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An initial assessment of sampling procedures for juvenile pallid sturgeon in the Missouri River downstream of Fort Randall Dam, South Dakota and Nebraska

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Summary

We compared the effectiveness of passive gill nets, hoop nets, set lines, and drifted trammel nets, towed beam trawls and otter trawls to develop criteria to best determine the mean catch per unit effort (CPUE) for juvenile pallid sturgeon (*Scaphirhynchus albus*) based on selectivity and seasonal efficiency in various habitats of the Missouri River downstream of Fort Randall Dam, South Dakota. Sampling occurred from April to November in 2003 and 2004 and from March to November in 2005. We captured 29 juvenile pallid sturgeon in a total of 498 overnight gill net sets, 55 in 870 drifted trammel nets, 19 on 1683 set lines, and six in 166 otter trawl tows. No pallid sturgeon were captured in 515 beam trawl tows or 520 overnight hoop net sets. Seasonal trends in mean CPUE were found and the relative precision was the greatest in October and November for gill nets, in August for trammel nets, in April for set lines, and in October for otter trawls. A higher proportion of pallid sturgeon captures for gill nets were in the inside bend macrohabitat generally associated with lower water velocities, trammel nets over sand substrate and in the outside bend macrohabitat typically associated with higher water velocities and greater depths, set lines in lower water velocities, and otter trawls in depths >2.5 m and over sand substrate. Although we found trends among seasons and habitats for gill nets, trammel nets, set lines, and otter trawls, the catch rates were low and annual point estimates of relative abundance are not adequate to detect changes in relative abundance of juvenile pallid sturgeon in this reach of the Missouri River. Independently, gill nets, trammel nets, and otter trawls likely captured the size structure of the population of pallid sturgeon in the Missouri River downstream of Fort Randall Dam. Based on our results, a standardized protocol can now be established to systematically monitor juvenile pallid sturgeon, an essential element for determining responses to recovery efforts in the Missouri River.

Introduction

The pallid sturgeon (*Scaphirhynchus albus*) was listed as a federally endangered species in 1990. Substantial anthropogenic activities along the Missouri River have blocked fish movement, destroyed or altered spawning areas, reduced prey sources, altered water temperatures, reduced turbidity, and altered the hydrograph, all to the detriment of the pallid sturgeon (U. S. Fish and Wildlife Service (USFWS), 1993). Therefore, the USFWS initiated a stocking program in 1994 to augment pallid sturgeon populations in the lower Missouri River (USFWS, 2005).

The '2000 Missouri River Biological Opinion' (Opinion) addressed the pallid sturgeon as an endangered species in the Missouri River (USFWS, 2000). In response to the Opinion, the U. S. Army Corps of Engineers (Drobish, 2006) developed standard operating procedures for a long-term monitoring program for pallid sturgeon within the Missouri River. However, there is little knowledge of when or where to effectively capture pallid sturgeon. Technical experts from state and federal agencies, universities, and private organizations also identified the need to develop standardized protocols for sampling and monitoring pallid sturgeon at all life history stages (Quist et al., 2004). The Upper Basin Pallid Sturgeon Work Group (2002) similarly identified the need to evaluate sampling techniques and gears, particularly for juvenile pallid sturgeon.

Fisheries managers and researchers require unbiased estimates of fish population characteristics. Sampling techniques should provide a measure of relative abundance, and the fish captured should accurately reflect the size structure of the fish population (Guy et al., 1996; Colvin, 2002; Paukert, 2004). Sampling must also be standardized to obtain precise, unbiased estimates of fish population size and age structure and relative abundance (Allen et al., 1999). Catch per unit effort (CPUE) is often used to index the abundance of a fish population (Hubert, 1996). Whether sampling for fish with passive or active gear, gear bias is evident for various fish species and habitats (Hayes et al., 1996; Hubert, 1996). Sampling data may also be affected by seasonal behaviors in fish populations associated with changes in temperature, dissolved oxygen, turbidity, food supplies, photoperiod, and spawning (Pope and Willis, 1996). Thus, there is a need to identify sampling gears that minimize variation and decrease bias associated with different sampling techniques. Standardized methods will allow direct comparisons of catch statistics among different reaches along the Missouri River and analysis of trends within distinct pallid sturgeon recovery priority management areas (RPMA) through time. Long-term data sets from standardized methods will enable managers to make decisions related to pallid sturgeon stockings, habitat restoration, water use, and main stem dam operations along the Missouri River.

The objective of this study was to determine the precision of mean CPUE for juvenile pallid sturgeon collected with six sampling gears in unique riverine habitats. Knowledge of gear efficiency in various habitats and during different seasons will enable fisheries biologists to better monitor population status and trends. Establishment of baseline relative abundance data through systematic monitoring of populations is an essential element in measuring responses to recovery efforts (USFWS, 1993).

Study site

The Missouri River, upstream of Lewis and Clark Lake and downstream of Fort Randall Dam, South Dakota and Nebraska (Fig. 1), extends approximately 85 km, and has a maximum depth of 12 m and a channel width of 45–90 m. The Pallid Sturgeon Recovery Team determined that the riverine reach upstream of Lewis and Clark Lake near Santee, NE [river kilometer (rkm) 1340] was one of the six RPMA (USFWS, 1993). Identified as RPMA 3, it was selected based on suitable habitat diversity for restoration and recovery of the pallid sturgeon. As a result, the USFWS instituted an annual stocking program in RPMA 3 in 2000 (USFWS, 2005). All hatchery-reared juvenile pallid sturgeon released into RPMA 3 were tagged with passive integrated transponder (PIT), dangler, or elastomer tags. The historical temperature and flow (i.e., the hydrograph) in the riverine section has been altered due to Fort Randall Dam and water levels unnaturally fluctuate, both daily (> 0.75 m) and seasonally (> 1.85 m) (Jordan et al., 2006). In addition, water clarity is much higher than in the historical Missouri River, due to a lack of suspended sediment in the hypolimnetic discharge from Fort Randall Dam, resulting in a degrading channel (National Research Council, 2002) downstream to the confluence of the Missouri and Niobrara rivers (rkm 1351).

Materials and methods

Sampling

Fish sampling occurred monthly (April–November, 2003 and 2004; March–November, 2005) using standardized gears as part of a long-term pallid sturgeon and associated fish community assessment for the Missouri River (Drobish, 2006). The standard gears employed were passive gill nets and hoop nets, drifted trammel nets, and a towed benthic beam trawl and otter trawl. Additionally, we targeted sturgeon with set lines.

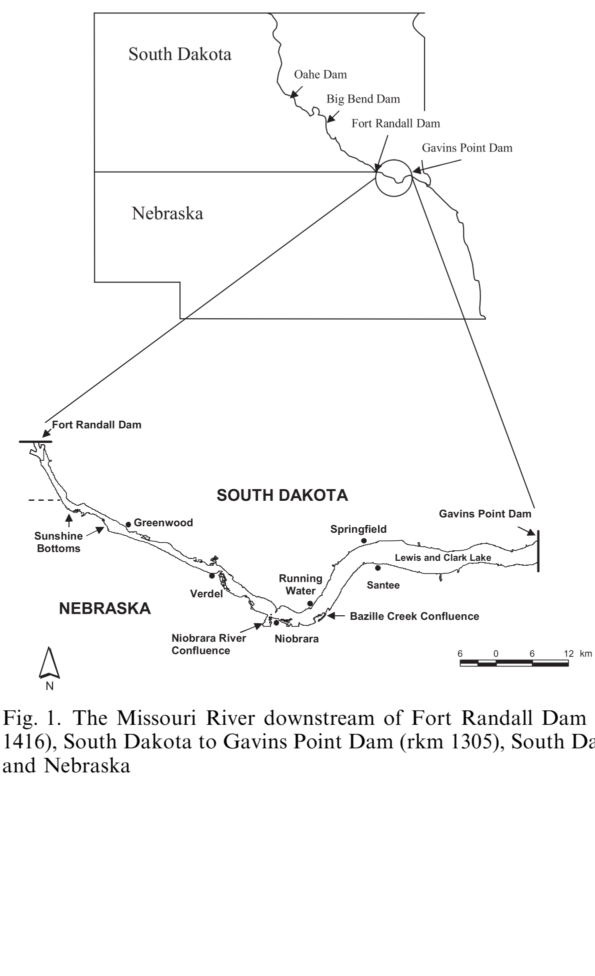

Fig. 1. The Missouri River downstream of Fort Randall Dam (rkm 1416), South Dakota to Gavins Point Dam (rkm 1305), South Dakota and Nebraska

All sturgeon captured were measured for fork length (FL; mm), weighed (g), scanned for PIT tags, and underwent gastric lavage as part of a food habits study (Wanner et al., 2007) before being released. Based on PIT tag codes, we identified the captured pallid sturgeon as juveniles because they exhibit delayed sexual maturation with males maturing after age 7 and females at ages 13–15 (Keenlyne and Jenkins, 1993). We were unable to determine the sex of the sturgeon in the field.

At the beginning of each year, all river bends in the study area were numbered prior to sampling and a minimum of 10 river bends were then randomly selected during each sampling period. Sampling periods were during spring (March–June) and fall (July–November). Specific river bends were also non-randomly sampled because of reports of anglers catching pallid sturgeon. These non-randomly sampled bends were not included in CPUE analyses, but the data were evaluated for variations in size structure of pallid sturgeon among gears.

All macrohabitats and mesohabitats were identified within each selected bend. Eight macrohabitats were identified in the Missouri River downstream of Fort Randall Dam including, outside bend, inside bend, channel crossover, river confluence, braided channel, large secondary connected channel (≥50 m wide), small secondary connected channel (< 50 m wide), and secondary channel non-connected (Drobish, 2006). Within each macrohabitat, mesohabitats were defined as sandbar pools, island tips, and channel borders (Drobish, 2006).

A minimum of eight deployments for each standard gear occurred in each randomly selected bend during each sampling period. A minimum of two samples were taken for each standard gear in the identified macrohabitats within each bend. The gears were deployed at systematic intervals throughout the available macrohabitats in a bend.

Depth (m), temperature (°C), and global positioning system (GPS) locations (latitude; longitude) were recorded at the time and location of all gear deployments. Bottom water velocity (m s^{-1}), turbidity (NTU), and substrate were quantified randomly between the two samples within each macrohabitat. Additionally, these habitat measurements were always taken whenever a pallid sturgeon was captured. The habitat data were collected at the transect midpoint of the beam and otter trawl tow and drifted trammel net after the tow or drift was completed; habitat measurements for passive gears were taken at the location set immediately after gear retrieval (Drobish, 2006).

As part of pallid sturgeon collection protocol (USFWS, 2002), overnight (9–13 h) gill net sets were only deployed when water temperatures remained below 12°C. Gill nets were set from April to May and October to November in 2003 and 2004 and in March and November in 2005. We used experimental multifilament gill nets that were 38 m in length, 1.8 m in depth, with five 8-m long panels with bar mesh sizes, in order, of 2.5, 3.8, 5.1, 7.6, and 10.2 cm, composed of number 139 nylon twine. Float lines were 1.3 cm polyfoamcore and lead lines were 22.7 kg leadcore. Gill nets were set parallel to the flow of the river. The gill net panel (i.e., 2.5 or 10.2 cm bar mesh) set upstream was randomly selected.

Multifilament trammel nets were drifted April through October in 2003, in April, May, July, and October in 2004, and from April through August and in October 2005. Trammel nets were drifted perpendicular to the current for a target distance of 300 m. A GPS unit quantified the actual distance sampled. Trammel nets were 38 m in length, 1.8 m in depth, with outside wall panels of 15.2 cm bar mesh (number 9 nylon twine), and inside wall panels of 2.5 cm bar mesh (number 139 nylon twine). Float lines were 1.3 cm poly-foamcore and lead lines were 22.7 kg leadcore. Typical duration of drift was 5–15 min depending on water velocity.

A beam trawl was towed from April though August in 2003 and in June, August, and October in 2004. In 2003, the beam trawl towed had a height of 0.5 m, a width of 2.0 m, and a length of 5.5 m. The outer chafing net had a bar mesh of 0.6 cm and the inner netting was an 'ace type' nylon mesh having a bar mesh of 0.3 cm with a cod-end opening of 16.5 cm. The beam trawl was towed downstream from the stern of a jet boat attached to a hydraulic winch though an A-frame. The targeted towing distance for each tow was 300 m. Due to the lack of fish captured with this beam trawl design in 2003, a beam trawl with the same dimensions constructed with 'sapphire' twine was towed in 2004. Sapphire twine is a high density polyethylene fiber with hard knots and stiffer mesh making the trawl more resistant to abrasion, and it can be pulled faster with less head pressure compared to regular nylon mesh trawls. Typical duration of tow was 2–3 min.

Otter trawls became a standard gear in 2005, replacing the beam trawl after two successive years of limited captures of any fish species. An otter trawl was towed downstream from May through June, August, and October in 2005. The otter trawl was a 4.9 m wide by 0.9 m high skate trawl. Otter boards were 38.1 cm high, 76.2 cm long, and weighed 13.6 kg each. The outer chafing mesh was a 'sapphire' twine with a 1.9 cm bar mesh and the inner netting was 0.6 cm bar mesh. The cod-end opening was 0.4 m. The footrope was 4.9 m long having a 4.8 mm diameter chain attached to help maintain contact with the substrate. The headrope was 4.6 m long with floats spaced every 0.9 m. The otter trawl was towed similar to the beam trawl with 38.1 m towlines. Typical duration of tow was 2–3 min.

Hoop nets were set from April through August in 2003, in April, May, July, and October in 2004, and from May through August and in October in 2005. Hoop nets (1.4 m diameter hoop; 4.8 m in length with 3.8 cm bar mesh) were set overnight without bait for 9–13 h.

Set lines with Mustad® Tuna Circle hooks (10/0 and 12/0, O. Mustad and Son Inc., Auburn, NY, USA) were used from April through October in 2003, in April, May, July, and October in 2004, and from May through July and September through October in 2005. Each set line had only one 10/0 and one 12/0 hook. The two different-sized hooks were tied on the set line with half of the set lines having the 12/0 hook at the end of the set line and half with the 10/0 hook tied at the end. Each set line was 2 m in length and was anchored with a 1.4 kg folding grapnel anchor to keep the bait near the river bottom to target benthic fish. The main line was #60 braided nylon twine with hooks tied on 1/0 barrel swivels directly to the main line at 1-m intervals from the anchor. Each set line was baited with earthworms (*Lumbriscus terrestris*) and set overnight for 8–12 h.

Statistical analysis

Mean CPUE was calculated for the passive sampling gear as number of fish/overnight set for each gill net, hoop net, and set line. The mesh or hook size that captured the pallid sturgeon was recorded. Mean CPUE for each drifted trammel net and towed beam trawl and otter trawl was calculated as number of fish/100 m. We used the coefficient of variation (CV = 100 × SD/mean) to compare the relative precision for mean CPUE estimates among gears across the months sampled for each gear. Low sample size resulted in low power (1-β) for statistical analysis of gear effectiveness among habitat types (Wanner, 2006).

We chose a Monte Carlo bootstrap technique (Efron, 1982) to estimate the minimum sample sizes required for mean CPUE for a low-density population of juvenile pallid sturgeon collected with gill nets, drifted trammel nets, set lines, and otter trawls in the Missouri River below Fort Randall Dam, South Dakota. The bootstrap technique was used to randomly resample the CPUE data for each gear using combined 2003–2005 sampling data. Bootstrapping allowed us to estimate the potential error at different sampling effort levels. Because of the high number of zero catches, we $\log_{10}$ (CPUE + 1) transformed the mean CPUE data for all gears. The mean CPUE data were randomly sampled with replacement at increments of 15 (gill net), 25 (drifted trammel net), 50 (set line), or 5 (otter trawl), up to the nearest increment not exceeding the base sample size (gill net, n = 498; drifted trammel net, n = 870; set line, n = 1,683; otter trawls, n = 166). A total of 250 iterations was conducted at each increment, which provided stable estimates of the sample mean. At each increment, the sample mean and variance were estimated with the bootstrap model. We also used the percentile method (Efron, 1982) to provide 90% confidence bands for the mean CPUE from the bootstrap estimates for each gear. Finally, we visually estimated the minimum reliable sample size from scatterplots of variance and 90% confidence bands around the mean CPUE. All Monte Carlo bootstrap analyses were performed using macros in SAS 9.1 software (SAS Institute, 2002). Transformed CPUE data were used for all analyses, but unadjusted CPUE is reported for descriptive statistics.

A Kolmogorov–Smirnov (K-S) test was used to compare cumulative length frequency distributions of pallid sturgeon captured among gears. No more than three simultaneous K-S comparisons (α was not adjusted) were done for an individual gear. We believe that adjusting α for three comparisons would be overly conservative for our analysis and interpretation of length frequency differences among gears in this study. Additionally, a K-S test was used to compare length frequency distributions among five gill-net panels and between the two hook sizes for set lines. Length frequency data for sturgeon captured from 2003 to 2005 were combined to increase sample size. FLs were measured to the nearest mm for all pallid sturgeon captured. The K-S analyses of length frequency distributions were performed with Number Cruncher Statistical Software (NCSS) 2000 (Hintze, 1998). In all comparisons, significance was determined at $\alpha = 0.05$.

Results

The total number of juvenile pallid sturgeon captured from 2003 to 2005 was 130. Based on PIT tag codes, all pallid sturgeon captured were juveniles ranging from 1 to 8 years of age. Sixteen sturgeon were captured without PIT, elastomer, or dangler tags. All were the size of stocked fish and thus were considered hatchery-reared. However, we cannot exclude the possibility of natural recruitment. Twenty-nine juvenile pallid sturgeon were captured in 498 overnight gill net sets, nine were

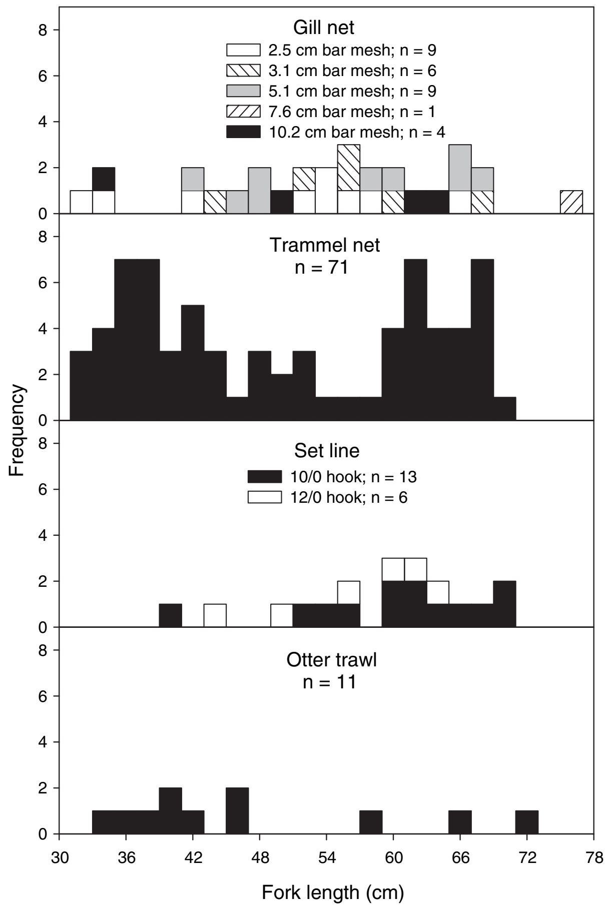

Fig. 2. Fork length frequencies (2-cm length groups) of hatchery-reared juvenile pallid sturgeon captured in experimental gill nets, trammel nets, set lines, and otter trawls in the Missouri River below Fort Randall Dam, South from 2003 to 2005 (combined)

captured in the 2.5-cm mesh, six in the 3.8-cm mesh, nine in the 5.1-cm mesh, one in the 7.6-cm mesh, and four in the 10.2-cm mesh. Fifty-five juvenile pallid sturgeon were captured in 870 trammel net drifts from 2003 to 2005. Nineteen juvenile pallid sturgeon were captured on 1683 set lines, 13 were captured on the 10/0 size hook compared to six on the 12/0 size hook from 2003 to 2004. Six juvenile pallid sturgeon were captured in 166 otter trawl tows in 2005 (Fig. 2). One adult pallid sturgeon (143 cm FL) was captured by a trammel net in June of 2003 near the confluence of Bazille Creek, Nebraska (1350 rkm) (Fig. 1). The adult pallid sturgeon was not included in further analyses. An additional eight juvenile pallid sturgeon in 2003 and eight in 2005 were captured in trammel nets and five were captured in otter trawls that were non-randomly sampled in areas where we previously captured pallid sturgeon. The non-random samples were not used for CPUE, but were included in size structure analyses (Fig. 2). No pallid sturgeon were captured in 515 beam trawl tows from 2003 to 2004, or in 520 overnight hoop net sets from 2003 to 2005.

The mean CPUE was low and CV was high for all gears from 2003 to 2005 across all months (Table 1). The highest monthly gill net mean CPUE in each year was 0.18 fish/net (SD = 0.61) in November 2003, 0.10 fish/net (SD = 0.31) in October 2004, and 0.08 fish/net (SD = 0.34) in November 2005 (Fig. 3). The highest monthly drifted trammel net mean CPUE in each year was 0.14 fish/100 m (SD = 0.36) in August 2003, 0.05 fish/100 m (SD = 0.18) in April 2004, and 0.10 fish/100 m (SD = 0.27) in August 2005 (Fig. 3). The highest monthly mean CPUE for set lines was 0.04 fish/set line (SD = 0.19) in October 2003 and 0.02 fish/set line (SD = 0.14) in April 2004 (Fig. 3). No pallid sturgeon were captured on set lines in 2005. The highest monthly mean CPUE for otter trawls was found in October at 0.04 fish/100 m (SD = 0.10) (Fig. 3). For each gear, the number of juvenile pallid sturgeon captured was associated to the number of gill net, trammel net, set line, and otter trawl samples taken in each season and habitat category (Table 2). However, observed trends were that a higher proportion of pallid sturgeon captures for gill nets were in the inside bend of the river with low water velocities. Most captures in trammel nets occurred in the outside bend, over sand substrate, higher water velocities, and greater depths. Set lines had a higher proportion of sturgeon captures in lower water velocities and otter trawls in depths greater than 2.5 m over sand substrate regardless of water velocity.

The sample variance for juvenile pallid sturgeon mean CPUE in the Monte Carlo bootstrap models declined exponentially as sample size increased for gill nets, trammel nets, set lines, and otter trawls (Fig. 4). Based on the variance of the mean CPUE in relation to the incremental sample sizes, a minimum sampling effort during each sample period should be 105 overnight sets for gill nets, 250 drifts of 100 m for trammel nets, 400 overnight sets for set lines, and 40 tows of 100 m for otter trawls. These minimums represent 'conservative' sample sizes as they were selected at units of effort that clearly were past the inflection point on the variance plots. Additionally, these sample sizes are logistically feasible to obtain. The 90% confidence bands converged exponentially on the sample means as sample size increased (Fig. 5).

No significant differences were found in length frequency distributions of pallid sturgeon captured between gill nets and trammel nets (K-S, P = 0.067), gill nets and set lines (K-S, P = 0.148), gill nets and otter trawls (K-S, P = 0.102). No significant differences were found between trammel nets and otter trawls (K-S, P = 0.703), but significant differences were found between trammel nets and set lines (K-S, P = 0.008). Significant differences were also found between otter trawls and set lines (K-S, P = 0.024). Trammel nets and otter trawls both captured shorter sturgeon compared to set lines (Fig. 2). No significant differences were found in length frequency distributions among gill net panels (K-S, P ≥ 0.167) or between set line hook sizes (K-S, P = 0.553).

Discussion

Mean CPUE of juvenile pallid sturgeon was very low for gill nets, drifted trammel nets, set lines, and otter trawls and no pallid sturgeon were captured by beam trawling or hoop nets. The low catches, a direct result of low population abundance, led to high variability in mean CPUE. Even though we knew the number of hatchery-reared juvenile pallid sturgeon stocked into the Missouri River downstream of Fort Randall Dam, survival is not known for those fish. Thus, it is not possible to determine if the nets caught fish in proportion to their abundance. By October 2005, 3237 hatchery-reared juvenile pallid sturgeon had been stocked into the 111 km stretch of the Missouri River between Fort Randall and Gavins Point dams (USFWS, 2005). Even if we assumed no mortality, immigration, or emigration, which is unlikely, there would only be 29.2 fish rkm^{-1}. We know that emigration occurred as a 424 mm pallid sturgeon that was stocked in RPMA 3 in 2003

Table 1
Summary of juvenile pallid sturgeon catch statistics for gill nets, trammel nets, set lines, and otter trawls in the Missouri River downstream of Fort Randall Dam, South Dakota from 2003 through 2005

	Gill nets				Trammel nets				Set lines				Otter trawls			
Year and month	n	Mean CPUE	SD	CV	n	Mean CPUE	SD	CV	n	Mean CPUE	SD	CV	n	Mean CPUE	SD	CV
2003																
April	24	0.083	0.282	339	50	0.028	0.119	432	127	0.024	0.152	645				
May	20	0	0	0	43	0	0	0	38	0.026	0.162	616				
June					117	0	0	0	65	0	0	0				
July					90	0.011	0.105	949	100	0.020	0.141	704				
August					58	0.135	0.356	263	99	0.020	0.141	700				
September					75	0.010	0.061	612	147	0.014	0.116	854				
October	22	0.091	0.294	324	80	0.014	0.072	517	160	0.038	0.191	508				
November	38	0.184	0.609	330												
Mean	104	0.107	0.418	391	513	0.024	0.143	597	736	0.022	0.146	671				
2004																
April	91	0.022	0.147	670	41	0.049	0.182	374	48	0.021	0.144	692				
May	5	0	0	0	67	0.018	0.089	484	266	0.004	0.061	1630				
June																
July					69	0.025	0.013	406	174	0.006	0.076	1319				
August																
September																
October	20	0.100	0.308	308	17	0.039	0.111	282	75	0	0	0				
November	80	0.038	0.191	510												
Mean	196	0.036	0.186	521	194	0.029	0.120	413	563	0.005	0.073	1367				
2005																
March	70	0.029	0.168	587												
April	28	0	0	0	15	0.061	0.235	387								
May					46	0.009	0.060	678	166	0	0	0	52	0.007	0.052	721
June					16	0	0	0	60	0	0	0	30	0.022	0.085	381
July					6	0	0	0	78	0	0	0				
August					32	0.102	0.265	260					56	0	0	0
September									52	0	0	0				
October					48	0.081	0.208	256	28	0	0	0	28	0.035	0.102	294
November	100	0.080	0.339	423												
Mean	198	0.051	0.262	518	163	0.052	0.183	351	384				166	0.012	0.063	519

Sampling effort (n) is the number of overnight sets for gill nets and set lines and the number of trammel net drifts and otter trawl tows.
Untransformed mean catch per unit effort (CPUE) is the number of fish/overnight set for gill nets and set lines and number of fish/100 m drift for trammel nets or tow for otter trawls.
The coefficient of variation (CV $= 100 \times$ SD/mean) represents the relative precision for each gear.

was captured 90 rkm below Gavins Point Dam in May 2006 (S. Stukel, South Dakota Department of Game, Fish and Parks, pers. comm.). Two additional pallid sturgeon stocked into RPMA 3 have been captured over 110 rkm below Gavins Point Dam near Sioux City, Iowa in July 2004 and April 2006 (K. Steffensen, Nebraska Game and Parks Commission, pers. comm.).

The Missouri River below Fort Randall Dam has a diversity of habitats as the main channel meanders across a wide floodplain with side channels connecting many backwater areas, making it difficult to capture sturgeon that are relatively low in abundance. However, trends in mean CPUE of juvenile pallid sturgeon in RPMA 3 can now be compared to the baseline data we have collected with standardized gill nets, drifted trammel nets, set lines, and otter trawls.

Seasonal variability in mean CPUE can be attributed to changes in fish behavior, physiology, and environmental factors such as changes in temperature, dissolved oxygen, turbidity, food supplies, and photoperiod (Pope and Willis, 1996). A seasonal pattern was evident during the spring as mean CPUE of juvenile pallid sturgeon for gill nets declined from April to May in both 2003 and 2004 and from March to April in 2005. However, during the fall the mean CPUE decreased from October to November in 2003 and increased from October to November in 2004. Sampling only occurred in November in 2005 where the mean CPUE fell in between the 2003 and 2004 means. Although catches were low, the relative precision of mean CPUE was highest for gill nets in October in 2003 and 2004 and in November in 2005. Therefore, fall may be the best (i.e., most precise) time to sample for juvenile pallid sturgeon with gill nets. From 2003 through 2005, there was evidence of a bimodal pattern in trammel net mean CPUE as there was a peak in April followed by a decline into May and June and then a sharp increase in mean CPUE in August. The relative precision of the mean CPUE in trammel nets was highest in August in 2003 and 2005, which may be the best time to sample for juvenile pallid sturgeon with trammel nets. In 2003, there appeared to be a bimodal pattern in set line mean CPUE, as April and May had similar mean CPUE with no sturgeon captured in June followed by a general increase in mean CPUE from July through October. However, in 2004, mean CPUE was highest in April and then decreased in May where it remained low throughout the remainder of the year. The relative precision of the mean CPUE in set lines was similar in April during both years of sampling and may be the best time of year to sample sturgeon with this gear. Bimodal seasonal patterns in mean CPUE with spring and fall peaks have been found in many lentic fish populations (Pope and Willis, 1996) and in some lotic species in the Missouri River

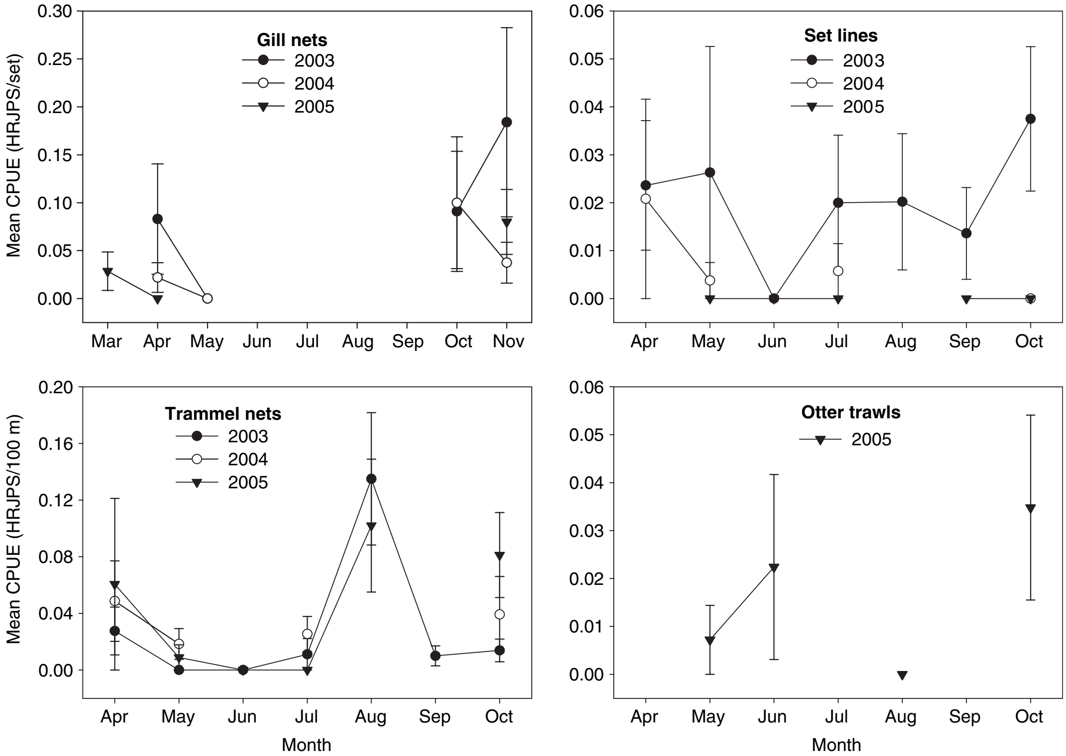

Fig. 3. Monthly mean catch per unit effort (CPUE) and standard error bars for hatchery-reared juvenile pallid sturgeon (HRJPS) captured with experimental gill nets, set lines, trammel nets, and otter trawls in the Missouri River below Fort Randall Dam, South Dakota from 2003 to 2005

below Fort Randall Dam (Jordan and Willis, 2001). Otter trawls were most effective during October of 2005 when relative precision of mean CPUE was greatest. With an increase in the abundance of pallid sturgeon, either naturally or through stocking programs, further investigation is needed to verify the seasonal trends we observed with each sampling gear.

Because of the high number of zero catches for pallid sturgeon in all sampling gears, a normal approximation of the minimum sampling effort required for a reliable index of pallid sturgeon mean CPUE was not appropriate. Bootstrapping is commonly used to estimate population variances in the absence of conventional parametric estimation assumptions (Noreen, 1989). Bootstrapping has been used to calculate the sample size required to develop fish condition (relative plumpness) standards (Brown and Murphy, 1996) and to evaluate fish population size structure (Vokoun et al., 2001). Bootstrapping procedures using resampling with replacement from our mean CPUE data provided a valid approach to establishing a minimum sampling effort for juvenile pallid sturgeon mean CPUE in RPMA 3. Based on the variance of mean CPUE in relation to the incremental sample sizes, our recommendations of minimums for each sampling gear represent 'conservative' sample sizes as they were selected at units of effort that clearly were past the inflection point on the variance plots. However, based on the high variability in our mean CPUE data, annual point estimates of relative abundance are not adequate to detect changes in abundance of pallid sturgeon. A decline or increase in mean CPUE from 1 year to the next may be cause for concern, but we cannot be certain that it actually indicates an increase or decrease in relative abundance. However, if the trends of increasing or decreasing mean CPUE continue over the long term, then management actions may be justified. Additionally, as the stocking program for pallid sturgeon continues, there should be a continued increase in the abundance of sturgeon, which should result in an increase in mean CPUE and a reduction in sample variance.

Passive gill nets have been used to capture adult and juvenile pallid sturgeon (Erickson, 1992; Doyle et al., 2005; Steffensen and Mestl, 2005) in the Missouri River. Despite the low abundance of sturgeon, we found that gill nets were effective even though the CV for mean CPUE was high. Because of low sample size, substantial differences in the effectiveness of gill nets to capture sturgeon among habitats and seasons were difficult to detect from 2003 to 2005. However, there were some trends. A high proportion of juvenile pallid sturgeon were captured in bottom water velocities less than 0.4 m s^{-1}, at depths greater than 2.5 m, and in the inside bends of the river compared to the proportion of gill nets set in other habitats. Inside bends generally have lower water velocities so it is possible that gill nets fished more effectively in the lower water velocities. Gill nets were easily set in most areas of the Missouri River. However, in areas of the Missouri River where bottom water velocities exceeded 0.8 m s^{-1}, gill nets were difficult to anchor to the sand substrate. Additionally, large woody substrate carried by the swift current collected on gill nets making them less effective at capturing fish and occasionally destroyed the nets. Another disadvantage of gill nets was they could only be set when river water temperatures remained below 12°C in early spring and late fall, based on the perception that sampling at low temperatures would reduce the potential for killing pallid sturgeon (USFWS, 2002). Currently, there is limited information available on the effects of gill nets on captured pallid sturgeon. Future research is needed to investigate stress levels and the potential for delayed mortality of pallid sturgeon captured in passive gill nets at various water temperatures.

Table 2
Number (n) and percentage (%) of gill net, trammel net, set line, and otter trawl random samples and juvenile pallid sturgeon (JPS) captured in each season and where habitat variables were measured from 2003 to 2005 (combined) in the Missouri River downstream of Fort Randall Dam, South Dakota. Otter trawl sampling occurred only in 2005

	Gill nets				Trammel nets				Set lines				Otter trawls			
Category	No. of sets	% of sets	No. of JPS	% of JPS	No. of sets	% of sets	No. of JPS	% of JPS	No. of sets	% of sets	No. of JPS	% of JPS	No. of sets	% of sets	No. of JPS	% of JPS
Depth																
< 2.5 m	180	36	8	28	146	31	18	33	428	27	2	11	76	46	2	33
2.5 m ≤ X < 5 m	264	53	16	55	283	60	21	38	910	56	15	79	68	41	3	50
≥5 m	50	10	5	17	40	9	16	29	273	17	2	11	22	13	1	17
Substrate																
Sand > 75%	156	83	23	85	257	91	48	98	740	79	16	84	51	78	6	100
Sand and ≥25% silt	24	13	4	15	17	6	1	2	166	18	3	16	11	17	0	0
Sand and ≥25% gravel	8	4	0	0	8	3	0	0	31	3	0	0	3	5	0	0
Bottom velocity																
< 0.4 m s^{-1}	104	57	20	77	94	32	19	39	401	42	6	32	30	47	2	40
0.4 m s^{-1} ≤ X < 0.8 m s^{-1}	72	39	6	23	170	57	28	57	494	52	13	68	31	48	3	60
≥0.8 m s^{-1}	7	4	0	0	33	11	2	4	62	6	0	0	3	5	0	0
Season																
Spring (April–May)	238	48	7	24	262	30	12	22	672	35	6	32	52	31	1	17
Summer (June–August)	0	0	0	0	388	45	26	47	773	41	5	26	86	52	2	33
Fall (September–November)	260	52	22	76	220	25	17	31	462	24	8	42	28	17	3	50
Temperature																
< 10°C	301	60	19	66	132	15	8	15	283	15	4	21	0	0	0	0
10°C ≤ X < 20°C	197	40	10	34	446	51	21	38	961	50	9	47	86	52	6	100
≥20°C	0	0	0	0	292	34	26	47	663	35	6	32	78	48	0	0
Turbidity																
< 10 NTU	99	56	19	70	180	65	41	71	434	66	15	94	34	54	2	33
10 NTU ≤ X < 20 NTU	47	27	5	19	69	25	14	24	195	30	1	6	16	25	3	50
≥ 20 NTU	31	18	3	11	27	10	3	5	26	4	0	0	13	21	1	17
Macrohabitat																
Outside bend	140	29	8	28	244	28	20	36	513	27	8	42	28	17	1	20
Inside bend	146	30	12	41	207	24	8	15	544	29	4	21	32	20	1	20
Channel crossover	85	17	6	21	197	23	8	15	374	20	3	16	25	15	1	20
Large secondary channel	50	10	1	3	124	14	8	15	310	17	4	21	14	9	0	0
Braided channel	65	13	2	7	91	11	11	20	135	7	0	0	63	39	2	40
Mesohabitat																
Channel border	438	88	24	82	822	94	53	96	1,612	85	17	89	166	100	6	100
Pool	52	10	3	11	18	2	1	2	233	12	2	11	0	0	0	0
Island tip	8	2	2	7	30	3	1	2	62	3	0	0	0	0	0	0

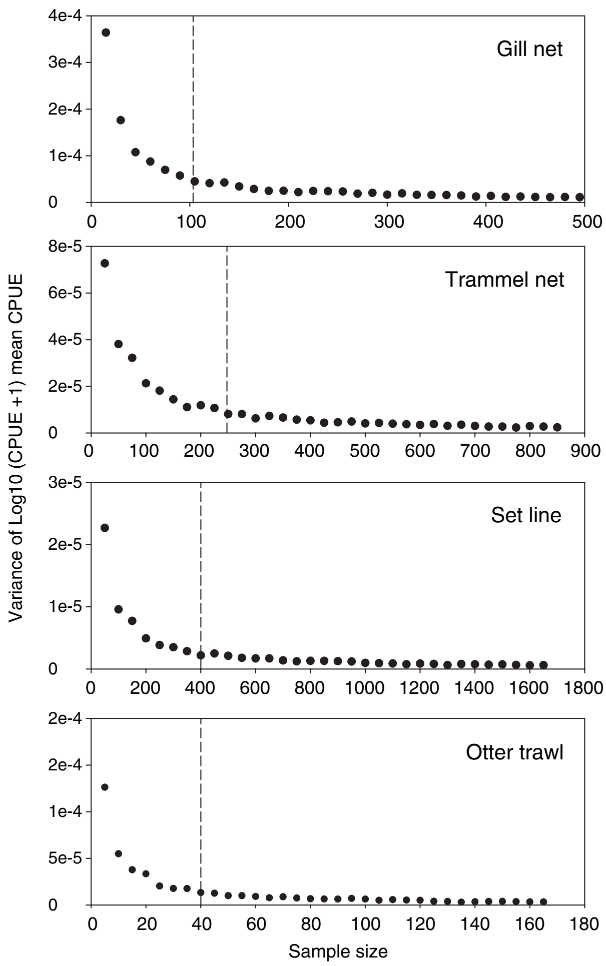

Fig. 4. Variance of mean CPUE in relation to incremental sample sizes from the Monte Carlo bootstrap models for gill nets, trammel nets, set lines, and otter trawls. Vertical dashed line denotes suggested minimum sampling effort for each gear

Drifting trammel nets is a common technique used to capture adult (Carlson et al., 1985; Bramblett and White, 2001; Berry et al., 2004) and juvenile pallid sturgeon (Doyle et al., 2005; Steffensen and Mestl, 2005; Gerrity et al., 2006) in the Missouri River. Low abundance of sturgeon in RPMA 3 resulted in low mean CPUE and associated low precision. However, some trends were detected as a higher proportion of pallid sturgeon were captured at depths greater than 5 m, in the outside bends, and over sand substrate compared to areas with more gravel or silt. Trammel nets likely drift more effectively over sand substrate compared to areas with silt that are usually associated with pools and woody substrate. Large gravel substrate may have slowed the drifting speed of trammel nets. In 2004, there were no pallid sturgeon captured in the inside bends while the majority of pallid sturgeon captures for passive gill nets were in the inside bends. Drifted trammel nets likely were not effectively fishing in the lower water velocities associated with inside bends. In 3 years of sampling, drifted trammel nets collected more juvenile pallid sturgeon than all other gears combined. However, drifting trammel nets in areas of the river with little flow, such as sandbar pools and backwater areas or when releases from Fort Randall Dam were low, was difficult or impossible. Where low flows were encountered, small woody substrate would inhibit the trammel net from drifting and reduced the effectiveness of this gear. In these low flow areas, gill nets, set lines, and otter trawls could be effectively fished. On nearly every trammel net drift, large woody substrate was collected in the net before the target distance of 300 m could be completed. Many times the large woody substrate could be dislodged from the bottom of the Missouri River but nonetheless would effectively reduce the speed at which the net drifted.

Set lines and trot lines have been successfully used to capture adult (Carlson et al., 1985; Erickson, 1992) and juvenile pallid sturgeon (Gerrity et al., 2006) in the Missouri River. We found that set lines were effective in capturing sturgeon even though the CV for mean CPUE was extremely high. Our set line design only allowed the capture of two fish, while our other gears could potentially capture many more fish. An increase in the number of hooks per set line would likely increase the effectiveness of the gear to capture more sturgeon. We found that set lines were easily deployed in most areas of the Missouri River including backwater areas, behind snags, pools, and in the main channel. However, in areas of the Missouri River where bottom water velocities exceeded 0.8 m s^{-1}, it was difficult to keep the set line anchored to the sand substrate. Also during high flows, the drag on the float and line connecting the float to the anchor would pull the float under water, making it difficult to retrieve, especially in turbid water. Larger floats made retrieving the set lines easier, but drag was greater making anchoring to the sand substrate even more difficult. Although no substantial differences were found in the probability of capturing a juvenile pallid sturgeon among seasons, it appeared that more fish, including shovelnose sturgeon (*Scaphirhynchus platorynchus*), were captured in the spring and fall. Set lines rarely had any earthworms remaining on the hook during the summer months when retrieved. Either small fish or benthic invertebrates removed the bait before sturgeon could be captured on the set line. When water temperatures were colder, there was often bait remaining on the hook when the set line was retrieved. Further research is needed to explore different types of bait. All sturgeon captured on set lines were released relatively unharmed with only a small puncture in the mouth.

A benthic Missouri trawl has been successful at capturing adult and larval pallid sturgeon (Herzog et al., 2005). We found that the otter trawl used in our study was also an effective technique to capture juvenile pallid sturgeon. Trends were found as a higher proportion of sturgeon were captured at depths greater than 2.5 m and over sand substrate compared to other habitats. At shallower depths, the jet wash may either frighten the fish or wash the fish out of the effective capture area of the trawl. However, we did attempt to drive the jet boat down river in an S-pattern to avoid this problem. Over sand substrate, the foot rope of the trawl is more likely to follow the contours of the river bottom without collecting gravel in the trawl. Additionally, the otter trawl was effective at capturing sturgeon in any water velocity encountered in the Missouri River, while gill nets, trammel nets, and set lines were affected by water velocity.

No significant differences were found in length frequency distributions of pallid sturgeon captured among gill nets, trammel nets, and otter trawls. However, set lines were more likely to capture larger sturgeon compared to trammel nets and otter trawls. Caution should be used in interpreting comparisons of length frequency distribution between set lines and otter trawls as no pallid sturgeon were captured with set lines in 2005 and otter trawls were first used that year. Gill nets, trammel nets, and otter trawls are all most likely

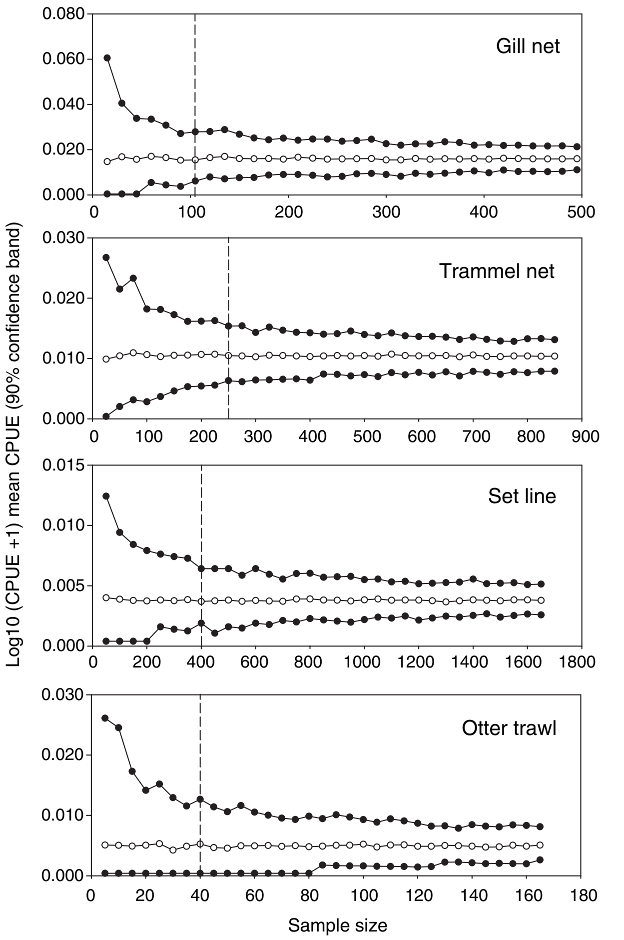

Fig. 5. Sample means (open circles) from simulation analyses with 90% confidence bands (filled circles) represents the 5th and 95th percentiles of mean estimates for gill nets, trammel nets, set lines, and otter trawls. Vertical dashed line denotes suggested minimum sampling effort for each gear

capturing the size structure of the pallid sturgeon population in RPMA 3. The scutes and rostrum on sturgeon made them very susceptible to entanglement in the mesh of the gears. We found no statistical differences in the length frequency distributions of sturgeon captured among gill net panels, but low sample sizes created low power for such analyses. A greater number of sturgeon were captured in the smaller gill net mesh (≤5.1 cm bar mesh). However, as stocked pallid sturgeon recruit to larger sizes in RPMA 3, the larger mesh size will likely capture more larger fish. The slender body form of sturgeon may have allowed small fish to pass through the larger gill net panels. We did not find any significant differences in the length frequency distribution of fish captured between the 10/0 and 12/0 Mustad® Tuna Circle hooks. Circle hooks are designed to hook the corner of the mouth as the fish pulls without the hook being swallowed. Because of the circle hook design, further research is needed to investigate effectiveness of capturing fish with smaller hooks. Smaller hooks may produce more bycatch, but will likely capture smaller juveniles while still capturing larger pallid sturgeon.

We did not capture any pallid sturgeon with hoop nets or beam trawls in the Missouri River downstream of Fort Randall Dam. Hoop nets could be fished in all habitats of the river and were effective in capturing some benthic fishes [i.e., channel catfish (*Ictalurus punctatus*), river carpsucker (*Carpiodes carpio*), smallmouth buffalo (*Ictiobus bubalus*), and blue suckers (*Cycleptus elongates*)] during various seasons of the year. Both the beam trawl with the 'ace' mesh (2003) and 'sapphire' mesh (2004) were ineffective at capturing any substantial numbers of any fish species in any season. In addition, we used both of these trawls at similar times of the year and at the same locations as gill nets, drifted trammel nets, and set lines that did capture juvenile pallid sturgeon.

Although our catches of juvenile pallid sturgeon were low, trends were found for the various gears among seasons and habitats. To be more efficient and reduce variability in mean CPUE data, we make the following recommendations to a standardized sampling program for juvenile pallid sturgeon: (i) use gill nets during the late fall on the inside bend of the river where water velocities are low; (ii) drift trammel nets during late summer over sand substrate in the outside bend where river velocities are high; (iii) use set lines during early spring in lower water velocities and increase the number of hooks per set line; and (iv) tow otter trawls during the fall over sand substrate regardless of water velocity. Hoop nets and the towed beam trawl were not effective at capturing pallid sturgeon in any season on this reach of the Missouri River. Further research is needed to explore modification of the gears used in this study. For example, different twine colors in trammel nets and gill nets may be more effective at capturing pallid sturgeon in rivers with low turbidity. Additionally, different hook sizes and baits on set lines and mesh sizes in trammel nets, gill nets, and the otter trawl need further investigation.

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