ASSESSMENT OF PALLID STURGEON RESTORATION EFFORTS IN THE LOWER YELLOWSTONE RIVER

Annual Report for 2007

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ABSTRACT

It is known that pallid sturgeon successfully spawn in the Yellowstone River downstream of Intake Diversion although long drift times following hatching may preclude recruitment; larval pallid sturgeon likely drift into Sakakawea Reservoir and die. Therefore, establishing spawning populations far upstream of reservoirs is necessary if natural recruitment is to occur. However, no stocking had occurred above Intake Diversion partly because these habitats were considered unsuitable; pallid sturgeon were thought to prefer downstream habitats with lower gradients, wider valleys, and sand substrates. Although stocking downstream of Intake Diversion began in 1998, few recaptures and violation of model assumptions precluded evaluation of the stocking program; no empirically derived survival estimates existed for hatchery-reared pallid sturgeon. To assess suitability of the Yellowstone River above Intake Diversion, post-stocking dispersal patterns of telemetered juvenile hatchery-reared pallid sturgeon released below Rancher and Cartersville diversions were compared to those of fish released below Intake Diversion. A habitat-based sampling design was developed that met model assumptions and yielded adequate recaptures to estimate apparent annual survival of three common stocking categories. Cartersville and Rancher pallid sturgeon dispersed longer distances downstream than Intake pallid sturgeon, although stocking temperature influenced dispersal distance; fish stocked at warmer temperatures dispersed shorter distances downstream. Irrespective of release site, pallid sturgeon dispersed into both higher gradient cobble-gravel reaches and lower gradient fines-sand reaches in River Breaks ecoregions characterized by high complexity and dynamic, natural channel processes. Within these reaches it appeared that telemetered fish preferentially selected bluff pools and selectively sampling this habitat type resulted in catch rates (8.7 fish per hour or 1.6 fish per trammel net drift) 20 to 90 times greater than those of previous sampling designs. Probability of survival to age 2 of summer yearlings (0.19) was higher than that of spring yearlings (0.08) and fingerlings (0.01). Annual probability of survival for summer yearlings increased and stabilized (0.70) by age 4. Survival estimates for all

stocking categories were lower than anticipated and suggest that stocking rates should be increased by an order of magnitude to meet current population targets. Initial results suggest that parts of the Yellowstone River upstream of Intake Diversion are suitable for pallid sturgeon restoration, although establishing pallid sturgeon populations in desirable locations further upstream of reservoirs is unlikely to be successful simply by stocking fish unless suitable habitat also exists and fish are stocked at warm water temperatures.

INTRODUCTION

Pallid sturgeon, a species native to the Yellowstone River, was listed as endangered in 1990. Declines in pallid sturgeon distribution and abundances are attributed to alteration of a natural flow regime and habitat degradation caused by impoundments and channelization throughout the upper Missouri River (Kallemeyn 1983). No recruitment has occurred in Recovery Priority Management Area (RPMA) 2 in at least 30 years and this species will likely be extirpated by 2024 (Klungle and Baxter 2005). Accordingly, recovery efforts have focused on preserving the pallid sturgeon genetic pool through a captive breeding program until habitat restoration permits the re-establishment of self-sustaining populations (U.S Fish and Wildlife Service 2008). Because limited time remains before extant populations senesce, identification of areas and stocking strategies that provide the best opportunity for survival to maturity and successful spawning and recruitment by hatchery-reared pallid sturgeon is essential for continued existence of this species.

Because of its relatively pristine character, including a near-natural hydrograph and associated temperature and sediment regimes, the Yellowstone River provides an excellent opportunity for pallid sturgeon recovery. The importance of natural riverine function is emphasized by the movements and behavior of extant pallid sturgeon; the Yellowstone River may be the only location in RPMA 2 that is used for and supports successful spawning (D. Fuller and M. Jaeger, Montana Fish, Wildlife & Parks, unpublished data; Bramblett and White 2001). However, inadequate larval drift distances between putative spawning areas downstream of Intake Diversion and the headwaters of Sakakawea Reservoir preclude recruitment; larval pallid sturgeon likely drift into the reservoir and die (P. Braaten, U.S. Geological Survey, Fort Peck, Montana, personal communication). Although establishment of spawning populations further upstream is necessary to facilitate successful recruitment, stocking had not occurred in the 356 kilometers between the Big Horn River and Intake Diversion because of concerns that habitats in this reach are unsuitable. Pallid sturgeon were thought to prefer habitats downstream of Intake Diversion with lower gradients, wider valleys, and sand substrates (Bramblett and White 2001). Although wild adult pallid sturgeon historically occupied the reach above Intake Diversion, its suitability for hatchery-reared juvenile pallid sturgeon had not been empirically determined.

Limited information also existed for hatchery-reared pallid sturgeon stocked downstream of Intake Diversion. Although pallid sturgeon were stocked in the Yellowstone River beginning in 1998 their survival had not been empirically assessed; low numbers of recaptures and violation of survival model assumptions precluded data analysis.

Information gaps regarding post-stocking movements and habitat selection limited the development of effective and statistically valid sampling designs. Because survival rates were unknown it was uncertain whether recovery and management goals could be attained by current stocking strategies (U.S Fish and Wildlife Service 2008).

Therefore, the goal of this study is to provide information that will result in formulation of management strategies that most effectively achieve pallid sturgeon recovery in the Yellowstone River. The specific objectives of this study are to 1) compare post-stocking behavior of fish released above Intake Diversion to that of fish released below Intake Diversion, 2) determine habitat selection and annual movement patterns of hatchery-reared pallid sturgeon that have survived at least one winter, 3) develop sampling designs that will provide adequate data to generate statistically valid survival estimates, and 4) determine survival rates of hatchery-reared pallid sturgeon stocked in the Yellowstone River.

STUDY AREA

The study area consists of the 470 km of the Yellowstone River below Rancher Diversion (Figure 1). Mean annual discharge at the USGS gauging station in Miles City, Montana, is 323 m^3/s and mean annual peak discharge is 1480 m^3/s. River geomorphology varies throughout the study area in direct response to valley geology; straight, sinuous, braided, and irregular-meander channel patterns occur (Silverman and Tomlinsen 1984). The channel is often braided or split and long side channels are common. Islands and bars range from large vegetated islands to unvegetated point and mid-channel bars (White and Bramblett 1993). Substrate is primarily gravel and cobble upstream of river kilometer 50 and is primarily fines and sand below (Bramblett and White 2001). The fish assemblage is comprised of 49 species from 15 families, including eight state-listed Species of Special Concern and one federally listed endangered species (White and Bramblett 1993; Carlson 2003). The primary deleterious anthropogenic effect on the fish assemblage is water withdrawal for agriculture (White and Bramblett 1993). About 90% of all water use on the Yellowstone River is for irrigation, which corresponds to annual use of 1.5 million acre-feet (White and Bramblett 1993). Six mainstem low-head irrigation diversions dams occur in the study area. The largest and downstream-most of these, Intake Diversion, diverts about 38 m^3/s during the mid-May to mid-September irrigation season (Hiebert et al. 2000).

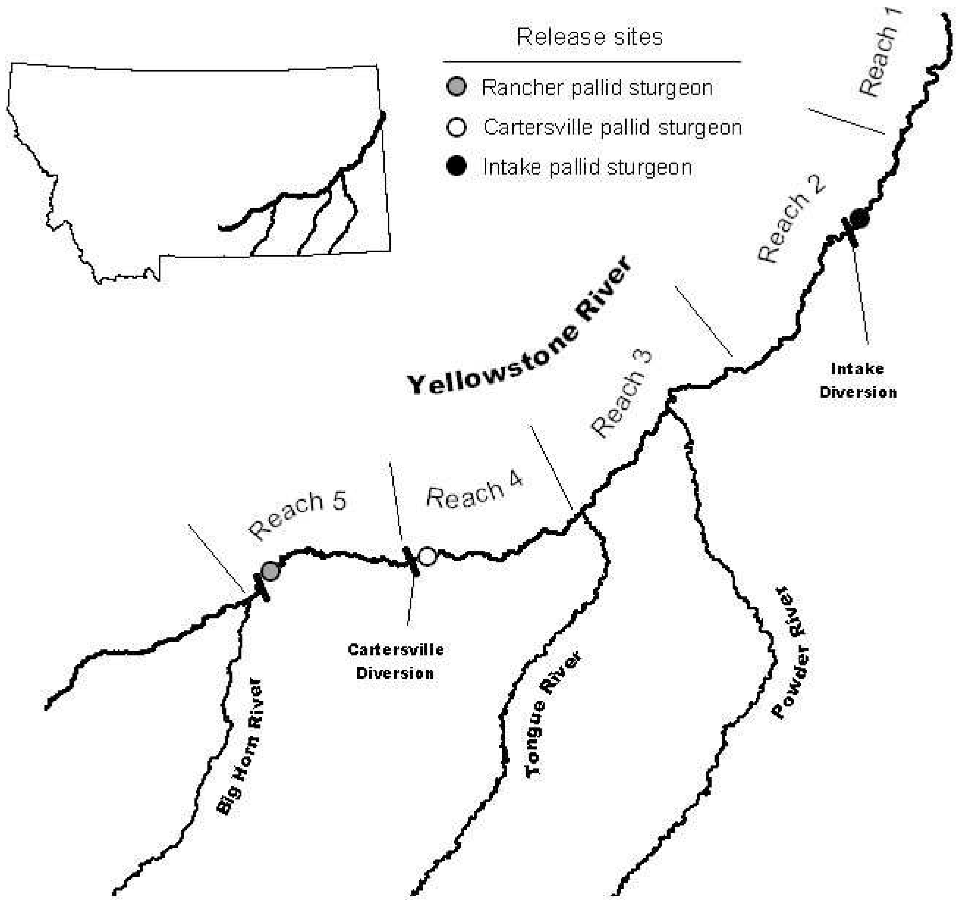


Figure 1. The lower Yellowstone River, its major tributaries, diversion dams, reaches, and release locations of telemetered juvenile pallid sturgeon.

METHODS

Telemetry: Telemetered 2004 year-class juvenile pallid sturgeon from the Miles City State Fish Hatchery (MCSFH) were released at three temperatures (7, 17, 24^{o}C) to assess post-stocking behavior. One hundred 102 to 250 g fish were telemetered with 15.1 mm long by 7.6 mm diameter, 1.4 g transmitters with a battery life of 38 to 87 days and released 12 September 2005 at 17^{o}C. Eighty-two 120 to 320 g fish were telemetered with 22.4 mm long by 9.1 mm diameter, 2.8 g transmitters with a battery life of 124 to 232 days and released 15 July 2006 at 24^{o}C. One hundred 58 to 370 g fish were telemetered with transmitters ranging in size from 17 mm long by 7.2 mm diameter and 1.2 g to 30.1 mm long by 9.1 mm diameter and 4.5 g with battery lives of 99 to 678 days and released 20 October 2006 at 7^{o}C. Each transmitter emitted a unique code detectable with radio antennae at either 148.640 or 148.800 MHz. Transmitters were surgically implanted using procedures modified from Hart and Summerfelt (1975). Incisions were closed using surgical staples. The 450-mm long whip antennae trailed externally (Ross and Kleiner 1982).

Telemetered pallid sturgeon were released at three sites in the Yellowstone River. Fish stocked at 17 and 24^{o}C were equally divided between release sites about 5 kilometers downstream of Cartersville Diversion (Cartersville pallid sturgeon) and about 6 kilometers downstream of Intake Diversion (Intake pallid sturgeon; Figure 1). Fish released at 7^{o}C were equally divided among the Cartersville and Intake diversion release sites and a third site immediately below Rancher Diversion (Rancher pallid sturgeon; Figure 1). Fish were relocated by boat about every other week during ice-free months (April to November) and by aircraft during winter months (November to March) about once every month in 2006 and once every two to three weeks in 2007. Following detection, coordinates of each pallid sturgeon location were determined using a hand-held global positioning unit. Location was converted to river kilometer using geographic information system (GIS) software. Fixed receiving stations were placed near Cartersville and Intake diversions and the confluence with the Big Horn, Tongue, Powder, and Missouri rivers to assess movements over diversion dams, into tributaries, and out of the Yellowstone River.

To assess transmitter expulsion and mortality related to surgery 25 hatchery-reared 2004 year-class pallid sturgeon weighing 78 to 335 g were surgically implanted with dummy transmitters at the Bozeman Fish Technology Center (BFTC) coinciding with the 17 and 24^{o}C releases of fish. Transmitter sizes and surgical methods used at BFTC for trial fish were the same as those used at MCSFH for study fish. Pallid sturgeon implanted with dummy transmitters were held at BFTC and monitored for transmitter expulsion and mortality throughout the period that telemetered fish were being relocated in the Yellowstone River.

Post-stocking dispersal patterns of Cartersville and Intake pallid sturgeon were assessed by calculating movement rates (km/d) during each 10-day interval at each release temperature for 60 days following release. This duration was selected because dispersal rates had stabilized by this time and it coincided with the shortest transmitter battery life (17^{o}C release). Movement rate was calculated by dividing the change in river kilometer between successive relocations by the number of days that had elapsed between relocations such that a positive rate indicated upstream movement and a negative rate indicated downstream movement (Bramblett 1996). Because additional movement may have occurred between relocations, calculated movement rates represent the minimum movement for the time period between relocations. Median movement rates of Cartersville and Intake pallid sturgeon at each 10-day interval following release for each temperature were compared using Mann-Whitney tests (Zar 1999). Median movement rates at each 10-day interval within and among release temperatures for each group of fish were compared using Kruskal-Wallis tests (Zar 1999). Directionality of movements was determined for each group at each 10-day interval following release using Wilcoxon signed-rank tests (Zar 1999).

Pallid sturgeon association with reach-scale habitat features was assessed by comparing distributions of telemetered fish and geomorphically distinct reaches. Reaches were delineated based on underlying geologic type (Montana Bureau of Mines and Geology 1979-2001b) and level IV ecorgeion (Woods et al. 1999). Geologic types and ecoregions were required to exist continuously for a minimum of 20 channel widths (about 4 km) to be considered a separate reach (Frissell et al. 1986; Leopold et al. 1992). Reaches were characterized by channel pattern (Silverman and Tomlinsen 1984; Boyd and Thatcher 2004), valley width (Boyd and Thatcher 2004), channel slope (Boyd and Thatcher 2004), braiding parameter (Boyd and Thatcher 2004), and dominant substrate (Koch et al. 1977; Bramblett and White 2001).

Annual movement patterns of pallid sturgeon following their first winter post-stocking were assessed by calculating and comparing movement rates as described above during each month from April 2007 through March 2008. Movement information was obtained from 60 of the fish released on 20 October 2006 with transmitter battery lives ranging from 200 to 582 days and an additional 21 hatchery-reared pallid sturgeon captured during monitoring efforts that were known to have survived for at least one winter following stocking. Fish telemetered during monitoring efforts were 145 to 650 g and implanted with 22.4 mm long by 9.1 mm diameter, 2.8 g transmitters with a battery life of 357 days between 9 August 2007 and 20 September 2007.

Habitat Selection: To determine what habitats are likely to support pallid sturgeon aggregations and commensurately high catch rates by monitoring crews, pallid sturgeon relocations will be characterized using two classification systems. The Missouri River Pallid Sturgeon Standard Operating Procedures (SOP) Habitat Classification (Drobish 2006) will be used to facilitate development of standardized sampling protocols and a large-river classification system developed for the Yellowstone River (Jaeger et al. 2005a) based on distinct pool-riffle scale habitat features hierarchically nested within geomorphically distinct reaches will be used to describe biologically relevant factors influencing habitat selection. Habitat use of Yellowstone River habitat types will be determined for all relocations and Missouri River SOP habitat types will be documented for boat-collected relocations.

All Yellowstone River habitat types (Jaeger et al. 2005a) between the confluence with the Missouri and Big Horn rivers were delineated using low-level 1:24,000 scale color infrared aerial photographs and physical features inventory (Natural Resources Conservation Service 2002), geologic maps (Montana Bureau of Mines and Geology 1979-2001b), and GIS software. Habitat type classification was predicated on geomorphic function (i.e. pool, crossover, side channel) and bank material (i.e. bedrock, alluvium, rip-rap).

When field relocation of telemetered fish is complete, total availability of each geomorphic reach and habitat type during base flow and runoff periods will be quantified using GIS software. Availability at base flow will be calculated by considering the amount of habitat provided by all habitat types except seasonally inundated side channels. Availability during runoff will include seasonally inundated side channels. Habitat use by pallid sturgeon will be determined using GPS coordinates of each relocation and GIS software. Chi-square tests with log-likelihood test statistics (Manly et al. 2002) will be used to test the null hypothesis of seasonal selection in proportion to availability for different geomorphic reaches, habitat types, or habitat types stratified by geomorphic reach. Selection ratios and simultaneous 95% Bonferroni confidence intervals (Manly et al. 2002) will be used to determine level of selection for specific resource categories. Selection ratios for the population will be obtained by averaging selection ratios calculated for individual telemetered fish (Manly et al. 2002).

To determine characteristics of selected or avoided habitat types, differences in depth, substrate, and velocity among habitat types were quantified and compared. Detailed survey of the physical characteristics of 50 individual habitat units between the confluence with the Missouri and Big Horn rivers occurred in 2006 and 2007 during baseflow conditions. Within a geomorphic reach, habitat units of each habitat type, if available, were randomly selected for physical characterization. Within each selected habitat unit, velocity, depth, and substrate were measured at 100 randomly selected points except channel crossovers which were surveyed at 50 points.

Monitoring: Although formal analysis of habitat selection has not yet occurred, it appeared that telemetered hatchery-reared pallid sturgeon were preferentially using bluff and terrace pool (Jaeger et al. 2005a) habitats. To corroborate this observation and evaluate survival of pallid sturgeon stocked in the Yellowstone River, five bluff pools and one terrace pool between the confluence with the Missouri River and Intake Diversion were sampled with drifting trammel nets in August and September 2006 and 2007. Trammel nets were 6 feet tall by 125 feet long with 1-inch inner mesh and 8-inch outer mesh.

Apparent annual survival and 95% confidence intervals were estimated from recapture data using Comack-Jolly-Seber models parameterized in Program MARK (White and Burnham 1999, Cooch and White 2001). Age-specific probability of survival was estimated for fingerlings, spring yearlings, and summer yearlings as available data allowed using annualized survival rates and 95% confidence intervals derived using the delta method (Seber 1982).

To assess potential bias caused by permanent emigration from our sampling area we 1) considered average emigration rates of telemetered fish following stocking and 2) compared C/f of fish stocked in the Yellowstone River and recaptured in the Yellowstone River to C/f of fish stocked in the Yellowstone River and recaptured in the Missouri River. When comparing C/f between the Yellowstone and Missouri rivers we only used data collected with identical sampling gears (drifting trammel nets) during the same time of year (late summer to early autumn) in 2006 and 2007.

RESULTS

Telemetry: Transmitter retention was high and mortality related to transmitter implantation was low. No mortality or expulsion of dummy transmitters occurred in trial fish during the 17^{o}C (60 days) or 24^{o}C (80 days) releases of study fish. However, assessment of mortality and transmitter retention was prematurely discontinued on 2 October 2006 due to iridovirus outbreak at BFTC. Trial fish implanted with dummy transmitters for the 17^{o}C release were the same length (*t* test; P = 0.603) but weighed less (*t* test; $P < 0.001$) than study fish and trial fish for the 24°C release were the same weight (*t* test; $P = 0.158$) but longer (*t* test; $P = 0.013$) than study fish. All transmitter weight-to-fish weight ratios were less than 2.3%.

Overall, Cartersville pallid sturgeon moved more than Intake pallid sturgeon at all release temperatures (Figure 2). Movement rates of Cartersville pallid sturgeon were greater than those of Intake pallid sturgeon at each 10-day interval following release for all release temperatures ($P < 0.05$) with the exception of the 24°C release at 40 days and the 7°C release at 40, 50, and 60 days. Within release sites, movement rates were significantly different among release temperatures for each 10-day interval ($P < 0.05$); fish released at warmer temperatures generally moved less than fish released at colder temperatures. Fish moved predominantly downstream following stocking; distributions of movement rates were less than zero ($P < 0.05$) at each 10-day interval at all release sites and temperatures with the exception of 17°C Intake fish 30 days post-release and 24°C Intake fish 10 days post-release. However, more Intake pallid sturgeon made upstream movements than Cartersville pallid sturgeon (Table 1). Cartersville pallid sturgeon stocked at warm temperatures were more likely to remain upstream of Intake Diversion and fish stocked at both sites at warm temperatures were more likely to remain in the Yellowstone River (Table 1). No upstream-moving pallid sturgeon that encountered Intake Dam successfully passed, although Cartersville pallid sturgeon migrated downstream over the dam.

Table 1. Proportion of fish released downstream of Cartersville and Intake diversions that made upstream movements of greater than 1.0 km, remained upstream of Intake Diversion, and remained in the Yellowstone River during the respective battery lives of their transmitters or the study period (7°C: 180 days, 17°C: 60 days, 24°C: 180 days).

Release site	Release temperature	% of fish that made an upstream movement	% of fish that remained above Intake Diversion	% of fish that remained in Yellowstone R.
Cartersville	7°C	6%	30%	73%
Cartersville	17°C	4%	48%	96%
Cartersville	24°C	61%	73%	100%
Intake	7°C	0%	--	82%
Intake	17°C	46%	--	90%
Intake	24°C	78%	--	100%

Pallid sturgeon generally dispersed into the same geomorphic reaches irrespective of release site, although rate and magnitude of dispersal was affected by stocking temperature. Five geomorphically distinct reaches occurred between the confluence with the Big Horn River and the confluence with the Missouri River (Figure 1). Intake pallid sturgeon remained in Reach 2 or dispersed downstream into Reach 1 (Figure 3). Cartersville pallid sturgeon stocked at 7°C and 17°C dispersed out of Reach 4, through Reach 3, and into Reaches 2 and 1 (Figure 3). Cartersville pallid sturgeon stocked at 24°C dispersed downstream into Reach 2 but also occupied Reach 3. Predominately occupied reaches (2 and 1) occurred in River Breaks ecoregions underlain by the Tongue River member of the Fort Union formation (Table 2), although higher channel slopes (*t* test, $P < 0.001$), narrower valleys (t test, $P < 0.001$), and larger substrate sizes (Koch et al. 1977; Bramblett and White 2001) occurred in Reach 2 than in Reach 1 (Table 2). The most frequently occupied reach (Reach 2) had the highest overall complexity (braiding parameter; Table 2).

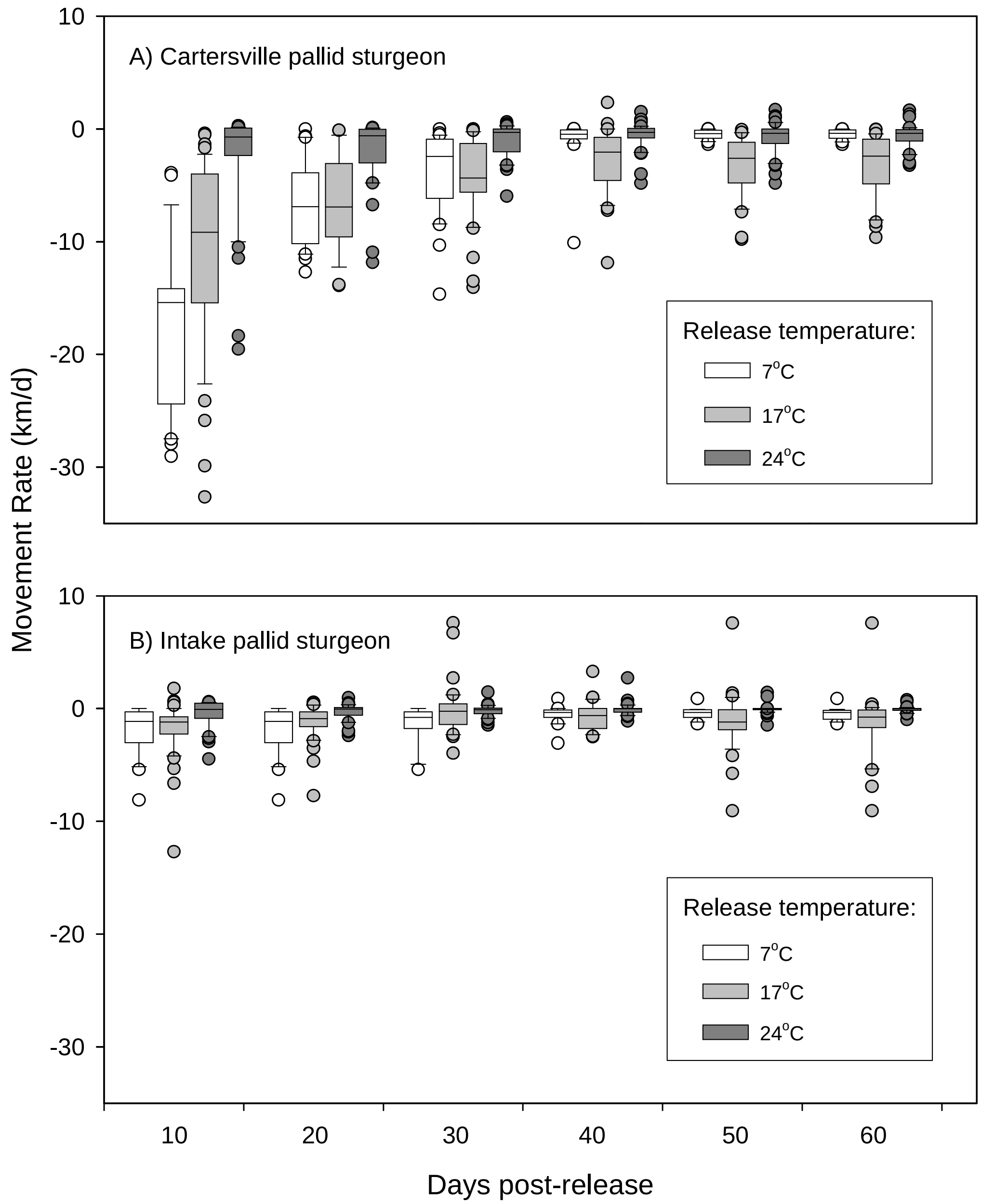


Figure 2. Movement rates by post release 10-day intervals of telemetered juvenile pallid sturgeon stocked in the Yellowstone River downstream of A) Cartersville Diversion and B) Intake Diversion at 7, 17, and 24°C for 60 days following release. Lines within boxes represent medians, boxes represent 25th and 75th percentiles, whiskers represent 10th and 90th percentiles, and circles represent outliers beyond the 10th and 90th percentiles. Negative values indicate predominantly downstream movement, positive values indicate predominantly upstream movement, and values near zero indicate no predominant directionality of movement.

Table 2. Description and characteristics of Yellowstone River reaches.

Reach (river km)	Ecoregion	Formation: Lithology Dominant (secondary)	Channel pattern Dominant (secondary)	Mean valley width (km)	Mean channel slope (%)	Mean braiding parameter	Dominant substrate
5 (473-378)	Sagebrush Steppe	Bearpaw: shale (Lance: sandstone, shale, coal) (Judith River: shale/sandstone)	Unconfined anabranching (Partially confined braided, strait, meandering)	4.2	0.08	3.5	Gravel - cobble
4 (378-301)	Central Grassland	Tullock: sandstone/shale/coal (Lance: sandstone/shale/coal)	Partially confined meandering/islands (Partially confined strait)	3.7	0.06	2.9	Gravel - cobble
3 (301-195)	River Breaks	Tullock: sandstone/shale/coal (Lebo member: shale)	Confined meandering (Confined strait)	4.0	0.07	1.8	Gravel - cobble
2 (195-56)	River Breaks	Tongue R: sandstone/shale/coal Ludlow: sandstone/shale/coal (Lance: sandstone/shale/coal) (Pierre: shale)	Partially confined anabranching (Partially confined meandering/islands)	4.7	0.05	3.6	Gravel - cobble
1 (56-0)	River Breaks	Tongue R: sandstone/shale/coal	Partially confined meandering/islands (Unconfined strait/islands)	7.4	0.02	2.7	Fines - sand

Fish released downstream of Rancher Diversion (Reach 5) at 7^{o}C exhibited the same movement pattern as those released at Cartersville Diversion at 7^{o}C and rapidly dispersed downstream into Reach 2 (Figure 3). Reach 5 had similar channel pattern, complexity, and substrate as Reach 2 but higher gradients (Table 2).

Movements of juvenile pallid sturgeon following survival through at least their first winter were significantly different among months (P= 0.008; Figure 4). Largest movements occurred during periods of increasing temperature and discharge. Predominantly upstream movements occurred during June, July, and August and predominantly downstream movements occurred during other months, although both up and downstream movements were observed during all months.

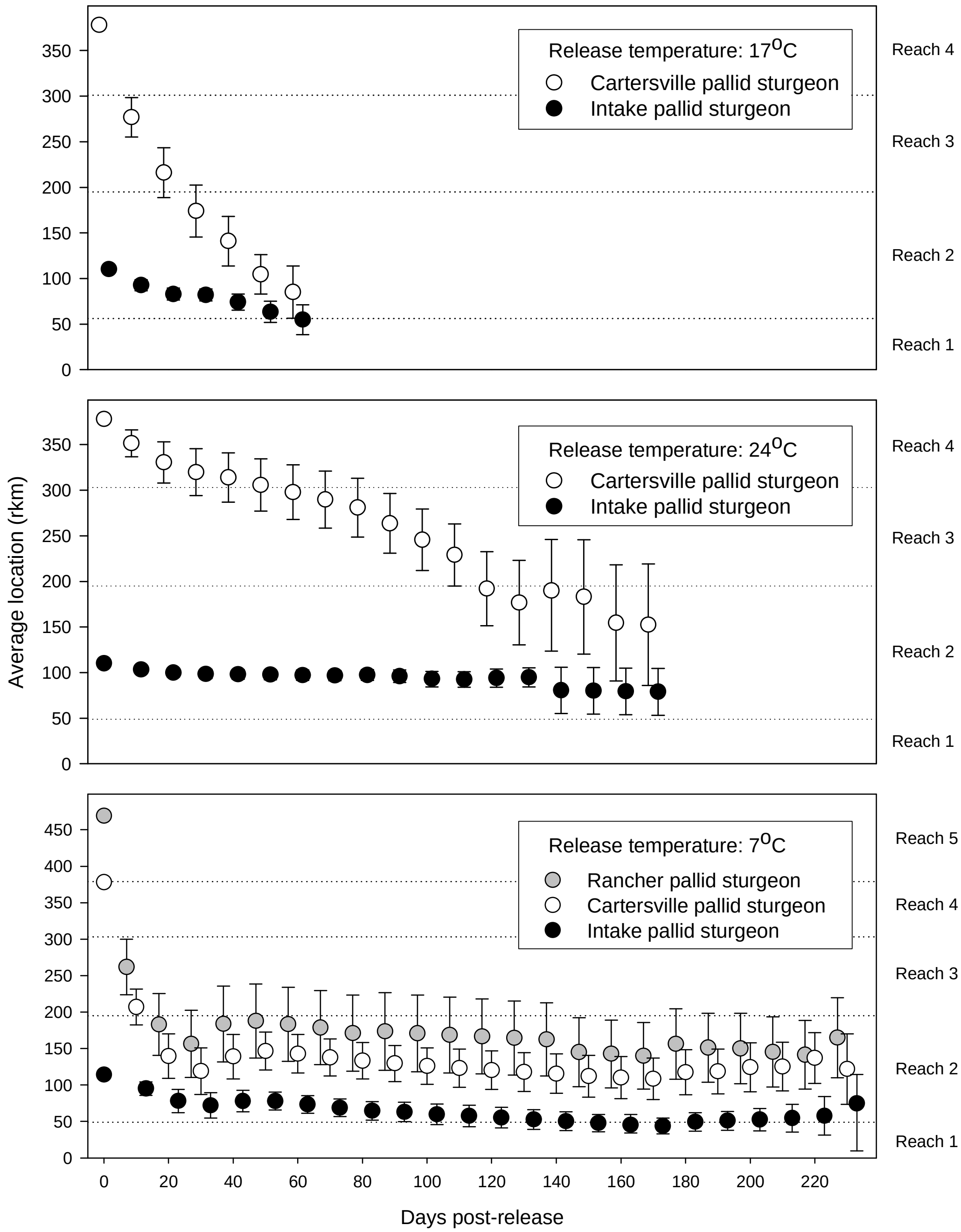


Figure 3. Distributions of telemetered juvenile pallid sturgeon stocked in the Yellowstone River at 7, 17, and 24°C at 10-day intervals post-release. Circles represent mean river location and whiskers represent 95% confidence intervals. River location describes the distance from the confluence with the Missouri River.

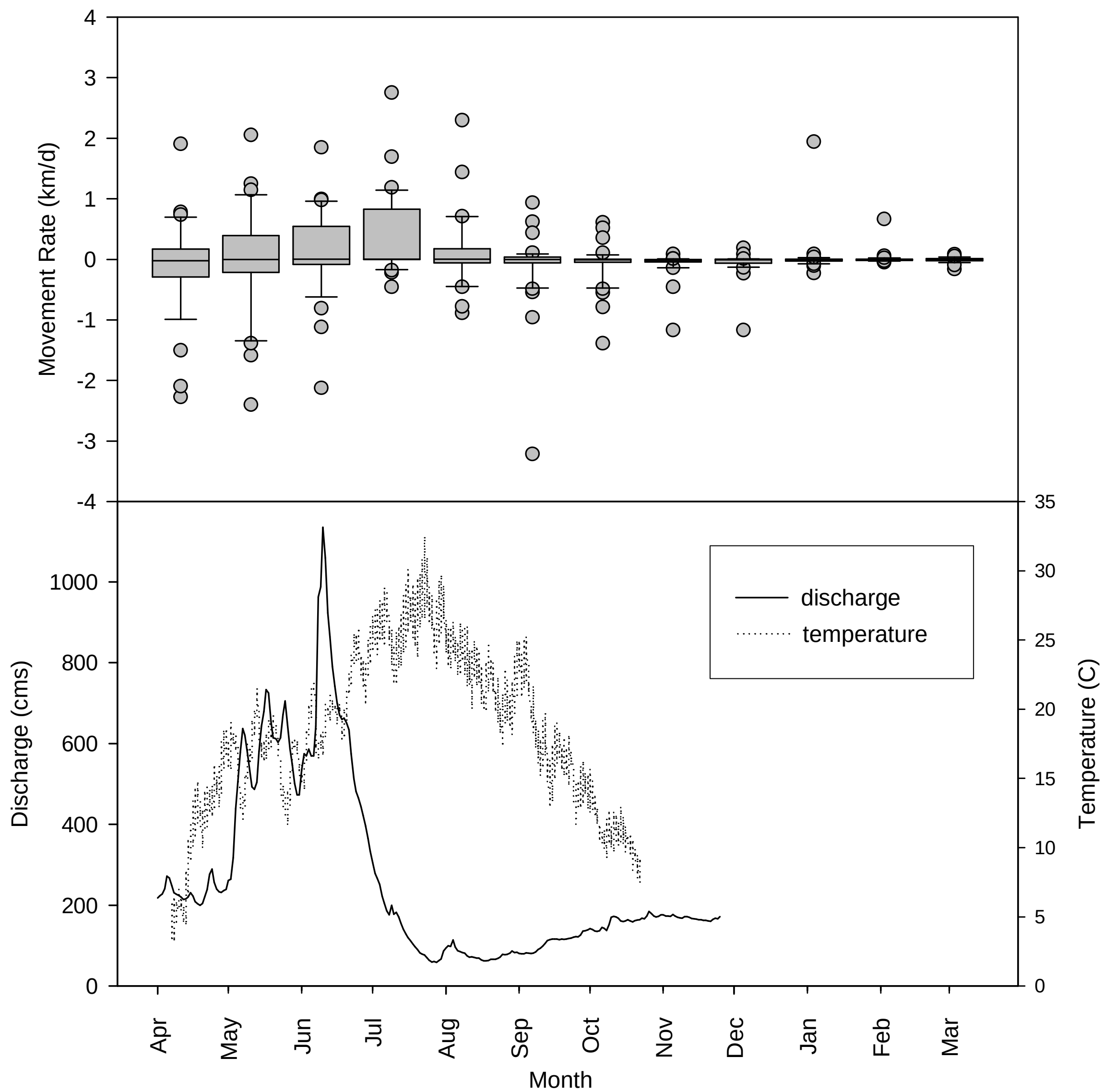


Figure 4. Movement rates by month of telemetered juvenile pallid sturgeon stocked in the Yellowstone River following survival of at least one winter. Lines within boxes represent medians, boxes represent 25th and 75th percentiles, whiskers represent 10th and 90th percentiles, and circles represent outliers beyond the 10th and 90th percentiles. Negative values indicate predominantly downstream movement, positive values indicate predominantly upstream movement, and values near zero indicate no predominant directionality of movement.

Habitat Selection: Although formal data analysis has not yet occurred we observed that a disproportionately high number of telemetered pallid sturgeon were using bluff pools in Reaches 2 and 1.

Preliminary analyses indicate that differences in width, average and maximum depth, average and bottom velocity, and percentage of boulder and bedrock substrate occur among habitat types (ANOVA; $P < 0.001$, Table 3). Mainstem pools at the valley margin (bluff, rip-rap valley margin) were generally longer and had lower average and bottom velocities than pools in the valley bottom (scour, rip-rap valley bottom). Armored pools (rip-rap valley margin, rip-rap valley bottom) generally had higher maximum and average depths, greater variability of depths, and a higher percentage of boulder and bedrock substrates than their unarmored equivalents (bluff pool, scour pool). Terrace pools had characteristics of pools at the valley margin and pools in the valley bottom. Channel crossovers were shorter, shallower, had higher velocities, and a lower percentage of boulder and bedrock substrates than other mainstem habitat types.

Table 3. Characteristics of Yellowstone River habitats. Standard errors are displayed in parentheses.

Habitat	Mean length (km)	Mean width (m)	Mean depth (m)	Mean max. depth (m)	Mean velocity (m/s)	Mean bottom velocity (m/s)	Mean % Bldr./ Bdrck.
Bluff pool	1.3	147 (1.71)	1.48 (0.04)	3.36 (0.31)	0.69 (0.02)	0.53 (0.01)	19.4 (6.43)
Terrace pool	0.9	138 (2.98)	1.52 (0.03)	3.11 (0.35)	0.92 (0.02)	0.72 (0.02)	16.6 (2.60)
Scour pool	0.7	115 (1.09)	1.27 (0.23)	2.35 (0.22)	0.92 (0.02)	0.73 (0.01)	3.2 (3.17)
Rip-rap valley margin pool	1.3	156 (0.56)	1.83 (0.46)	4.25 (0.48)	0.68 (0.01)	0.52 (0.01)	27.3 (7.68)
Rip-rap valley bottom pool	0.9	156 (1.00)	1.67 (0.41)	3.68 (0.56)	0.81 (0.02)	0.65 (0.02)	18.8 (9.82)
Channel Crossover	0.4	145 (1.64)	0.96 (0.02)	1.96 (0.20)	1.16 (0.02)	0.95 (0.02)	1.0 (0.67)
Secondary Channel	0.8	82 (0.84)	0.64 (0.01)	1.51 (0.13)	0.78 (0.01)	0.61 (0.01)	3.5 (2.30)

Monitoring: A total of 105 hatchery-reared pallid sturgeon were captured 12.5 hours during 2006 and 179 fish were captured in 20.5 hours during 2007. Catch rates were similar in 2006 (8.4 fish per hour) and 2007 (8.7 fish per hour) and were 20 to 90 times greater than those of fully randomized sampling designs. Catch rates were similar between pools with predominately gravel and cobble (4) and sand substrate (2). Growth in length (Figure 5) and weight (Figure 6) was variable during the first year fish were released but relatively consistent for fish that had been at large for at least one year.

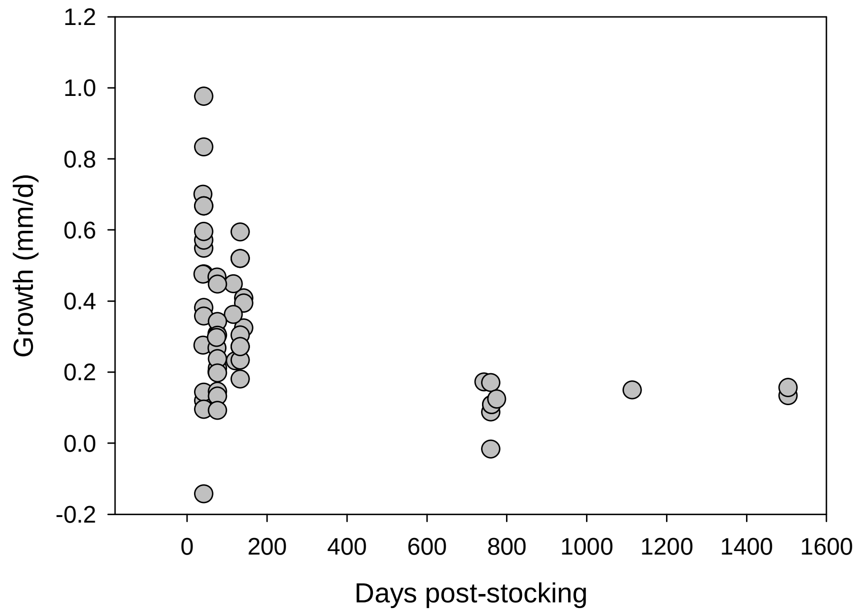


Figure 5. Growth in length (mm/d) of pallid sturgeon stocked and recaptured in the Yellowstone River in 2006.

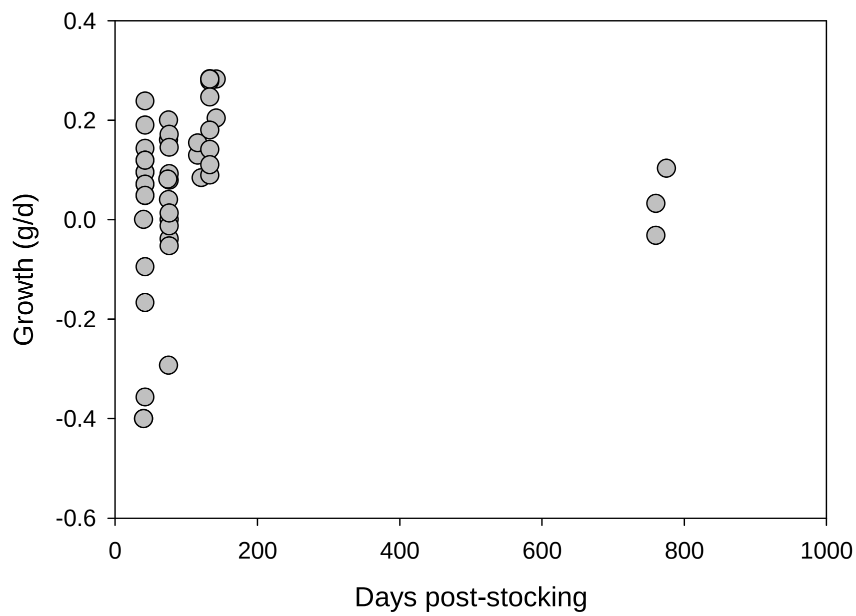


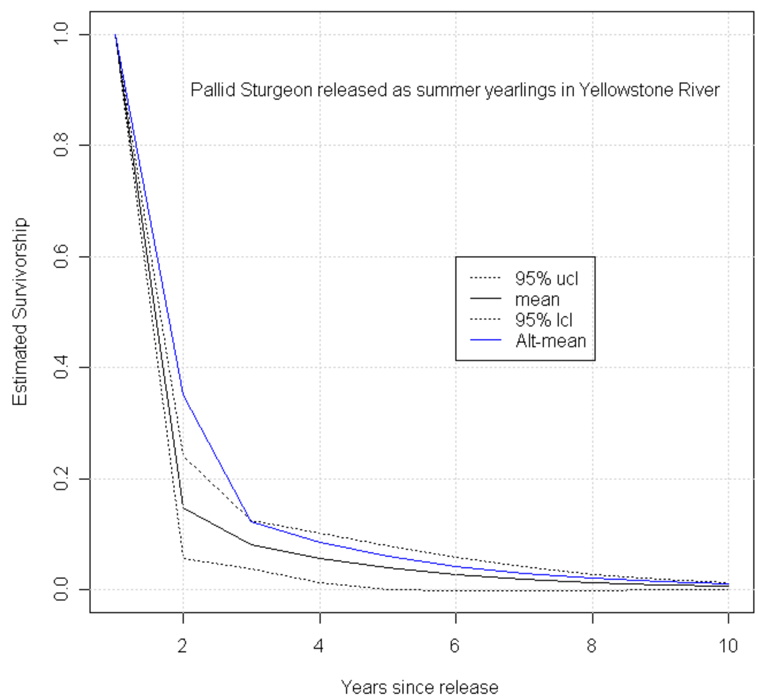
Figure 6. Growth in weight (g/d) of pallid sturgeon stocked and recaptured in the Yellowstone River in 2006.

Probability of survival to age 2 was higher for summer yearlings (0.19) than for spring yearlings (0.08) and fall fingerlings (0.01; Table 4). Annual probability of survival for summer yearlings increased and stabilized (0.70) by age 4 (Table 4), and predicted survivorship of summer yearlings to age 10 was less than 1% (Figure 7).

Table 4. Apparent annual probability of survival and 95% confidence intervals of pallid sturgeon stocked in the Yellowstone River as fingerlings, spring yearlings, and summer yearlings. Confidence intervals for parameter estimates are shown in parentheses.

Stocking category	S_{0-1}	S_{1-2}	S_{2-3}	S_{3-4}	S_{4-5}
Fingerlings	0.06 (0.01,0.11)	0.23 (0.04,0.43)	Na	Na	Na
Spring yearlings	--	0.08 (0.02,0.14)	Na	Na	Na
Summer yearlings	--	0.19 (0.09,0.30)	0.44 (0.24,0.64)	0.67 (0.53,0.82)	0.70 (0.48,0.86)

Figure 7. Survivorship of pallid sturgeon stocked in the Yellowstone River as summer yearlings. Survivorship was projected for fish that 1) were sampled in the year following release (black line) and 2) were not sampled in the year following release and had pooled survival estimates for age 1 and 2 (blue line).



Available data suggest that the proportion of fish stocked in the Yellowstone River that emigrate and survive is low relative to the proportion that remain and survive. On average, 8% of telemetered fish emigrated from the Yellowstone River (Table 5). Emigration was not related to transmitter battery life; most emigration occurred shortly following stocking even in fish with long-lived transmitters. C/f of fish stocked in the Yellowstone River and recaptured in the Yellowstone River was 30 to 40 times greater than that of fish stocked in the Yellowstone River and recaptured in the Missouri River (Table 6).

Table 5. Release temperature, date, battery life, and proportion of emigrants of telemetered pallid sturgeon stocked in the Yellowstone River downstream of Intake Diversion from 2005 to 2007.

Release temperature	Release Date	Battery life	Number stocked	Number emigrated	% emigration
24°C	7/15/06	230 d	41	0	0%
17°C	9/13/05	60 d	50	5	10%
7°C	10/20/06	99 d	14	3	21%
7°C	10/20/06	200 d	5	1	20%
7°C	10/20/06	285 d	7	0	0%
7°C	10/20/06	582 d	7	1	14%
Total			124	10	8%

Table 6. Catch per effort (C/f) of pallid sturgeon stocked in the Yellowstone River and recaptured in the Yellowstone and Missouri rivers, respectively in 2006 and 2007.

Year	YSR PDSG C/f in YSR	YSR PDSG C/f in MOR	X times greater
2006	8.4	0.2	43.5
2007	8.7	0.3	31.9

DISCUSSION

Behavior of telemetered fish released in the Yellowstone River was likely minimally affected by surgical implantation of transmitters. Methods used in this study resulted in no transmitter expulsion or mortality of fish held in captivity. High rates of transmitter expulsion (45% to 50%) and mortality (56%) of pallid sturgeon held in hatcheries following surgery have been reported (Jaeger et al. 2005b; G. Jordan, U.S. Fish and Wildlife Service, Billings, Montana, personal communication). Expulsion and mortality may have been influenced by larger transmitter weight-to-fish weight ratios in previous studies (1.6% to 3.5%) than in this study (0.6% to 2.3%). Likelihood of transmitter expulsion increases as transmitter weight-to-fish weight ratios increase (Summerfelt and Mosier 1984). Incision closure with surgical staples instead of suture material may also have contributed to lower rates of expulsion; faster surgeries, less infection, better tag retention, and reduced signs of systemic stress occur when surgical staples are used instead of suture material to close incisions (Swanberg et al. 1999).

Establishing pallid sturgeon populations in desirable locations further upstream of reservoirs is unlikely to be successful simply by stocking fish unless suitable habitat also exists and fish are stocked at warm water temperatures. Post-stocking movements and distributions were dictated by the presence of suitable habitats and secondarily influenced by stocking temperature. Following stocking at all temperatures, Intake pallid sturgeon dispersed relatively short distances upstream and downstream within Reaches 2 and 1 while Cartersville and Rancher pallid sturgeon stocked at cool (17°C) and cold (7°C) temperatures dispersed long distances downstream until they entered Reaches 2 and 1, at which point their behavior became similar to that of Intake pallid sturgeon. Lengthy downstream dispersal to suitable habitats was also observed for juvenile pallid sturgeon stocked upstream of areas commonly occupied by extant pallid sturgeon in RPMA 1 (Gardner 2005; C. Guy, Montana Cooperative Fisheries Research Unit, Bozeman, Montana, personal communication). However, Cartersville pallid sturgeon stocked at warm temperatures (24^{o}C) dispersed relatively short distances up and downstream immediately following stocking. Some of these fish also remained distributed in upstream reaches (Reach 3) during winter despite onset of cold water temperatures (Figure 3). Although adult pallid sturgeon historically occupied Reach 3 (Brown 1971; Watson and Stewart 1991), it may provide marginal rearing habitat for juvenile pallid sturgeon or was only seasonally occupied; adult pallid sturgeon annually migrate long distances (Bramblett and White 2001). Conversely, simply stocking juvenile pallid sturgeon at warmer water temperatures to minimize post-stocking dispersal and allow fish to become acclimated prior to the onset of winter temperatures may increase the likelihood that they will remain distributed in upstream reaches.

Survival rates of fish stocked for population augmentation below Intake Diversion in Reaches 2 and 1 provide a separate line of evidence that stocking at warm temperatures results in better retention; survival of summer yearlings stocked at warm temperatures was higher than that of spring yearlings stocked at cold temperatures (Table 4). These survival rates are consistent with the movement patterns of telemetered pallid sturgeon released below Intake Diversion; fish stocked at warmer temperatures dispersed shorter distances downstream (Figure 3) and are more likely to remain in the Yellowstone River (Table 5). Summer yearlings stocked at warm temperatures in RPMA 1 are also more frequently recaptured in future years than fingerlings or spring yearlings stocked at cold temperatures (Bill Gardner, Montana Fish, Wildlife & Parks, personal communication)

Suitable habitats were characterized by a combination of factors. Occupied reaches (2 and 1) occurred in a common ecoregion, geologic type, and degree of bedrock confinement, which resulted in similar channel patterns (anabranching or meandering/islands) characterized by relatively high complexity (braiding parameter) and dynamic, natural channel processes (Silverman and Tomlinsen 1984; Boyd and Thatcher 2004). Dynamic reaches that occur in River Breaks ecoregions were also preferentially used by juvenile pallid sturgeon in RPMA 1 (Gerrity 2005) and adult pallid sturgeon in RPMA 1 and 2 (Bramblett and White 2001; Gardner 2005). Although pallid sturgeon primarily occupy low gradients, wide valleys, and sand substrates (Bramblett and White 2001), reaches with relatively high gradients, narrow valleys, and gravel and cobble substrates used by fish in this study were also historically (Reach 3) or currently (Reach 2) occupied by wild pallid sturgeon (Brown 1971; Watson and Stewart 1991; Backes et al. 1994; Bramblett and White 2001). Avoided reaches (Reaches 5 and 4) occurred in different ecoregions and geologic types than preferred reaches. Non-River Breaks ecoregions were similarly avoided by hatchery-reared juvenile pallid sturgeon in RPMA 1 following stocking (Gardner 2005; C. Guy, Montana Cooperative Fisheries Research Unit, Bozeman, Montana, personal communication).

The suitability of reaches upstream of Cartersville Diversion is unknown. Because fish were only released into Reach 5 at cold temperatures (7^{o}C) limited inferences can be made, although it appears to be less suitable than Reaches 2 and 1; fish stocked into Reach 5 dispersed into Reaches 2 and 1. However, Reach 5 has similar channel pattern, complexity, and substrate as Reach 2 but higher gradients (Table 2). Stocking at warmer temperatures may result in increased retention in reaches upstream of Cartersville Diversion.

Habitats upstream of Intake Diversion are suitable for pallid sturgeon restoration efforts. Heretofore, stocking had not occurred upstream of Intake Diversion because it appeared this reach was unsuitable; few extant pallid sturgeon were captured (Watson and Stewart 1991) and telemetry studies in similar habitats (higher gradient, gravel and cobble substrates) elsewhere suggested that stocked fish would rapidly disperse out of this reach (Gardner 2005). However, the parts of Reach 2 that occur above Intake Diversion provide suitable habitat irrespective of stocking temperature and, although Cartersville fish dispersed further downstream than Intake fish, stocking at warm temperatures increases the likelihood that fish will remain upstream of Intake Diversion (Table 2). Stocking pallid sturgeon upstream of Intake Diversion at warm water temperatures would help bolster extant populations and may increase the likelihood of natural recruitment by allowing longer larval drift distances if spawning occurs.

Intake Diversion restricted pallid sturgeon movements. Juvenile pallid sturgeon commonly moved upstream to Intake Diversion but were not able to move above the dam. Similarly, telemetered adult pallid sturgeon have been documented moving up to but not beyond Intake Diversion (Bramblett and White 2001). Observations of adult and juvenile pallid sturgeon are common below the diversion but rare above (Watson and Stewart 1991; Backes et al. 1994). Laboratory trials suggest sturgeon have difficulty negotiating turbulent flow and high velocities over large substrates (White and Mefford 2002), which characterize Intake Diversion. Entrainment was not estimated by this study (Intake Diversion headgates were closed for the season before 7 and 17^{o}C fish were released and 24^{o}C fish did not disperse downstream to Intake Diversion until headgates were closed) but previous research and angler reports indicate that entrainment of juvenile (14.3%; Jaeger et al. 2005b) and adult pallid sturgeon occurs. About 576,629 fish of 36 species are annually entrained at Intake Diversion, of which as many as 8% are sturgeon (Hiebert et al. 2000). Future pallid sturgeon augmentation efforts are expected to occur at times when fish will disperse downstream to Intake Diversion during the irrigation season. Improved passage and reduced entrainment at Intake Diversion is needed to allow pallid sturgeon access to suitable and formerly occupied upstream habitats.

Habitat-based sampling may dramatically improve catch rates for juvenile hatchery-reared pallid sturgeon. Catch rates realized by selectively sampling bluff pools (8.7 fish per hour or 1.6 fish per trammel net drift) were 20 to 90 times more efficient than those of previous random sampling efforts. Catch rates were similar between bluff pools with gravel and cobble (4) and sand substrate (2), which suggests that pallid sturgeon select these habitat types irrespective of dominant substrate and increases the likelihood that these findings can be applied elsewhere in the Missouri River drainage. By taking a stratified random or selective sampling approach focusing on bluff pool habitats, greater information returns with lower expenditure of resources and effort may be possible.

Empirically derived survival estimates for hatchery-reared pallid sturgeon can be generated with reasonable precision using data collected by selectively sampling bluff pools. However, current data do not support much model complexity and inferences should be made cautiously; resightings in future years will improve estimates. Data from summer yearling recaptures currently allow estimation of age-specific survival rates over a greater range of ages than what is possible for fingerlings and spring yearlings. To obtain better survival estimates, 30 hatchery-reared pallid sturgeon were telemetered with 1-year transmitters and survival will be modeled in the next year using both telemetry and recaptures of traditionally marked fish.

Available data suggest that bias related to permanent emigration is likely low; a relatively low proportion of fish stocked in the Yellowstone River emigrated from the Yellowstone River. However, comparisons in C/f should be made cautiously because the sampling design used in the Missouri River (fully random) by the Fort Peck and Bismarck Population Assessment Crews was different than the design used in the Yellowstone River (stratified random). Although few (8%) telemetered fish emigrated, short transmitter battery lives precluded detection of delayed migration. It is similarly unknown whether emigrating fish permanently emigrated, temporarily emigrated, or died. Nonetheless both examined lines of evidence suggest that a low proportion of fish stocked in the Yellowstone River emigrate from the Yellowstone River and survive relative to the proportion that remain in the Yellowstone River and survive.

Survival estimates for all stocking ages were lower than anticipated and suggest that stocking rates should be increased by an order of magnitude to meet current population targets. To meet the defined RPMA 2 standing population size of 1,700 pallid sturgeon greater than or equal to 15 years of age annual RPMA 2 stocking goals should be elevated from 9,000 yearling equivalents to 70,000 yearling equivalents (U.S Fish and Wildlife Service 2008). Empirically derived survival estimates suggest that yearling equivalent values in the Stocking Plan should also be adjusted (U.S Fish and Wildlife Service 2008); stocking 15 fingerlings or 2.5 spring yearlings was estimated to produce the same number of age 2 fish as stocking 1 summer yearling.

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River and recaptured in the Missouri River was collected and provided by Tyler Haddix and Ryan Wilson and their respective Army Corps of Engineers funded Population Assessment Crews. The Army Corps of Engineers funded Fort Peck Flow Modification Crew provided data recorded at a fixed receiving station they maintain at the confluence of the Yellowstone and Missouri rivers.

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