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Abstract.—The population of pallid sturgeon *Scaphirhynchus albus* in the lower Missouri River between Gavins Point Dam (river kilometer [rkm] 1,305.2) and the confluence with the Mississippi River (rkm 0.0) remains imperiled, little to no natural recruitment occurring. Artificial propagation and subsequent population augmentation (i.e., stocking) may be the only viable option for maintaining pallid sturgeon populations in the lower Missouri River in the near term. Because relatively little is known about the ability of hatchery-reared pallid sturgeon to survive, the objective of this study was to quantify survival estimates for hatchery-reared pallid sturgeon stocked into the lower Missouri River. We used stock–recapture data collected from 1994 to 2008 to derive survival estimates based on the Cormack–Jolly–Seber model within program MARK. Since 1994, a total of 78,244 hatchery-reared pallid sturgeon have been released and 1% of these have been recaptured. Recapture numbers by size at stocking were as follows: 48 age 0, 730 age 1, and 38 older than age 1. Stocked age-0 hatchery-reared pallid sturgeon had an estimated apparent survival rate of 0.051 (SE = 0.008), compared with 0.686 (SE = 0.117) for age-1 fish and 0.922 (SE = 0.015) for fish older than age 1. Our analysis confirms that hatchery-reared pallid sturgeon can survive in the wild and contribute to the overall population of this species. These estimates should provide critical information for decisions regarding stocking strategies within the lower Missouri River and enable biologists to estimate the number of stocked pallid sturgeon that reach sexual maturity.

The pallid sturgeon *Scaphirhynchus albus* is native to the Mississippi and Missouri river systems (Bailey and Cross 1954; Kallemeyn 1983); because of its declining population, it was listed as federally endangered in 1990 (USFWS 1990). Modification of pallid sturgeon habitat by human activities has blocked fish movement, destroyed or altered spawning areas, reduced food sources or the ability to obtain food, altered water temperatures, reduced turbidity, and changed the hydrograph (Keenlyne and Evenson 1989; USFWS 1993; Pegg et al. 2003). Given these aforementioned anthropogenic modifications, natural recruitment is minimal to nonexistent (Snyder 2000; Hrabik et al. 2007; USFWS 2007).

The short-term recovery objective for pallid sturgeon is the creation of a captive broodstock and stocking program while providing protection of the remaining wild individuals from harm, harassment, or death (USFWS 1993). Artificial propagation and subsequent population augmentation (i.e., stocking) may be the only viable option to maintain pallid sturgeon populations in the lower Missouri River in the near term. Hatcheries that were traditionally used to produce fish for harvest or for supplementation to natural spawning events are now being used to conserve several sturgeon populations (Secor et al. 2000, 2002; Irelands et al. 2002; Smith et al. 2002). Targeted collection efforts for sexually mature wild pallid sturgeon began shortly after the endangered listing, the first successful propagation efforts occurring at the Missouri Department of Conservation's Blind Pony State Fish Hatchery in 1992 (Krentz et al. 2005).

The primary goals of stocking pallid sturgeon in the lower Missouri River are to (1) establish multiple year-classes capable of recruiting to spawning age to reduce the threat of local extirpation; (2) establish or maintain refugia populations within the species' historic range; (3) mimic haplotype and genotype frequencies of the wild populations in hatchery broodstock and progeny; and (4) prevent the introduction of disease into the wild population. The Middle Basin Pallid Sturgeon Work-

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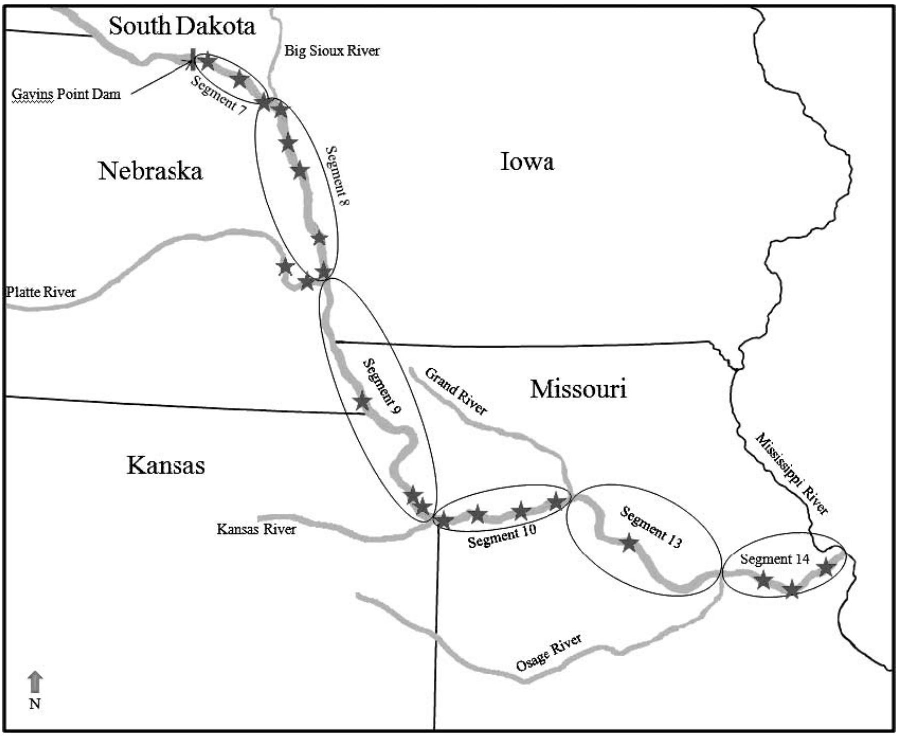

FIGURE 1.—Map of the lower Missouri River from Gavins Point Dam at Yankton, South Dakota (rkm 1,305.2), to the confluence with the Mississippi River at St. Louis, Missouri (rkm 0.0). Stars indicate pallid sturgeon stocking locations.

group recommends a stocking rate of 24.5 age-1 pallid sturgeon per river kilometer per year (USFWS 2008b). To prevent concerns regarding genetic overrepresentation, the number of age-1 pallid sturgeon that can be stocked from a single female is limited to 10,000 (USFWS 2008b).

Stocking rates of pallid sturgeon are based on many factors, including the survival of the individuals stocked into the Missouri River system. Unfortunately, the survival rates of those individuals are unknown. Currently, survival estimates for pallid sturgeon (USFWS 2008b) are based on estimates reported by Irelands et al. (2002) for white sturgeon *Acipenser transmontanus* stocked in the Kootenai River, Idaho. Similar to pallid sturgeon, white sturgeon recruitment ceased after major river alteration when Libby Dam was completed in 1972 (Anders et al. 2002; Irelands et al. 2002). Therefore, the objective of this study was to quantify survival estimates for hatchery-reared pallid sturgeon by age-class in the lower Missouri River.

Methods

The study area included the lower Missouri River from Gavins Point Dam at Yankton, South Dakota (river kilometer [rkm] 1305.2), to the confluence with the Mississippi River at St. Louis, Missouri (rkm 0.0; Figure 1).

Before 2003, minimal sampling was directed at the benthic fish community on the lower Missouri River; from 2003 to 2007, however, three large monitoring programs were initiated on the Missouri River. The Pallid Sturgeon Population Assessment Project Team developed standard operating procedures (SOP) for long-term monitoring of pallid sturgeon and the associated fish community in the Missouri River. Sampling began in March 2003, when the U.S. Army Corps of Engineers (USACE) funded the Nebraska Game and Parks Commission (NGPC)) and the U.S. Fish and Wildlife Service Columbia Fishery Resources Office (CFRO) to sample benthic fishes in the Missouri River from rkm 957.6 to rkm 591.4 and from rkm 402.3 to rkm 0.0, respectively, under the guidelines of these SOPs. Before the start of the 2005 sampling season, the Pallid Sturgeon Population Assessment Project was fully implemented on the lower Missouri River when (1) the South Dakota Department of Game, Fish, and Parks (SDGFP) began sampling from the Gavins Point Dam (rkm 1,305.2) to Ponca, Nebraska (rkm 1211.8); (2) NGPC began sampling from Ponca, Nebraska (rkm 1,211.8), to the confluence of the Platte and Missouri rivers (rkm 957.6); and (3) the Missouri Department of Conservation (MDC) began sampling the lower half of segment 9 and the reach from the Kansas River confluence (rkm 591.4) to the Grand River confluence (rkm 402.3). Also during the summer of 2005, the USACE funded crews from NGPC (to cover 1,148.7–885.8 rkm) and CFRO (to cover 539.4–51.3 rkm) under the Pallid Sturgeon Habitat Assessment and Monitoring Project (HAMP). The Off-Channel Monitoring and Assessment Project started during the 2006 sampling season. This project funded the Iowa Department of Natural Resources (IDNR; for rkm 1,116.9–1,048.8), NGPC (for rkm 1,048.8–948.3), MDC (for rkm 893.0–837.7), and CFRO (for rkm 354.1–186.5) to sample side channels and the backwaters on the lower Missouri River. During 2007, the United State Geological Survey (USGS) and NGPC began a cooperative research project to collect pallid sturgeon and examine their movements by using telemetry (rkm 1,305.2–957.6). Recapture data from all previously mentioned projects were utilized for this analysis.

Sampling regimes and gears followed the individual project's SOPs (Drobish 2008a, 2008b; USFWS 2008a). Pallid sturgeon were examined for passive integrated transponder (PIT) tags, coded wire tags, elastomer marks, and scute removal to determine the origin of the individual (i.e., hatchery-reared or wild; USFWS 2008a). The tagging regime distinguished year-class, stocking site, and stocking size for each individual (Steffensen et al. 2008). If no tags were present at the time of collection, a genetic sample was taken for analysis to determine hatchery from wild origin and to identify year-class (DeHaan et al. 2008). These results provided the individual's stocking history based on parental cross. Fork length (FL) to the nearest millimeter and weight to the nearest gram were recorded.

Hatchery-reared juvenile pallid sturgeon were initially stocked in the lower Missouri River in 1994 (USFWS 2008b). Before being released, hatchery-reared pallid sturgeon were measured and tagged. If large enough to accommodate a PIT tag, each fish was individually measured (FL) to the nearest millimeter and weighed to the nearest gram. However, pallid sturgeon too small for a PIT tag were batch-measured and marked with a combination of coded wire tags, visible implant elastomer (VIE) marks, or scute removal. Unique combinations of marks enabled identification as to year-class, stocking site, stocking size, and age-class (i.e., age 0, age 1, or >age 1). Stocking has continued in our study site, but analyses were terminated with the 2007 cohort.

Pallid sturgeon have been stocked at age 0, at age 1, and as juveniles of multiple advanced ages. Most pallid sturgeon were stocked at age 0 and age 1; however, given the low numbers of pallid sturgeon stocked at age 2, age 3, age 5, age 6, and age 7, we lumped these age-classes into a single category (>age 1) for this analysis. Multiple stocking sites were utilized in the lower Missouri River, based on local biologists' recommendations, to conform to the regulations outlined in the Pallid Sturgeon Range-Wide Stocking and Augmentation Plan (USFWS 2008b).

We used capture histories of each released cohort to estimate annual survival rates; maximum likelihood estimators (MLE) were based on the standard mark–recapture Cormack–Jolly–Seber (CJS) model within program MARK (White and Burnham 1997; Cooch and White 2001). Using 1-year increments to create capture histories resulted in 15 time intervals. Stocking schedules and concern of overwintering mortalities dictated our time intervals, which began on 1 July and ended on 30 June of each year; thus, our apparent survival estimates can be interpreted as the probability of a fish's surviving through this time period, given that the fish does not emigrate from our system. Because CJS estimates of survival are of "apparent survival," emigrating fish cannot be separated from mortalities. Fish were grouped by year-class, stocking site, and stocking size. Only fish that had been at large for 1 year were included in this analysis, which allowed not only an adaptation period for stocked pallid sturgeon but also a better fit into the model. The CJS model assumes that (1) every animal present in the population at sampling time *i* has an equal probability of capture; (2) survival is equal for every marked animal that is present from one sampling period to the next; (3) tags or marks are not overlooked or lost; (4) all animals are released immediately after the sampling period, and all sample periods have a short duration; and (5) all animals behave independently with respect to survival and capture processes (Pollock et al. 2007).

A set of models that corresponded to hypotheses regarding survival and recapture rates for fish in our sample was constructed. Annual changes in sampling effort would be expected to affect recapture rates, so the model allowed recapture rate (the probability of being recaptured in a given time period), *p*, to vary by year (*t*) in all models (p_t). The first hypothesis was that survival (Ø) would vary by size-class ($Ø_{size}$, p_t; sizes: age 0, age 1, and >age 1; Irelands et al. 2002). We constructed age-based models, which allowed fish stocked at age 0 and age 1 to transition to the next age-class (age 1 and >age 1, respectively) by the following time period. Because of the overarching potential effects of size on survival, we compared our age model with a null model (Ø., p_t), in which survival did not

TABLE 1.—Numbers of known hatchery-reared pallid sturgeon stocked and recaptured by year-class and age at stocking in the lower Missouri River from Gavins Point Dam to St. Louis from 1992 to 2006.

Year-class	Age-group	Number stocked	Number recaptured	Percentage recaptured
1992	>1	2,436	14	0.57
1997	>1	35	2	5.71
1997	0	2,018	22	1.09
1999	>1	532	22	4.14
2001	1	7,454	206	2.76
2002	1	9,241	298	3.22
2003	0	5,311	18	0.34
2003	1	4,744	89	1.88
2004	0	30,628	8	0.03
2004	1	8,534	75	0.88
2004	>1	15	0	0.00
2005	1	3,654	51	1.40
2006	1	3,642	11	0.30
	Total	78,244	816	1.04

differ between age classes; however, this model maintained year-specific recapture rates. By comparing the ($Ø_{size}$, p_t) and ($Ø.$, p_t) models, we could determine whether size affected survival rates. Both of these models were also compared against a basic null model ($Ø.$, $p.$), in which survival and recapture rates were constant through time and across all individuals. We used Akaike's information criterion (AIC) adjusted for small sample sizes to compare models (Burnham and Anderson 2002). We used 95% confidence intervals to assess differences between demographic rate estimates for groups.

Results

A total of 78,244 hatchery-reared pallid sturgeon were released from 1994 through 2007 (Table 1). Age-0 fish were reared from 64 to 166 d in the hatchery and were then stocked in September, October, November, or December. Three age-0 year-classes (1997, 2003, and 2004) were stocked and varied in size from 101 to 203 mm FL. Age-1 fish were kept overwinter in the hatchery and were stocked between ages 281 and 496 d. Seven year-classes (2001 through 2007) of age-1 pallid sturgeon were stocked, varying in size from 178 to 496 mm FL. A total of 3,018 >age-1 hatchery-reared pallid sturgeon have been stocked; ages at time of stocking ranged from 626 to 2,521 d. Numbers of fish stocked varied by year-class and ranged from 532 fish for the 1999 year-class to 39,177 fish in the 2004 year-class. The majority ($N = 30{,}628$) of the 2004 year-class were stocked at age 0 (Table 2).

Recapture numbers varied with size at stocking. A total of 1,029 hatchery-reared pallid sturgeon was recaptured from March 1999 to June 2008 in the lower Missouri River; however, 213 fish were excluded from the analysis. Groups removed included 27 pallid sturgeon that were stocked above Gavins Point Dam, 20 fish that had undetermined stocking data because of tag loss, and 166 fish that had been at large for less

TABLE 2.—Numbers of hatchery-reared pallid sturgeon ages 0, 1, and greater than 1 stocked and recaptured in the lower Missouri River from 1993 to 2008. Time periods are 1-year increments from July 1 to June 30.

		Period recaptured										
Period stocked	Number stocked	1998–1999	1999–2000	2000–2001	2001–2002	2002–2003	2003–2004	2004–2005	2005–2006	2006–2007	2007–2008	Total recaptures
						Age 0						
1997–1998	2,018	0	0	0	0	1	3	5	4	4	5	22
2003–2004	5,311							0	1	5	2	8
2004–2005	30,628								3	4	11	18
Total	37,957	0	0	0	0	1	3	5	8	13	18	48
						Age 1						
2001–2002	6,498					0	1	6	36	74	85	202
2002–2003	956						0	1	0	2	2	5
2003–2004	9,241							18	38	66	175	297
2004–2005	11,451								11	38	114	163
2005–2006	3,081									1	0	1
2006–2007	6,042										62	62
Total	37,269					0	1	25	85	181	438	730
						>Age 1						
1993–1994	2,337	1	1	0	0	2	0	1	0	1	6	12
1997–1998	84	0	0	0	0	0	0	0	0	0	2	2
1998–1999	15		0	0	0	0	0	0	0	0	0	0
2001–2002	380					0	0	1	3	4	2	10
2002–2003	187						1	1	5	2	5	14
2005–2006	15									0	0	0
Total	3,018	1	1	0	0	2	1	3	8	7	15	38

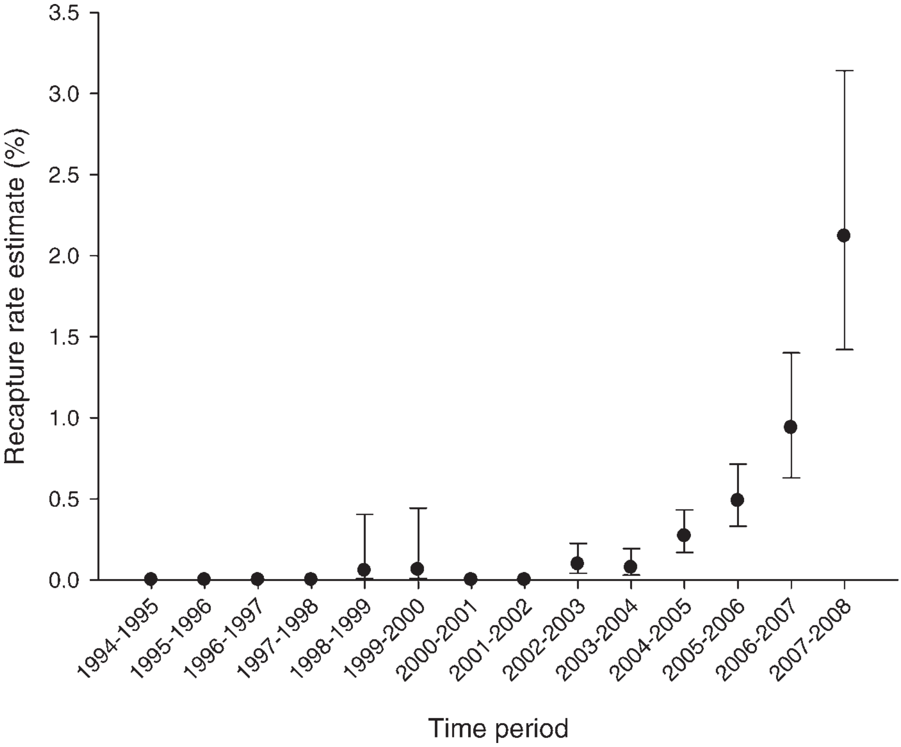

FIGURE 2.—Capture rate probability estimates for known hatchery-reared pallid sturgeon in the lower Missouri River. The estimates were derived from the best model (Table 3), which allowed capture rate to vary by time period. The errors bars represent 95% confidence intervals.

than 1 year. The remaining 816 hatchery-reared pallid sturgeon accounted for 749 unique recaptures (Table 1). Sixty-four fish were collected twice, two fish were collected three times, and one fish was collected four times. One percent of all the hatchery-reared pallid sturgeon stocked was recaptured (Table 2).

The total number of recaptured hatchery-reared pallid sturgeon varied from 0 to 471 within each period (Table 2). In general, capture probability estimates (model: $Ø_{\text{age}}$, p_t) were almost zero during the first 8 time periods (through 2001; Figure 2). Capture probabilities (P) increased slightly during 2002–2004 (2002–2003: $P = 0.0009$, SE = 0.0004; 2003–2004: $P = 0.0007$, SE = 0.0003), and increased during 2004–2008 to a high of 0.021 (SE = 0.004) in 2007–2008.

Survival varied dramatically by age-class, and recapture rates varied by year ($Ø_{\text{size}}$, p_t $w_{\text{AIC}_c} = 1.00$; Table 3; Figures 2 and 3). Survival estimates (model: $Ø_{\text{age}}$, p_t) for hatchery-reared pallid sturgeon increased from 0.051 (SE = 0.008) for age-0 fish to 0.686 (SE = 0.117) for age-1 fish to 0.922 (SE = 0.015) for age-1+ fish.

Discussion

Our data provide the first survival estimates for hatchery-reared pallid sturgeon in the lower Missouri River. Our survival estimates for pallid sturgeon are similar to those reported for white sturgeon in the Kootenai River (Irelands et al. 2002), white sturgeon in the lower Columbia River (Irvine et al. 2007), and pallid sturgeon in the upper Missouri River (Hadley and Rotella 2009). Irelands et al. (2002) estimated a 0.60 survival rate during the first year, approaching 1.00 in subsequent years, whereas Irvine et al. (2007) estimated an overall survival rate of 0.90, and Hadley and Rotella (2009) estimated an annual survival rate of 0.75 for spring-stocked age-1 pallid sturgeon after being at large for 1 year and 0.97 after being at large for 2 years in the Fort Peck–Lake Sakakawea reach of the upper Missouri River (Montana and North Dakota). Our results were similar, indicating survival rates of 0.68 for age-1 pallid sturgeon and 0.92 for fish older than age 1. Unfortunately, age-0 pallid sturgeon survival rates could not be compared with those of white sturgeon because age-0 white sturgeon were not stocked in the Kootenai or Columbia rivers. However,

TABLE 3.—Comparison of competing models of apparent survival (Ø) and recapture (p) of hatchery-reared pallid sturgeon in the lower Missouri River during 1993–2008. Models are ranked by Akaike's information criterion adjusted for small sample sizes (AIC_c); k is the number of parameters, ΔAIC_c is the difference of each model's AIC value from that of the highest-ranked model (first row), and w_{AIC_c} is the Akaike weight (sum of all weights: 1.00). Models varied by whether survival was age specific ($Ø_{age}$) or not (Ø.) and whether recapture rates were year specific (p_t) or not (p.).

Model	k	AIC_c	ΔAIC_c	w_{AIC_c}
$Ø_{age}$, p_t	17	10,451.8	0.0	1.00
Ø., p_t	15	11,266.9	814.9	0.00
Ø., p.	2	11,807.5	1,355.6	0.00

age-0 pallid sturgeon survival estimates (0.05) derived from this analysis were identical to survival estimates for age-0, hatchery-reared, stocked pallid sturgeon in the Fort Peck Dam–Lake Sakakawea reach. We caution that survival estimates might be underestimated as a result of immigration out of the main-stem Missouri River, an indeterminate tagging regime, or tag loss. However, even when tags were shed, genetic analysis allowed some stocking information return.

Kallemeyn (1983) stated that pallid sturgeon are unquestionably rare; however, a portion of this rareness may be due to the inefficiency of sampling methods that are used in large rivers. Recapture data from the monitoring programs indicate that trot lines are an efficient method for collecting pallid sturgeon. Although they have only been utilized for the past 2 years, trot lines have collected 44% ($n = 457$) of all fish collected, and our recapture rates increased dramatically during 2006–2008. Fewer fish were collected with static gill nets ($n = 214$) and active trammel nets ($n = 210$), and recapture rates were lowest during years that crews utilized only these methods. Nonetheless, these netting methods have been utilized since the inception of all pallid sturgeon–related projects. Our results certainly support the continued use of trot lines for sampling pallid sturgeon on the Missouri River.

The mortality rates ($M = 1 - Ø$) estimated by our analyses include natural mortality and mortality from commercial and recreational fishermen, as well as emigration from our system. Thus, our estimates can be used to assess the survival of pallid sturgeon under the threat of mistaken harvest. Bettoli et al. (2009) reported that commercial fisherman mistakenly harvested 29% of the pallid sturgeon they caught in the middle Mississippi River, and indirect evidence suggests that commercial fishing is hampering species recovery efforts. Killgore et al. (2007) also suggested that in the middle Mississippi River, where commercial harvest of shovelnose sturgeon *S. platorynchus* is

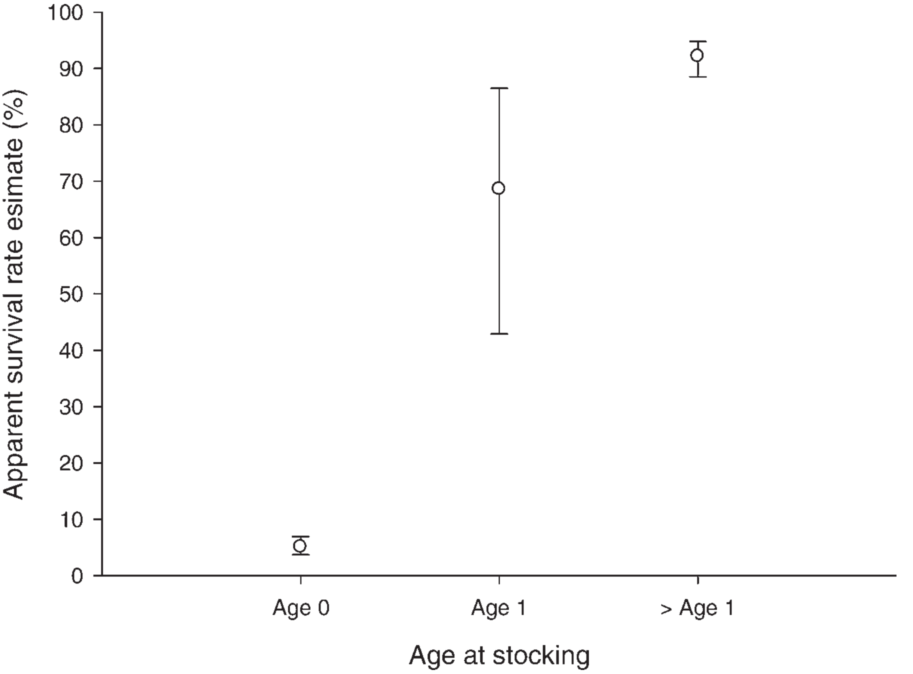

FIGURE 3.—Estimated annual apparent survival rates of hatchery-reared pallid sturgeon in the Missouri River during 1992–2007 for three age-classes. The errors bars represent 95% confidence intervals.

allowed, pallid sturgeon exhibit truncated age and size structure and high annual mortality. Conversely, pallid sturgeon stocks in river reaches closed to commercial sturgeon fishing are characterized by larger, older fish with lower mortality rates (Bettoli et al. 2009). This is a concern for the lower 599.5 km of the Missouri River, where a substantial commercial shovelnose sturgeon fishery exists. Generally, recreational fishermen exhibit the same difficulty distinguishing among the *Scaphirhynchus* species. Peters and Parham (2008) reported that anglers targeting shovelnose sturgeon were able to correctly differentiate shovelnose and pallid sturgeon 87% of the time, whereas other anglers were able to correctly identify the species 66% of the time.

Local biologists need to be conscious of their stocking decisions to increase the likelihood of survival of stocked pallid surgeon. Survival of stocked fish is a function of habitat availability around stocking sites, river conditions (i.e., temperature and discharge) at time of stocking, and disease status (i.e., fin curl or iridovirus affected). We were not able to collect adequate samples of recaptured fish for stratification by stocking reach or segment. In addition, we would expect the ability of individual field crews to collect pallid sturgeon to affect recapture estimates within the study area. Again, the limited number of recaptures prevented us from assessing within-reach or within-segment estimates of recapture. As sample sizes increase through future sampling, we encourage biologists to consider stratifying our study site to look at local-scale effects of stocking and capture on survival and recapture rates. We would also anticipate large-scale estimates of survival to increase in precision as more data are collected, which may refine calculations of the number of pallid sturgeon that could be expected to reach sexual maturity. Finally, inclusion of recapture data from the Mississippi River and other tributaries could provide survival estimates with inference to the entire system; such an approach would also reduce the portion of individuals lost from our regional system to emigration, which in our regional, CJS model structure are assumed to be mortalities.

Given their late sexual maturity and long intervals between spawning, the overall pallid sturgeon population may be only beginning to benefit from this stocking program. While the population remains imperiled, the pallid sturgeon community may be showing early signs of recovery as a result of artificial propagation; however, an increase in the pallid sturgeon population in the lower Missouri River through artificial propagation is only a short-term recovery goal. The long-term recovery goal is a self-sustaining, naturally reproducing population. The survival estimates derived within this analysis were based on artificially produced fish, which may exhibit different survival rates than naturally produced fish. However, our results show that stocked fish can adapt to natural systems, which illustrates the success of the pallid sturgeon propagation and stocking programs.

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References

Anders, P. J., D. L. Richards, and M. S. Powell. 2002. The first endangered white sturgeon population (*Acipenser transmontanus*): repercussions in an altered large-river–floodplain ecosystem. Pages 67–82 *in* W. Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, management, and protection of North American sturgeon. American Fisheries Society, Symposium 28, Bethesda, Maryland.

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

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

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach, 2nd edition. Springer, New York.

Cooch, E., and G. White. 2001. Using MARK: a gentle introduction, 2nd edition. Cornell University, Ithaca, New York.

DeHaan, P. W., G. R. Jordan, and W. R. Ardren. 2008. Use of genetic tags to identify captive-bred pallid sturgeon (*Scaphirhynchus albus*) in the wild: improving abundance estimates for an endangered species. Conservation Genetics 9:691–697.

Drobish, M. R., editor. 2008a. Missouri River standard operating procedures for fish sampling and data collection. U.S. Army Corps of Engineers, Yankton, South Dakota.

Drobish, M. R., editor. 2008b. Pallid sturgeon population assessment project. U.S. Army Corps of Engineers, Yankton, South Dakota.

Hadley, G. L., and J. J. Rotella. 2009. Upper-basin pallid sturgeon survival estimation project. Montana State University, Bozeman.

Hrabik, R. A., D. P. Herzog, D. E. Ostendorf, and M. D. Petersen. 2007. Larvae provide first evidence of successful reproduction by pallid sturgeon, *Scaphirhynchus albus*, in the Mississippi River. Journal of Applied Ichthyology 23:436–443.

Irelands, S. C., R. C. P. Beamesderfer, V. L. Paragamian, V. D. Wakkinen, and J. T. Siple. 2002. Success of hatchery-reared juvenile white sturgeon (*Acipenser transmontanus*) following release in the Kootenai River, Idaho, USA. Journal of Applied Ichthyology 18:642–650.

Irvine, R. L., D. C. Schmidt, and L. R. Hildebrand. 2007. Population status of white sturgeon in the lower Columbia River within Canada. Transactions of the American Fisheries Society 136:1472–1479.

Kallemeyn, L. 1983. Status of the pallid sturgeon *Scaphirhynchus albus*. Fisheries 8(1):3–9.

Keenlyne, K. D., and P. D. Evenson. 1989. Standard and relative weight for the pallid sturgeon (*Scaphirhynchus albus*). Proceedings of the South Dakota Academy of Sciences 2:41–49.

Killgore, K. J., J. J. Hoover, J. P. Kirk, S. G. George, B. R. Lewis, and C. E. Murphy. 2007. Age and growth of pallid sturgeon in the free-flowing Mississippi River. Journal of Applied Ichthyology 23:452–456.

Krentz, S., R. Holm, H. Bollig, J. Dean, M. Rhodes, D. Hendrix, G. Heidrich, and B. Krise. 2005. Pallid sturgeon spawning and stocking summary report, 1992–2004. U.S. Fish and Wildlife Service, Bismarck, North Dakota.

Pegg, M. A., C. L. Pierce, and A. Roy. 2003. Hydrological alteration along the Missouri River basin: a time series approach. Journal of Aquatic Science 65:63–72.

Peters, E. J., and J. E. Parham. 2008. Ecology and management of the sturgeon in the lower Platte River, Nebraska. Nebraska Game and Parks Commission, Technical Series 18, Lincoln.

Pollock, K. H., J. Yoshizaki, M. C. Fabrizio, and S. T. Schram. 2007. Factors affecting survival rates of a recovering lake trout population estimated by mark–recapture in Lake Superior, 1969–1996. Transactions of the American Fisheries Society 136:185–194.

Secor, D. H., V. Arevyev, A. Nikolaev, and A. Sharov. 2000. Restoration of sturgeons: lessons from the Caspian Sea sturgeon ranching program. Fish and Fisheries 1:215–230.

Secor, D. H., P. J. Anders, W. Van Winkle, and D. A. Dixon. 2002. Can we study sturgeons to extinction? What we do and don't know about the conservation of North American sturgeons. Pages 3–10 *in* W. Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, management, and protection of North American sturgeon. American Fisheries Society, Symposium 28, Bethesda, Maryland.

Smith, T. I. J., M. C. Collins, W. C. Post, and J. W. McCord. 2002. Stock enhancement of shortnose sturgeon: a case study. Pages 31–44 *in* W. Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, management, and protection of North American sturgeon. American Fisheries Society, Symposium 28, Bethesda, Maryland.

Snyder, D. E. 2000. Identification of sturgeon larvae collected from the Missouri River at Lisbon Bottoms, MO, 13 August 1998 and 23 July 1999. Larval Fish Laboratory, Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins.

Steffensen, K. D., R. A. Klumb, and W. J. Doyle. 2008. Protocols for tagging and marking hatchery-reared pallid sturgeon in recovery priority management area 4. Middle Basin Pallid Sturgeon Workgroup, Lincoln, Nebraska.

USFWS (U.S. Fish and Wildlife Service). 1990. Endangered and threatened wildlife and plants: determinations of endangered status for the pallid sturgeon. Federal Register 55:173(6 September 1990):36641–36647.

USFWS (U.S. Fish and Wildlife Service). 1993. Recovery plan for the pallid sturgeon (*Scaphirhynchus albus*). USFWS, Bismarck, North Dakota.

USFWS (U.S. Fish and Wildlife Service). 2007. Pallid sturgeon (*Scaphirhynchus albus*) 5-year review: summary and evaluation. USFWS, Billings, Montana.

USFWS (U.S. Fish and Wildlife Service). 2008a. Biological procedures and protocols for researchers and managers handling pallid sturgeon. USFWS, Billings, Montana.

USFWS (U.S. Fish and Wildlife Service). 2008b. Pallid sturgeon (*Scaphirhynchus albus*) rangewide stocking and augmentation plan. USFWS, Billings, Montana.

White, G. C., and K. P. Burnham. 1997. Program MARK: survival estimation from populations of marked animals. Colorado State University, Fort Collins.