Journal of Applied Ichthyology

J. Appl. Ichthyol. 27 (2011), 436–443

ISSN 0175–8659

Received: February 9, 2010
Accepted: December 3, 2010
doi: 10.1111/j.1439-0426.2010.01651.x

Effects of acclimation on poststocking dispersal and physiological condition of age-1 pallid sturgeon

By E. W. Oldenburg[1], C. S. Guy[2], E. S. Cureton[3], M. A. H. Webb[3] and W. M. Gardner[4]

[1]*Montana State University, Department of Ecology, Fish & Wildlife Management Program, Bozeman, MT, USA;* [2]*Montana Cooperative Fishery Research Unit, U.S. Geological Survey, Department of Ecology, Fish & Wildlife Management Program, Montana State University, Bozeman, MT, USA;* [3]*U.S. Fish and Wildlife Service, Bozeman Fish Technology Center, Bozeman, MT, USA;* [4]*Montana Department of Fish, Wildlife & Parks, Lewistown, MT, USA*

Summary

The objective of this study was to evaluate the effects of acclimation to flow and site-specific physicochemical water conditions on poststocking dispersal and physiological condition of age-1 hatchery-reared pallid sturgeon. Fish from three acclimation treatments were radio-tagged, released at two locations (Missouri River and Marias River), and monitored using passive telemetry stations. Marias treatment was acclimated to flow and site-specific physicochemical conditions, Bozeman treatment was acclimated to flow only, and controls had no acclimation (reared under traditional conservation propagation protocol). During both years, fish released in the Missouri River dispersed less than fish released in the Marias River. In 2005, Marias treatment dispersed less and nearly twice as many fish remained in the Missouri River reach as compared to control fish. In 2006, pallid sturgeon dispersed similarly among treatments and the number of fish remaining in the Missouri River reach was similar among all treatments. Differences in poststocking dispersal between years were related to fin curl which was present in all fish in 2005 and only 26% in 2006. Pallid sturgeon from all treatments in both years had a greater affinity for the lower reaches of the Missouri River than the upper reaches. Thus, release site influenced poststocking dispersal more than acclimation treatment. No difference was observed in relative growth rate among treatments. However, acclimation to flow (i.e., exercise conditioning) prevented fat accumulation from rupturing hepatocytes. Acclimation conditions used in this study did not benefit pallid sturgeon unless physiological maladies were present. Overriding all treatment effects was stocking location; thus, natural resource agencies need to consider stocking location carefully to reduce poststocking dispersal.

Introduction

Pallid sturgeon *Scaphirhynchus albus* are native to the Missouri and Mississippi river drainages. No evidence of successful recruitment of pallid sturgeon has been observed in the Missouri River above Fort Peck Reservoir (hereafter called the upper Missouri River) in the past 30 years (Gardner, 1997). It is estimated that 50 wild (i.e., naturally produced in the river) pallid sturgeon occur in the upper Missouri River, and it is expected that these fish will be extirpated within 10–20 years (Gardner, 2005). The exact mechanisms for the lack of recruitment in the upper Missouri River are unknown.

A conservation propagation program to increase the number of pallid sturgeon in the upper Missouri River was implemented by the U. S. Fish and Wildlife Service in 1994. In 1998, 732 age-1 hatchery-reared pallid sturgeon (1997 year class) from the Gavins Point National Fish Hatchery were released in the upper Missouri River. In 2001, pallid sturgeon were reared at the U.S. Fish and Wildlife Service Bozeman Fish Technology Center (BFTC). Of the 732 hatchery-reared pallid sturgeon released from the 1997 year class, 29 were recaptured by age 5 (Gardner, 2004). However, only 11 of the 2221 fish stocked from the 2001 year class were recaptured by age 5 (Gardner, 2007). It is likely the 2001 year class dispersed downstream into Fort Peck Reservoir, experienced high mortality, or both.

A preliminary study was conducted in 2004 to evaluate poststocking dispersal of age-1 pallid sturgeon. Twenty-nine radio-tagged pallid sturgeon were stocked in the Marias River at river kilometer (rkm) 93 and their movements were recorded using passive remote telemetry stations. Twenty-six of the twenty-nine fish had dispersed downstream 93 km within the Marias River and entered the Missouri River in 33 days. Additionally, 19 of those fish had passed the lowest remote station at Judith Landing (210 km downstream of release) by the same date. These data indicated rapid downstream poststocking dispersal by hatchery-reared age-1 pallid sturgeon; thus, these fish may have dispersed into Fort Peck Reservoir and experienced increased mortality.

Limited information exists regarding poststocking dispersal of hatchery-reared age-1 pallid sturgeon throughout their range. However, juvenile (age-3) pallid sturgeon released in the Missouri River below Fort Randall Dam generally remained near the stocking location or moved upstream during the first year after stocking (Jordan et al., 2006). Although some downstream dispersal may be natural in juvenile pallid sturgeon, the rate and magnitude of dispersal may be related to hatchery rearing conditions and stocking strategies.

Many differences exist between the hatchery environment and the river environment (e.g., flow, physicochemical conditions, food, habitat), and poststocking dispersal of hatchery-reared pallid sturgeon is likely a function of physical condition and chronic stress related to the transition between these environments (Mueller et al., 2003). Hatchery-reared pallid sturgeon may not become acclimated to the river environment during their first year post-release (Jordan et al., 2006). Further, survival, growth rate, and condition factors of hatchery-reared white sturgeon *Acipenser transmontanus* released in the Kootenai River, Idaho, suggest that most are not acclimated to natural conditions until 1–3 years after release (Ireland et al., 2002). Hatchery-reared age-1 lake sturgeon *Acipenser fulvescens* (Lake Winnebago origin; mean length = 30 cm) stocked in the Menominee River, Wisconsin, dispersed rapidly downstream as far as 32 km in 24 h after stocking and out of the stretch of river where the investigators wanted the fish to reside (Thuemler, 1988). However, most wild caught lake sturgeon (Menominee River origin; mean length = 48 cm) transplanted from lower reaches to an upper reach of the Menominee River remained in the upper reach of the river and most did not move downstream (Thuemler, 1988).

Although acclimation experiments have had mixed results (Cresswell and Williams, 1983; Minckley et al., 1991), acclimation to flow has positively affected some large river fishes. Exercising fish that were reared in tanks with little to no flow may improve swimming performance and increase survival (Ward and Hilwig, 2004). Poststocking dispersal decreased when razorback suckers *Xyrauchen texanus* were preconditioned to flow (Mueller et al., 2003) and swimming performance increased for flannelmouth sucker *Catostomus latipinnis* by 10%, bonytail *Gila elegans* by 15%, razorback sucker by 26%, and spikedace *Meda fulgida* by 40% after exercise conditioning in flowing water (Ward and Hilwig, 2004).

In addition to increasing swimming performance and reducing poststocking dispersal, acclimation to flow (exercise conditioning) may also increase the physiological condition of pallid sturgeon. The hatchery environment can negatively influence the normal physiological activities of pallid sturgeon and shovelnose sturgeon *Scaphirhynchus platorynchus* which reduces metabolism and promotes accumulation of fat in the liver (USFWS 2003). Fatty liver can be pathologic in fish and accumulation of lipids in the liver causes a metabolic disorder of the liver (Zhang et al., 2004). However, lipids are an important source of potential chemical energy and their presence or absence reflects the metabolic capacity of fish (Busacker et al., 1990). Acclimation to flow may reduce liver fat content in hatchery-reared pallid sturgeon while maintaining enough potential chemical energy to aid in the hatchery to river transition.

The successful use of hatcheries for recovery of pallid sturgeon will depend on how well hatchery-reared pallid sturgeon can acclimate to natural conditions. Acclimation to flow and site-specific physicochemical water conditions may aid pallid sturgeon in adapting more quickly to the river environment. Understanding conditions that better acclimate hatchery-reared pallid sturgeon to the river environment and the duration of exposure needed will be an important tool for managers to reduce downstream poststocking dispersal of pallid sturgeon. The objectives of this study were: (i) to evaluate the effects of acclimation to flow and site-specific physicochemical conditions on poststocking dispersal, growth, energy reserves, and liver fat score of age-1 pallid sturgeon, and (ii) to evaluate the effects of stocking location on poststocking dispersal of age-1 pallid sturgeon.

Materials and methods

The effects of acclimation on the poststocking dispersal of hatchery-reared pallid sturgeon from the BFTC were evaluated in 2005 (2004 year class) using one treatment (Marias treatment; see below) and a control group. The study was repeated in 2006 (2005 year class) using two treatments (Marias and Bozeman treatments; see below) and a control group, and additionally examined the effects of acclimation on the physiological condition of pallid sturgeon. The largest pallid sturgeon from the BFTC (n = 60 in 2005; n = 270 in 2006) were selected, measured [mean (±SE) length = 330 ± 3 mm and weight = 121 ± 4 g in 2005; length = 302 ± 2 mm and weight = 96 ± 2 g in 2006], and tagged with passive integrated transponder (PIT) tags and elastomer tags. The PIT tags were inserted below the dorsal fin, and elastomer tags were injected in the ventral surface of the rostrum (UBPSPC 2005). Pallid sturgeon were randomly assigned to treatments and each treatment was assigned two tanks containing 15 fish (observational unit) per tank in 2005 and 45 fish per tank in 2006. Pallid sturgeon were reared for 36 and 74 days (acclimation periods) in 2005 and 2006, respectively. All individuals were implanted with a Lotek coded radio nanotag transmitter (2.1 g; 150.300, 150.420, or 150.680 MHz) [see Gerrity (2005) for surgical methods], returned to the tanks and held until release (see Table 1 for tagging and release dates). In 2006, individuals not implanted with radio-transmitters were sampled to assess physiological condition (see below).

Table 1
Acclimation and rearing (control) conditions including mean (SE) physicochemical water parameters by treatment for 2005 and 2006. Dissolved oxygen, turbidity, and velocity levels are mean values from measurements collected every 14 days throughout the acclimation period. Temperature was recorded in 1-h increments and is reported as the mean of mean daily temperatures throughout the acclimation period

		Treatment		
Year	Parameter	Marias	Bozeman[a]	Control
2005	N acclimated / reared	30		30
	Fish density (kg m^{-2})	0.33		0.64
	Water supply rate (L min^{-1})	102		20
	Food per fish per day [% of fish weight (g)]	1 (10)		1 (10)
	Acclimation / rearing duration (days)	36		36
	Implantation date	8/30/2005		8/30/2005
	Release date	9/2/2005		9/2/2005
	Dissolved oxygen (mg l^{-1})[b]	8.19 (0.01)		
	Daily temperature (°C)	21.0 (<0.1)		17.8 (<0.1)
	Turbidity (NTU)[b]	12.0 (<0.1)		
	Velocity (m s^{-1})	0.23 (0.03)		0.01 (<0.01)
2006	N acclimated / reared	90	90	90
	Fish density (kg m^{-2})	0.78	0.78	1.53
	Water supply rate (L min^{-1})	102	22	20
	Food per fish per day [% of fish weight (g)]	2.5 (60)	2.5 (60)	2.5 (60)
	Acclimation / rearing duration (days)	74	74	74
	Implantation date	8/14/2006	8/14/2006	8/14/2006
	Release date	8/25/2006	8/25/2006	8/25/2006
	Dissolved oxygen (mg l^{-1})	8.11 (0.03)	6.23 (0.01)	6.90 (0.02)
	Daily temperature (°C)	21.9 (<0.1)	21.4 (<0.1)	21.1 (<0.1)
	Turbidity (NTU)	17.1 (1.1)	1.0 (0.1)	0.6 (0.1)
	Velocity (m s^{-1})	0.23 (0.04)	0.20 (0.03)	0.01 (<0.01)

[a]Bozeman treatment was not implemented in 2005.
[b]Data not collected for control in 2005.

Treatments

The Marias treatment was acclimation of pallid sturgeon to flow and site-specific physicochemical water conditions in tanks near the Marias River. Pallid sturgeon were transported from the BFTC and placed in Marias treatment tanks on July 28 in 2005 and June 12 in 2006. Marias treatment acclimation tanks were 7.3-m long, 1.5-m wide and had a water depth of 0.5 m. Pumps were used to generate flow around semi-circular false ends and a 3.0-m center divider. This created an enclosed system where water was continually replaced concomitant with flow being generated around the center divider (counterclockwise). Each tank contained gravel substrate, was covered with 6-mm wire mesh lids, and a canopy was erected over the tanks to provide shade. Acclimation conditions can be found in Table 1.

The Bozeman treatment (implemented only in 2006) was acclimation of pallid sturgeon to flow at the BFTC using spring water (i.e., not stocking site-specific physicochemical water conditions). On day 1 of the acclimation period, Bozeman treatment pallid sturgeon were placed in a hatchery truck at the BFTC and transported for four hours to keep Marias treatment transportation time from being a confounding variable and then placed in two tanks at the BFTC. All design specifications, conditions, and monitoring were identical to the Marias treatment tanks except for water source. Water temperatures in the BFTC were adjusted to follow the thermograph of the Marias River as closely as possible.

Control fish were reared at the BFTC using traditional methods (not acclimated to flow or site-specific physicochemical water conditions). On day 1 of the experiment, control fish were also trucked for four hours to keep transportation from being a confounding variable and then placed in two 1.8-m diameter circular tanks at the BFTC.

Fish were fed a mix of 50% Silver Cup No. 4 (2.00–3.36 mm) Crumbled Salmon Feed (sinking) and 50% Bio-Products 3 mm BioDiet Grower. Due to fungal growth on uneaten food and mortality of pallid sturgeon during preliminary trials, it was decided to feed 1% (10 g) of mean fish weight per fish per day of feed in 2005. However, due to low and negative growth rates that were observed in 2005 (see Results), tanks were supplied with 2.5% (60 g) per fish per day in 2006. Fungal growth was not encountered in 2006.

Physicochemical parameters

Physicochemical parameters were measured every 14 days in all tanks. Temperature (°C; Onset Optic StowAway® Temp data loggers; hourly measurements), dissolved oxygen (mg L^{-1}; YSI Model 50B), turbidity (NTU; Hach 2100P), and water velocity (m s^{-1}; Marsh-McBirney Model 2000) were measured to ensure that levels of these parameters remained within suggested physiological tolerance limits of similar species (see Mims et al., 2002; Portz et al., 2006). These parameters were also used to characterize treatments (Table 1). All equipment was calibrated and tested prior to and monthly throughout the study.

Physiological condition

Prior to treatment assignment, all individuals were examined for fin curl: a deformation primarily of the pectoral fins characterized by curling of the fins in a dorsal direction. Although varying severity of fin curl existed among individuals, fin curl was measured as present or absent.

Growth rate by treatment was determined for the acclimation period by year. Length and weight were measured immediately prior to the acclimation period and near the end of the acclimation period (day 33 in 2005 and day 63 in 2006). Growth rate was calculated using relative growth rate (Isely and Grabowski, 2007).

Body lipid content (%) and liver fat content were evaluated in 2006. Mean percent lipid and liver fat content were each measured from six randomly selected individuals prior to treatment assignment (day 0; pre-treatment level) and from six randomly selected individuals for each treatment on day 63 to obtain post-treatment levels. Lipid content was measured using methods similar to the American Oil Chemists' Society Official Procedure Am 5-04 (AOCS 2008). Each fish was homogenized and lyophilized using a Labconco Freezone 12. Lipid was measured using a petroleum ether extraction (Ankom^{XT10}). For liver fat content evaluation, pallid sturgeon were euthanized, weighed (wet weight), and tissue collected and fixed in Davidson's solution. Liver tissue was embedded in paraffin, sectioned at 5 μm, and stained using hematoxylin and eosin (Luna, 1968). Histological slides were scored according to the Upper Basin Pallid Sturgeon Propagation Plan (UBPSPC 2005) based on fat vacuolation of hepatocytes (liver fat score 0 = no fat vacuoles present, 1 = few hepatocytes contain fat vacuoles, 2 = <50% of hepatocytes contain fat vacuoles, 3 = most hepatocytes contain fat vacuoles but cells retain normal shape, 4 = hepatocytes are greatly enlarged and normal cytoplasm is displaced by fat but membranes are intact, 5 = numerous hepatocytes show ruptured cell membranes due to fat accumulation).

Plasma cortisol concentration was used as an indicator of stress in 2006 (Webb et al., 2007). Blood (200 μl) was collected from the caudal vasculature of six randomly selected individuals prior to treatment, and from each treatment at 0, 12, 24, and 48 h, and 7, 14, and 63 days after being placed into acclimation tanks. Blood was immediately transferred to a heparinized vacutainer, centrifuged, and plasma was collected and frozen at −80°C until analyzed for cortisol. Plasma cortisol was measured by radioimmunoassay following the protocol of Foster and Dunn (1974) and modified by Redding et al. (1984).

Poststocking Dispersal

Pallid sturgeon poststocking dispersal was quantified using remote telemetry stations [see Oldenburg (2008) for system specifications] at one location along the Marias River (both years), four locations along the Missouri River in 2005, and five locations along the Missouri River in 2006 (Fig. 1). The remote station along the Marias River (Loma; both years) was placed at rkm 0.8. Remote stations along the Missouri River were at Coal Banks (rkm 3270; 2005), Virgelle (rkm 3274; 2006) Judith Landing (rkm 3190; both years), Power Plant Ferry (rkm 3118; 2006), Mauland Island (rkm 3076; both years), and Squaw Creek (rkm 3001; both years) (Fig. 1).

After the 36-d (2005) and 74-d (2006) acclimation period, 15 of the radio-tagged pallid sturgeon from each treatment (seven randomly selected from one tank and eight from the other) were released in the Marias River (Circle Bridge in 2005, Marias River acclimation location in 2006). The remaining 15 radio-tagged pallid sturgeon from each treatment were released in the Missouri River at the Fred Robinson Bridge (Fig. 1). Poststocking dispersal was quantified using remote

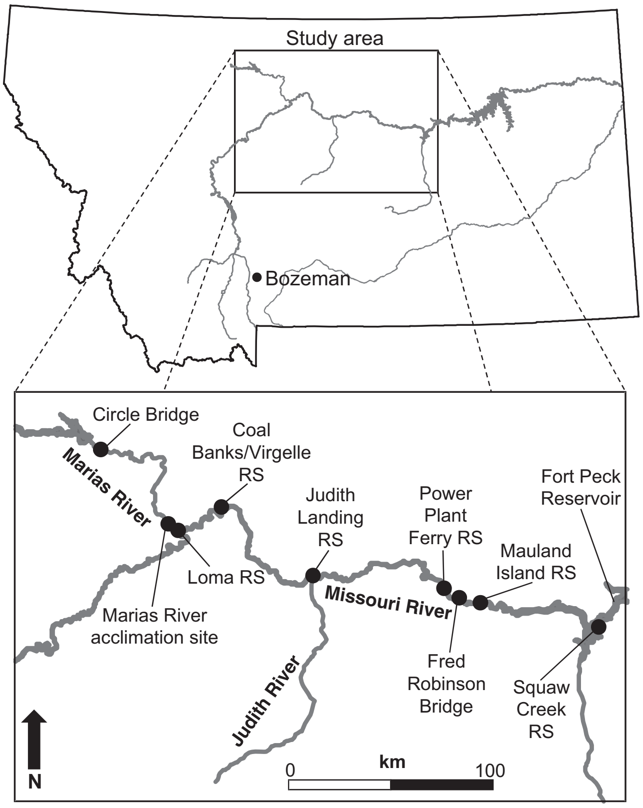

Fig. 1. Map of the study area with remote stations (RS), release sites (Marias River release: Circle Bridge in 2005 and Marias River acclimation site in 2006; Missouri River release: Fred Robinson Bridge both years), and the Marias River and Bozeman Fish Technology Center acclimation sites denoted

stations from release until day 68 post-release in 2005 and day 64 post-release in 2006 (dispersal period). Downstream dispersal rate was calculated as kilometers per day (km ⁄ d). Dispersal rate was calculated for each individual from the release site to the first remote station encountered and for each reach between remote stations thereafter.

Poststocking dispersal was also analyzed using fish locations at the end of the dispersal period. For each year and release site combination, remote station data were used to determine the number of pallid sturgeon from each treatment that remained in a reach (between remote stations) at the end of the dispersal period. In 2006, these locations were validated by comparing them to the fish locations observed during active tracking by jet boat at the end of the dispersal period.

Data analysis

A nested analysis of variance (ANOVA; tank nested within treatment) was used to compare growth rate for length and weight among treatments. Mean body lipid content was square root arcsine transformed (Zar, 1984), and ANOVA was used to compare lipid content among treatments (pre-treatment was not included in the ANOVA). A Fisher-Freeman-Halton test was used to evaluate differences in liver fat score among treatments (pre-treatment was not included in the Fisher-Freeman-Halton test). All plasma samples were analyzed in duplicate. The lower limit of detection was 0.98 ng ml^{-1}. The intra and interassay coefficients of variation for all assays were <5 and 10%, respectively. Analysis of variance was used to compare 63-d plasma cortisol concentration among treatments. A two-way ANOVA with repeated measures and a nested design (tanks nested within treatments) was used to analyze dispersal rate. The main effects were treatment and release site. The interaction term for the main effects was included in the model. A Fisher-Freeman-Halton test was used to test for differences among treatment distributions by release site.

All data were analyzed using Statistical Analysis System (SAS for Windows, version 9.1; SAS Institute, Inc., Cary, NC, 2003) and alpha was 0.05 for all analyses. Years were analyzed separately for all data analyses because several extraneous variables differed between years (e.g., acclimation period duration, release site locations, remote station locations, amount of feed, post-surgery recovery time, and presence or absence of fin curl). Mixed models were used for all ANOVAS with repeated measures (Wolfinger and Chang, 1995) and general linear models were used for all ANOVAS not containing repeated measures. All models containing two main effects were run with the interaction term included. Multiple comparisons were conducted using least-squares means (lsmeans) with Tukey–Kramer adjustment. Model assumptions of normality and homogeneity of variance were evaluated for all ANOVA models through visual examination of normal probability and residual plots.

Results

Physiological Condition

One hundred percent of the pallid sturgeon had fin curl in 2005. In 2006, 26% of the fish used in the poststocking dispersal experiment had fin curl (10 from Marias treatment, seven from Bozeman treatment, and six controls). Fin curl was most prevalent in the pectoral fins during both years.

Relative growth rate differed significantly between treatments in length ($F_{3,55}$ = 12.97, P < 0.01) and weight ($F_{3,55}$ = 58.50, P < 0.01) in 2005, being lower for the Marias treatment compared to control fish. Relative growth rate did not differ significantly among treatments for length ($F_{5,84}$ = 1.62, P = 0.16) or weight ($F_{5,84}$ = 1.43, P = 0.22) in 2006.

Basal lipid content assessed in 2006 was 9.2 ± 1.6%. Lipid content differed significantly among treatments ($F_{2,15}$ = 7.94, P = 0.004), being significantly greater for the Bozeman treatment (12.6 ± 0.5%) compared to the Marias treatment (9.3 ± 0.4%) (lsmeans, n = 12, P = 0.003), while controls (10.8 ± 0.8%) did not differ from the Marias (lsmeans, n = 12, P = 0.215) or Bozeman (lsmeans, n = 12, P = 0.101) treatments.

The majority of pallid sturgeon sampled had a mean liver fat score 4 with no significant differences among treatments (n = 18, P = 0.81). Five of the six livers sampled from control fish contained localized areas of liver fat score 5, where fat vacuolation of hepatocytes was extreme and caused cell membranes to rupture. No ruptured cell membranes were observed in Marias, Bozeman, or pre-treatment fish.

Mean plasma cortisol concentration did not differ significantly ($F_{2,3}$ = 1.37, P = 0.37) among treatments after the 63-d acclimation period in 2006. All treatments experienced a spike in plasma cortisol concentration (i.e., 4.7–8.6 ng ml^{-1}) between 0 and 48 h and then declined to nearly 0 ng ml^{-1} by the end of the acclimation period (Fig. 2). However, plasma cortisol concentrations were elevated in Marias treatment pallid sturgeon at 7 and 14 days.

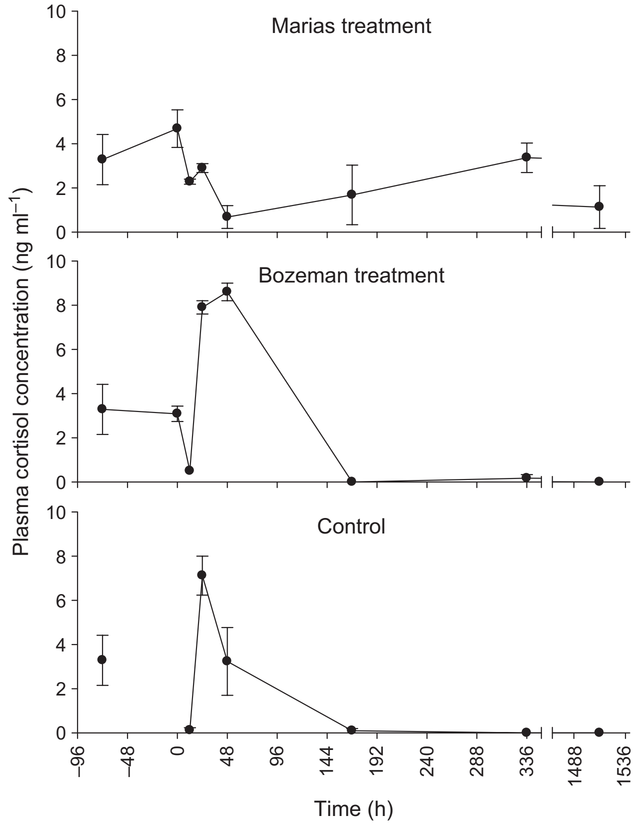

Fig. 2. Mean plasma cortisol concentration of Marias and Bozeman treatments and control pallid sturgeon 3 days prior to, and 0, 12, 24, and 48 h, and 7, 14, and 63 days after treatment commencement. Error bars denote standard error. Hour zero measurements were not obtained for the control group

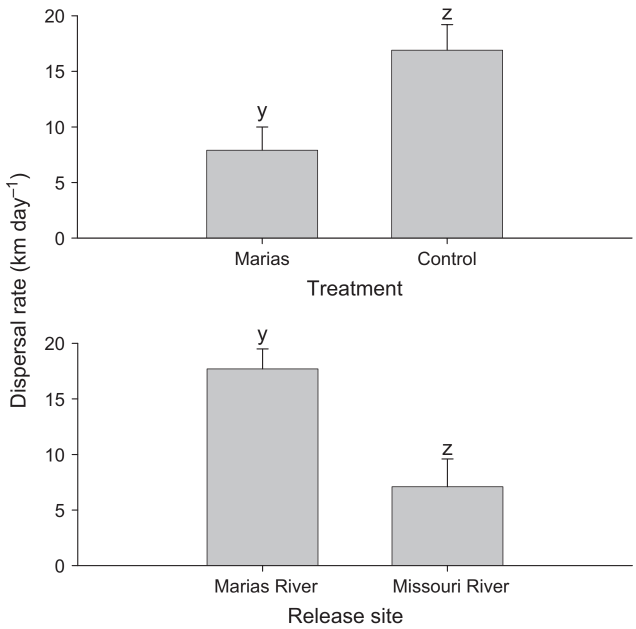

Fig. 3. Downstream dispersal rate by treatment and release site in 2005. Dissimilar letters indicate significant differences between treatments or release sites. Error bars denote standard error. Bozeman treatment was not conducted in 2005

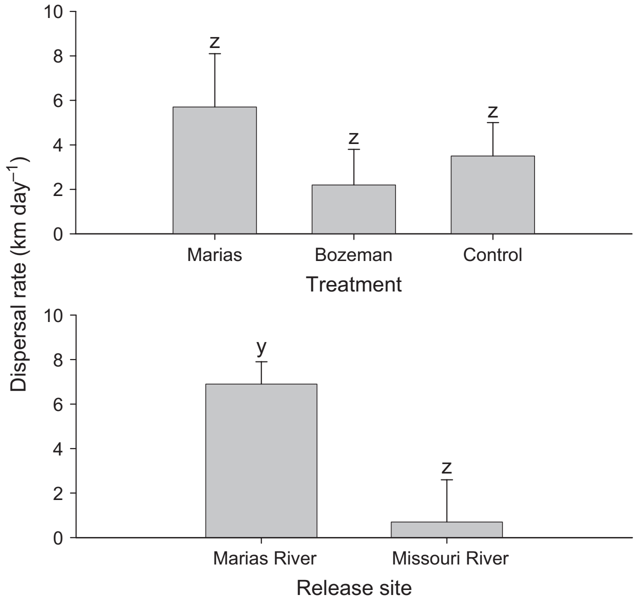

Fig. 4. Downstream dispersal rate by treatment and release site in 2006. Dissimilar letters indicate significant differences among treatments or between release sites. Error bars denote standard error

Poststocking Dispersal

In 2005, 37% (22 ⁄ 60) of the fish released were located through active tracking by jet boat at the end of the dispersal period and locations were consistent with the end location data obtained from remote stations. Three control fish were identified as mortalities.

In 2006, 82% (74 ⁄ 90) of the fish released were located through active tracking by jet boat at the end of the dispersal period and no mortalities were observed. Seventy-two fish were located in the reach (between remote stations) that was consistent with the end location data obtained from remote stations. The Virgelle remote station did not detect 24% (7 ⁄ 29) of the fish that dispersed downstream of that location.

In 2005, the treatment-release site interaction was non-significant ($F_{1,66.4}$ = 0.53, P = 0.47). Downstream dispersal rate differed significantly between treatments [$F_{1,66.4}$ = 8.08, P = 0.01 (pooled by release site)], being greater for the controls than for the Marias treatment (Fig. 3). Further, downstream dispersal rate differed significantly between release sites [$F_{1,66.4}$ = 11.43, P < 0.01 (pooled by treatment)] where pallid sturgeon released in the Marias River dispersed at a greater rate than fish released in the Missouri River (Fig. 3).

In 2006, the treatment-release site interaction was non-significant ($F_{2,56.9}$ = 0.94, P = 0.40). Dispersal rate did not differ significantly among treatments [$F_{2,56.9}$ = 0.77, P = 0.47; Fig. 4 (pooled by release site)], but differed significantly between release sites [$F_{1,58.1}$ = 8.24, P = 0.01 (pooled by treatment)]. As in 2005, fish released in the Marias River dispersed at a greater rate than fish released in the Missouri River (Fig. 4).

Treatments did not differ significantly with respect to end location distribution for a given release site in 2005 [Marias River release (n = 27, P = 0.07), Missouri River release (n = 30, P = 0.16); Fig. 5] or 2006 [Marias River release (n = 45, P = 0.22), Missouri River release (n = 45, P = 0.17); Fig. 6]. In 2005, 27% of the Marias treatment and 33% of the control fish released in the Marias River dispersed downstream >400 km into Fort Peck Reservoir, while 40% of the Marias treatment and 60% of the control fish released in the Missouri River dispersed 92 km or greater into Fort Peck Reservoir (Fig. 5). In contrast, in 2006, none of the

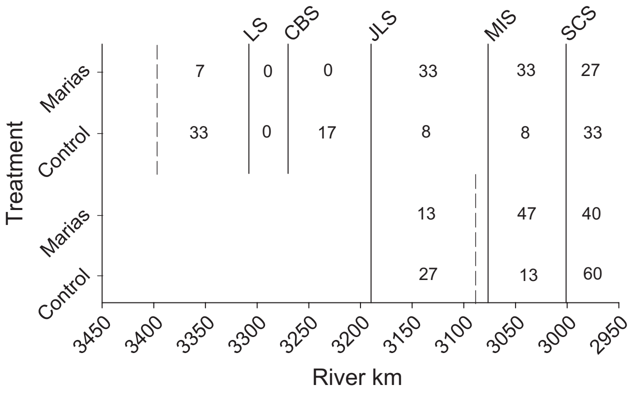

Fig. 5. Percent of pallid sturgeon remaining in each reach at the end of the dispersal period by release site and treatment in 2005. Dashed lines represent release site locations (upper line is Marias River release, lower line is Missouri River release). Solid lines represent remote station locations [LS, Loma station; CBS, Coal Banks station; JLS, Judith Landing station; MIS, Mauland Island station; SCS, Squaw Creek station (headwaters of Fort Peck Reservoir)]. Figure excludes three mortalities from the Marias River release, control group

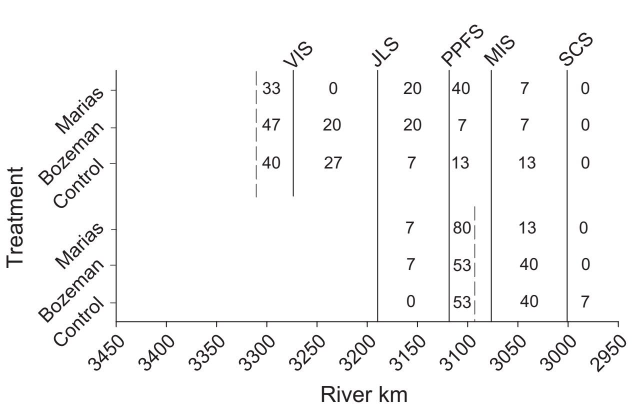

Fig. 6. Percent of pallid sturgeon remaining in each reach at the end of the dispersal period by release site and treatment in 2006. Dashed lines represent release site locations (upper line is Marias River release, lower line is Missouri River release). Solid lines represent remote station locations [VIS, Virgelle station; JLS, Judith Landing station; PPFS, Power Plant Ferry station; MIS, Mauland Island station; SCS, Squaw Creek station (headwaters of Fort Peck Reservoir)]

45 individuals released in the Marias River and 1 of the 45 individuals released in the Missouri River dispersed into Fort Peck Reservoir (Fig. 6).

Discussion

Neither treatment was fed to satiation in 2005 as growth rates were lower than those observed in 2006. The difference between treatments in 2005 may have been caused by feed in the Marias treatment tanks settling into the interstitial spaces in the gravel substrate where it was unavailable for consumption. The control tanks contained no substrate making it likely that the difference observed between the Marias treatment and controls in 2005 was a function of the amount of available feed.

Although lipid content differed among treatments, all treatments had sufficient levels to aid in the transition between hatchery and river environment (Volkman et al., 2004). Thus, the acclimation treatments did not negatively influence lipid content (i.e., did not exhaust energy reserves). Further, although no differences were found in liver fat score among treatments, it is possible that a difference did exist and was not detectable due to low sample size (i.e., Type II error) or insufficient criteria for fat score values. It is physiologically meaningful that fat accumulation was so severe that livers from 80% of control fish contained localized areas of ruptured hepatocytes whereas no ruptured hepatocytes were observed among livers from pallid sturgeon that were acclimated to flow. The high liver fat content and ruptured hepatocytes observed in localized areas of livers from control fish resulted in the loss of normal liver architecture, is considered pathological (UBPSPC 2005), causes metabolic disorder of the liver (Zhang et al., 2004), and may decrease survival (Feng and Jia, 2005). Therefore, exercise conditioning (acclimation to flow) appears to be beneficial in reducing liver fat content.

Release site (i.e., habitat) appeared to influence poststocking dispersal rate more than treatment conditions. Thus, hatchery-reared pallid sturgeon that were acclimated to river conditions dispersed downstream similarly to non-acclimated pallid sturgeon and all treatments exhibited selection for the lower reaches of the upper Missouri River. The river reach extending from slightly above the Fred Robinson bridge (rkm 3098; Missouri River release site) downstream to the headwaters of Fort Peck Reservoir (rkm 3001) retains many of the characteristics of a large warmwater river and is an important reach for hatchery-reared juvenile pallid sturgeon and their prey (Gerrity et al., 2008). Hatchery-reared juvenile pallid sturgeon are primarily associated with fines and sand substrate (Gerrity et al., 2008), the most common substrate in the upper Missouri River, while gravel and cobble compose the preponderance of substrates above this reach (Gardner, 1994). The reach between rkm 3001 and rkm 3098 is thought to contain the most suitable habitat for juvenile pallid sturgeon in the upper Missouri River (Gerrity et al., 2008), and these telemetry data corroborate that assertion.

Fin curl likely influenced dispersal rate between 2005 and 2006. Fin curl was more severe and expressed in more individuals in 2005 as compared to 2006. Pectoral fins have been demonstrated to be critical to swimming performance and station-holding (maintaining station without actively swimming by using pectoral fins and body morphology to generate negative lift) efficacy of sturgeons (Adams et al., 1997, 1999, 2003; Wilga and Lauder, 1999). Therefore, the diminished pectoral fin condition of the pallid sturgeon in 2005 likely increased downstream poststocking dispersal relative to the pallid sturgeon in 2006.

In 2005, pallid sturgeon acclimated to river conditions along the Marias River dispersed at a slower rate than those not acclimated and fewer acclimated fish dispersed into Fort Peck Reservoir. In 2006, all treatments were similar with respect to dispersal rate. Thus, acclimation to river conditions may be important when fin curl is present. It has been demonstrated that fish that are forced to swim for long periods of time (exercised fish) have greater swimming stamina than unexercised fish (Leon, 1986; Ward and Hilwig, 2004). However, pallid sturgeon spend approximately 18% of their time free swimming (Adams et al., 2003). Therefore, acclimation to flow may not be necessary for pallid sturgeon that have no physiological maladies because they are efficient at station-holding. Conversely, acclimation may be highly beneficial if pallid sturgeon have reduced swimming and station-holding ability due to fin curl. This contention is supported by the results from the plasma cortisol. These results suggest that the magnitude of flow in the acclimation tanks was not great enough to be considered a stressor to juvenile pallid sturgeon that do not have fin curl; thus, they were likely not truly acclimated to flow, or were acclimated to flow by day 7. Unfortunately, plasma cortisol was not measured in 2005 to determine if the hypothesized fin curl induced decrease in station holding-ability was correlated with greater plasma cortisol concentrations.

Fish size may have also contributed to the differences in dispersal between years. The maximum observed sustained swimming speed of age-0 pallid sturgeon was 0.25 m s^{-1} for large fish (170–205 mm) and 0.10 m s^{-1} for small fish (130–168 mm) (Adams et al., 1999). Although the pallid sturgeon used in Adams et al. (1999) were slightly smaller and eight months younger than the fish used in this study, they demonstrate that relatively small differences in size may have a great impact on swimming ability. Thus, the size difference in pallid sturgeon between years and the additional acclimation time in 2006 along with fin curl likely explains the differences in dispersal rate between years.

Although these results seem to indicate that there is little benefit in acclimating pallid sturgeon that have no physiological anomalies, a few alternative hypotheses should be considered. Due to transmitter size restraints, only the largest pallid sturgeon from the BFTC were selected for use in this study. The effects of acclimating smaller pallid sturgeon to flow and physicochemical conditions remain unknown. Further, it has been suggested that it may take more than 1 year for hatchery-reared pallid sturgeon to become acclimated to the river environment (Jordan et al., 2006). Thus, a longer acclimation period may be desirable. Moreover, acclimation over a longer period of time or at greater velocities, may affect swimming performance and liver fat content. Lastly, it may not be desirable for pallid sturgeon to remain in the upper reaches of the upper Missouri River because of the lack of suitable habitat. Thus, stocking at a single location (Fred Robinson Bridge) rather than multiple locations may be beneficial to pallid sturgeon recovery.

Acknowledgements

The MTFWP, PPL Montana, and Western Area Power Administration provided funding for this study. We thank Ross Epley, Amber Goodman, Brian Bellgraph, Jim Boyd, Windy Davis, Jen Dodge, Paul Gerrity, Casey Jensen, Ben Goodman, Eli McCord, Mike Meeuwig, Bob Oldenburg, Glenda Oldenburg, Lek Oldenburg, Randy Rodencal, Mike Wente, Ryan White, and Dr. Alexander Zale for assistance with this project; the entire staff of the BFTC for facility and logistical contributions; Linda Beck for liver fat score confirmation; and the Cornell family for their hospitality while in the field. The Montana Cooperative Fishery Research Unit is jointly sponsored by Montana Fish, Wildlife and Parks, Montana State University, and the U.S. Geological Survey. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

Adams, S. R.; Parsons, G. R.; Hoover, J. J.; Killgore, K. J., 1997: Observations of swimming ability in shovelnose sturgeon (*Scaphirhynchus platorynchus*). J. Freshw. Ecol. **12,** 631–633.

Adams, S. R.; Hoover, J. J.; Killgore, K. J., 1999: Swimming endurance of juvenile pallid sturgeon, *Scaphirhynchus albus*. Copeia **1999,** 802–807.

Adams, S. R.; Adams, G. L.; Parsons, G. R., 2003: Critical swimming speed and behavior of juvenile shovelnose sturgeon and pallid sturgeon. Trans. Am. Fish. Soc. **132,** 392–397.

American Oil Chemists Society (AOCS), 2008: Official methods and recommended practices of the AOCS, 5th edn. American Oil Chemists Society, Champaign, IL.

Busacker, G. P.; Adelman, I. R.; Goolish, E. M., 1990: Growth. In: Methods for fish biology. C. B. Schreck and P. B. Moyle (Eds), Am. Fish. Soc, Bethesda, MD, pp. 363–387.

Cresswell, R. C.; Williams, R., 1983: Post-stocking movements and recapture of hatchery-reared trout released into flowing waters—effect of prior acclimation to flow. J. Fish Biol. **23,** 265–276.

Feng, J.; Jia, G., 2005: Studies on the fatty liver diseases resulting from different lipid levels in *Sciaenops occellatus* diets. Shuisheng Shengwu Xuebao **29,** 61–64.

Foster, L. B.; Dunn, R. T., 1974: Single antibody technique for radioimmunoassay of cortisol unextracted serum or plasma. Clin. Chem. **20,** 365–368.

Gardner, W. M., 1994: Missouri River pallid sturgeon inventory. Montana Department of Fish, Wildlife and Parks, Federal Aid to Fish and Wildlife Restoration Project F-46-R-7, Helena, MT.

Gardner, W. M., 1997: Middle Missouri River fisheries evaluation. Annual report for 1997. Montana Department of Fish, Wildlife and Parks, Federal Aid to Fish and Wildlife Restoration Project F-78-R-4, Helena, MT.

Gardner, W. M., 2004: Middle Missouri River fisheries evaluation. Annual report for 2001 and 2002. Montana Department of Fish, Wildlife and Parks, Federal Aid to Fish and Wildlife Project F-113-R3, F-113-R4, Helena, MT.

Gardner, W. M., 2005: Montana endangered fishes program. Pallid sturgeon annual report. Montana Department of Fish, Wildlife and Parks, Report E-7-11, Helena, MT.

Gardner, W. M., 2007: Montana endangered fishes program. Pallid sturgeon annual report. Montana Department of Fish, Wildlife and Parks, Report E-7-13, Helena, MT.

Gerrity, P. C., 2005: Habitat use, diet, and growth of hatchery-reared juvenile pallid sturgeon and indigenous shovelnose sturgeon in the Missouri River above Fort Peck Reservoir. Master's thesis. Montana State University, Bozeman, MT.

Gerrity, P. C.; Guy, C. S.; Gardner, W. M., 2008: Habitat use of juvenile pallid sturgeon and shovelnose sturgeon with implications for water-level management in a downstream reservoir. N. Am. J. Fish. Manage. **28,** 832–843.

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

Isely, J. J.; Grabowski, T. B., 2007: Age and growth. In: Analysis and interpretation of freshwater fisheries data. C. S. Guy and M. L. Brown (Eds), Am. Fish. Soc., Bethesda, MD, pp. 187–228.

Jordan, G. R.; Klumb, R. A.; Wanner, G. A.; Stancill, W. J., 2006: Poststocking movements and habitat use of hatchery-reared juvenile pallid sturgeon in the Missouri River below Fort Randall Dam, South Dakota and Nebraska. Trans. Am. Fish. Soc. **135,** 1499–1511.

Leon, K. A., 1986: Effects of feed consumption, growth, food conversion, and stamina of brook trout. Prog. Fish-Cult. **48,** 43–46.

Luna, L. G., 1968: Manual of histological staining methods of the Armed Forces Institute of Pathology. McGraw-Hill, New York.

Mims, S. D.; Lazur, A.; Shelton, W. L.; Gomelsky, B.; Chapman, F., 2002: Species profile: production of sturgeon. Southern Regional Aquaculture Center 7200.

Minckley, W. L.; Marsh, P. C.; Brooks, J. E.; Johnson, J. E.; Jensen, B. L., 1991: Management toward recovery of the razorback sucker. In: Battle against extinction: native fish management in the American West. W. L. Minckley and J. E. Deacon (Eds), University of Arizona Press, Tucson, AZ, pp. 303–357.

Mueller, G. A.; Marsh, P. C.; Foster, D.; Ulibarri, M.; Burke, T., 2003: Factors influencing poststocking dispersal of razorback sucker. N. Am. J.Fish. Manage. **23,** 270–275.

Oldenburg, E. W., 2008: Effects of acclimation on poststocking dispersal of age-1 pallid sturgeon. Master's thesis. Montana State University, Bozeman, MT.

Portz, D. E.; Woodley, C. M.; Cech., J. J., Jr, 2006: Stress-associated impacts of short-term holding on fishes. Rev. Fish Biol. Fish. **16,** 125–170.

Redding, J. M.; Schreck, C. B.; Birks, E. K.; Ewing, R. D., 1984: Cortisol and its effects on plasma thyroid hormone and electrolyte concentrations in freshwater and during seawater acclimation in yearling coho salmon, *Oncorhynchus kisutch*. Gen. Comp. Endocrinol. **56,** 146–155.

Thuemler, T. F., 1988: Movements of young lake sturgeons stocked in the Menominee River, Wisconsin. Am. Fish. Soc. Symp. **5,** 104–109.

Upper Basin Pallid Sturgeon Propagation Committee (UBPSPC), 2005: Upper basin pallid sturgeon propagation plan, Bozeman, MT.

US Fish Wildlife Service (USFWS), 2003: Pallid sturgeon fish health summary, Bozeman Fish Health Center, Bozeman, MT.

Volkman, E. T.; Pangle, K. L.; Rajchel, D. A.; Sutton, T. M., 2004: Hatchery performance attributes of juvenile lake sturgeon fed two natural food types. N. Am. J. Aquacult. **66,** 105–112.

Ward, D. L.; Hilwig, K. D., 2004: Effects of holding environment and exercise conditioning on swimming performance of southwestern native fishes. N. Am. J. Fish. Manage. **24,** 1083–1087.

Webb, M. A. H.; Allert, J. A.; Kappenman, K. M.; Marcos, J.; Feist, G. W.; Schreck, C. B.; Shackleton, C. H., 2007: Identification of plasma glucocorticoids in pallid sturgeon in response to stress. Gen. Comp. Endocrinol. **154,** 98–104.

Wilga, C. D.; Lauder, G. D., 1999: Locomotion in sturgeon: function of the pectoral fins. J. Exp. Biol. **202,** 2413–2432.

Wolfinger, R.; Chang, M., 1995: Comparing the SAS GLM and MIXED procedures for repeated measures. Proceedings of the twentieth annual user group international conference. SAS Institute Inc., Cary, NC.

Zar, J. H., 1984: Biostatistical analysis, Prentice-Hall, Englewood Cliffs, NJ.

Zhang, H.; Wang, A.; Li, G.; Sun, C., 2004: Effect of nutrient on the fatty liver disease of fish. Mar. Sci. Bull. ⁄ Haiyang Tongbao **23,** 82–89.

Author's address: Eric W. Oldenburg, Pacific Northwest National Laboratory, Ecology Group, Mail Stop K6-85, Post Office Box 999, Richland, Washington 99354, USA. E-mail: eric.oldenburg@pnl.gov