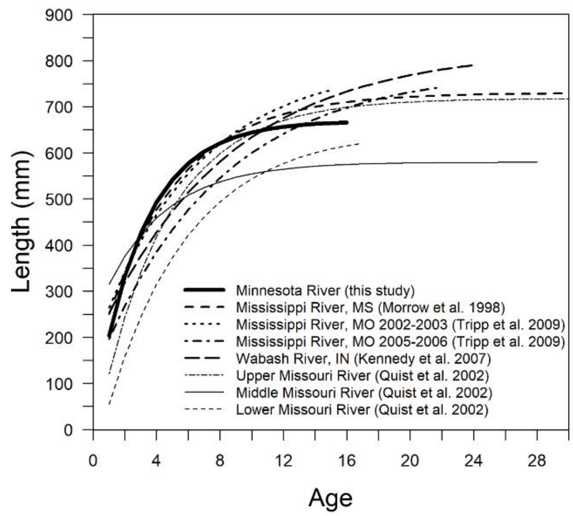

Figure 6. Von Bertalanffy growth curve estimated for Minnesota River Shovelnose Sturgeon from this study and Von Bertalanffy growth curves reported for seven additional Shovelnose Sturgeon populations in other North American river systems.

with relatively fast growth up to age-8 (Figure 6). Based on catch curve analyses using estimated age frequency data pooled among sites, we estimated total annual mortality (A) of 0.33 (95% CI = 0.20–0.44) for age-7 and older Shovelnose Sturgeon.

Based on telemetry data collected during active tracking trips at all study reaches combined, mean probability of a tagged fish occupying its respective study reach during any subsequent tracking event within the same calendar year it was tagged is 0.62, during the following calendar year is 0.29, and two calendar years later is 0.31. Using these probabilities and recapture rates, we estimated mean density of Shovelnose Sturgeon ≥ 560 mm FL is 96/rkm with site-specific density estimates varying from 71/rkm at North Redwood to 122/rkm at Chaska.

Table 2. Telemetry summary for 36 Shovelnose Sturgeon implanted with acoustic transmitters in the Minnesota River during August 2016–October 2018. Linear home range is the distance (river kilometer) between the furthest upstream and furthest downstream detection. Cumulative movement is the sum of distances between detections. We classified fish with a small linear home range (< 20 rkm) as resident and fish with linear home ranges ≥ 20 rkm that exhibited one large migratory movement as migratory.

Fish	Duration (months)	Dates detected	Linear home range (rkm)	Cumulative movement (rkm)	Cumulative movement per month (rkm)	Classification
			North Redwood Site			
SLS 1	11.7	5	144	144	12.3	Migratory
SLS 2[a]	3.0	6	0	0	0.0	NA
SLS 3[a]	1.9	4	0	0	0.0	NA
SLS 4	11.0	8	144	144	13.1	Migratory
SLS 5	25.2	8	17	17	0.7	Resident
SLS 6	24.4	7	17	34	1.4	Resident
SLS 7	21.0	9	17	17	0.8	Resident
SLS 8	24.4	10	0	0	0.0	Resident
SLS 9	21.0	4	17	17	0.8	Resident
			Judson Site			
SLS 10	23.0	9	44	88	3.8	Migratory
SLS 11[a]	6.9	6	0	0	0.0	NA
SLS 12	22.9	4	0	0	0.0	Resident
SLS 13	23.0	8	0	0	0.0	Resident
SLS 14	22.1	19	161	322	14.6	Migratory
SLS 15	23.0	9	0	0	0.0	Resident
SLS 16[a]	1.6	3	0	0	0.0	NA
SLS 17	23.0	44	3	6	0.3	Resident
SLS 18	24.2	7	0	0	0.0	Resident
			Mankato Site			
SLS 19	6.4	11	24	24	3.8	Migratory
SLS 20[b]	6.9	4	3	3	0.4	NA
SLS 21	17.0	4	0	0	0.0	Resident
SLS 22[b]	7.5	5	3	3	0.4	NA
SLS 23	22.7	6	0	0	0.0	Resident
SLS 24[b]	5.4	4	3	3	0.6	NA
SLS 25	22.7	10	0	0	0.0	Resident
SLS 27	16.8	5	3	6	0.4	Resident
SLS 28[b]	1.5	4	3	3	2.0	NA
			Chaska Site			
SLS 26	20.0	5	21	21	1.1	Migratory
SLS 29	13.7	10	0	0	0.0	Resident

Table 2. Continued

SLS 30	15.3	38	8	16	1.0	Resident
SLS 31	17.7	16	0	0	0.0	Resident
SLS 32	10.8	9	0	0	0.0	Resident
SLS 33[a]	0.5	4	0	0	0.0	NA
SLS 34	12.4	27	116	116	9.4	Migratory
SLS 35[a]	0.0	1	0	0	NA	NA
SLS 36[b]	13.1	5	0	0	0.0	NA
			Means			
	14.5	9.4	20.8	27.3	1.9	

[a]Unkown fate (may have died or shed tag)

[b]Insufficent detections

Telemetry

During this project we implanted 36 Shovelnose Sturgeon with acoustic transmitters; 9 at each of four study reaches. We implanted 26 fish with transmitters during fall 2016 and the remaining 10 during spring

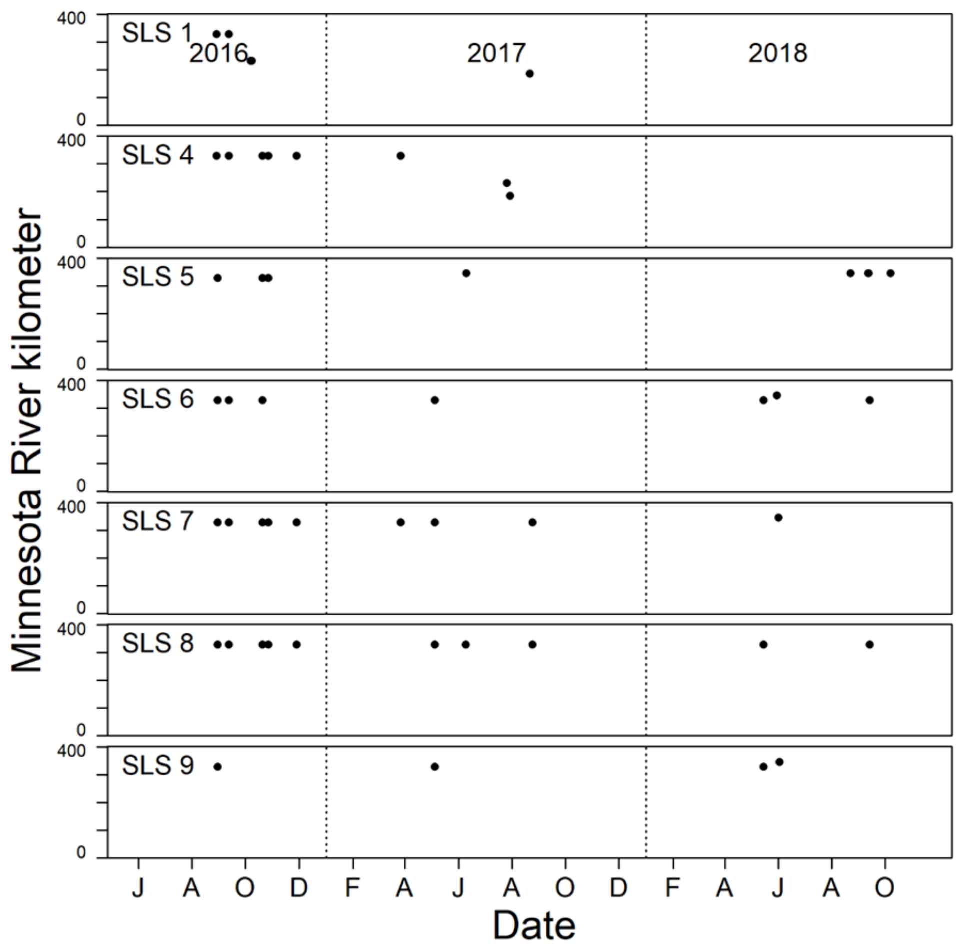

Figure 7. Detection location and date for seven Shovelnose Sturgeon implanted with acoustic transmitters at the North Redwood study reach of the Minnesota River, Minnesota. Location is river kilometers from the mouth of the Minnesota River.

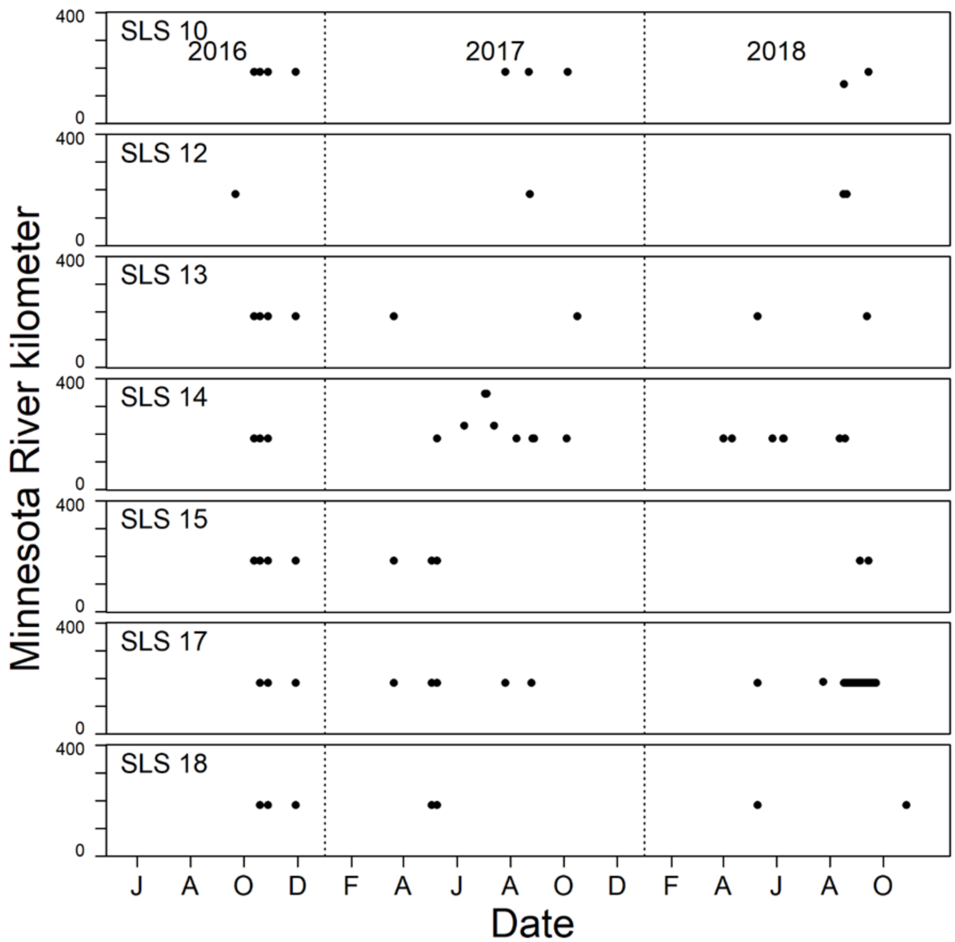

Figure 8. Detection location and date for seven Shovelnose Sturgeon implanted with acoustic transmitters at the Judson study reach of the Minnesota River, Minnesota. Location is river kilometers from the mouth of the Minnesota River.

2017. We excluded six transmitter tagged fish from telemetry analyses (2 from North Redwood, Judson, and Chaska) that we never detected beyond a few days after release.

We conducted at least five active tracking trips at respective study reaches after implanting fish with transmitters with the total number of active tracking trips at each study reach varying 7–11. Based on movements detected during active tracking trips and with stationary receivers, we confirmed 25 of 30 fish were alive at least 6 months after initial capture. The duration (time between first and last detection) of telemetry detections varied 1.5–25.2 months and the number of dates detected varied 4–44 for the 30 Shovelnose Sturgeon (Table 1).

Overall, Shovelnose Sturgeon exhibited small home ranges with 23 of 30 fish never detected > 20 rkm away from their respective study reach and a mean linear home range of 20.8 rkm for all 30 fish (Figures 7–10, Table 2). Of the 23 fish with small home ranges, detections were sufficient to classify 18 as resident fish (Table 2). We classified seven fish as migratory that exhibited movements > 20 rkm; four making downstream movements and three making upstream movements. Detections were insufficient for classifying the remaining 11 fish and we classified zero fish as nomadic. Only four fish made detected movements of >

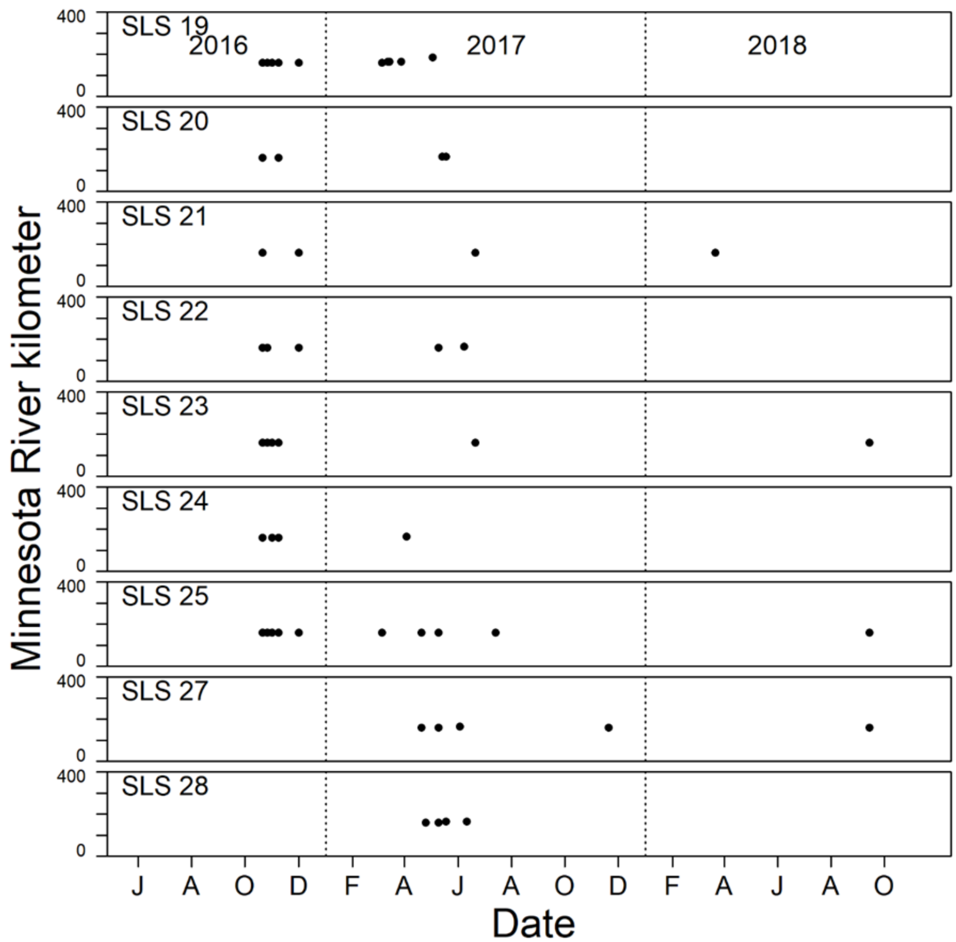

Figure 9. Detection location and date for nine Shovelnose Sturgeon implanted with acoustic transmitters at the Mankato study reach of the Minnesota River, Minnesota. Location is river kilometers from the mouth of the Minnesota River.

100 rkm; two downstream and two upstream. All upstream movements > 15 rkm occurred during May–June. Shovelnose Sturgeon remained within study reaches for long periods with 24 of 30 remaining for at least 6 months after initial capture, 16 for at least 12 months, and 12 for at least 18 months. After leaving study reaches, many fish returned with 20 of 30 fish detected within their respective study reach a year or more after their initial capture. Several fish exhibited rather extended periods of very little movement. For instance, we detected Shovelnose Sturgeon (SLS) 17 within the same 1-rkm reach during eight consecutive active tracking surveys over a 17 month period before we detected the fish 3 rkm upstream (see Figure 8).

Discussion

This study is the first comprehensive evaluation of Shovelnose Sturgeon population dynamics in the Minnesota River. We captured 65–156 Shovelnose Sturgeon from each of four study sites providing evidence of an abundant population with typical to fast growth rates, consistent recruitment, and moderate annual adult mortality rates reflective of a healthy unexploited population. However, we captured very few young (i.e., < age 5) fish, likely resulting from size bias of sampling methods, but potentially indicating poor recruitment during recent years. We also

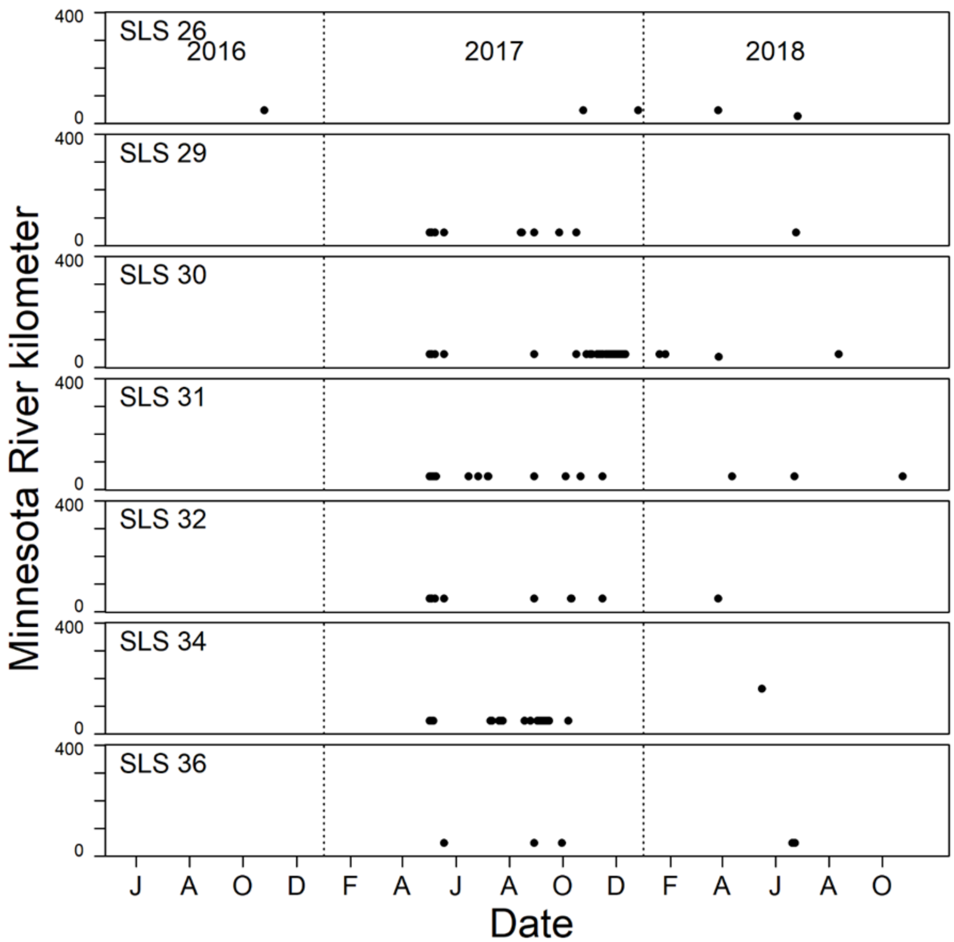

Figure 10. Detection location and date for seven Shovelnose Sturgeon implanted with acoustic transmitters at the Chaska study reach of the Minnesota River, Minnesota. Location is river kilometers from the mouth of the Minnesota River.

learned that a majority of Shovelnose Sturgeon occupy rather small home ranges, often remaining within a very small reach of river for extended durations. Yet, some Shovelnose Sturgeon exhibited migratory behavior that is common of Sturgeon spp., including upstream movements > 100 km likely associated with spawning. Future investigations should focus on understanding spawning habitats and recruitment success within the Minnesota River system.

This study also provided an opportunity to evaluate Shovelnose Sturgeon sampling methods that will inform future monitoring efforts. Contrary to other studies that report greater adult Shovelnose Sturgeon catch rates with gill nets (e.g., Phelps et al. 2009) or boat electrofishing (e.g., Kennedy et al. 2007; Nepal et al. 2015), we considered fall trotline assessments conducted after water temperatures fell below 10 °C most effective for capturing adult Shovelnose Sturgeon from the Minnesota River. Phelps et al. (2009) reported greater mean catch rates with 5.08-cm bar mesh gill nets set in the middle Mississippi River (3.6 per 24-hour set) among five evaluated gear types, but found trotlines often produced the second greatest mean catch rates (0.8 fish per 24-hour set with 20 hooks). During our study, we captured a mean of 1.3 fish per 10-hook trotlines set for approximately 24-h. Trotlines are an ideal sampling gear because they can target a variety of habitat types found in the Minnesota River during various flow conditions. Whereas boat electrofishing is typically most effective for capturing Shovelnose Sturgeon during lower flow conditions over shallow (< 1.5 m) sand and gravel flats, and very ineffective during high flows or in depths > 1.5 m. Trammel nets, gill nets, and benthic trawls can also capture Shovelnose Sturgeon but often snag on debris or become twisted in strong and complex Minnesota River currents making them less efficient and difficult to deploy in many habitat types. We believe trotline assessments were most effective during colder water temperatures because they captured significantly less bycatch compared to trotlines set during warmer periods.

Similar to others, we found all of the gears types we evaluated, including trotlines, were size biased primarily capturing Shovelnose Sturgeon > 570 mm FL and rarely < 500 mm FL (Morrow et al. 1998; Kennedy et al. 2007; Koch et al. 2009; Nepal et al. 2015). Morrow et al. (1998) primarily captured Shovelnose Sturgeon with trotlines from the lower Mississippi River and concluded Shovelnose Sturgeon are fully vulnerable to capture at ≥ 625 mm FL. In the middle and lower Mississippi River, Doyle et al. (2008), Phelps et al. (2009), and Tripp et al. (2009) showed success capturing < 200 mm FL Shovelnose Sturgeon with benthic trawls (described by Tripp et al. 2009 and Herzog et al. 2005). During our study, we only captured 26 Shovelnose Sturgeon with benthic trawls and most were > 500 mm FL, but one was 282 mm FL which was the only fish < 400 mm FL that we captured. We suspect that refining benthic trawl methods and targeting habitats most likely utilized by juvenile Shovelnose Sturgeon (e.g., 2–5 m depths around islands; Phelps et al. 2010) may result in greater catch rates of < 500 mm fish. Thus, we recommend using fall trotlines for future evaluation of adult Shovelnose Sturgeon relative abundance and size structure, but recognizing that these assessments are biased for larger fish. Other methods should be developed for sampling smaller Shovelnose Sturgeon and monitoring recruitment success.

Population dynamics of Minnesota River Shovelnose Sturgeon are relatively similar to those reported from other large rivers across their distribution and particularly the upper Mississippi River (e.g., Koch et al. 2009). In general, most studies report that Shovelnose Sturgeon grow relatively fast for several years (e.g., 5–8), followed by a dramatic decrease in growth rate, presumably after sexual maturity (Quist et al. 2002; Hamel et al. 2015). For some populations, few Shovelnose Sturgeon reach > 600 mm FL (Quist et al. 2002; Hamel et al. 2015). We estimated a similar growth pattern of rapid growth up to 600 mm FL around age-8, followed by slow growth with relatively few Shovelnose Sturgeon exceeding 700 mm FL and a maximum age of 15. Quist et al. (2002) and Koch et al. (2009) reported comparable growth curves similarly derived from pectoral fin ray age estimates for upper Missouri River and upper Mississippi River populations, respectively. Quist et al. (2002) reported much slower growth rates and smaller maximum lengths for Shovelnose Sturgeon populations in the hydrologically altered middle Missouri and channelized lower Missouri River, whereas, Kennedy et al. (2007) found Shovelnose Sturgeon lived longer (up to 30 years) and reached greater lengths in the largely unaltered free-flowing Wabash River compared to most other populations. Using mark-recapture data as a more robust and accurate method for estimating growth rates, Hamel et al. (2015) reported generally slower growth for many Missouri River and

Mississippi River basin Shovelnose Sturgeon populations compared to previous estimates derived from counting annuli on calcified structures. Hamel et al. (2015) also suggested that highly exploited populations exhibited reduced longevity and smaller asymptotic lengths. Fast growth of Minnesota River Shovelnose Sturgeon during early life may indicate minimal density-dependent effects and an abundance of quality habitat and food resources.

For this study, we estimated age at capture and subsequently growth, age structure, and annual mortality of adult Shovelnose Sturgeon by counting annuli on sectioned pectoral fin rays. Pectoral fin ray sections are the most common structure used for estimating *Scaphirhynchus* spp. ages, and similar to the 87% agreement of age estimates within 1-year between readers during this study, Koch et al. (2008) and Nepal et al. (2015) respectively reported 88% and 94% agreement within 1-year among readers. However, several recent studies identify issues with these methods and urge caution when interpreting age data estimated from *Scaphirhynchus* spp. pectoral fin ray sections (Hurley et al. 2004; Whiteman et al. 2004; Rugg et al. 2014). Of significant concern, Rugg et al. (2014) demonstrated poor relationships between annuli formation and age of Shovelnose Sturgeon in the lower Platte River, Nebraska. We recommend continued monitoring of Shovelnose Sturgeon age structure and annual mortality by estimating ages from sectioned pectoral fin rays, but interpreting the results with extreme caution and utilizing mark-recapture data to validate estimated growth curves.

Although relatively low compared to mortality rates reported for many other freshwater fish populations, an estimated adult Shovelnose Sturgeon annual mortality rate of 0.33 is on the higher end of annual mortality rates reported for Shovelnose Sturgeon populations in other rivers. Even the most heavily exploited upper and middle Mississippi River Shovelnose Sturgeon populations have reported annual mortality rates varying 0.32–0.45 (e.g., Koch et al. 2009; Tripp et al. 2009). Whereas unexploited to lightly exploited populations generally have estimated annual mortality rates of < 0.10 to 0.27 (e.g., Quist et al. 2002; Koch et al. 2009). However, in the lower Platte River, where commercial harvest is illegal, Anderson (2010) estimated an annual mortality rate of 0.44. Despite slightly greater than expected estimated annual mortality for an unexploited population, Shovelnose Sturgeon are abundant and fast growing in the Minnesota River. Mean fall trotline catch rates (0.13/hook) during this study are similar or greater than mean trotline catch rates reported from the lower Mississippi River (0.116/hook; Morrow et al. 1998), middle Mississippi River (0.04/hook; Phelps et al. 2009), and Platte River (0.07/hook during high water; Hammen 2016); and we conservatively estimated an adult density of 96 ≥ 560 mm FL fish per km. However, other studies have reported greater densities of > 200 fish/km (e.g., Hammen et al. 2016; Hintz et al. 2016) and up to 2,500 fish/km in the un-channelized Missouri River (Keenlyne 1998).

Sturgeons are renowned for their migratory behavior (Pikitch et al. 2005; Tripp et al. 2019) as demonstrated through mark-recapture and telemetry studies (e.g., Rusak and Mosindy 1997; Welch et al. 2006). However, relatively few published studies have evaluated movement patterns and migratory behaviors of Shovelnose Sturgeon. For this study, we found a majority (23 of 30) of Shovelnose Sturgeon exhibited small home ranges confined to less than 20-km reaches of river during a two-year period. In the lower Platte River, Hammen (2016) also observed generally small home ranges exhibited by Shovelnose Sturgeon with roughly half of over 200 fish recaptured within 5 km of their initial capture location. As the most extreme example, Hammen (2016) reported that five fish at large for an average of 2,580 days were recaptured an average of 4.8 km from their initial capture location. Yet, some fish were recaptured > 50 km away and exhibited movement between the Platte River and Missouri River. Nepal et al. (2015) also recaptured a vast majority (90%) of marked Shovelnose Sturgeon within 4-km of their initial capture location, but the greatest distance between capture locations was 459 km. During our study, only seven fish exhibited movements > 20 km, with four fish exhibiting the long distance (i.e., > 100 km) migrations that are often reported of sturgeons in other rivers (e.g., Rusak and Mosindy 1997; Welch et al. 2006; Tripp et al. 2019). Tripp et al. (2019) reported linear home ranges varying 17–333 km for 217 Shovelnose Sturgeon implanted with acoustic transmitters in the upper Mississippi River and mean absolute movement (i.e., sum of all detected upstream and downstream movements) of 499 km; commonly including movements between rivers. Despite a large mean linear home range of 226 km, Tripp et al. (2019) classified approximately 50% of Shovelnose Sturgeon as resident fish occupying a relatively small area compared to the population range. Tripp et al. (2019) may have observed greater movement and home ranges of Shovelnose Sturgeon since they tracked movements for up to 10 years compared to two years during our study. Large migratory movements are likely associated with spawning, and since Shovelnose Sturgeon may only spawn once every 2–3 years, we may not have captured spawning migrations for a majority of the fish we implanted with acoustic transmitters.

Tripp et al. (2014) further highlighted the mobile behavior of Shovelnose Sturgeon and importance of connectivity by documenting 126 downstream passages and 156 upstream passages through Mississippi River lock and dams by 311 tagged Shovelnose Sturgeon. However, a vast majority of passages occurred during open river conditions (i.e., when gate were completely lifted out of the water) which occur infrequently at some lock and dams, and passages through lock chambers were rare. Shovelnose Sturgeon are uncommon downstream of the Minnesota River in Mississippi River Pool 2 (J. Stiras, Minnesota Department of Natural Resources, personal communication) and zero fish tagged during this study emigrated downstream. Thus, we are unsure how much the Minnesota River population mixes with other populations nor how much Mississippi River lock and dams impact Shovelnose Sturgeon in the Minnesota River. Yet, based on migratory behavior of some Shovelnose Sturgeon in the Minnesota River and the absence of Shovelnose Sturgeon upstream of Granite Falls Dam, it is clear that the species requires connectivity of free-flowing rivers, and is negatively affected by habitat fragmentation (e.g., dams).

The general belief is Shovelnose Sturgeon primarily spawn over riffle habitats with coarse substrates, such as gravel and rock, when spring water temperatures reach 17–21 ℃ (Keenlyne 1997). Yet, we are unaware of any studies that have specifically quantified or identified spawning habitats and substrates. In a field experiment, Goodman et al. (2013) found Shovelnose Sturgeon spawned in a tributary of the Missouri River during increased spring flows when water temperatures were 11–23 ℃, but only when spring peaks in discharge exceeded a threshold of 28 m^3/s. Despite capturing few young (< age 5) Shovelnose Sturgeon during this study, we captured fish of all ages from 2 thru 15 indicating that successful spawning is likely occurring annually within the Minnesota River system. However, we have zero evidence of where Shovelnose Sturgeon are successfully spawning within the Minnesota River or its tributaries, and if the amount or quality of spawning habitat is a limiting factor. Thus, future investigations should focus on identifying spawning habitats and recruitment success within the Minnesota River system to ensure sustainability of the population. Phelps et al. (2012) used relatively novel techniques to identify natal origins of age-0 sturgeons by comparing Sr:Ca signatures of water samples and pectoral fin rays. As a first step, we hope to determine the potential for differentiating reaches of the Minnesota River and its tributaries with similarly unique water microchemistry signatures. If viable, future studies will use water microchemistry signatures to identify source locations of Shovelnose Sturgeon recruitment in the Minnesota River system.

The Minnesota River likely has the greatest Shovelnose Sturgeon population density of any system in Minnesota, which is important for the species conservation and provides a unique opportunity for anglers to catch and release this prehistoric fish. This study indicates the current population is likely robust to incidental catch and release mortality with a moderate adult mortality rate and a conservatively estimated population density of > 90 adult fish/rkm. The next steps for ensuring sustainability of the Minnesota River Shovelnose Sturgeon population include 1) identifying sources of recruitment (e.g., reaches, tributaries), critical spawning habitats, and connectivity with other populations, and 2) continued monitoring of population dynamics. Importantly, results from this study will allow for the detection of shifts in abundance and population dynamics associated with future perturbations (e.g., altered hydrology, climate change) or management actions, and inform management strategies to ensure sustainability of the population.

Supplemental Materials

Table S1. Complete length (fork length), weight, capture date, capture location, capture method, and tag information for all Shovelnose Sturgeon captured from the Minnesota River, Minnesota during this study (2016–2018). Attached file.

Table S2. Location and dates of active recording for all acoustic receivers deployed in the Minnesota River by Minnesota Department of Natural Resources Staff.

Table S3. Date and location summary of all acoustic tagged Minnesota River Shovelnose Sturgeon detections on active or passive acoustic receivers in the Minnesota River during this study (2016–2019). Attached file.

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Table S2.

Receiver	River kilometer	Deployed	Last upload	Active
127612	27	Fall 2015	9/5/2018	Yes
127611	48	Fall 2015	9/5/2018	Yes
127616	107	Fall 2015	12/1/2017	Yes
129943	141	Summer 2017	8/7/2018	Yes
127613	164	Fall 2015	8/17/2018	Yes
129941	185	Summer 2017	11/6/2018	Yes
127615	232	Fall 2015	8/17/2018	Yes
127614	346	Fall 2015	11/6/2018	Yes
129942	371	Fall 2017	11/6/2018	Yes