Paddlefish inhabiting the Minnesota River

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Executive Summary

Project activity 4B: Evaluate population dynamics, movement, and habitat use of Paddlefish in the Minnesota River.

Project Objectives

- Evaluate presence and abundance of Paddlefish within the Minnesota River.
- Quantify movement patterns and identify habitat use of Minnesota River Paddlefish.

Significant Outcomes

- A more significant number of Paddlefish inhabit the Minnesota River than previously perceived and ensuring the persistence and health of this population warrants continued monitoring efforts.
    - DNR staff captured 85 Paddlefish from the Minnesota River compared to one prior to this study.
    - Captured Paddlefish varied 669–1,098 mm in length (eye–fork) indicating presence of multiple year-classes.
- We identified at least four locations where Paddlefish tend to congregate, and suspect many other similar locations exist throughout the 395 rkm free-flowing reach of Minnesota River.
    - Paddlefish congregations are often associated with large slack-water areas.
    - Some congregation areas may be seasonally important because of zooplankton inputs from nearby backwater habitats.
- At least some Paddlefish inhabit the Minnesota River for long periods of time (> 1 year), providing evidence of a persistent Minnesota River population.
- Paddlefish frequently move among the Minnesota River, Mississippi River, and St. Croix River and some fish pass upstream and downstream through lock and dams.
- We summarized movement behaviors of Paddlefish into three categories.
    - One group of **resident** fish that exhibit little movement and occupy a small home range (≤ 50 rkm).
    - Another group of **migratory** Paddlefish that exhibited either one large migration or patterned seasonal migratory movements.
    - The third group of **nomadic** Paddlefish exhibit frequent and seemingly random upstream and downstream movements.
- Some Minnesota River Paddlefish exhibited one-directional migrations > 230 rkm and the most mobile Paddlefish traveled > 1,200 rkm cumulatively during a 2-year period.
- We determined that drifted or stationary hobbled gill nets with 12.7 cm bar mesh are effective for capturing Paddlefish in the Minnesota River but may be size selective for 800–1,000 mm eye–fork length fish.

Remaining Questions

- How large is the Minnesota River Paddlefish population?
    - Did this study reveal the "tip of the iceberg" or stumble upon the few habitats utilized by Paddlefish in the Minnesota River?
- Do Paddlefish successfully spawn within the Minnesota River?
    - If yes, where, and how often are they successful?
    - If no, why, and where are the nearest and most critical spawning habitats?
- What are growth rates, mortality rates, age at maturity, and spawning frequency of Minnesota River Paddlefish?
- How important are backwater habitats for Paddlefish in the Minnesota River?
- What habitats within the Minnesota River are critical for Paddlefish?
    - Do they warrant special protection?
- What are the major threats or factors limiting Paddlefish in the Minnesota River?
- How important is movement among connected rivers for the persistence and health of Paddlefish populations in Minnesota?

Abstract

Minnesota is at the northern periphery of the Paddlefish's *Polyodon spathula* native range, and similar to other regions, habitat alterations (e.g., dams) and commercial fishing likely led to population declines during the early 1900s. By the late 1900's many Paddlefish populations were increasing, but confirmed records from upstream of Mississippi River Navigation Pool 4 remained rare. In fact, prior to 2016, Minnesota Department of Natural Resources fisheries assessments only captured one Paddlefish from the Minnesota River. With a seemingly increasing number of recreational angler and commercial fisher reports of Paddlefish catches during recent years, the goal of this study was to increase understanding of the presence and habitat use of Paddlefish in the Minnesota River. With experimental targeted sampling efforts we captured 85 Paddlefish varying 669–1,098 mm eye-fork length from the Minnesota River during August 2016–October 2018. We captured all Paddlefish from four small reaches of the Minnesota River, two of which appear to have large congregations of Paddlefish nearly year-round. We surgically implanted acoustic transmitters into 14 Paddlefish that exhibited a mean linear home range of 124 river km, but varying widely 0–398 river km. The greatest cumulative movement detected for an individual fish was 1,281 river km during a 2-year period. Four fish tagged during this study emigrated from the Minnesota River while six Paddlefish initially captured in the St. Croix River or Mississippi River immigrated into the Minnesota River. Results from this study provide encouraging evidence of a more abundant population of Paddlefish inhabiting the Minnesota River than previously perceived, and that Paddlefish frequently move between the Minnesota, Mississippi, and St. Croix Rivers. Identifying and protecting important spawning habitats within the upper Mississippi River basin is an important next step for ensuring sustainability of the population.

Introduction

Paddlefish *Polyodon spathula* were historically abundant throughout the Mississippi River drainage and several smaller gulf slope drainages in North America (Gengerke 1986). During the late 1800's and early 1900's several factors led to declines in Paddlefish abundance throughout their native range. Industrialization and manipulation of waterways for navigation, hydropower, and flood control destroyed critical habitats (e.g., spawning habitats), made waters uninhabitable for aquatic life, and fragmented populations (Carlson and Bonislawsky 1981; Sparrowe 1986; Jennings and Zigler 2009). By 1940 a series of locks and dams were constructed along the Upper Mississippi River for navigation, and are linked to the decline or localized extirpation of many aquatic species (e.g., American Eel *Anguilla rostrata*, Blue Sucker *Cycleptus elongates*, Ebonyshell mussel *Fusconaia ebena*, Skipjack Herring *Alosa chrysochloris*) including Paddlefish (Coker 1929; Kelner and Sietman 2000). As sturgeon (*Acipenseridae* spp.) stocks declined during the late 1800s, commercial fishing for Paddlefish significantly increased since their roe was a suitable substitute for making caviar (Stockard 1907; Carlson and Bonislawsky 1981). Paddlefish, like most species of order Acipenseriformes, are particularly susceptible to overharvest since they sexually mature late in life (e.g., age 10 for females), have specific spawning habitat requirements, and females may spawn as infrequently as once every 4–5 years (Russel 1986; Pikitch et al. 2005; Scholten 2009). Paddlefish are also highly vulnerable to commercial fishing gears (Scholten 2009), and in some regions, commercial fishing was so intensive that subpopulations were nearly extirpated (Stockard 1907; Pasch and Alexander 1986). Paddlefish abundances declined throughout the early- and mid-1900's, and the species distribution shrunk (Carlson and Bonislawsky 1981) as a result of compounding stressors. Fortunately, increased regulation, habitat restoration, and stocking efforts led to range-wide improvements in many Paddlefish stocks by the late 1990s. Yet, overfishing of some Paddlefish stocks is still suspected, inciting the need for increased monitoring and regulation (Scholten and Bettoli 2005; Hupfeld et al. 2016).

Minnesota is at the northern periphery of the Paddlefish's native range where they were historically abundant in the Mississippi River and larger tributaries including the Minnesota River and St. Croix River. Similar to other regions, habitat alterations, habitat fragmentation, urban and industrial waste, and commercial fishing likely led to significant declines of Paddlefish within Minnesota waters during the early 1900s. Records of Paddlefish in Minnesota were rare during the mid-1900s, but by the late 1900s incidental catches by commercial fishers and recreational anglers became more frequent. By the 1990s fisheries biologists from Wisconsin and Minnesota were capturing Paddlefish with regularity from the Mississippi River and some tributaries and began studying population dynamics and habitat use (e.g., Lyons 1993; Zigler et al. 1999, 2003; Runstrom et al. 2001). However, records from the Minnesota River, St. Croix River, and upper Navigation Pools (i.e., 1–3) of the Mississippi River remained rare through the turn of the century. Although biologists believe Paddlefish populations are stable or increasing within Minnesota waters (Bettoli et al. 2009), Paddlefish remain listed as a state threatened species since 1996. Yet, recreational Paddlefish fisheries exist in the Mississippi River as nearby as below Lock and Dam 9 along the Iowa and Wisconsin border (315 river kilometers [rkm] downstream from the Minnesota River) and commercial fisheries exist downstream of Lock and Dam 19 along the Iowa and Illinois border (770 rkm downstream of the Minnesota River).

The oldest photograph evidence of Paddlefish inhabiting the Minnesota River is from 1957 and shows commercial fishermen holding two Paddlefish caught below the Minnesota Falls Dam (Figure 1). There is a large gap in confirmed Minnesota River Paddlefish records from 1957–1993 supporting the assumption that few Paddlefish inhabited the river. Then, during 2004, Minnesota Department of Natural Resources (DNR) staff captured their first and only Paddlefish from the Minnesota River (prior to this study). Increasing occurrences of incidental Paddlefish catches by commercial fishers and recreational anglers during the early 2000s provided evidence of potentially greater numbers of Paddlefish inhabiting the Minnesota River than believed. Yet, biologists were unsure if Paddlefish captured in the

Figure 1. Oldest photograph evidence of Paddlefish in the Minnesota River. The photograph shows commercial fishermen holding Paddlefish captured in seine hauls below Minnesota Falls in fall 1957.

Minnesota River indicated a self-sustaining population within the Minnesota River or infrequent forays into the Minnesota River from known downstream populations (e.g., Mississippi River Navigation Pool 4). To the best of our knowledge, the nearest confirmed Paddlefish spawning occurs greater than 125 rkm downstream of the Minnesota River in the Chippewa River, a Wisconsin tributary of the Mississippi River (Zigler et al. 2003).

Large-scale movements of Paddlefish are common since they are a migratory potadromous species that often travels great distances between spawning, feeding, and over-wintering habitats (Russell 1986; Zigler et al. 2003). This knowledge of Paddlefish life history leads to uncertainty whether Paddlefish captured in the Minnesota River are simply migrating from source populations for one of these reasons, self-sustaining within the river, or inhabiting the river for significant amounts of time or biologically important reasons. Although Paddlefish passage through Mississippi River Lock and Dams has been documented, there is uncertainty about how Paddlefish within the Upper Mississippi River are impacted by varying conditions among each Navigation Lock and Dam; several of which rarely provide open-water conditions (e.g., Navigation Lock and Dam 2; Southall and Hubert 1984; Zigler et al. 2004; Tripp et al. 2014).

During 2016–2019, funding from the Environment and Natural Resources Trust Fund (ENRTF; lccmr.org) provided the DNR with the capacity to address questions regarding Paddlefish in the Minnesota River. With the seemingly increasing number of angler and commercial fisher reports of Paddlefish catches during recent years, the goal of this study was to increase understanding of the presence and habitat use of Paddlefish in the Minnesota River through experimental targeted sampling. Additionally, we sought to evaluate movement patterns and habitat use with acoustic telemetry, optimistically assuming targeted sampling efforts would be successful at capturing Paddlefish.

Study Site

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 2). Although Paddlefish may have 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 eighth-order warm water river flowing through the agriculturally dominated prairie region of southern Minnesota. The Minnesota River is generally characterized as 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 directed targeted Paddlefish sampling effort towards areas of the Minnesota River where DNR staff, recreational anglers, or commercial fishers reported capturing or observing Paddlefish. Specific sites included a large eddy and surrounding habitat near the city of St. Peter (rkm 140–142; hereafter referred to as St. Peter); a reach of river near the city of Mankato that contains wing dams and a warm water discharge (rkm 160.5–161.5; hereafter referred to as Mankato); two oxbow lakes near the city of New Ulm (rkm 217–222; hereafter referred to

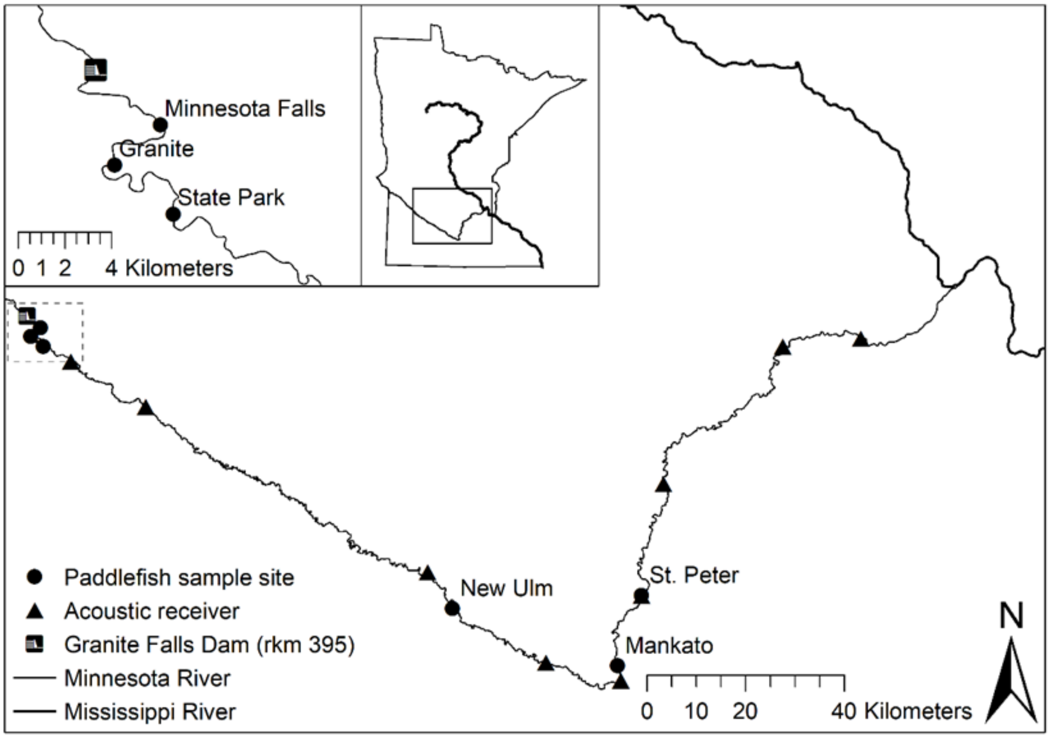

Figure 2. Location of six sites where targeted Paddlefish surveys were conducted along with the location of nine stationary acoustic receivers within the 395-km free-flowing reach of the Minnesota River downstream of Granite Falls Dam.

as New Ulm); a reach of river near Upper Sioux Agency State Park with a large backwater outflow channel (rkm 378–381; hereafter referred to as State Park); a reach of river approximately 8 rkm downstream of Granite Falls Dam (rkm 385.5–387.5; hereafter referred to as Granite); and downstream of Minnesota Falls (rkm 389.5–390.5; Figure 2).

Methods

Paddlefish sampling

We primarily conducted targeted Paddlefish sampling with stationary or drifted monofilament or multifilament gill nets, although some sampling occurred with boat electrofishing or hoop nets. Gill nets varied in length (30.5–91.4 m), depth (2.4–7.3 m) and bar mesh (10.2 cm, 12.7 cm, and 15.2 cm). However, a majority of Paddlefish sampling was conducted with 30.5 m long by 3.0 m deep floating gill nets constructed with 12.7 cm monofilament bar mesh that were generally hobbled (i.e., vertical ties between the float and lead line preventing the mesh from stretching taut) to approximately 2.0 m deep. Although Paddlefish sampling was conducted at all six study sites, greater effort occurred at sites where prior sampling was most successful.

We weighed, measured (eye–fork length), and examined all captured Paddlefish for external or internal tags. We tagged Paddlefish with a uniquely numbered size 16 monel jaw band (National Band and Tag Company, Newport, Kentucky, USA) on the lower left jaw and injected a 11.4 x 2.18 mm FDX-B polymer passive integrated transponder (PIT) tag (Hallprint, Hindmarsh Valley, Australia) into the left dorsal musculature near the dorsal fin. Fish selected for telemetry were not given a jaw band or PIT tag. We

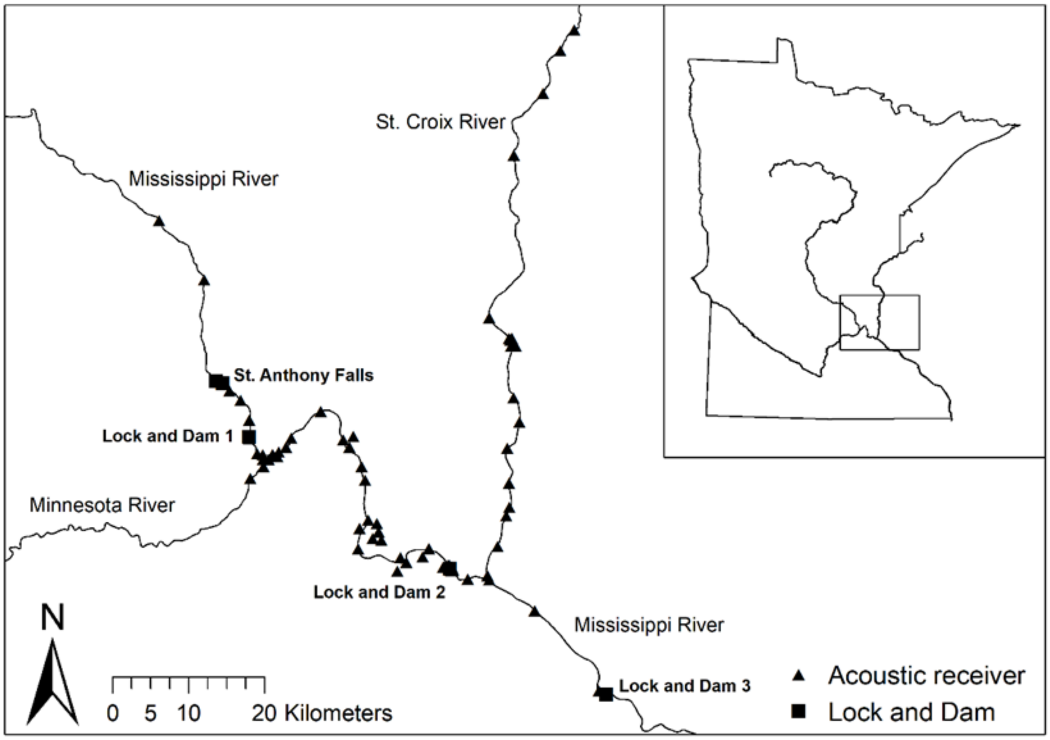

Figure 3. Array of Vemco acoustic receivers maintained by the Minnesota Department of Natural Resources within displayed reaches of the lower Minnesota River, Mississippi River, St. Croix River, and connected backwaters.

released all fish near (within 0.5 km) their capture location.

Telemetry

Captured Paddlefish that we selected for the telemetry component of this study had a 69-kHz V9-2x (4 tags), V16-4x (5 tags), or V16-6x (5 tags) acoustic transmitter tags (Vemco, Bedford, Nova Scotia, Canada) surgically implanted into their peritoneal cavity. Vemco transmitters were programmed to emit a signal every 80–160 seconds. Battery life is approximately 802 days for V9-2x tags, 1,825 days for V16-4x tags, and 3,650 days for the V16-6x tags. Transmitters were implanted through a 2.5–5.0 cm incision immediately posterior and dorsal of the left pelvic fin. We closed incisions with three to five interrupted sutures and held fish for a short recovery period prior to release.

Movement and habitat use of Paddlefish implanted with acoustic transmitters was determined 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's 27, 48, 107, 141, 164, 185, 232, 346, and 371 (Figure 2). Six receivers were installed during fall of 2015 while the remaining three at rkm 141, 185, and 371 were installed during July–September 2017. Additionally, the DNR and various other agencies maintain an array of compatible Vemco acoustic receivers near the mouth of the Minnesota River, along the Mississippi River (including some major tributaries), and within the St. Croix River (Figure 3). We sporadically conducted active tracking surveys at Paddlefish study sites using a VR100 receiver and omni-directional hydrophone (Vemco). We drifted the boat with the speed of the current along the length

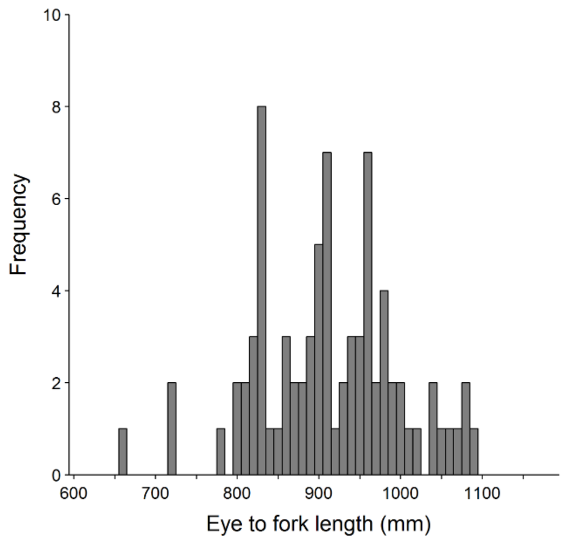

Figure 4. Length (eye–fork) frequency of Paddlefish captured from the Minnesota River during 2016–2018.

of the study reach with the hydrophone deployed in the water. If we heard transmitter signals that were not completely detected by the receiver, we held the boat stationary (with either the motor or an anchor) or re-drifted through the area until the transmitter code was detected. 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 Paddlefish into three general categories: 1) resident fish with home ranges ≤ 50 rkm that exhibited little movement, 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.

Results

Paddlefish sampling

We captured 85 Paddlefish from the Minnesota River with targeted sampling during August 2016–October 2018 that varied 669–1,098 mm eye–fork length and 4,700–20,500 g (Figure 4). We captured a majority of Paddlefish with gill nets (74), five with boat electrofishing, and one in a hoop net. Fifty-one captures occurred at St. Peter, 18 at Granite, 10 at State Park, 6 at Mankato, and zero at Minnesota Falls and New Ulm. Five captured Paddlefish were previously tagged (three tagged during this study and one tagged in Mississippi River Navigation Pool 2) including one fish that was captured three times at the Granite site during May 5, 2018–October 3, 2018. Although we captured zero Paddlefish at New Ulm, we believe Side Imaging and Down Imaging sonar (Humminbird 899ci HD, Johnson Outdoors Inc., Wisconsin, USA) indicated the likely presence of Paddlefish during sampling events. Similarly, we believe sonar indicated the likely presence of Paddlefish (sometimes what appeared to be congregation of greater

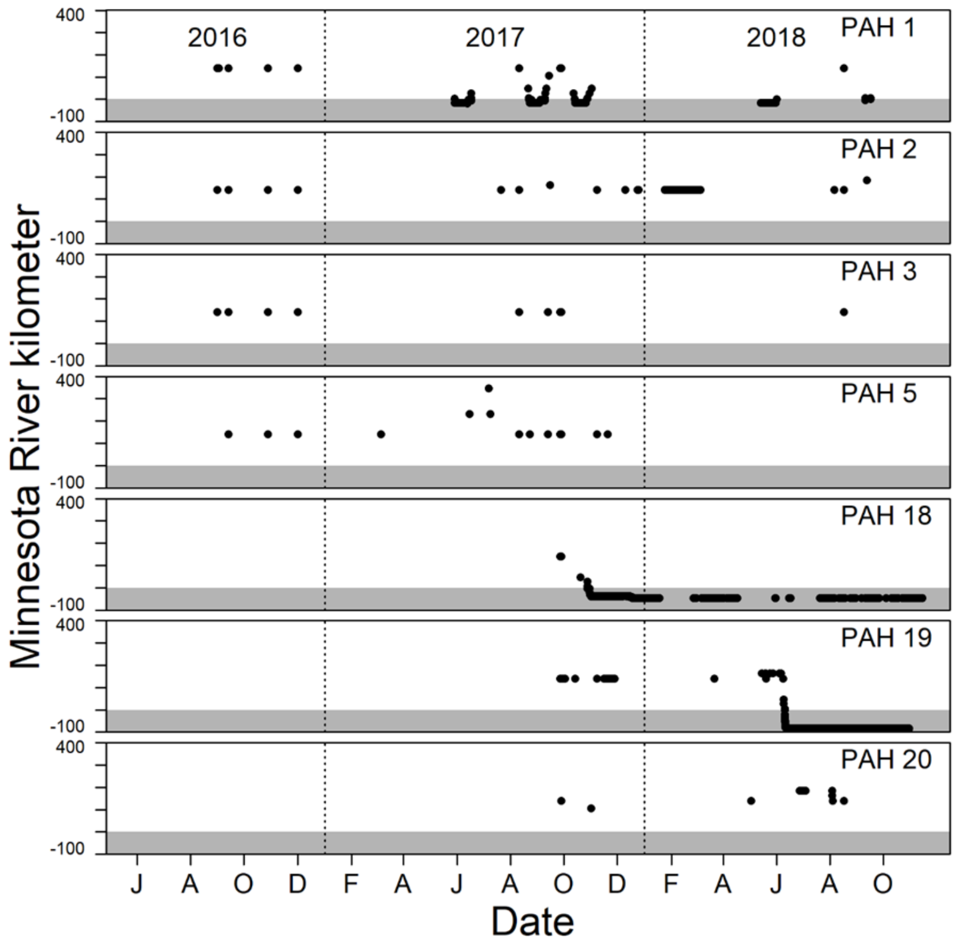

Figure 5. Detection location and date for seven Paddlefish implanted with acoustic transmitters at the St. Peter site of the Minnesota River. Location is river kilometers from the mouth of the Minnesota River with negative values (shaded region) representing emigration distances away from the mouth. Upstream movement of Paddlefish in the Minnesota River is restricted to the lower 395 river kilometers downstream of Granite Falls Dam.

than 20 fish) at St. Peter, Mankato, and Granite; even when we captured zero with sampling gears.

Initially, we planned targeted Paddlefish surveys for New Ulm and Mankato based on recent angler and commercial fisher reports. However, serendipitously during August 2016 (one month after special funding for the project began), DNR staff unexpectedly encountered a large school of Paddlefish at the St. Peter site while collecting fish for display at a local county fair (B. Eder and S. Wigen, Minnesota Department of Natural Resources, personal communication). Therefore, we conducted all targeted sampling efforts at the St. Peter site during 2016, capturing five Paddlefish, four of which we surgically implanted with a V9 acoustic transmitter. We captured an additional 46 Paddlefish at this site during 2017.

Coincidentally, we visually observed another concentration of Paddlefish during other fieldwork at the State Park site during spring of 2017. During subsequent sampling trips we captured 10 Paddlefish at this site. We discovered a third concentration of Paddlefish at the Granite site during spring 2018 when we detected four of the Paddlefish initially tagged at the State Park site inhabiting

Table 1. Summary of telemetry detections of 14 Paddlefish implanted with acoustic transmitters at the St. Peter and Granite sites in the Minnesota River during August 2016–January 2019. Duration is time (months) between the first and last detection, linear home range is the distance (river kilometers) between the furthest upstream and furthest downstream detections, and cumulative movement is the sum of distances between detections. Fish with linear home ranges ≤ 50 rkm are classified as resident while fish with linear home ranges > 50 rkm are classified as nomadic if they make frequent upstream and downstream movements or migratory if they made a single one-directional migration or patterned seasonal migrations.

Fish	Duration (months)	Dates detected	Linear home range (rkm)	Cumulative movement (rkm)	Cumulative movement per month (rkm)	Classification
			St. Peter Site			
PAH 1	24.5	83	160	1281	52.3	Nomadic
PAH 2	24.3	56	44	90	3.7	Resident
PAH 3	23.5	9	0	0	0.0	NA
PAH 5	14.2	14	205	410	28.9	Migratory
PAH 18*	13.5	197	188	290	21.5	Migratory
PAH 19	13.0	171	253	384	29.5	Migratory
PAH 20	10.6	12	78	198	18.7	Nomadic
			Granite Site			
PAH 6	16.1	13	201	207	12.9	Migratory
PAH 7	19.2	15	40	73	3.8	Resident
PAH 8	10.2	6	398	415	40.7	Migratory
PAH 9	19.2	15	7	21	1.1	Resident
PAH 10	19.2	24	154	616	32.1	Migratory
PAH 11*	19.2	16	7	7	0.4	Resident
PAH 12	19.2	16	7	21	1.1	Resident
			Means			
	17.6	46	124	287	17.6	

* Suspected shed tag or death

one small reach of river. Subsequently we captured 15 different Paddlefish from this site.

Telemetry

During this project we implanted 14 Paddlefish with acoustic transmitters; 7 at the St. Peter site and 7 at the State Park site. We implanted V9 transmitters into four Paddlefish with battery lives expected to expire during the study period (i.e., expire November 2018). We implanted the other 10 Paddlefish with V16 transmitters that have battery life expectancies extending beyond the duration of this particular study (e.g., 5–10 years). Additionally, passive and active acoustic receivers detected six Paddlefish in the Minnesota River that were initially implanted with transmitters in the Mississippi River or St. Croix River (J. Stiras and J. Hoxmeier, DNR, personal communication). We uploaded telemetry data from all Minnesota River stationary receivers as recently as August–November 2018, except we most recently uploaded the receiver at rkm 107 during December 2017. We conducted the most recent active tracking survey on 14 January 2019 at the Granite Site.

Based on detected movements, at least six of seven Paddlefish implanted with transmitters at the St. Peter site survived and retained their transmitter for the duration of this study (Figure 5). One Paddlefish (PAH 18) emigrated to the Mississippi River during

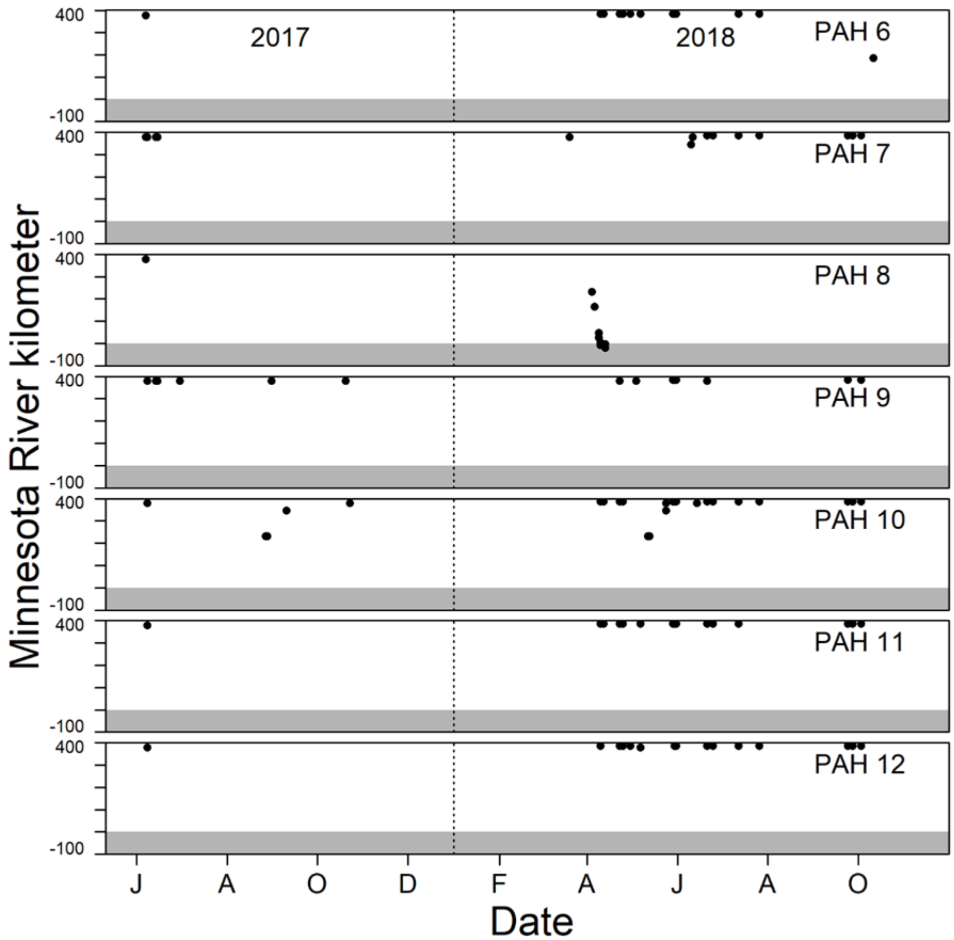

Figure 6. Detection location and date for seven Paddlefish implanted with acoustic transmitters at the State Park site of the Minnesota River. Location is river kilometers from the mouth of the Minnesota River with negative values (shaded region) representing emigration distances away from the mouth. Upstream movement of Paddlefish in the Minnesota River is restricted to the lower 395 river kilometers downstream of Granite Falls Dam.

October 2017 (less than 1 month after capture) and remained in the tailwater habitat of Mississippi River Navigation Pool 3 for greater than one year indicating it may have shed its tag or died at this location. Six of the fish exhibited preference for the St. Peter site by remaining within the site for long periods or by frequently returning to the site. Three of the seven fish (including PAH 18) made significant downstream movements (> 140 rkm) emigrating out of the Minnesota River during this study. For instance, PAH 1 emigrated out of the Minnesota River and returned to the Minnesota River four times during 2017 and 2018, exhibiting > 1,200 rkm of cumulative upstream and downstream movements (Table 1). Another fish (PAH 19) traveled > 250 rkm downstream to the St. Croix River. Only one Paddlefish (PAH 5) from St. Peter made a significant upstream movement > 200 rkm before returning to the St. Peter site during 2017. None of the Paddlefish tagged at St. Peter were detected within the State Park or Granite sites during this study.

Based on detected movements, at least six of seven Paddlefish implanted with transmitters at the State Park site also survived and retained their transmitter for the duration of this study (Figure 6). One

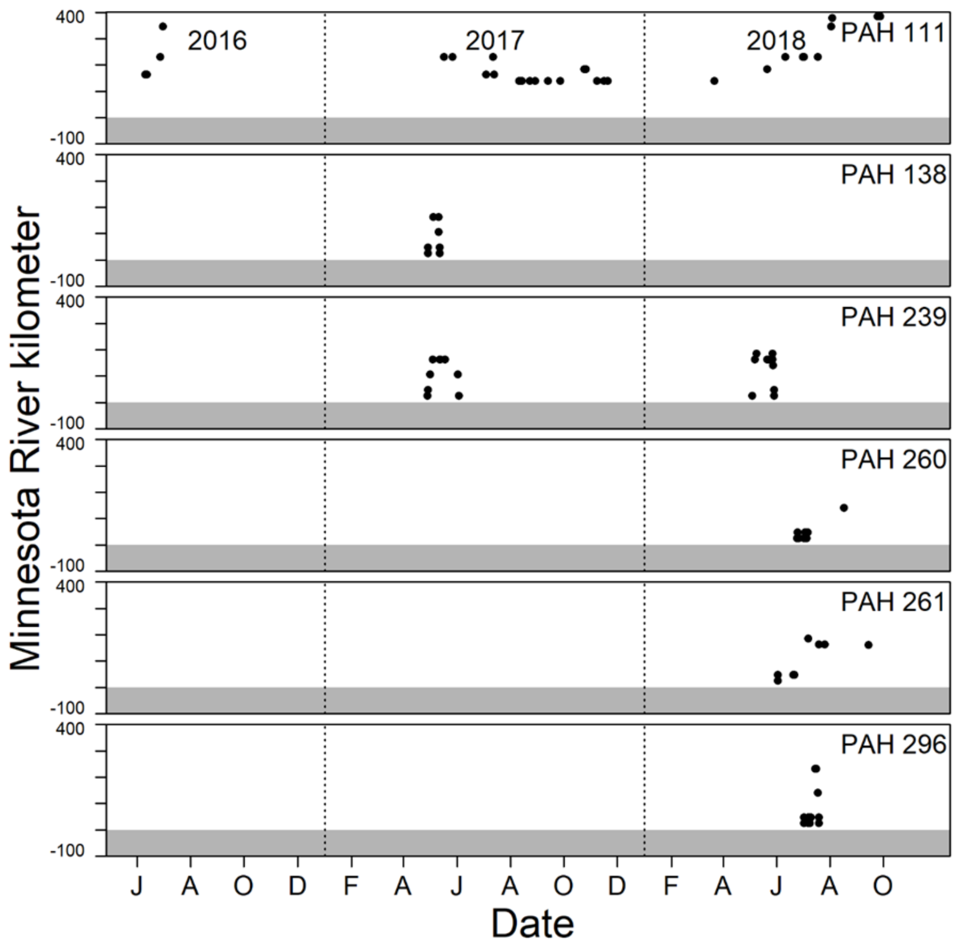

Figure 7. Detection location and date for six Paddlefish implanted with acoustic transmitters in the Mississippi River or St. Croix River detected at least once within the Minnesota River. Location is river kilometers from the mouth of the Minnesota River with negative values (shaded region) representing emigration distances away from the mouth. Upstream movement of Paddlefish in the Minnesota River is restricted to the lower 395 river kilometers downstream of Granite Falls Dam.

Paddlefish (PAH 11) remained within the Granite site since April 2018 indicating it may have shed its tag or died at this site. Except for PAH 8, all Paddlefish from State Park site exhibited preference for the Granite Site by presumably occupying the site for periods of > 100 days. During the study period, four of the fish remained within the upper 50 rkm of the Minnesota River downstream of Granite Falls Dam while another two fish remained within the Minnesota River but exhibited at least one downstream movements of > 100 rkm. Only one fish (PAH 8) from State Park site emigrated out of the Minnesota River, traveling > 300 rkm downstream (and has not been detected since April 2018). Paddlefish 10 exhibited the greatest cumulative movement (> 600 rkm) of fish tagged at the State Park site by making two downstream trips of > 100 rkm followed by upstream return trips to the State Park or Granite sites.

The duration (time between first and last detection) of telemetry detections varied 10.6–24.5 months and the number of dates detected varied 6–197 for the 14 Paddlefish implanted with acoustic transmitters (Table 1). Mean linear home range of all Paddlefish during this study was 124 rkm, but varied widely from 0 rkm to 398 rkm. Although we classified four of seven fish captured at the Granite site as resident fish that exhibited rather small linear home ranges (i.e., ≤ 50 rkm), mean linear home range was similar for fish captured at both St. Peter (133 rkm) and Granite (116 rkm). However, fish captured at the St. Peter site were more mobile with mean cumulative movement of 22 rkm per month compared to 13 rkm per month by fish captured at the Granite site. We classified 5 of 14 fish as residents, 6 as migratory, and 2 as nomadic. We did not classify PAH 3 based on insufficient detections.

During this study, we also detected six Paddlefish in the Minnesota River that were initially implanted with transmitters in the Mississippi River or St. Croix River (J. Stiras, J. Hoxmeier, DNR, personal communication; Figure 7). Five exhibited one or more excursions into Minnesota River, often quickly returning downstream and emigrating. However, we frequently detected PAH 111 (originally implanted with a transmitter in Mississippi River Navigation Pool 2 during April 2016) within the Minnesota River during 2016–2019, including multiple detections at the St. Peter and Granite sites.

Two Paddlefish implanted with acoustic receivers during this study (PAH 18 and PAH 19) passed downstream through Mississippi River Lock and Dam 2 while zero passed upstream. Paddlefish initially tagged in Mississippi River Navigation Pool 3 (PAH 138) and the St. Croix River (PAH 239) that we detected in the Minnesota River must have passed upstream through Lock and Dam 2. Additionally, PAH 296 passed upstream through Lock and Dam 3 and Lock and Dam 2.

Discussion

Outcomes from this project, made possible with funding from the ENRTF, provide encouraging evidence that Paddlefish are more abundant in the Minnesota River than previously perceived. Before this study, evidence of Paddlefish inhabiting the Minnesota River include infrequent reports of incidental catches by anglers and commercial fishers along with one individual captured by DNR staff during 2004. With targeted sampling efforts, we captured 81 different Paddlefish from four study sites that cumulatively represent < 1.0% of the free-flowing reach of the Minnesota River. Data collected during this study are insufficient for estimating population size or other important population dynamics (e.g., growth rate, mortality rate). However, few recaptures, observations of large congregations of Paddlefish within study sites, and the limited spatial extent of sampling effort provides strong evidence that a rather large and significant number of Paddlefish may be inhabiting the Minnesota River. Concurrent sampling efforts in Mississippi River Navigation Pools 2–4 and the St. Croix River also captured many Paddlefish (John Hoxmeier, Joel Stiras, John Waters; DNR; personal communication) indicating an overall healthier population or populations of Paddlefish within Minnesota waters than previously perceived.

Capturing Paddlefish required identifying effective sampling methods and dedicating resources for targeted sampling efforts. During this study we found hobbled 12.7 cm bar mesh gill nets effective for capturing Paddlefish, either drifted or set stationary depending on habitat conditions. However, 12.7 cm bar mesh gill nets appear size selective, primarily capturing 800–1,000 mm eye–fork length Paddlefish. Many other studies report similar success capturing Paddlefish with gill nets (Paukert and Fisher 1999; Budnik et al. 2014; Hupfeld et al. 2016), while few studies report success with other gears such as boat electrofishing (Lein and

DeVries 1997). Lein and DeVries (1997) found that pulsed DC boat electrofishing could be more efficient for capturing Paddlefish than 12.7 cm bar mesh gill nets under certain conditions, but also noted 10% mortality of Paddlefish captured with electrofishing compared to 0% with gill nets. Paukert and Fisher (1999) evaluated hobbled gill nets with 12.7 cm, 15.2 cm, and 20.3 cm bar mesh and showed mean length of captured Paddlefish increased and catch rates decreased with increasing mesh size. Therefore, we recommend future sampling efforts for Paddlefish in the Minnesota River should utilize gill nets with a variety of mesh sizes (e.g., 10.2–20.3 cm bar mesh) to gather a more representative sample of the population.

Similar to observations in other rivers, we observed Paddlefish congregating within very specific habitats that had slow currents or large current eddies downstream of unique features (e.g., wing dams, rock outcroppings, sandbars) within the main channel (Rosen et al. 1982; Moen et al. 1992; Zigler et al. 1999; Zigler et al. 2003). Other studies report Paddlefish commonly inhabiting backwater habitats and oxbow lakes, particularly during summer and fall months (Rosen et al. 1982; Southall and Hubert 1984; Hoxmeier and DeVries 1997). During a large-scale telemetry study, Zigler et al. (2003) found Paddlefish tended to utilize and congregate within very specific habitats and reaches of the Chippewa River, Wisconsin River, and Mississippi River. Although we did not capture Paddlefish in backwaters during this study, commercial fishers typically report incidental Paddlefish catches when seining connected backwaters. We observed congregations of Paddlefish at all four sites where we successfully captured Paddlefish, and Paddlefish appeared to congregate at both the St. Peter and Granite sites nearly year-round. We initially hypothesized that a school of Paddlefish at the Granite site (8 rkm downstream of Granite Falls Dam) was a pre-spawn aggregation similar to those observed in other systems, including Lake Francis Case, South Dakota by Stancill et al. (2002) and in the Lower Mobile River Basin of Alabama by Mettee et al. (2009). This may have been true, but Paddlefish continued occupying the same location throughout the remainder of the year indicating the site provides year-round habitat requirements (e.g., abundant forage, adequate over-wintering conditions) rather than only proximity to a spawning area. We suspect there are many other areas where Paddlefish may also congregate throughout the 395 rkm of free-flowing Minnesota River.

Many studies evaluating Paddlefish movement find some Paddlefish migrate long distances while other individual fish exhibit rather small home ranges and little migratory behavior (e.g., Rosen et al. 1982; Moen 1992; Zigler et al. 2003; Tripp et al. 2019). For instance, Tripp et al. (2019) found a mean linear Paddlefish home range of 284 km in the Upper Mississippi River, but linear home range varied 16–503 km among 77 tagged fish. In the Missouri River below Gavins Point Dam, Rosen et al. (1982) similarly reported that although some Paddlefish exhibited small home ranges, fish that moved downstream moved an average of 198 km with one fish moving nearly 2,000 km downstream to the Mississippi River in Tennessee. Tripp et al. (2019) categorized the movement patterns of the 77 Upper Mississippi River Paddlefish into three categories: 1) resident fish that occupied a relatively small area; 2) migratory fish with a regular long-distance pattern of movement between seasonal ranges; and 3) nomadic fish that exhibited long-distance movements with wide variation among individuals and seasons. Although the temporal extent of our study is limited, we also observed varying movement patterns among Paddlefish implanted with acoustic transmitters that we summarized into three similar categories. On one end of the spectrum, two paddlefish (along with PAH 111 initially captured in the Mississippi River) exhibited nomadic behavior typified by frequent upstream and downstream movements and movement between rivers. On the other end of the spectrum, we classified five Paddlefish as residents exhibiting very little movement and typically occupying one small reach of river. In contrast, we classified six Paddlefish that typically exhibited very little movement but made one large downstream movement or patterned seasonal movements as migratory. Five other Paddlefish initially captured in the Mississippi River or St. Croix River also exhibited evidence of migratory behavior, making forays into the Minnesota River, potentially associated with spawning.

Connectivity of aquatic systems is important for potadromous species such as Paddlefish that often migrate long distances between spawning, feeding, and winter habitats. Our results support findings by others, showing that Paddlefish migrate long distances over short time periods, often among multiple rivers, and often across political and management boundaries (Firehammer and Scarnechia 2006; Mettee et al. 2009; Pracheil et al. 2012; Tripp et al. 2019). For example, during this study, 10 of 20 acoustic tagged Paddlefish detected in the Minnesota River spent time in multiple rivers including the Minnesota River, Mississippi River, and St. Croix River with one directional migrations exceeding 200 rkm and linear home ranges exceeding 400 rkm. These findings further support the notion that cooperative interjurisdictional management rather than independent management among individual political units (e.g., states, provinces) or management agencies is essential for migratory large river species such as Paddlefish and sturgeons (Pracheil et al. 2012; Hupfeld et al. 2016; Tripp et al. 2019).

Declines in Paddlefish populations throughout their distribution is attributed to habitat fragmentation (e.g., dams) that prevent access to important habitats required for spawning, foraging, and over-wintering as well as recolonizing (Unkenholz 1986; Jennings and Zigler 2009). Several studies provide evidence that some Mississippi River Lock and Dams serve as barriers to Paddlefish movement under certain conditions (Tripp et al. 2014) while this study and others demonstrate that Paddlefish are able to move both upstream and downstream through lock and dams during other conditions (Zigler et al. 2004; Tripp et al. 2014). During a telemetry study in the Mississippi River, Zigler et al. (2004) found that 71 radio tagged Paddlefish made 20 upstream and 33 downstream passages through lock and dams during 1994–1997, but that upstream passage was rare when head height exceeded 1.0 m. However, the timing of when lock and dams are passable may have consequential impacts on Paddlefish that are attempting to access spawning or over-wintering habitats. Future studies should continue to evaluate Paddlefish passage through barriers (e.g., lock and dams) and evaluate approaches for increasing passage during critical times.

The most important unanswered question regarding Paddlefish in the Minnesota River is “do they represent a self-sustaining population that is successfully spawning within the Minnesota River?” During this study, at least 10 Paddlefish remained within the Minnesota River for greater than one year providing evidence of suitable forage, habitat, and over-wintering conditions for adult Paddlefish. However, we were unable to determine if the Minnesota River contains suitable spawning habitat or if Paddlefish even attempt to spawn in the Minnesota River. Yet, upstream movements and forays into the Minnesota River by Paddlefish during late-spring and summer may be indicative of spawning migration. Spawning Paddlefish broadcast their eggs over gravel (or other coarse substrates clear of silt) bars within flowing waters coinciding with increased discharge and temperature (Purkett 1961; Russel 1986; Lien and DeVries 1998). Similar to the Minnesota River, spawning locations are unknown for most Paddlefish populations (Jennings and Zigler 2009). The Minnesota River is complex with diverse habitat types and we hypothesize suitable gravel bars for Paddlefish spawning are likely available. In other rivers, researchers have confirmed Paddlefish spawning activity by capturing larval fish or eggs with active gears such as benthic trawls or passive gears such as egg mats (Firehammer et al. 2006; Braaten et al. 2009; Phelps et al. 2009). For instance, Firehammer et al. (2006) confirmed specific spawning habitats in the Lower Yellowstone River by collecting Paddlefish eggs with modified egg mats. Braaten et al. (2009) used 750 µm mesh larval nets fished on the bottom, in the middle of the water column, and near the surface to capture larval Paddlefish in the Upper Missouri River and tributaries. Similarly, Phelps et al. (2009) captured over 2,000 age-0 Paddlefish from the Middle Mississippi River with benthic trawls over a 9 year period. We believe implementing similar methods for determining if and where Paddlefish spawn in the Minnesota River is vital for identifying and protecting potentially critical habitats. Continued monitoring of acoustic tagged Paddlefish movements will also provide insight into likely locations and timing of spawning events. If Paddlefish are unsuccessful at spawning in the Minnesota River, identifying where they do successfully spawn and determining what limits them from spawning in the Minnesota River will be important for conservation of the population.

Throughout North America, restoration and conservation efforts have successfully improved the status of Paddlefish (Bettoli et al. 2009). Unfortunately, the spread and establishment of invasive species such as invasive carps (Bighead Carp *Hypophthalmichthys nobili* and Silver Carp *Hypophthalmichthys molitrix*) provides new threats to Paddlefish. Several studies describe changes in plankton resources attributed to invasive carps (e.g., Sass et al. 2014) and Schrank et al. (2003) demonstrated potential negative impacts of Bighead Carp on age-0 Paddlefish growth. Other studies also show that invasive carps likely reduce body condition and relative abundance of native planktivorous Bigmouth Buffalo *Ictiobus cyprinellus* and Gizzard Shad *Dorosoma cepedaium* in the Illinois River (Irons et al. 2007; Pendleton et al. 2017). Yet, encouragingly Sampson et al. (2009) found very little diet overlap between invasive carps and Paddlefish in backwaters of the Illinois and Mississippi River. Regardless of competitive interactions, invasive carps may also have the potential to displace Paddlefish from important foraging and over-wintering habitats such as backwaters and deep slack water areas. For these reasons among others, quickly developing baseline understanding of Paddlefish population dynamics within Minnesota is important for understanding and quantifying the effects resulting from establishment of invasive species.

Paddlefish appear more abundant in Minnesota than previously perceived and are listed as protected within the state and neighboring Wisconsin. Although protected from harvest, continued recovery and sustainability of populations is likely dependent upon habitat protection and restoration along with connectivity of aquatic habitats that allows for migration among important habitats for varying life history requirements (e.g., spawning, overwintering). Furthermore, invasive carps may stress local Paddlefish populations if they expand and establish populations throughout upstream portions of the Upper Mississippi River basin. Effective management and conservation of Minnesota River Paddlefish is reliant upon first better understanding important habitats (e.g., spawning habitats), population dynamics (e.g., abundance, growth rates, mortality rates), reproduction (e.g., age at maturity, spawning frequency), and limiting factors (e.g., recruitment success, habitat fragmentation). Cooperative management among states and resource agencies across the entire Upper Mississippi River watershed will provide the greatest likelihood of sustaining healthy populations of Paddlefish within Minnesota waters and throughout the region.

Supplemental Materials

Table S1. Complete length (eye-to-fork), weight, capture date, approximate capture coordinates, and tag information for all Paddlefish captured from the Minnesota River, Minnesota during this study (August 2016 – January 2019).

Table S2. Coordinates and dates of active recording for all acoustic receivers deployed in the Minnesota River, Mississippi River, and St. Croix River by Minnesota Department of Natural Resources Staff. Attached file.

Table S3. Date and location summary of all acoustic tagged Minnesota River Paddlefish detections on active or passive acoustic receivers in the Minnesota River, Mississippi River, or St. Croix River during this study (August 2016 – July 2019). Attached file.

Images S1–S5. Photographs of Paddlefish captured from the Minnesota River as part of this ENRTF funded project during 2016–2019.

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Table S1.

Date	Site	Latitude	Longitude	Fish #	Eye–fork length (mm)	Weight (g)	PIT tag	Jaw band	Recap	Acoustic transmitter
8/31/2016	St. Peter	44.324171	-93.952977	PAH 3	890					52316
8/31/2016	St. Peter	44.324171	-93.952977	PAH 2	860	8600				52317
8/31/2016	St. Peter	44.324171	-93.952977	PAH 1	1047					52318
9/13/2016	St. Peter	44.324171	-93.952977	PAH 5	1045					52315
9/13/2016	St. Peter	44.324171	-93.952977	PAH 4	889					
6/7/2017	State Park	44.754777	-95.491160	PAH 7	995					14160
6/7/2017	State Park	44.754777	-95.491160	PAH 8	1015					14162
6/7/2017	State Park	44.754777	-95.491160	PAH 6	721					14164
6/8/2017	State Park	44.754777	-95.491160	PAH 9	1000					14154
6/8/2017	State Park	44.754777	-95.491160	PAH 10	969					14155
6/8/2017	State Park	44.754777	-95.491160	PAH 12	955					14156
6/8/2017	State Park	44.754777	-95.491160	PAH 11	984					14158
6/13/2017	State Park	44.754777	-95.491160	PAH 13	1080	17000	79813F1			
6/13/2017	State Park	44.754777	-95.491160	PAH 14	960	12000	7980960			
6/16/2017	State Park	44.754777	-95.491160	PAH 21	1003	12000	794CA18			
7/21/2017	St. Peter	44.324171	-93.952977	PAH 15	1098	16000	7980F4C	10570		
8/29/2017	St. Peter	44.324171	-93.952977	PAH 16	968	12000	7981A38	10571		
9/13/2017	St. Peter	44.324171	-93.952977	PAH 17	930	15750	7981DC9	10572		
9/27/2017	St. Peter	44.324171	-93.952977	PAH 19	1078	13600				14151
9/27/2017	St. Peter	44.324171	-93.952977	PAH 18	910	12400				14153
9/28/2017	St. Peter	44.324171	-93.952977	PAH 20	1060	16000				14152
9/28/2017	St. Peter	44.324171	-93.952977	PAH 18					Yes	14153
11/8/2017	St. Peter	44.324171	-93.952977	PAH 22	812	8000	7984EF0	10573		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 23	813	8100	79822FD	10574		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 24	915	9600	79806A7	10575		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 25	852	9000	79809C6	10576		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 26	830	9300	7984D05	10577		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 27	885	12000	79806C2	10578		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 28	1052	15600	79844FF	10579		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 29	959	17400	7982626	10580		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 30	830	9100	7985F7A	10581		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 31	835	9400	79824BC	10582		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 32	925	11500	79802BF	10583		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 33	830	9100	79806BE	10584		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 34	875	10000	7985383	10585		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 35	838	8800	798221A	10586		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 36	915	10000	7981EF7	10587		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 37	669	4700	7982309	10588		
11/8/2017	St. Peter	44.324171	-93.952977	PAH 38	1088	17400	798117A	10589		
11/16/2017	St. Peter	44.324171	-93.952977	PAH 39	910	11400	798225D	10590		
11/16/2017	St. Peter	44.324171	-93.952977	PAH 40	985	13000	79811E8	10591		
11/16/2017	St. Peter	44.324171	-93.952977	PAH 41	841	8600	7981AC9	10592		
11/16/2017	St. Peter	44.324171	-93.952977	PAH 42	895	10000	79825AB	10594		
11/16/2017	St. Peter	44.324171	-93.952977	PAH 43	980	12400	7981B3E	10593		
11/16/2017	St. Peter	44.324171	-93.952977	PAH 44	874	10200	79810BF	10595		
11/16/2017	St. Peter	44.324171	-93.952977	PAH 45	946	12800	7982440	10596		
11/16/2017	St. Peter	44.324171	-93.952977	PAH 46	829	7600	7982850	10597		
11/16/2017	St. Peter	44.324171	-93.952977	PAH 47	726	6200	798195F	10598		
11/16/2017	St. Peter	44.324171	-93.952977	PAH 48	917	14000	7980224	10599		

11/16/2017	St. Peter	44.324171	-93.952977	PAH 49	823	8000	79805BB	10600		
11/17/2017	St. Peter	44.324171	-93.952977	PAH 50	1030	20500	7980ECC			
11/17/2017	St. Peter	44.324171	-93.952977	PAH 51	985	12800	7981A6C			
11/17/2017	St. Peter	44.324171	-93.952977	PAH 52	902	8800	7981A7B			
11/17/2017	St. Peter	44.324171	-93.952977	PAH 53	831	7800	7986240			
11/20/2017	Mankato	44.197593	-94.011468	PAH 54	900	10400	7981123			
11/20/2017	Mankato	44.197593	-94.011468	PAH 55	910	11800	7982553			
11/20/2017	Mankato	44.197593	-94.011468	PAH 56	955	18000	79807B4			
11/20/2017	St. Peter	44.324171	-93.952977	PAH 59	867	10000	7985141		Yes	27124
11/20/2017	St. Peter	44.324171	-93.952977	PAH 57	831	9000	7980329			
11/20/2017	St. Peter	44.324171	-93.952977	PAH 58	805	7200	7981161			
11/20/2017	St. Peter	44.324171	-93.952977	PAH 60	979	13600	7980402			
11/20/2017	St. Peter	44.324171	-93.952977	PAH 61	830	7800	7981BE2			
11/27/2017	Mankato	44.197593	-94.011468	PAH 64	945	11400	7980A25			
11/27/2017	Mankato	44.197593	-94.011468	PAH 65	865	9800	79813E4			
11/27/2017	Mankato	44.197593	-94.011468	PAH 66	910	12000	7982332			
11/27/2017	St. Peter	44.324171	-93.952977	PAH 62	809	6200	7980F6B			
11/27/2017	St. Peter	44.324171	-93.952977	PAH 63	965	10600	79824E4			
5/30/2018	Granite	44.774539	-94.526282	PAH 67	827	8500	7980F42	10601		
5/30/2018	Granite	44.774539	-94.526282	PAH 68	938	12000	7980626	10602		
5/31/2018	Granite	44.774539	-94.526282	PAH 69	890	11000	7980219	10603		
5/31/2018	Granite	44.774539	-94.526282	PAH 70	905	18000	798200B	10604		
5/31/2018	Granite	44.774539	-94.526282	PAH 71	990	17800	798183E	10605		
6/26/2018	Granite	44.774539	-94.526282	PAH 71	963	15200	798183E	10605	Yes	
10/3/2018	Granite	44.774539	-94.526282	PAH 72	965	12000	7980AF0	10606		
10/3/2018	Granite	44.774539	-94.526282	PAH 73	905	11400	7981DF0	10607		
10/3/2018	Granite	44.774539	-94.526282	PAH 71			798183E	10605	Yes	
10/3/2018	Granite	44.774539	-94.526282	PAH 74	972	16000	7981EFD	10608		
10/3/2018	Granite	44.774539	-94.526282	PAH 75	945	12800	7983FC9	10609		
10/3/2018	Granite	44.774539	-94.526282	PAH 76	962	12600	79824C9	10610		
10/3/2018	Granite	44.774539	-94.526282	PAH 77	869	11000	79862B6	10611		
10/3/2018	Granite	44.774539	-94.526282	PAH 78	1025	15800	7981D71	10612		
10/3/2018	Granite	44.774539	-94.526282	PAH 70	966		798200B	10604	Yes	
10/3/2018	Granite	44.774539	-94.526282	PAH 79	900	12400	7984D6D	10613		
10/3/2018	Granite	44.774539	-94.526282	PAH 80	789	7200	79823D6	10614		
10/3/2018	Granite	44.774539	-94.526282	PAH 81	968	11400	7981B62	10615		

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

Table S3. File attached

Image S1.

Image S 1. Mike Wolf (DNR) holding a Paddlefish captured in a gill net near St. Peter, MN during November 2017.

Image S2.

Image S 2. Michael Vaske (DNR) holding a Paddlefish captured in a gill net near Upper Sioux Agency State Park during August 2017.

Image S3.

Image S 3. Drifting a gill net for Paddlefish in the Minnesota River (pictured: Michael Vaske and Kayla Stampfle, DNR).

Image S4.

Image S 4. Kayla Stampfle and Michael Vaske measuring the length of a Paddlefish captured in the Minnesota River.

Image S5.

Image S 5. Michael Vaske (assisted by Kayla Stampfle, DNR) attaching a jaw band to the lower left jaw of a Paddlefish captured near Granite Falls, MN.