Pallid sturgeon detectability, catchability and post-handling survival with four standardized sampling gears, and movement of pallid sturgeon during the 2011 flood

Report prepared for the Western Area Power Administration, Billings, Montana
and the
Upper Basin Pallid Sturgeon Workgroup

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CHAPTER 1 - General Introduction

In 2010, the Upper Basin Pallid Sturgeon Workgroup, in cooperation with Western Area Power Administration, Billings, Montana, prioritized the need to understand capture probabilities of pallid sturgeon caught in sampling gears used by the majority of field crews in the Pallid Sturgeon Population Assessment Program (PSPAP). A 3-year project was approved to begin in 2011, but due to the historic Missouri River flood in 2011 and other unforeseen circumstances, the project did not fully begin until 2013.

The PSPAP is designed to track changes and assess trends in the relative abundance of Missouri River fishes downstream of Fort Peck Dam, Montana to the confluence of the Mississippi River, excluding reservoirs (Welker and Drobish 2012a). This task is accomplished with standardized sampling (gears and deployment procedures) throughout 1,718 river kilometers (rkm) of the Missouri River by the PSPAP. Standardization of gear types, specifications, and data collection are needed to make spatial and temporal comparisons of fish relative abundance, size structure, and condition (Bonar et al. 2009). Relative abundance is comprised of the ratio of numbers of fish captured (C) divided by the effort expended (f), and is commonly called catch per unit effort (C/f). Relative abundance for the PSPAP (Welker and Drobish 2012a) is reported as numbers of fish per net or hook night for passive gears (i.e., gill net and trot line, respectively), and numbers of fish per 100 m of river bottom sampled for active gears (i.e., otter trawl and trammel net). Mathematically, C/f is related to N as: $C/f = q*N$, where q is the probability of capture of an individual fish in one unit of effort and N is true abundance (Hubert and Fabrizio 2007).

Fundamental to using *C/f* as an index for spatial and temporal comparisons of abundance is constancy of *q*. Differences in *q* betweens reaches, habitats, season, or size classes can affect *C/f* independent of the population's true abundance (*N*). However, if *q* for pallid sturgeon is known for different size classes, habitats, or time periods, then changes in relative abundance can be more confidently interpreted as changes in true abundance.

Since the suite of standard sampling gears used within the PSPAP are well-established, improvements should now focus on how each gear captures different size classes of pallid sturgeon in different habitats and seasons to increase precision of *C/f* and minimize variability in *q*. Once variability in catchability is known, increasing confidence in *C/f* can then be scaled by habitat area to provide a measure of population density (Hubert and Fabrizio 2007). Additionally, survival rate estimation with Cormack-Jolly-Seber mark-recapture models is reliant on concurrent estimates of detection probability of pallid sturgeon (Hadley and Rotella 2009). Low estimates of detection probability result in low confidence around survival estimates. Direct measurement of capture probability in this study can further refine current survival rate estimates of pallid sturgeon.

Despite the importance of catchability, it has been rarely measured directly. Calculation of *q* usually necessitates large-scale mark-recapture studies to estimate *N,* which then enables assessment of relations between actual and relative abundance (i.e., *N* and *C/f*; Forney 1980). However, telemetry studies allow for known locations of individual fish, which enables direct determination of "conditional capture probabilities" (Guy et al. 2009; Steffensen et al. 2015). For drifted trammel nets in the riverine section of the Missouri River upstream of Fort Peck Lake, Guy et al. (2009) determined conditional capture probabilities to be 0.37, 0.51, 0.67, and

0.75 for the first through fourth sampling attempts over the known locations of radio-tagged pallid sturgeon and shovelnose sturgeon *Scaphirhynchus platorynchus*. However, variability in length of radio-tagged pallid sturgeon was low and the trammel net outer mesh size used by Guy et al. (2009) was larger (25.4-cm) than that used in the remainder of the Missouri River by the PSPAP (15.2-cm). Additionally, the total width of the trammel net used by Guy et al. (2009) was wider (45.8 m) than the standard trammel (38.1 m) used by the crews of the PSPAP. Similarly, Steffensen et al. (2015) evaluated conditional capture probability of pallid sturgeon with otter trawls and found conditional capture probabilities increased from 0.08 on the first trawl to 0.26 after three trawls. Our goal was to expand the study of Guy et al. (2009) and Steffensen et al. (2015) by assessing conditional capture probability using two active gears (otter trawl and trammel net), using a wider size-range of pallid sturgeon, and exploring a wider variation in environmental conditions (i.e., two seasons across two years, different sampling reach). Additionally, we aimed to assess the ability of the PSPAP sampling design to detect pallid sturgeon, when present in a sampling section, using four gears (active: otter trawl and trammel net; Passive: gillnet and trotline).

This multi-year study also sought to assess the post-handling survival of pallid sturgeon captured in all standard gears of the PSPAP. A handling protocol exists to protect pallid sturgeon from capture-induced mortality by setting an upper thermal limit for deployment of gill nets (USFWS 2005). However, no published data exists to support this thermal limitation for gill net deployment. Currently, no limitations exist for sampling pallid sturgeon with otter trawls, trammel nets, and trot lines while post-capture mortality for these four gears is unknown.

Objectives

(1) Determine the capture/detection probability (i.e. detectability) of pallid sturgeon in active and passive gears currently used in the PSPAP.

(2) Determine the conditional capture probability (i.e. catchability) of pallid sturgeon in active gears currently used in the PSPAP.

(3) Estimate post handling survival of age-1+ hatchery propagated pallid sturgeon captured with currently used PSPAP standardized gear.

Additionally, due to the availability of ultrasonic tagged pallid sturgeon during the 2011 flood, we evaluated the movement patterns of Pallid Sturgeon during the flood event.

4) Document general movement patterns of pallid sturgeon implanted with ultrasonic transmitters during the 2011 Missouri River flood.

Overview of Study Area

Lewis and Clark Lake, bounded upstream by Fort Randall Dam, South Dakota, and downstream by Gavins Point Dam, Nebraska-South Dakota, is the most downstream reservoir of the Missouri River (Figure 1.1). The lake was formed by the closure of Gavins Point Dam in 1955 and is operated by the U.S. Army Corps of Engineers (USACOE). The primary function of Gavins Point Dam is to even out water release fluctuations from Fort Randall Dam that serve downstream purposes such as navigation, flood control, and municipal water supply. This intra-reservoir reach contains two distinct habitat types, riverine and reservoir. The primary habitat type of interest in this study is the riverine reach that extends 87 rkm from Fort Randall Dam (rkm 1416) to the headwaters of Lewis and Clark Lake (rkm 1329, downstream of Springfield, South Dakota). The reservoir reach extends an additional 24 rkm to Gavins Point Dam (rkm 1305).

This study primarily occurred in the riverine section, which includes Segments 5 and 6 in the PSPAP (Welker and Drobish 2012a), and was previously known as Recovery Priority Management Area 3 (Dryer and Sandvol 1993). This reach retains many natural characteristics expected in unaltered rivers such as side channels, islands, sand bars, backwater areas, unregulated tributaries, and old-growth riparian corridors. The maximum depth of the riverine section is about 12 meters (m), although water levels can substantially fluctuate (i.e., up to 1 m) daily and seasonally (Troelstrup and Hergenrader 1990). In the most upstream portion of this reach, water temperatures are depressed by hypolimnetic discharges from Fort Randall Dam and turbidity is low (Pegg et al. 2003). The remaining portion has more naturalized water temperatures and turbidity due to inflows from the Niobrara River, which includes the large braided delta formed in the headwaters of Lewis and Clark Lake. Lowest daily flows generally occur at 0600 hours with peak flows occurring between 1200 to 1900 hours to support power generation demands (USACE 1994). The USACOE Missouri River Main Stem Reservoirs 2000-2001 Annual Operating Plan (http://www.nwd-mr.usace.army.mil/rcc/reports/aop.html) reported highest seasonal releases from Fort Randall Dam from August through November to support navigation on the Missouri River downstream of Sioux City, Iowa. Lowest releases occurred from December through April to prevent flooding due to ice jams.

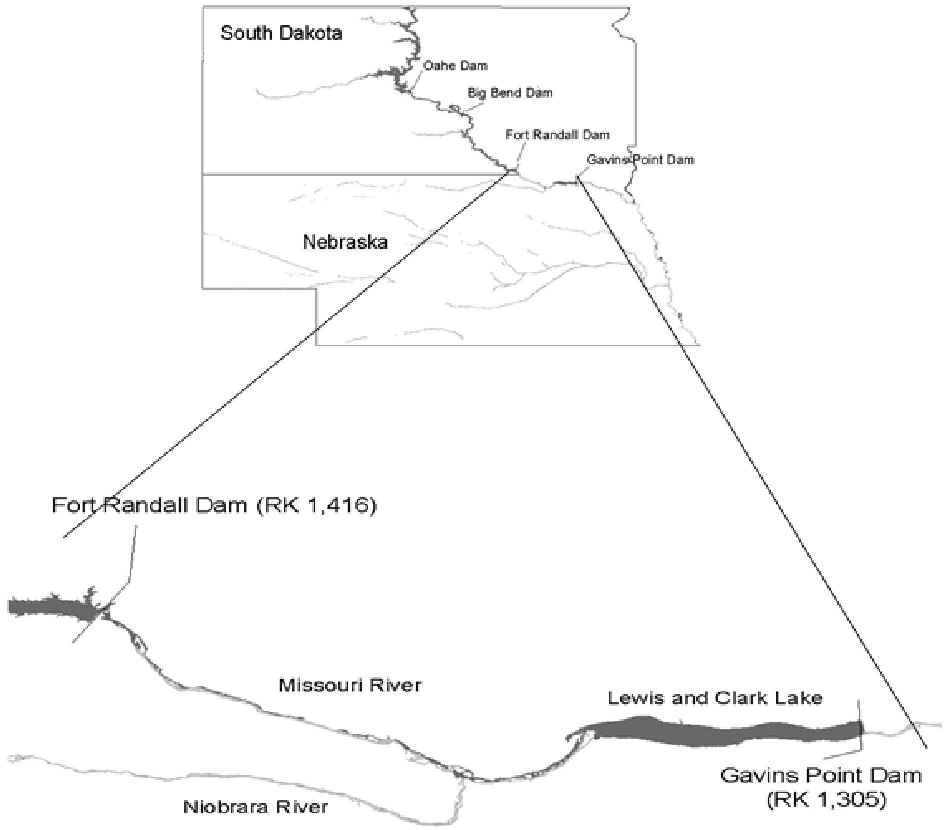


Figure 1.1. Map of the mainstem Missouri River reservoirs in South Dakota and Nebraska with the Fort Randall to Gavins Point section enlarged.

Methods

Telemetry

Hatchery-reared pallid sturgeon, raised by the U.S. Fish and Wildlife Service (USFWS) at Gavins Point National Fish Hatchery in Yankton, South Dakota and Garrison Dam National Fish Hatchery in Riverdale, North Dakota were used in this study. Two size classes of pallid sturgeon were implanted with ultrasonic transmitters (Sonotronics Tuscon, Arizona; Table 1.1, Table 1.2) and stocked into the river at four stocking locations (Figure 1.2). Ninety-four small pallid sturgeon (339-500 mm FL; age 1 and age 3) were stocked with model PT-04 (25.0 mm in length; 9.0 mm outside diameter; 2.3 g weight) transmitters, and 63 large pallid sturgeon (564-1,105 mm FL; age 6, age 7, and age 16) were stocked with model CT-05 (63.0 mm in length; 15.6 mm outside diameter; 10.g weight) transmitters. An additional 14 fish implanted with transmitters were not stocked due to suture failure. This includes four large fish from the 2010 stocking, four small fish from the 2011 stocking; and six small fish from the 2014 stocking. Each tag emitted a unique aural code at frequencies that ranged from 70-83 kHz. Maximum estimated battery life for tags implanted in large pallid sturgeon was three years, while battery life of tags implanted in small fish was approximately five months. Prior to surgery, fish were not fed for five days. Surgeries were conducted without anesthesia and ranged from 128-220 seconds for large and 91-272 seconds for small fish after which fish were treated with a 1% salt treatment (flow through) to reduce handling stress. Mean transmitter to pallid sturgeon weight ratios were 0.6-0.9% for large fish and 0.9-1.2 % for small fish, to minimize the effects of transmitter weight on fish behavior and survival (Table 1.2).

Report Structure

This report is divided into chapters that each address all or part of the major objectives.

Chapter 2 details the capture probability for Pallid Sturgeon using the PSPAP Protocol.

Chapter 3 details the conditional capture probability of Pallid Sturgeon using trammel nets.

Chapter 4 details the post-handling survival of hatchery-propagated pallid sturgeon captured with standardized gear used by the PSPAP.

Chapter 5 details the movements of Pallid Sturgeon implanted with ultrasonic tags during the 2011 Missouri River flood event.

Table 1.1. Pallid sturgeon with ultrasonic transmitters stocked into Segments 5 and 6 of the Missouri River. Fish size: Small = 339-500 mm FL, Large = 564-1,105 mm FL.

Year stocked	Fish size	Year class	Date stocked	Stocking site	N
2010	Large	2004	10/29	Running Water	11
	Large	2004	10/29	Verdel	13
2011	Small	2010	5/13	Verdel	27
2013	Large	1997	5/29	Running Water	2
	Large	1997	5/29	Springfield	3
	Large	1997	5/29	Sunshine Bottoms	3
	Large	1997	5/29	Verdel	1
	Large	2003	5/29	Running Water	8
	Large	2003	5/29	Springfield	2
	Large	2003	5/29	Sunshine Bottoms	4
	Large	2003	5/29	Verdel	11
	Large	2006	5/29	Running Water	3
	Large	2006	5/29	Springfield	1
	Large	2006	5/29	Verdel	1
	Small	2010	5/29	Running Water	15
	Small	2010	5/29	Springfield	7
	Small	2010	5/29	Sunshine Bottoms	6
	Small	2010	5/29	Verdel	11
2014	Small	2013	8/5	Sunshine Bottoms	5
	Small	2013	8/11	Sunshine Bottoms	23

Table 1.2. Number, mean (SE) length and weight, and percent transmitter tag weight to fish body weight for fish stocked into the Missouri River. Small = 339-500 mm FL, Large = 564-1,105 mm FL.

	Small pallid sturgeon				Large pallid sturgeon			
	N	Mean length (SE)	Mean weight (SE)	% fish wt to Trans wt	N	Mean length (SE)	Mean weight (SE)	% fish wt to Trans wt
2010					24	652 (10.07)	1,154 (56.22)	0.9 (0.05)
2011	27	369 (1.81)	193 (3.2)	1.2 (0.02)				
2013	39	436 (4.48)	285 (10.89)	0.9 (0.03)	39	821 (15.35)	2,137 (172.49)	0.6 (0.03)
2014	28	372 (3.34)	210 (6.62)	1.1 (0.04)				

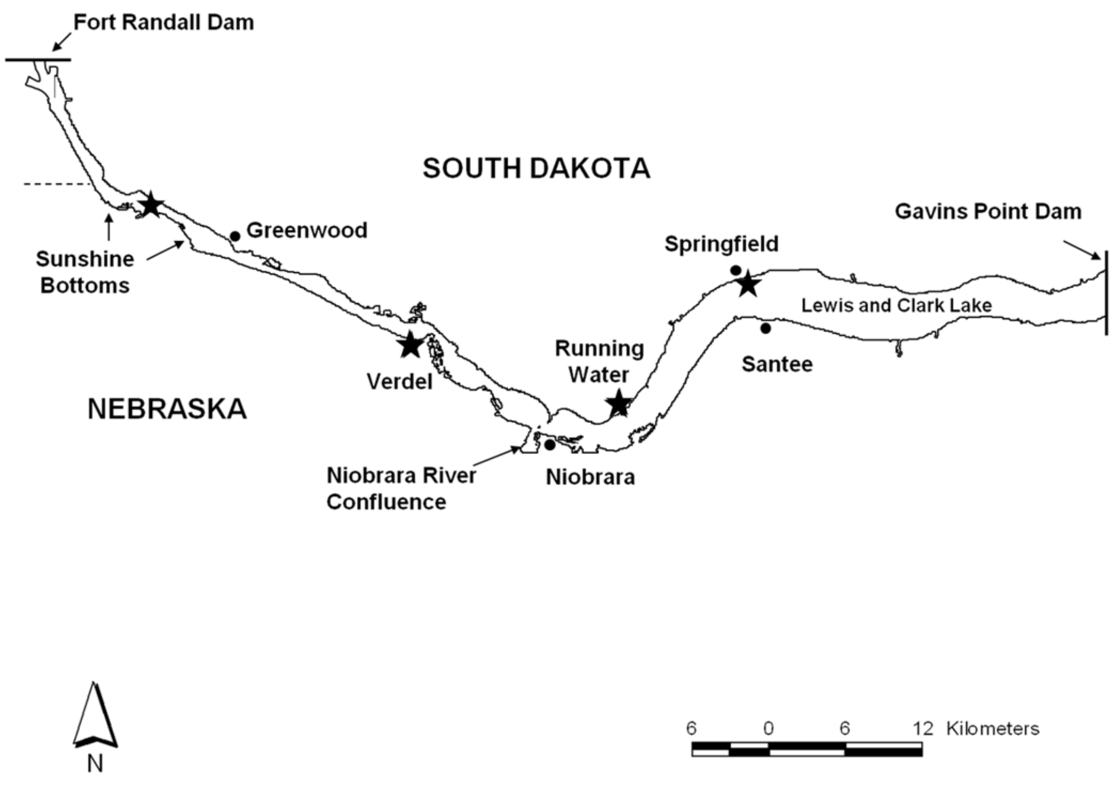


Figure 1.2. Map showing the Missouri River, South Dakota and Nebraska, where ultrasonic tagged hatchery-reared pallid sturgeon were released (stars), tracked, and sampled during 2011-2014. The riverine/lacustrine boundary is located just downstream of Santee, Nebraska.

CHAPTER 2- Capture/Detection Probability (i.e. Detectability) of Pallid Sturgeon in Active and Passive Gears Currently Used in the PSPAP.

Introduction

A primary objective of the Pallid Sturgeon Population Assessment Program (PSPAP) is to "evaluate annual and long-term trends in Pallid Sturgeon population abundance and geographic distribution throughout the Missouri River System" (Welker and Drobish 2012a). Currently, the PSPAP uses multiple sampling gears to index population abundance with relative abundance [i.e., *C/f*; *C/f* = number of fish captured (*C*) / effort expended (*f*)] (Welker and Drobish 2012a). Within the PSPAP sampling design, "river bends" (i.e. sample unit) are randomly selected for sampling within each river segment (i.e. sample population). Each bend is sampled with a standardized level of effort (8-10 subsamples, depending on gear type) with a suite of gears (gill net, trammel net, otter trawl, and trotline). *C/f* is first calculated for each subsample for each gear and then averaged to create a bend mean *C/f*. Finally, bend mean *C/f* values are averaged to achieve a segment mean *C/f*.

Fundamental to using *C/f* as an index of true abundance (*N*) for spatial and temporal comparisons is an understanding of capture probability (*q)* and factors that may affect *q*. Mathematically, *C/f* is related to *N* as: $C/f = q*N$, where *q* is the probability of capture of an individual fish in one unit of effort (Hubert and Fabrizio 2007). Therefore, differences in *q*, potentially due to fish size, sampling crew, habitat, season, discharge, etc., can affect *C/f* estimates independent of the population's true abundance.

Despite the importance of catchability to using *C/f* as an index of population abundance, it has been rarely measured directly, or at the scale and sampling effort consistent with *C/f* estimates of the PSPAP. To date, conditional capture probabilities have been quantified for individual gear deployments (trammel nets and otter trawls) at known pallid sturgeon locations (Guy et al. 2009; Steffensen et al. 2015), but they have not been quantified at the river bend spatial scale and subsequent level of sampling effort (8-10 subsamples per gear per bend).

Given the importance of *q* to tracking changes in abundance and the lack of information regarding *q* for pallid sturgeon, the objective of this study was to quantify capture probabilities of pallid sturgeon within the PSPAP framework at the bend scale.

Methods

Approach

To quantify the conditional capture probabilities of Pallid Sturgeon within the PSPAP Standard Operating Procedure framework (i.e. bend level sampling), we used standardized PSPAP sampling effort and tracked the same sampling area (i.e. bend) to determine if tagged fish were present within the sampling area at the time of sampling. Upon completion of sampling and tracking, we determined if fish present within the sampling area were captured during standardized sampling. Two teams were required to accomplish this approach: a telemetry team and a fish sampling team. Prior to gear deployment, the telemetry team identified the location of any ultrasonic tagged pallid sturgeon within the sampling area; any identified fish locations were unknown to the fish sampling crew. Following gear retrieval, the sampling area was tracked again to determine if fish not captured by the fish sampling crew immigrated, emigrated, or remained within the bend.

Telemetry component

Pallid sturgeon were first located in the river by using an omni-directional hydrophone (Sonotronics; model TH-2) and receivers (Sonotronics: model USR-08 and USR-96) while moving downstream at 6-8 km/h. Omni-directional hydrophones, one each on the port and starboard side, were extended about 2 m behind the stern outside the propeller wash while the receivers automatically cycled through all tag frequencies. The boat traversed an average 172 m (± 6 m SE) during each cycle. Once an ultrasonic tag was detected, we used a unidirectional hydrophone (Sonotronics: model DH-4) and the sensitivity (i.e., gain) adjustment capability of the receiver to locate a more precise location of the tag's location. Past detection limits downstream of Fort Randall Dam for similar ultrasonic tags was about 0.4 km using a single unidirectional hydrophone (Jordan et al. 2006). Accuracy using this technique was estimated at 6.5 m (SE=0.2; James et al. 2014). We recorded the geographic position (latitude and longitude) with a WAAS enabled Garmin GPSMAP 168 sounder (Garmin Corporation, Olathe, Kansas) and general location (Segment and Bend).

Fish sampling component

The stratified random sampling design and protocol of the PSPAP, which used active and passive gears (Welker and Drobish 2012a), was used to determine the catchability of pallid sturgeon in this study. Within the PSPAP, 10 river bends are randomly selected within Segments 5 and 6 (five from each segment) for sampling each year. Standard PSPAP sampling effort within the 10 bends was used: 10 gill net subsamples per bend during spring, eight trammel net subsamples per bend during spring and summer (i.e., 16 total subsamples per bend per year), eight otter trawl subsamples per bend during spring and summer (i.e., 16 total subsamples per bend per year), and eight trotline subsamples per bend during spring (20 nightcrawler-baited hooks per trotline). See Welker and Drobish (2012a, 2012b) for additional information regarding the standardized sampling protocol and gears.

Data Analysis

Mean conditional capture probability was calculated for each gear at the bend scale. Our sample unit was a bend that contained a tagged pallid sturgeon during standard PSPAP sampling. First, we calculated the conditional capture probability for each bend by gear, by solving the equation $C/f = q*N$ for q. In this study, C equaled the number of tagged fish that were captured, N was the number of tagged fish present in the bend, and f equaled 1 standard unit of PSPAP effort for the bend (i.e., 8-10 subsamples, depending on gear). Therefore, for each sampled bend, q = # tagged fish caught / # tagged fish present. We then averaged these values to acquire the mean conditional capture probability for each gear type at the bend spatial scale. Mean capture probabilities for otter trawl and trammel net include both spring and summer sampling events combined due to low sample sizes. Additionally, the limited number of occurrences and captures of tagged fish in randomly-selected bends prevented statistical evaluation of factors affecting conditional capture probability at the bend scale.

Results

Ninety-four small (339-500 mm FL; 136-500g) and 63 large (564-1,105 mm FL; 700-5,850 g) pallid sturgeon were stocked with ultrasonic telemetry transmitters from 2010 to 2014 (Table 1.1; Table 1.2). Tracking and sampling began in the fall of 2010 with gillnet sampling, and continued through trammel net and trotline sampling in May 2011. Sampling and tracking was postponed from late May 2011 to March 2012 due to flooding during the summer and fall of 2011. Small fish were present in randomly-selected bends on eight occasions (20 fish total; Table 2.1). Seven of these occasions occurred during trammel net sampling and one occurred during otter trawl sampling. Small fish were not located during trotline and gillnet sampling as these fish were stocked after sampling was completed for the year and tag battery life expired prior to sampling with these gears the following year. Large fish were present on 26 occasions (34 fish total; Table 2.1). Large fish were present in the sampling area during gillnet sampling on five occasions, otter trawl sampling on six occasions, trotline sampling on seven occasions, and trammel net sampling on eight occasions.

Table 2.1. Number of bends sampled by fish size and gear when tagged Pallid Sturgeon were present during 2011-2014. Small= 339-500 mm FL, large = 564-1,105 mm FL.

	Small Pallid Sturgeon			Large Pallid Sturgeon		
Gear	# Bends w/ fish present	# fish present	# fish caught	# Bends w/ fish present	# fish present	# fish caught
Gill net	0	0	0	5	9	0
Otter trawl	1	1	0	6	9	0
Trotline	0	0	0	7	10	3
Trammel net	7	19	0	8	9	1
Total	8	20	0	26	37	4

Zero small pallid sturgeon located within sampled bends were captured with otter trawls and trammel nets, resulting in a conditional capture probability estimate of 0.00. Three large pallid sturgeon located within sampled bends were captured with trotlines and one was captured in a trammel net resulting in mean conditional capture probability estimates of 0.36 (SE=0.18) for trotlines (N=7), 0.13 (SE=0.13) for trammel nets (N=8), 0.00 for the otter trawl (N=6), and 0.00 for gill nets (N=5; Figure 2.1).

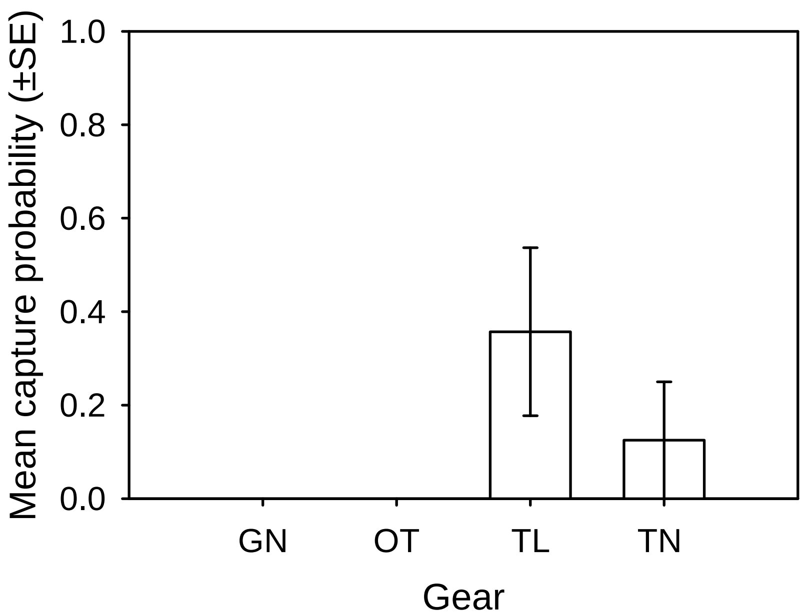


Figure 2.1. Mean conditional capture probability estimates of large (564-1,105 mm FL) pallid sturgeon sampled following the standardized sampling protocol of the PSPAP for Segments 5 and 6 of the Missouri River during 2011-2014. GN = Gill net, OT = Otter trawl, TL = Trotline, and TN = Trammel net.

Discussion

Trotlines were the most efficient sampling gear for capturing juvenile and adult pallid sturgeon (≥339 mm FL) in this study. Trotlines had the highest capture probability for large pallid sturgeon and had the greatest catch rates of large pallid sturgeon (>500 mm FL) per deployment (0.530 fish/deployment) during PSPAP standard sampling in Segments 5 and 6 over the same time period (i.e. 2011 to 2014 sampling years; Pierce, unpublished data). The most effective sampling gear for small pallid sturgeon, based on capture probabilities, remains unclear because we were unable to evaluate capture probabilities for trotlines and gill nets. Furthermore, capture probabilities for trammel nets and otter trawls were zero. However, trotlines (0.050 fish/deployment) had the greatest catch rates of small pallid sturgeon (≤500 mm FL) per deployment during standard PSPAP sampling over the course of this study (sample years 2011-2014), followed by trammel nets (0.030 fish/deployment), otter trawls (0.008 fish/deployment), and gill nets (0.004 fish/deployment; Pierce, unpublished data). Similarly, Steffensen et al (2015) indicated that trammel nets are likely more efficient for targeted recaptures (i.e., deployment of gears at known fish locations) of juvenile pallid sturgeon than otter trawls (see Guy et al. 2009), which is likely due to width sampled per trawl versus trammel net and the associated error of determining the fishes' exact location.

Although the random selection of bends in the PSPAP sampling protocol is intended to allow for an accurate inference of relative abundance to the entire river segment, there is potential for over- and under-estimation of abundance due to non-uniform distribution of fishes. *C/f* estimates can vary greatly due to spatial and temporal variability in fish distributions (Hubert and Fabrizio 2007). In cases where fish are concentrated in randomly-selected bends, abundance may be overestimated. Conversely, when fish are concentrated in non-selected bends, abundance may be underestimated. The low number of randomly-selected sample bends that were occupied by tagged fish in this study (i.e., sample size) highlights the potential effects of bend selection and fish distributions on relative abundance estimates. We randomly selected 10 (36%) of 28 potential river bends for sampling each year, yet these bends were only occupied by large, tagged fish during approximately 14% (26 out of 180) of sampling occasions, suggesting that *C/f* estimates during this time period may have underestimated abundance due to spatial distribution of fish and sampling effort. One promising sampling approach for alleviating these concerns is to adopt an adaptive sampling strategy in which an initial level (i.e. "Phase 1") of sampling is conducted to identify areas of high abundance or variability that informs future sampling efforts, and subsequent sampling (i.e. “Phase 2”) effort is focused on areas of high abundance or variability (Thompson et al. 1992). Within the PSPAP, this approach would provide C/f estimates (Phase 1), and would likely increase sample sizes for studies of population dynamics by focusing effort in areas that fish are abundant (Phase 2).

CHAPTER 3- Conditional Capture Probability (i.e. Catchability) of Pallid Sturgeon in Active Gears Currently used in the PSPAP.

Introduction

Knowledge of capture probability for pallid sturgeon caught in sampling gears that index relative abundance [i.e., *C/f*; *C/f* = number of fish captured (*C*) / effort expended (*f*)] is critical for effective management and conservation of the species. Relative abundance is commonly used in fisheries science as an index of true population abundance (*N*; Hubert and Fabrizio 2007). For example, the Pallid Sturgeon Population Assessment Program (PSPAP) uses *C/f* derived from trotlines, trammel nets, otter trawls, and gill nets to "evaluate annual and long-term trends in pallid sturgeon population abundance and geographic distribution throughout the Missouri River System" (Welker and Drobish 2012a). A fundamental component of using *C/f* as an index of *N* for spatial and temporal comparisons is an understanding of capture probability (*q)* and factors that may affect *q* (Hubert and Fabrizio 2007). Mathematically, *C/f* is related to *N* as: $C/f = q*N$, where *q* is the probability of capture of an individual fish in one unit of effort (Hubert and Fabrizio 2007). Therefore, differences in *q*, potentially due to factors such as fish size, sampling crew, habitat, season, discharge, etc., can affect *C/f* estimates independent of *N*.

Despite the importance of *q* when using *C/f* as an index of Pallid Sturgeon abundance, *q* has been rarely measured directly and biotic and abiotic factors that affect *q* are relatively unclear. To date, conditional capture probabilities of juvenile Pallid Sturgeon have been quantified for trammel nets in the Missouri River above Fort Peck Dam, Montana (Guy et al.

2009) and for otter trawls in the lower, channelized Missouri River below Gavins Point Dam, Nebraska-South Dakota (Steffensen et al. 2015). However, it is unclear how *q* differs throughout different reaches of the Missouri River or if *q* differs between various sizes of Pallid Sturgeon.

Given the importance of *q* to tracking changes in abundance (*N*) and the lack of information regarding *q* for pallid sturgeon, the objectives of this study were to 1) quantify conditional capture probabilities of pallid sturgeon using trammel nets and otter trawls in the Missouri River, and 2) evaluate the effects of fish size and abiotic conditions on the probability of successful capture of pallid sturgeon in trammel nets and otter trawls.

Methods

Approach

To quantify the conditional capture probabilities of pallid sturgeon, we deployed trammel nets at known locations of pallid sturgeon using two teams: a telemetry team and a fish sampling team. The telemetry team found and marked a pallid sturgeon's location, after which the fish sampling team attempted to catch the fish using a trammel net or otter trawl. With this approach, the sample unit (hereafter referred to as an "attempt") consisted of a series of trammel net drifts or trawls over an individual fish at a known location until the fish was captured, or not captured after five attempts.

Telemetry component

Pallid Sturgeon were located in the river using a unidirectional hydrophone (Sonotronics: model DH-4). The sensitivity (i.e., gain) adjustment capability of the receiver was used according to the methods reported in James et al. (2014) to locate the exact location of the transmitter. Once a fish's location was pinpointed, the telemetry boat maintained position above the fish using the 'anchor' or 'spot lock' function of a GPS-enabled trolling motor; accuracy using this technique was 6.5 m (SE=0.2; James et al. 2014).

Fish sampling component

Multifilament trammel nets (38.1 m long; inner wall: 2.5 cm-bar mesh, 2.4 m deep; outer wall: 20.3 cm-bar mesh, 1.8 m deep; see Welker and Drobish 2012b for additional specifications and deployment procedures) were deployed perpendicular to streamflow approximately 75-100 m upstream of the telemetry boat (i.e., the pallid sturgeon estimated location) and drifted directly underneath the telemetry boat's location. Trammel net drifts were repeated as necessary until the fish 1) was captured, 2) moved >100 m from its original location, 3) moved to a location that was not able to be sampled, or 4) was not captured after a maximum of five unsuccessful drifts were completed. We recorded river depth (m) at the beginning, middle, and end of each net deployment. For a subset of attempts, we measured water velocity (m/s) near the substrate (approximately 25 cm above substrate) and at 80% of water depth using a Marsh-McBirney Flo-Mate Model 2000 mounted to a sounding weight and hanging bar. We also measured surface turbidity (NTU) using a Hach Turbidimeter Model 2100P.

Numerous capture attempts with the otter trawl (see Welker and Drobish 2012b gear description and deployment procedures) were conducted, but these attempts were not included in this analysis (and further sampling with otter trawl was terminated) because we were not able to locate the the transmitter with sufficient accuracy (i.e., overall mean accuracy=6.5 m ±0.2; James et al. 2014) relative to the width of the otter trawl (i.e., 4.9 m) to confidently ensure the fish's location was sampled.

Data Analysis

Conditional capture probability given multiple trammel net drifts (p_i^*) for each size class (i.e., small = 339-500 mm FL, large = 564-1,105 mm FL) of pallid sturgeon with trammel nets was calculated as described by Guy et al. (2009):

$$p_i^* = 1 - \prod_{j=1}^{K}(1 - p_i),$$

where (p_i^*) is the probability that individual *i* was captured at least once given multiple net drifts (j = 1, …, K) and p_i is the probability of successfully capturing the individual in any one drift. In other words, the probability of capturing a pallid sturgeon on the first attempt equals 1 minus the probability that it was not captured [i.e. 1 - (1– p_i)]. Further, the probability of capturing a pallid sturgeon on the second drift equals 1 minus the probability that it was not captured on either of the two drifts [i.e. 1-(1 – p_i)* (1 – p_i)]. This calculation requires the assumption that p_i is constant for all drifts on an individual during an attempt.

Logistic regression was used to evaluate if fish size class (i.e., small, ≤ 500 mm FL and large, ≥ 564 mm FL) or selected abiotic conditions affected the probability that an individual fish was captured in an attempt (up to five drifts). Abiotic data from one drift per attempt (typically the final drift) were used for the analysis. For all attempts, we evaluated the effects of fish size class, mean depth, and variability in depth (i.e., coefficient of variation [CV]) on probability of capturing a fish in at least one drift. For attempts with velocity and turbidity measurements, we evaluated the effects of mean depth, variability in depth (i.e., coefficient of variation [CV]), turbidity, bottom velocity, and float-lead line torque on probability of capturing a fish in at least one drift. Float-lead line torque was calculated as the difference between velocity at 80% depth and bottom velocity (Guy et al. 2009).

Results

Thirty-nine fish (23 small fish and 16 large fish) were targeted for capture on 56 occasions (31 on small fish and 25 on large fish), resulting in 210 trammel net drifts. Thirteen fish (seven small fish and six large fish) were targeted multiple times because they were found multiple times during different time periods. Ten fish were targeted twice, two fish were targeted three times, and one fish was targeted four times. At least 28 days separated attempts on an individual fish, with the exception of one fish that was attempted on two consecutive days. On one occasion, two large fish were located at the same location, so these records were combined for logistic regression analysis (neither fish was captured) to avoid psuedoreplication. Velocity and turbidity measurements were collected at 38 of the 56 attempts.

Targeted pallid sturgeon were captured in 16 of the 56 (29%) attempts. Capture probability of an individual drift (p_i) for both size classes (pooled) ranged from 0.00 to 0.11 (Table 3.3). The probability of capture in multiple drifts (p_i^*) increased from 0.07 in one drift to 0.32 in five drifts (Table 3.3; Figure 3.2).

Table 3.3. Probabilities of successful capture of pallid sturgeon in individual trammel net drifts (Pi) and cumulative probabilities of successful capture in multiple trammel net drifts (Pi*) by size class (small: 339-500 mm FL, large: 564-1,105 mm FL, and pooled: 339-1,105 mm FL).

		Attempts				
Fish size	Drift	Successful	Unsuccessful	Total	P_i	P_i^*
Small	1	2	29	31	0.06	0.06
	2	2	26	28	0.07	0.13
	3	3	21	24	0.13	0.24
	4	2	18	20	0.10	0.32
	5	0	18	18	0.00	0.32
Large	1	2	23	25	0.08	0.08
	2	1	22	23	0.04	0.12
	3	2	18	20	0.10	0.21
	4	1	12	13	0.08	0.27
	5	1	7	8	0.13	0.36
Pooled	1	4	52	56	0.07	0.07
	2	3	48	51	0.06	0.13
	3	5	39	44	0.11	0.23
	4	3	30	33	0.09	0.30
	5	1	25	26	0.04	0.32

Small pallid sturgeon were captured in nine of the 31 (29%) attempts. All nine of these individuals were captured during the first four drifts. Capture probability (p_i) was greatest for the third drift (0.13), followed by the fourth drift (0.10), second drift (0.07), and the first drift (0.06; Table 3). The probability of capture in multiple drifts (p_i^*) increased from 0.06 in one drift to 0.32 in four or more drifts (Table 3.3; Figure 3.2).

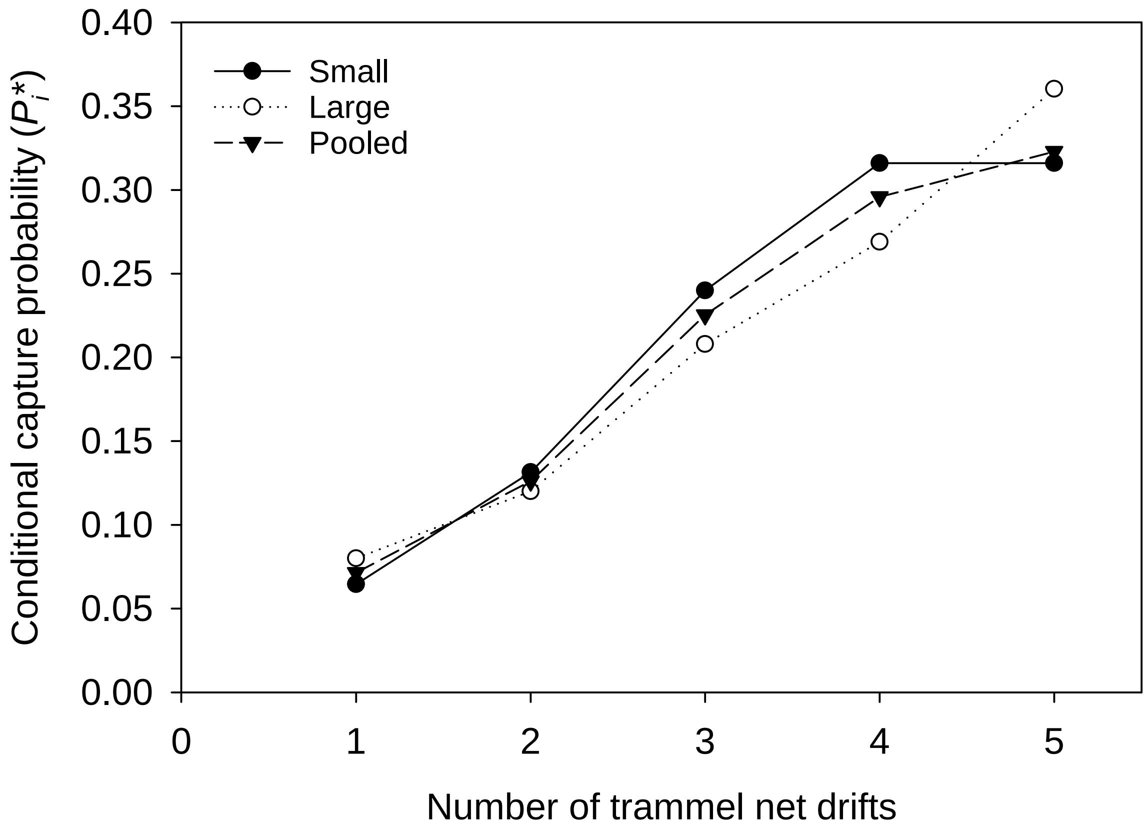


Figure 3.2. Conditional capture probabilities of pallid sturgeon in multiple trammel net drifts (P_i*) in the Missouri River downstream of Fort Randall Dam, South Dakota, by size class (small: 339-500 mm FL, large: 564-1,105 mm FL, and pooled: 339-1,105 mm FL).

Large pallid sturgeon were captured during seven of the 25 (28%) attempts. Capture probability (p_i) was greatest for the fifth drift (0.13), followed by the third drift (0.10; Table 3.3). The probability of capture in multiple drifts (p_i^*) increased from 0.08 in one drift to 0.36 in five drifts (Table 3.3; Figure 3.2).

Fish size and abiotic factors were not significant predictors of the probability of successful capture of pallid sturgeon in trammel nets in the logistic regression model for all attempts (p≥0.16) or the model for the subset of attempts with velocity and turbidity data (p≥0.10; Table 3.4).

Table 3.4. Estimates, SE of estimate, and P-value for each variable of the logistic regression models used to predict successful capture of targeted pallid sturgeon in trammel nets for all attempts and the subset of attempts that velocity and turbidity data were collected.

Variable	Estimate	SE	p-value
All attempts (N=55)			
Intercept	-2.33	1.10	0.03
Size class	0.14	0.63	0.82
Depth (mean)	0.31	0.22	0.16
Depth variability (CV)	0.03	0.04	0.45
Attempts with velocity and turbidity data (N=38)			
Intercept	-7.73	5.41	0.15
Size class	-0.74	0.88	0.40
Turbidity	0.18	0.21	0.39
Depth (mean)	2.28	1.37	0.10
Depth variability (CV)	0.00	0.06	0.97
Velocity (bottom)	11.11	9.23	0.23
Float-lead line torque	-1.77	3.28	0.59
Depth (mean)*Velocity (near bottom)	-3.66	2.42	0.13

Discussion

The conditional capture probabilities of pallid sturgeon in drifted trammel nets in this study were substantially lower than a similar study conducted in Montana. Guy et al. (2009) found that the probability of success of an individual trammel net drift (P_i) ranged from 0.18 to 0.39 for juvenile (521±13 mm FL) pallid sturgeon and ranged from 0.20 to 0.60 for the first three drifts for shovelnose sturgeon (512±37 mm FL). Conversely, the highest probability of a successful capture using a trammel net drift (P_i) in our study was 0.13. Additionally, Guy et al. (2009) found that conditional capture probability (P_i^*) of sturgeon (i.e., pallid sturgeon and shovelnose sturgeon attempts pooled for analysis) reached 0.75 after four drifts, whereas conditional capture probability (P_i^*) was 0.27-0.32 after four drifts in our study.

Differences in trammel net specifications may be responsible, in part, for differences in capture probability between our study and that of Guy et al. (2009). Trammel nets used by Guy et al. (2009) were longer (45.8 m compared to 38.1 m), allowing for a greater margin for error in net placement when drifting over a known fish location. Additionally, the outer mesh (254-mm bar) used by Guy et al. (2009) was slightly larger than the outer mesh of the trammel nets used in our study (203-mm bar). The larger outer mesh likely allowed for larger bags to be formed when fish encountered the net and may have increased the capture efficiency, but the effects of trammel net outer mesh size on sampling efficiency of sturgeon have not been evaluated. In our study on two separate occasions, we observed a suspected telemetry-tagged pallid sturgeon entangled in the trammel net as it was being retrieved to the boat, but then observed the fish escape the net before it could be physically handled by the biologist. These fish were then located approximately 200 m downstream of their previous location, which suggests that the fish was initially entangled in the net as it was drifting, but then escaped the net, possibly because the outer mesh of the net was not large enough to contain it.

Differences in abiotic conditions between sampling areas may also be responsible for differences in capture probability between our study and that of Guy et al. (2009), but the effects of abiotic factors on sampling efficiencies of pallid sturgeon in active gears (i.e., otter trawl and trammel net) are unclear. We did not find associations between the probability of successful capture and depth, velocity, or turbidity. Similarly, habitat parameters did not explain capture success of pallid sturgeon in otter trawls (Steffensen et al. 2015). Guy et al.

(2009) found that the presence of snags, float-lead line torque, and variability in depth were significant in logistic regression models predicting capture of pallid sturgeon in trammel nets, but these models had poor predictive power. Although these studies were unable to make definitive links between capture probabilities and abiotic factors, it is hypothesized that fine-scale habitat conditions (e.g., fish positioned immediately downstream of sand dunes) affect capture probabilities (Guy et al. 2009; Steffensen et al. 2015). Additionally, we did not find an effect of velocity on probability of capture success, but velocity likely affected capture success because there were multiple occasions that the tracking crew confirmed (through use of sonar) that the net was not on the river bottom as it passed under the boat. This suggests that in high-velocity habitats, the trammel nets used in this study may not fish effectively in the first 75-100 m because the water velocity prevented the net from sinking to the bottom of the river before the net reached the fish's location.

On three separate occasions fish were located in locations that would not be accessible during a typical sampling occasion. One location was immediately downstream of a large shallow (<1 m) underwater mud/sand flat covered with numerous exposed large and small woody debris. Any attempts to sample this fish by drifting a net downstream would have likely resulted in numerous failed attempts because the net would have snagged in debris. Another fish was located in a known submerged stump field and any trammel net deployments would have likely been entangled in tree stumps. Additionally, sampling fish in these locations would have jeopardized crew safety and unnecessarily destroyed gear. The third fish was located immediately (<1 m) downstream of the bank line of a large island limiting our ability to successfully deploy and drift the trammel net. These fish locations indicate that some fish are inaccessible to effective sampling with trammel nets despite knowing their exact location within the river.

CHAPTER 4- Post Handling Survival of Age-1+ Hatchery Propagated Pallid Sturgeon Captured with PSPAP Standardized Gear

Pallid sturgeon *Scaphirhynchus albus* are frequently targeted for capture for population monitoring, research, and propagation. The Pallid Sturgeon Population Assessment Team collects pallid sturgeon annually with a variety of sampling gears, including gill nets, trotlines, trammel nets, and otter trawls, to monitor the status of the population and collect broodstock for hatchery propagation (Welker and Drobish 2012a, 2012b). Within the Pallid Sturgeon Population Assessment Program (PSPAP), captured fish are tagged with uniquely-coded PIT tags that allow individuals to be identified for survival, growth, and abundance analyses. Similarly, pallid sturgeon are often captured and implanted with telemetry tags to assess movements and habitat use (DeLonay et al. 2016).

Sampling and tagging effects (e.g., mortality or changes in behavior) can have substantial implications on studies of fish populations. Mark-recapture survival and population abundance analyses and telemetry studies commonly assume that tagged fish behave similarly as untagged fish so that inferences can be made to the entire population (i.e., that sampling and handling of fish does not affect survival or behavior; Hayes et al. 2007; Miranda and Bettoli 2007; Rogers and White 2007). If sampling mortality (or tag loss) occurs and is not accounted for in analyses, then survival rates of the population will be underestimated and abundance will be overestimated (see Pine et al. 2003). Additionally, if sampling and tagging results in mortality or behavioral changes relative to untagged individuals, then inferences made to the entire population would be suspect.

Currently, however, it is unclear how sampling and handling affects pallid sturgeon survival. Therefore, the objective of this study was to evaluate the effects of sampling and handling on survival of pallid sturgeon captured with currently used PSPAP standardized gear.

Methods

We conducted a mark-recapture study to evaluate the effects of capture and handling on pallid sturgeon survival. Pallid sturgeon were captured and implanted with PIT tags (if fish did not already have a tag), and later recaptured from 2003 to 2015 following the sampling design and protocol of the PSPAP (Welker and Drobish 2012a). This analysis was limited to current standard sampling gears within the PSPAP (i.e., gill nets, trammel nets, otter trawls, and trotlines). Gill nets and trammel nets have been deployed since 2003, and otter trawls have been used since 2005. Trotlines were first deployed as an experimental sampling gear in 2009 and became a standard gear in 2010. See Welker and Drobish (2012a, 2012b) for additional information regarding the standardized sampling protocol and gears.

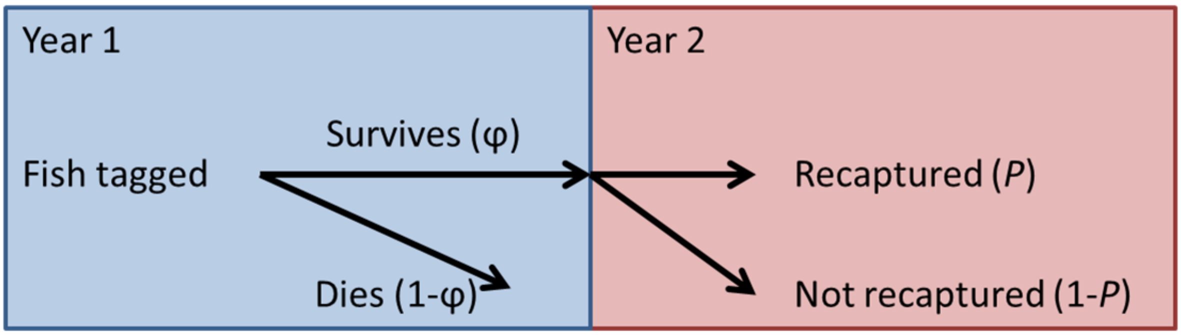
We represented post-sampling/handling mortality hypotheses with Cormack-Jolly-Seber (CJS) live recapture models in Program MARK (White and Burnham 1999). The CJS model uses the apparent survival (ϕ) and recapture (p) probability parameterization (Cooch and White 2008). The illustration below describes how these parameters represent the potential encounter histories of tagged individuals. Program MARK uses maximum-likelihood estimation to identify parameter values for φ and p that maximize the probability of observing the data (Cooch and White 2008). In our study, tag loss and emigration were included in mortality (i.e., 1- ϕ) because data on tag loss and emigration rates were unavailable. Cooch and White (2008) identified multiple assumptions of the CJS model:

1) Every marked animal present at time (i) has the same probability of recapture (p_i),

2) Every marked animal in the population immediately after time (i) has the same probability of surviving to time (i+1),

3) Marks are not lost or missed, and

4) All samples are instantaneous, relative to the interval between occasion (i) and (i+1), and each release is made immediately after the sample.



Summary of probabilities:

Survives year 1 = φ

Dies in year 1 = 1-φ

Recaptured in year 2= *P*

Not recaptured in year 2= 1-*P*

Survives year 1 and is recaptured in year 2= φ*P

Survives year 1 and is not recaptured in year 2= φ*(1-P)

We modeled the effects of capture and handling on survival by allowing survival estimates to differ between the year of capture and subsequent years. Within this framework, we compared combinations of five survival hypotheses and four recapture hypotheses, resulting in 20 candidate models (Table 4.1). Fish were classified into groups based on 1) the gear of initial capture, and 2) the date of their initial capture (January-June, and July-December) to account for potential influences of capture date on water temperature and the length of the first-year survival time period. Within this modeling framework, we assumed: 1) survival probabilities in subsequent years (after initial capture) were constant across years and independent of the initial capture gear, and 2) the effect of initial capture and handling on mortality was similar across years. See Figure 4.2 for an additional example of how model parameters were used to represent hypotheses.

Survival hypotheses included:

1) Survival was constant across years, sampling gears, and sampling seasons (model notation ϕ(.); Table 4.1);
2) Survival was different in the year of first capture than subsequent years (model notation ϕ(Capture); Table 4.1);
3) Survival was different in the year of first capture than subsequent years, and survival during the year of first capture was dependent on sampling gear (model notation ϕ(Capture [gear]); Table 4.1);
4) Survival was different in the year of first capture than subsequent years, and survival during the year of first capture was dependent on sampling season (model notation ϕ(Capture [season]); Table 4.1);
5) Survival was different in the year of first capture than subsequent years, and survival during the year of first capture was dependent on sampling gear and season (model notation ϕ(Capture[gear*season]); Table 4.1).

Recapture hypotheses included:

1) Recapture probability was constant across years (model notation *p*(.); Table 4.1);
2) Recapture probability was constant across years prior to trotlines becoming a standard sampling gear (i.e. 2004-2009), and constant after trotlines became a standard sampling gear (i.e. 2010- 2015), but recapture probability differed between time periods (model notation *p*(TL2010); Table 4.1);
3) Recapture probability was constant across years prior to the use of trotlines as sampling gear (experimental or standard gear; i.e. 2004-2008), and constant after trotline sampling began (i.e. 2009- 2015), but recapture probability differed between time periods (model notation *p*(TL2009); Table 4.1).
4) Recapture probability differed annually (model notation *p*(t); Table 4.1).

Table 4.1. Cormack-Jolly Seber model descriptions and rankings of pallid sturgeon captured in the Fort Randall Reach of the Missouri River from 2003 to 2015. K = number of parameters in model; * indicates that an additional parameter added to account for calculation of Ĉ (Anderson and Burnham 2002).

Model	Model notation		Hypothesis: Apparent survival (φ)	Hypothesis: Recapture (p)	$QAIC_c$	Δ $QAIC_c$	$QAIC_c$ Weights	K*	QDeviance
1	ϕ (.)	p(.)	Survival was constant across years, sampling gears, and sampling seasons	Recapture probability was constant across years	337.63	0.00	0.31	3	121.76
2	ϕ (Capture)	p(.)	Survival was different in the year of first capture than subsequent years	See Model 1	338.99	1.35	0.16	4	121.10
3	ϕ (.)	p(TL2010)	See Model 1	Recapture probability was constant across years prior to trotlines becoming a standard sampling gear (i.e. 2004-2009), and constant after trotlines became a standard sampling gear (i.e. 2010-2015), but recapture probability differed between time periods	339.09	1.46	0.15	4	121.21
4	ϕ (.)	p(TL2009)	See Model 1	Recapture probability was constant across years prior to the use of trotlines as sampling gear (experimental or standard gear; i.e. 2004-2008), and constant after trotline sampling began (i.e. 2009-2015), but recapture probability differed between time periods	339.64	2.01	0.11	4	121.76
5	ϕ (Capture)	p(TL2010)	See Model 2	See Model 3	340.28	2.64	0.08	5	120.37
6	ϕ (Capture [season])	p(.)	Survival was different in the year of first capture than subsequent years, and survival during the year of first capture was	See Model 1	340.76	3.12	0.07	5	120.85

Model	Model notation		Hypothesis: Apparent survival (φ)	Hypothesis: Recapture (*p*)	QAIC$_c$	Δ QAIC$_c$	QAIC$_c$ Weights	K*	QDeviance
			dependent on sampling season						
7	*ϕ* (Capture)	*p*(TL2009)	See Model 2	See Model 4	341.00	3.37	0.06	5	121.10
8	*ϕ* (Capture [season])	*p*(TL2010)	See Model 6	See Model 3	342.22	4.59	0.03	6	120.29
9	*ϕ* (Capture [season])	*p*(TL2009)	See Model 6	See Model 4	342.77	5.14	0.02	6	120.84
10	*ϕ* (.)	*p*(t)	See Model 1	Recapture probability differed annually	348.40	10.77	0.00	14	110.13
11	*ϕ* (Capture)	*p*(t)	See Model 2	See Model 10	349.43	11.80	0.00	15	109.10
12	*ϕ* (Capture [season])	*p*(t)	See Model 6	See Model 10	351.49	13.86	0.00	16	109.09
13	*ϕ* (Capture [gear])	*p*(t)	Survival was different in the year of first capture than subsequent years, and survival during the year of first capture was dependent on sampling gear	See Model 10			N/A		
14	*ϕ* (Capture [gear*season])	*p*(t)	Survival was different in the year of first capture than subsequent years, and survival during the year of first capture was dependent on sampling gear and season	See Model 10			N/A		
15	*ϕ* (Capture [gear])	*p*(.)	See Model 13	See Model 1			N/A		
16	*ϕ* (Capture [gear])	*p*(TL2010)	See Model 13	See Model 3			N/A		
17	*ϕ* (Capture [gear*season])	*p*(.)	See Model 14	See Model 1			N/A		
18	*ϕ* (Capture [gear])	*p*(TL2009)	See Model 13	See Model 4			N/A		
19	*ϕ* (Capture	*p*(TL2010)	See Model 14	See Model 3			N/A		

Model	Model notation	Hypothesis						
		Apparent survival (φ)	Recapture (p)	$QAIC_c$	Δ $QAIC_c$	$QAIC_c$ Weights	K*	QDeviance
	[gear*season])							
20	ϕ (Capture [gear*season]) p(TL2009)	See Model 14	See Model 4			N/A		

Initial Capture Year	Survival (φ) Year											
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2003	**1**	2	2	2	2	2	2	2	2	2	2	2
2004		**1**	2	2	2	2	2	2	2	2	2	2
2005			**1**	2	2	2	2	2	2	2	2	2
2006				**1**	2	2	2	2	2	2	2	2
2007					**1**	2	2	2	2	2	2	2
2008						**1**	2	2	2	2	2	2
2009							**1**	2	2	2	2	2
2010								**1**	2	2	2	2
2011									**1**	2	2	2
2012										**1**	2	2
2013											**1**	2
2014												**1**

Initial Capture Year	Recapture (*P*) Year											
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
2003	**3**	**3**	**3**	**3**	**3**	**3**	4	4	4	4	4	4
2004		**3**	**3**	**3**	**3**	**3**	4	4	4	4	4	4
2005			**3**	**3**	**3**	**3**	4	4	4	4	4	4
2006				**3**	**3**	**3**	4	4	4	4	4	4
2007					**3**	**3**	4	4	4	4	4	4
2008						**3**	4	4	4	4	4	4
2009							4	4	4	4	4	4
2010								4	4	4	4	4
2011									4	4	4	4
2012										4	4	4
2013											4	4
2014												4

Figure 4.2. Diagram of model parameters for Model 5 to illustrate how model structure is used to represent hypotheses. The top panel illustrates that the capture year survival parameter (boldface “1” along diagonal) was modeled with a different parameter from other survival estimates (normal typeface “2”). The bottom panel illustrates that recapture probability (P) from 2004 to 2009 (boldface “3”) differed from 2010 to 2015 (normal typeface “4”) when trotlines became a standard sampling gear.

We assessed the goodness of fit (GOF), represented as $\hat{C}$, of the most-parameterized model in the final candidate with bootstrap GOF tests in Program MARK (Cooch and White 2008). We selected the most conservative of the two $\hat{C}$ estimates available (i.e. observed deviance/ mean deviance of simulations or observed $\hat{C}$/ mean $\hat{C}$ of simulations) to indicate the fit of our models to the data (Cooch and White 2008). A $\hat{C}$ value of 1.00 indicates the data fits the expectations of the CJS model, whereas values greater than 1.00 indicate that the data do not meet the assumptions of the CJS model (i.e. overdispersion; Cooch and White 2008). Given the apparent lack of model fit ($\hat{C}$ = 4.7 for Model 12) we adjusted $\hat{C}$ in our model evaluations and ranked models by Akaike's Information Criterion adjusted for small sample size and overdispersion ($QAIC_c$) scores to determine the most parsimonious model given the data and candidate models evaluated. Equations 1-3 (below) show how AIC, AIC_c (AIC adjusted for small sample size), and $QAIC_c$ are calculated. Models with ΔAIC< 2 are considered to have similar support as the most-supported model (Cooch and White 2008). When 2< ΔAIC<7, there is considerable support that there is a difference between the model and the most-supported model. Finally, if ΔAIC > 7, then there is strong support that there is a difference between the model and the most-supported model. Models that produced unrealistic parameter estimates

$$AIC = -2\ln(L) + 2k \qquad \text{Equation 1;}$$

$$AICc = -2\ln(L) + 2k + \frac{2k(k+1)}{n-k-1} \qquad \text{Equation 2;}$$

$$QAICc = \frac{-2\ln(L)}{\hat{C}} + 2k + \frac{2k(k+1)}{n-k-1} \qquad \text{Equation 3;}$$

where L = model likelihood, k = number of model parameters, n = sample size, and $\hat{C}$ = measure of lack of fit (i.e. variance inflation factor; Cooch and White 2008).

(i.e. 0.00 ≥ ϕ or P ≥1.00, or confidence intervals that ranged from 0.00 to 1.00) of estimable parameters were removed from consideration in the final model candidate set.

Results

From 2003 to 2014, 823 pallid sturgeon were captured and implanted with PIT tags (if they were not previously tagged or had shed their tag); 160 individuals were first captured with gillnets, 164 with otter trawl, 226 with trotlines, and 273 with trammel nets. Of the tagged individuals, 152 (18%) were recaptured on at least one occasion. The number of individuals recaptured at least once was greatest for fish initially captured by otter trawl (N=50; 30%), followed by gill net, (N=37; 23%), trammel net (N=43; 16%), and trotline (N=22; 10%). Average length at first capture (± 95% confidence limit) was smallest for trammel nets (516.1 ± 15.7 mm; range: 213-1,430 mm), followed by otter trawl (551.0 ± 23.0 mm; range: 179-1,100 mm), trotlines (565.7 ± 14.0 mm; range: 378-1,067 mm), and gill nets (579.0 ± 23.3 mm; range: 321-1,437 mm).

The most-supported model (i.e., Model 1; Table 4.1) represented constant survival (i.e., no effect of capture and handling on survival) and recapture probabilities across years, but model rankings were greatly influenced by the adjustment of $\hat{C}$ for lack of model fit. Two models received similar support as Model 1 ($\Delta QAIC_c$ ≤ 2; Models 2-3 in Table 4.1), but the addition of a parameter to represent a separate first year survival rate (Model 2) or a different recapture rate following implementation of trotline sampling (Model 3) did not improve model fit enough [i.e., two log-likelihood units; Anderson (2008)] to overcome the penalty for the addition of the parameter in the AIC calculation (see Equations 1-3). Therefore, we concluded that Model 1 (i.e., constant survival and recapture probabilities) was the most-supported and most-parsimonious model of the candidate models evaluated. Prior to adjustment of $\hat{C}$, the most-supported model was Model 11, which represented an effect of capture on first year survival with time-dependent recapture rates. Models 12 and 10 were also supported ($\Delta AIC < 3$), but the addition of a season effect on first year survival did not improve the fit of Model 12, relative to Model 11, enough to overcome the penalty for the addition of the parameter in the AIC calculation. Meanwhile, the addition of the parameter to estimate first year survival in Model 11 improved model fit, relative to Model 10, enough to justify the including the parameter. Models 13-20 provided unrealistic survival and/or recapture probability estimates or confidence limits, and were not included in our model ranking evaluation (Table 4.1).

Annual apparent survival probability of the most-supported model (i.e., Model 1) was 0.83 (SE=0.06), and annual recapture probability was 0.08 (SE=0.02; Table 4.2). Annual apparent survival probability of the most-supported model prior to the adjustment of $\hat{C}$ (i.e., Model 11) was 0.62 (SE=0.19) during the year of initial capture, and 0.89 (SE=0.07) in subsequent years. Annual recapture probabilities for Model 11 ranged from 0.02 (SE=0.02) to 0.16 (SE=0.07; Table 4.2).

Table 4.2. Survival and recapture probability estimates (SE) of the most-supported Cormack-Jolly Seber models, before (Model 11) and after (Model 1) adjustment for model fit, for pallid sturgeon captured in the Fort Randall Reach of the Missouri River from 2003 to 2015. Cell shading used to identify probabilities that were modeled across multiple parameters. See Table 4.1 for model descriptions.

			First-year survival probability (ϕ)				Subsequent survival probability (φ)	Recapture probability (p)											
Model	Model notation		Gill net	Otter trawl	Trotline	Trammel net		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	ϕ (.)	p(.)	0.83 (0.06)					0.08 (0.02)											
11	ϕ (Capture)	p(t)	0.62 (0.19)				0.89 (0.07)	0.10 (0.15)	0.07 (0.11)	0.06 (0.08)	0.12 (0.09)	0.11 (0.07)	0.15 (0.07)	0.16 (0.07)	0.06 (0.03)	0.07 (0.04)	0.14 (0.06)	0.06 (0.03)	0.02 (0.02)

Discussion

Sampling and handling did not appear to affect pallid sturgeon survival, but further study is warranted. Our most-supported model suggested that survival was not affected by sampling, but the most-supported model prior to adjusting for model fit indicated survival was substantially lower during the year of capture (ϕ = 0.62) than in subsequent years (ϕ = 0.89). Additionally, the percent of fish recaptured varied markedly between initial capture gears (i.e., 10-30%), but this metric may be biased low for fish initially captured with trotlines (10% recaptured) because they had fewer recapture opportunities (relative to fish captured with other gears) due to the recent implementation of trotline sampling. Given the uncertainty in model selection (due to model fit), and the potential magnitude of sampling and handling mortality (0.27; i.e., 0.89 - 0.62) observed in this study, the potential effects of sampling and handling on pallid sturgeon deserve further consideration and study.

Our inability to document effects of sampling and handling on survival may be due to sturgeon physiology, sampling design of the PSPAP, or model fit. Research on paddlefish *Polyodon spathula* and sturgeon *Scaphirhynchus spp.* suggests a lower stress response in these species (i.e., chondrosteans) compared to teleost fishes (Barton 2002). Additionally, the current sampling design and handling protocols used by the PSPAP are intended to minimize stress and take (i.e., mortality) of pallid sturgeon (Welker and Drobish 2012a, 2012b). Finally, poor model fit may have obscured significant effects of sampling on pallid sturgeon survival. Our estimate of $\hat{C}$ was particularly high and greatly influenced our model rankings. Hadley and Rotella (2009) observed $\hat{C}$ = 0.98 for stocked juvenile pallid sturgeon in the same study reach. Additionally, Cooch and White (2008) indicated that values of $\hat{C}$ >2 are generally considered large. As $\hat{C}$ increases, models with fewer parameters are favored in $QAIC_C$ model rankings because as $\hat{C}$ increases (see Equation 3), the importance of model likelihood to $QAIC_C$ is reduced relative to the number of parameters (Cooch and White 2008).

Recapture rates were generally higher in this study than similar pallid sturgeon studies, but survival rates were typically lower those reported in other studies. Recapture rates reported by Hadley and Rotella (2009; p=0.00-0.03) for the same population as this study and Steffensen et al. (2010; p=0.00-0.02) for the population downstream of Gavins Point Dam were considerably lower than our study (p=0.08 for Model 1; p=0.02-0.16 for Model 11). Meanwhile, Steffensen et al. (2010) estimated survival of fish greater than age-1 at 0.92, and Hadley and Rotella (2009) estimated annual survival 2-3 year post stocking at 0.92-0.98.

Differences in parameter estimates between our study and those described above may be due to differences in study design or differences in population dynamics and sampling efficiency between populations. Steffensen et al. (2010) and Hadley and Rotella (2009) tracked stocking cohorts through time, whereas we tracked recaptures of fish captured in the field through time. Therefore, individuals in our study are analogous to a subset of the fish used in those studies that 1) did not emigrate, and 2) survived until they were captured in a sampling gear. Differences in survival and recapture probabilities could also differ between our study and Steffensen et al. (2010) for the lower Missouri River due to differences in sampling efficiency and population dynamics between populations. Downstream emigration from our study area represents a permanent loss to the population, whereas emigration from the lower Missouri River (e.g., to the Mississippi River) may be temporary. Additionally, differences in population dynamics and sampling efficiency may be due to differences in habitat between our study area and the lower Missouri River. For example, Wanner et al. (2007a) suggested that efficiency of commonly used gears to capture pallid sturgeon varied depending on the types of habitat sampled.

CHAPTER 5- Movement Patterns of Pallid Sturgeon in an Inter-Reservoir, Riverine Reach of the Missouri River During a Major Flood Event

Introduction

Pallid sturgeon *Scaphirhynchus albus* was listed by the U.S. Fish and Wildlife Service (USFWS) as an endangered species under the U.S. Endangered Species Act in 1990 (USFWS 1990). The historic range for the pallid sturgeon included the entire Missouri River, the lower Mississippi River from Iowa downstream to Louisiana, and major tributaries of both the Missouri and Mississippi rivers that include the Yellowstone, Platte, Kansas, and St. Francis rivers (Kallemeyn 1983). Anthropogenic actions such as reservoir development in the upper Missouri River and channelization in the lower Missouri and Mississippi rivers are thought to have fragmented and degraded habitat in addition to altering the natural hydrograph, which has led to the population's current limited distribution and reduced abundance (Dryer and Sandoval 1993).

Through the use of telemetry, prior studies examined movements and habitat use of pallid sturgeon in the Missouri and Mississippi basins (Hurley 1999; Bramblett and White 2001; Snook et al. 2002; Swigle 2003; Hurley et al. 2004; Gerrity 2005; Jordan et al. 2006; Wanner et al. 2007b; Gerrity et al. 2008; DeLonay et al. 2009; Koch et al. 2012). These researchers described microhabitat, macrohabitat, and other habitat relationships, movement rates and patterns, seasonal distribution, and emigration under normal flow conditions. Researchers often identified river discharge as 1) greater than, 2) less than, or 3) similar to previous years, or described the river hydrograph as still having a spring pulse. Despite all this research, no specific study has been conducted during a major flood event.

During the spring of 2011, the upper Missouri River basin experienced record inflows as a result of large rainfall that coincided with heavy plains and mountain snowpack. Basin runoff upstream of Sioux City, Iowa, from March to July 2011 totaled 59,700 gigaliters (48.4 million acre-feet), exceeding the system's design by 20 percent (U. S. Army Corps of Engineers [USACOE] 2012) and storage capacity of the system was virtually at capacity (99.5%; USACOE 2012). As a result, the entire Missouri River basin was at or above flood stage for nearly four months and all six mainstem reservoirs experienced record discharges during 2011. Although research has been conducted on pallid sturgeon movement patterns previously, no information exists on movement patterns of pallid sturgeon during abnormally high discharge events such as the one observed in 2011. The goal of our investigation was to determine directionality, extent, and general response of pallid sturgeon to the record discharge that occurred in the Missouri River downstream of Fort Randall Dam during 2011.

Methods

Pallid Sturgeon telemetry

Pallid sturgeon, produced by the U.S. Fish and Wildlife Service (USFWS) at Gavins Point National Fish Hatchery (GPNFH) in Yankton, South Dakota, were implanted with ultrasonic transmitters (Sonotronics, Tucson, AZ) for this study. Two size categories of pallid sturgeon, small (330-629 mm, FL) and large (630-839 mm, FL), were used. Larger transmitters (model CT-05; 63.0 mm in length, 15.6 mm outside diameter, 10.0 g weight) were implanted into large pallid sturgeon while smaller transmitters (model PT-4; 25.0 mm in length, 9.0 mm outside diameter, 2.3 g weight) were put into smaller fish. Each transmitter emitted a unique aural code specific to a frequency (range=70-83 MHz). Prior to surgery, pallid sturgeon were not fed for five days. Surgeries were conducted without using anesthesia, but pallid sturgeon were treated with a 1% salt treatment (flow through) following implantation.

After transmitter implantation, large pallid sturgeon (n=24) were stocked at the Running Water, South Dakota (n=12) and Verdel, Nebraska (n=12) boat ramps on 29 October 2010 (Figure 1.2). All 27 small pallid sturgeon were stocked at the Verdel boat ramp on 13 May 2011.

Pallid sturgeon were first generally located in the river by using an omnidirectional hydrophone (Sonotronics; model TH-2) and receivers (Sonotronics: model USR-08 and USR-96) while moving downstream at 6-8 km/h. Once a transmitter was detected, we used a unidirectional hydrophone (Sonotronics: model DH-4) and the sensitivity (i.e. gain) adjustment capability of the receiver to locate the transmitter's signal origin. Accuracy using this technique was estimated at 6.5 m (SE=0.2; James et al. 2014). We recorded the location (latitude and longitude; decimal degrees) with a WAAS enabled Garmin GPSMAP 168 sounder (Garmin Corporation, Olathe, Kansas). We also measured water depth (m) and classified macrohabitat at each location as braided channel, channel cross-over, confluence area, inside bend, island tip, outside bend, or secondary connected channe (See Welker and Drobish 2012b for descriptions of macrohabitat types).

Because of safety concerns and river-use restrictions due to the high water discharge from Fort Randall Dam, we were only able to track pallid sturgeon on six different occasions between 22 April and 17 November 2011. Tracking events occurred twice in the spring (i.e. ascending limb of the hydrograph), twice near the peak of the hydrograph in July and August, and twice during the descending limb of the hydrograph in the fall. We assessed potential emigration from the riverine reach to Lewis and Clark Lake proper by searching for pallid sturgeon in the reservoir from 27-29 May 2011 and in the Missouri River downstream of Gavins Point Dam to 1.6 rkm downstream of the Vermillion River on 22 September 2011.

Data Analyses

Movement patterns were summarized in two ways. Total, or gross, movement was defined as the sum of all the recorded distances moved by an individual fish during its tracking period, regardless of upstream or downstream direction (Brown et al. 2001; James et al. 2007). Net movement was defined as the sum of all movements made during an individual fish's tracking period, where upstream movements were given a positive value and downstream movements a negative value (Brown et al. 2001, James et al. 2007). Positive and negative values were summed to provide net movement.

Delineation of pre- and post-peak flood event were defined as the period of time prior to 4,500 m^3s^{-1} (Pre: 15 May-22 July) to the remainder of the study period (Post: 23 July-18 November). Hourly discharge records were obtained from Fort Randall Dam for water years 2000 to 2011 from the USACOE, Northwest Division, Missouri River Basin Water Management Division, Omaha, Nebraska. The effects of discharge on gross and net movement were analyzed with linear regression. Linear regression was also used to assess the relation of net movement between successive relocations and the net change in discharge over that time period. Analysis of variance was used to assess bottom depth used between small and large fish. Statistical significance was set to α=0.10 for all statistical tests.

Results

Prior to the 2011 flood, mean daily discharge from Fort Randall Dam ranged from 14-1,373 m^3s^{-1} and averaged 581 m^3s^{-1} (SE=9.2; Figure 5.2) over a 10-yr time period (1 March to 30 November). During 2011, mean daily discharge was >2,123 m^3s^{-1} for a total of 115 days (i.e. 31 May to 22 September; Figure 5.2). Discharge exceeded 2,832 m^3s^{-1} from 4 June to 27 August, while from 25 June to 31 July, discharge exceeded 4,248 m^3s^{-1}. Extensive floodplain inundation occurred throughout the entire river valley downstream of Sunshine Bottoms (Figure 1.2), which did not occur during the previous 10 years.

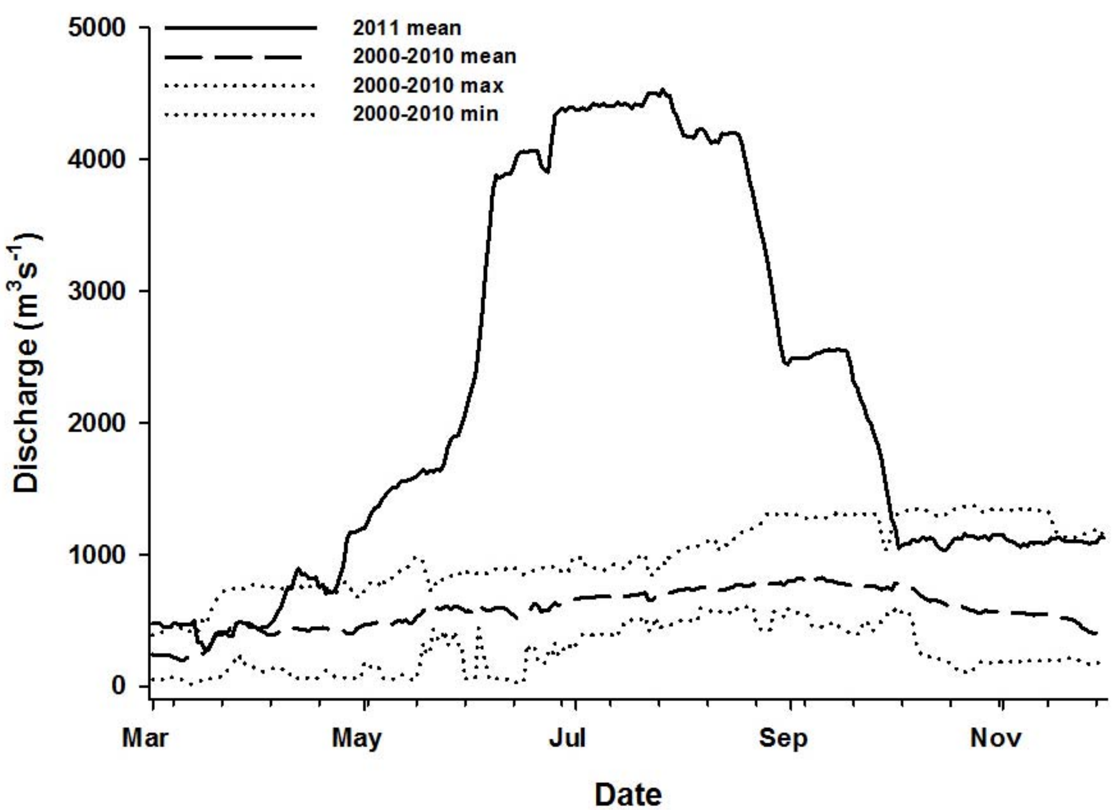


Figure 5.2. Missouri River mean daily discharge from Fort Randall Dam, South Dakota from March 1 to November 30, 2011 (solid line). The maximum (dotted line), minimum (dotted line), and overall mean daily (dashed line) discharges from 2000 to 2010 are also shown.

Pallid Sturgeon Surgery and Telemetry

Large and small pallid sturgeon were surgically implanted with transmitters on 19 October 2010 and 3 May 2011, respectively (Table 1.1). Large pallid sturgeon ranged in length from 564-723 mm (mean=652 mm, SE=10.1) and weighed 700-1,600 g (mean=1,154 g; SE=56.2; Table 1.2). Small pallid sturgeon ranged in length from 352-389 mm (mean=369 mm; SE=1.8) weighed 165-235 g (mean=193 g; SE=3.2; Table 1.2).

After being stocked, 33 individual pallid sturgeon (67% of both large and small) were located at least once; 82% of large (n=18) and 56% of small (n=15) fish were found. Large pallid sturgeon were found 41 times (individual mean=2.3; SE=0.2; range: 1-3) and small pallid sturgeon were found 16 times (individual mean=1.1; SE=0.1; range: 1-2).

Large pallid sturgeon were located primarily in outside bends (36%), but were also located in channel crossovers (21%), large secondary connected channels (15%), braided channels (13%), inside bends (8%), island tips (5%), and confluence (2%) macrohabitats. Small fish were located in the outside bend (50%), inside bend (38%), and channel crossover (12%) macrohabitats. Pallid sturgeon were not located on the inundated floodplain outside of the main or secondary river channel. The mean water depth at river locations where large and small pallid sturgeon were found was not different (ANOVA: $F_{1, 56}$=1.73, P=0.19); mean depth was 6.0 m (SE=0.4) for large and 7.0 m (SE=0.5) for small Pallid Sturgeon locations. Water depth (mean=5.4 m, SE=0.1 range: 1.6-14.0) across all macrohabitat types was similar (ANOVA: $F_{6, 56}$=1.14, P=0.35; Figure 5.3).

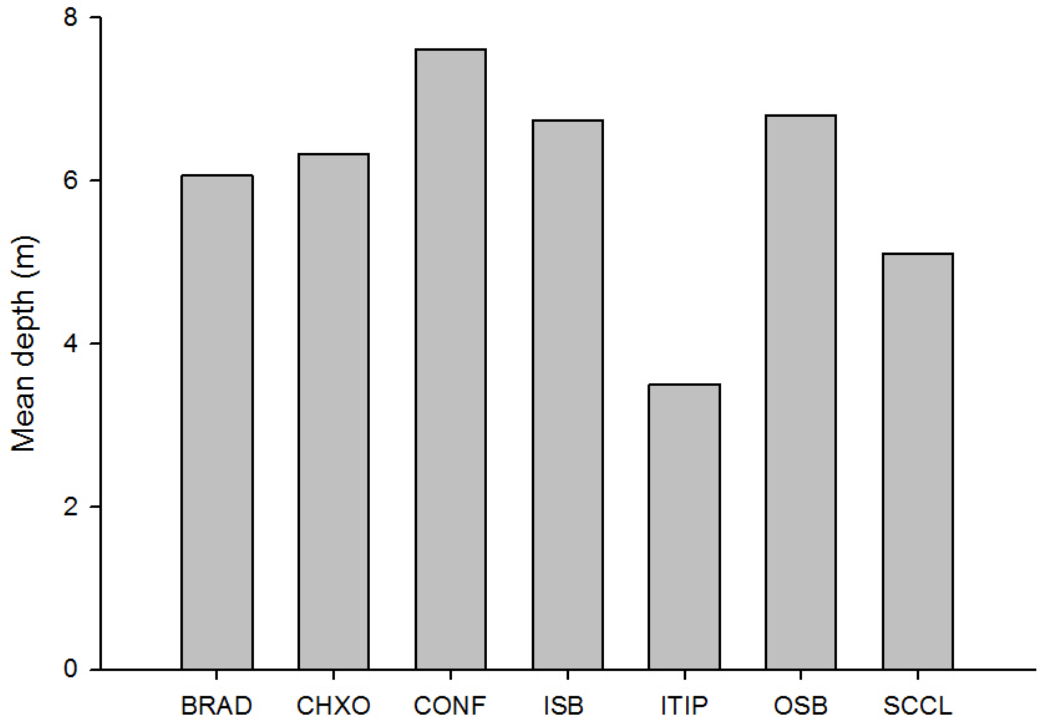


Figure 5.3. Mean water depth where Pallid Sturgeon were relocated by macrohabitat; braided (BRAD), channel crossover (CHX), confluence (CONF), inside bend (ISB), island tip (ISTP), outside bend (OSB) and secondary connected channel large (SCCL).

Pallid sturgeon, particularly large individuals, moved far distances during the 2011 flood. Overall mean gross movement for the entire tracking period was 43.3 km (SE=5.3, range: 13.8-96.6) for large pallid sturgeon and 3.3 km (SE=1.6, range: 0.2-18.5) for small fish. When accounting for directional movement (i.e., mean net movement), large pallid sturgeon net movement was 15.8 km (SE=4.9, range: -18.0-43.6) and small fish net movement was 1.9 km (SE=1.7, range: -3.5-18.5) upstream of their initial stocking location at the end of the tracking period in November.

Gross movement patterns of both size classes of pallid sturgeon were not related to discharge from Fort Randall Dam. Mean gross movement by each survey date (n=6) for both size groups pooled was not significantly related to discharge ($F_{1,5}$=0.383; r^2=0.09, P=0.57). Mean gross movement was not related to discharge for large ($F_{1,5}$=0.295; r^2=0.07, P=0.62) or small ($F_{1,2}$=6.661; r^2=0.87, P=0.24) pallid sturgeon (Figure 4). Additionally, gross movement was not related to change in discharge (i.e., net discharge; Figure 5) for large ($F_{1,4}$=1.395; r^2=0.32, P=0.32) or small ($F_{1,2}$=1.520; r^2=0.60, P=0.43) pallid sturgeon. The mean gross distance traveled for large pallid sturgeon during peak discharge in July and after discharge declined and stabilized in September was 18.7 and 8.4 km, respectively. Largest mean gross movement for small pallid sturgeon was in July.

Associations between net movement of pallid sturgeon and discharge were stronger than that for gross movement. Mean net movement for both size groups pooled was positively related with discharge ($F_{1,5}$=5.577; r^2=0.58, P=0.08). However, mean net movement was not significantly related to discharge for small ($F_{1,2}$=8.713; r^2=0.90, P=0.21) or large ($F_{1,5}$=2.366;

r^2=0.37, *P*=0.20) Pallid Sturgeon alone (Figure 5.4). Net movement of large pallid sturgeon and net discharge over the same time period was positively related ($F_{1, 4}$=177.877; r^2=0.98, *P*<0.001), but net movement of small fish was not significantly related to net discharge ($F_{1, 2}$=1.277; r^2=0.56, *P*=0.46; Figure 5.5).

Pallid Sturgeon were not located in Lewis and Clark Lake or downstream of Gavins Point Dam.

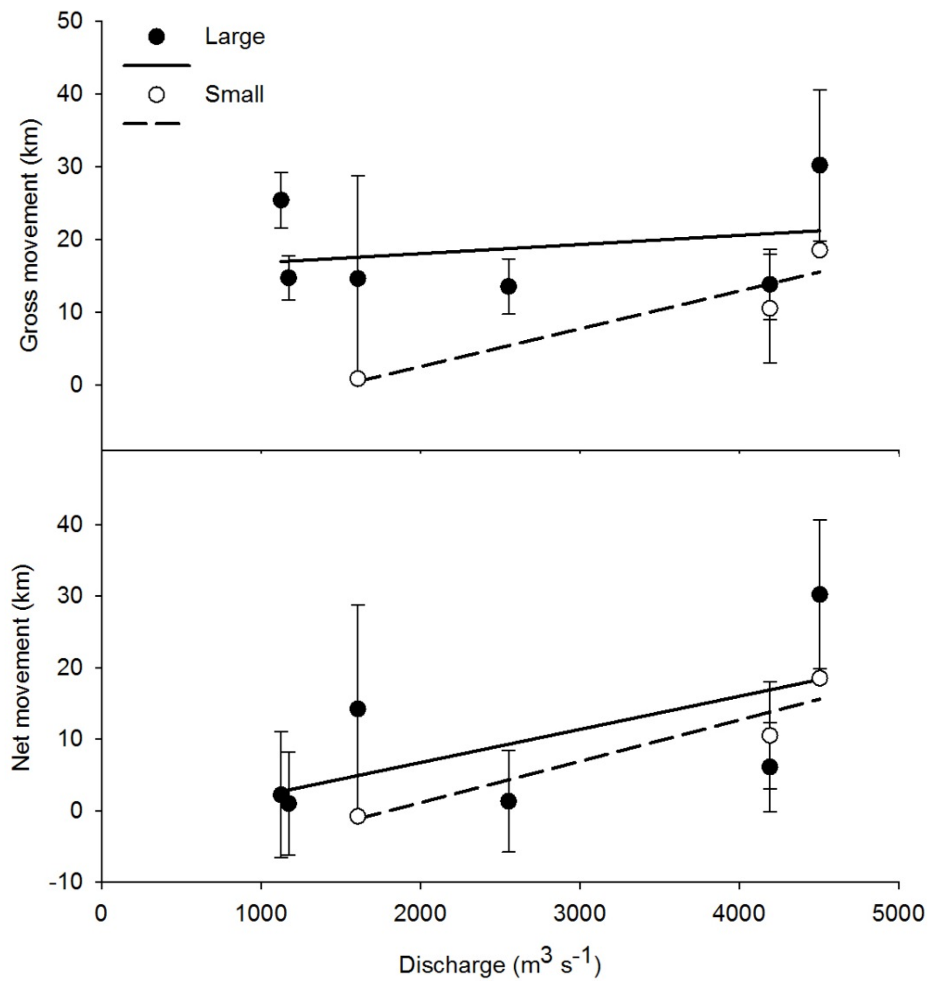


Figure 5.4. Relationship of river discharge to mean gross (upper panel) and net (lower panel) movement of large (closed circles, solid line) and small (open circles, dashed line) pallid sturgeon in the Missouri River downstream of Fort Randall Dam during 2011.

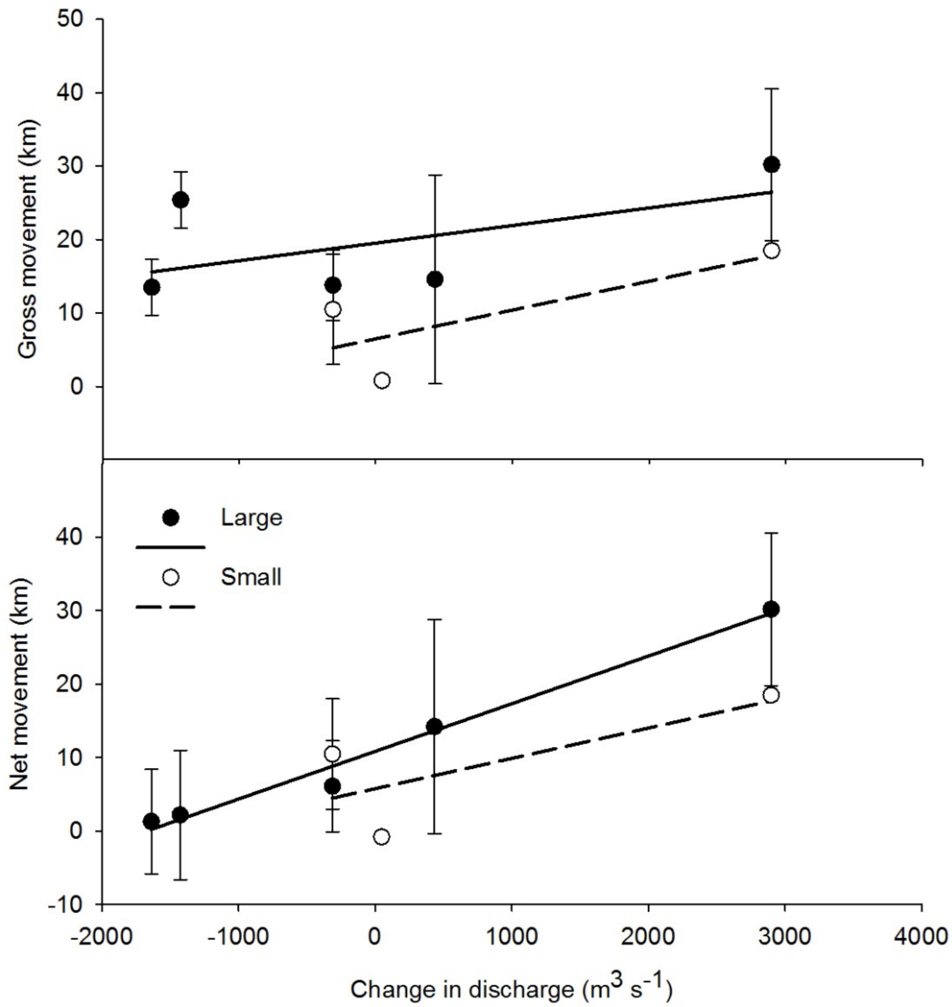


Figure 5.5. Relationship of net river discharge (i.e. change in discharge from one time period to another) to mean gross (upper panel) and net (lower panel) movement of large (closed circles, solid line) and small (open circles, dashed line) pallid sturgeon in the Missouri River downstream of Fort Randall Dam during 2011.

Discussion

The upstream gross and net movement of pallid sturgeon during the 2011 Missouri River flood provided little statistical evidence that discharge is a cue for upstream movement, despite the majority of fish being relocated upstream of their initial stocking sites at the end of the tracking period in November. Directional movement (net movement) was positively related to change in discharge for large fish while no statistical relationship was found for small fish which is likely influenced by the limited number of relocated small fish. Additionally, the largest mean gross movement for large and small pallid sturgeon both occurred during July, the period of greatest discharge.

We found 67% of large pallid sturgeon at least once during the flood period. A similar percentage of tagged fish (ages 3-6) were found by Jordan et al. (2006) during more “normal” discharge from 2000 to 2002. However, we only found 56% of small pallid sturgeon after stocking. Potential reasons for this include high mortality, tag failure, detection issues within large flooded areas, or emigration from the study area. We found no evidence of mortality or tag failure, although discovering these issues would be difficult. Transmitter detection issues in the floodplain are one plausible explanation for the small percentage of small pallid sturgeon relocations. At peak flood stage, the river width increased approximately five times its wetted width in some locations, which greatly increased the search area for any fish using the floodplain. In addition, because acoustic telemetry sound signals rely on “line of sight,” tracking on the floodplain was often impeded by manmade structures (e.g., houses, storage sheds, fences) or natural structures (e.g., tree rows, debris piles). Another potential reason is emigration. Although our lake-wide survey of Lewis and Clark Lake in late May two weeks after stocking, and our survey downstream of Gavins Point Dam in late September did not result in detection of tagged fish from our study, a large pallid sturgeon from our study was captured downstream of Gavins Point Dam, approximately 10 rkm upstream of Decatur, Nebraska (rkm 1,118; Nebraska Game and Parks Commission, personal communication) on 29 May 2012. This represented a net downstream movement of approximately 235 rkm from its previous known location on 14 September 2011 in the Fort Randall reach. Furthermore, other pallid sturgeon stocked in the Fort Randall reach have been recaptured by survey crews downstream of Gavins Point Dam from South Dakota and Nebraska to Missouri (Pallid Sturgeon Population Assessment Team, unpublished data). Therefore, we cannot eliminate the possibility that fish emigrated from our study area during the 2011 flood.

Movement rates from the stocking site of small pallid sturgeon two or three days post stocking (mean=0.36 rkm/d; ±SE=0.16) were similar to age-3 and 4 fish intensively tracked by Jordan et al. (2006). Maximum movement rate calculated for the two or three days since stocking for small fish in this study was 1.5 km/d (0.06 km/h) whereas the older fish in Jordan et al. (2006) had median movement rates of 0.03-0.08 km/h during spring and summer. With the exception of two fish, short-term dispersal distances of yearlings from the stocking site were low and generally directed downstream.

Historically, under normal discharge conditions, the spatial distribution of pallid sturgeon captured in annual surveys was generally highest downstream of the Niobrara River (Shuman et al. 2011). However in 2011, gill net, trammel net and trot line surveys completed during May found a majority (77%) of pallid sturgeon captured upstream of the Niobrara River (Shuman et al. 2012). Reasons for this shift in distribution are unknown but most of April and all of May had discharges greater than the maximum values observed from 2000-2010 (Figure 5.2), suggesting upstream movement of the population may be due to atypically high discharges. In a spawning study of shovelnose sturgeon *Scaphirhynchus platorynchus* at varying discharge treatments in the Marias River, Montana, Goodman et al. (2013) found that increased discharge provided the spawning cue for this sympatric surrogate species. Goodman et al. (2013) also suggest that a river specific discharge threshold (e.g., percentage of bankfull discharge) must be achieved to cue spawning, despite suitable water temperature. Record discharges on the Missouri River during 2011 very likely exceeded the discharge threshold to cue upstream movements for pallid sturgeon. The concept of discharge threshold is likely fundamental to understanding fish movements and migratory patterns in the Missouri River and continued research on a magnitude of discharge threshold (e.g., percent increase above normal) needs to be refined for portions of the Missouri River to aid in the natural recruitment of pallid sturgeon.

Prey fish availability may have contributed to the shift in pallid sturgeon distribution observed during 2011. During 2011, the number of fish captured in mini-fyke nets decreased with distance downstream of Fort Randall Dam (Shuman et al. 2013). The observed increase in fish abundance immediately downstream of Fort Randall Dam may have provided an optimal location for foraging during the flood of 2011. Downstream of Fort Randall Dam during 2006, abundance of Diptera and Ephemeroptera were the strongest predictors for juvenile and early adult pallid sturgeon occurrence among the habitat and prey availability variables studied (Spindler et al. 2012). However during 2011, the number of both Diptera and Ephemeroptera collected increased with distance downstream of Fort Randall Dam (Shuman et al. 2013), suggesting that Diptera and Ephemeroptera abundance was not a factor influencing movement.

A wide range of macrohabitats and depths were used by pallid sturgeon during this study. Large pallid sturgeon were located in seven macrohabitat types while small pallid sturgeon were located in only three. Large (36%) and small (50%) pallid sturgeon were both primarily located in outside bend habitats, while the second most often used macrohabitat for large fish was channel crossover and inside bend for small fish. Previous studies on the

Missouri and Mississippi rivers located pallid sturgeon in the main channel habitat 91% (Jordan et al. 2006) and 65% (Hurley et al. 2004) of the time,respectively, but main channel habitat types (e.g., channel crossover, inside bend, outside bend) were not fully differentiated. By pooling our data in a similar fashion, main channel vs side channels, pallid sturgeon were located in the main channel 78% of the time, despite having access to inundated floodplain habitats. Additionally, the minimum depth where pallid sturgeon were located in this study (1.6 m) was deeper than that found by Bramblett and White (2001; 0.6 m) from the upper Missouri River and that found by Jordan et al. (2006; mean=0.7m) in the exact same reach, further suggesting that juvenile pallid sturgeon used deep waters of the main channel despite having access to floodplain habitats.

Mean gross movement of large fish (43.3 rkm) was further than that of small fish (3.3 rkm). Although large fish moved, they ended up only 16 km upstream from their stocking location on average; while on average small fish were only 2 km upstream. Jordan et al. (2006) also reported most fish moving upstream after initial release but concluded that a one year study would have lessened importance of downstream habitats. Fork length of pallid sturgeon used in previously reported telemetry studies ranged between 520-1,600 mm (Bramblett and White 2001, Snook et al. 2002, Hurley et al. 2004, Jordan et al. 2006, Wanner et al. 2007b) with the exception being Gerrity et al. (2008; mean= 51; range 295-615 mm). The different movement patterns between the two size classes could be due to swimming capabilities. Adams et al. (1999) tested swimming stamina of two size classes of juvenile pallid sturgeon and suggested that endurance and swimming speed for the two size categories is likely different. We speculate that the difference in the gross movement rates between large and small fish is likely due to differences in endurance and swimming speed between the size classes, especially during extreme discharge events.

Mean net and gross movement for small and large pallid sturgeon was upstream of their stocking locations. Results of this study showed that movement by large pallid sturgeon, and to a lesser extent small juveniles, responded to increasing flows out of Fort Randall Dam; flows which may have facilitated increased availability of food resources upstream of the Niobrara River.

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