

FINAL REPORT

To

**Idaho Department of Fish and Game
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Dispersal Characteristics, Drift Distance, and Wintering Behavior of Young Kootenai River White Sturgeon: A Laboratory Study

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Synopsis

Kootenai white sturgeon *Acipenser transmontanus* free embryos observed in four artificial stream tanks with eddy and rock cover habitat and a channel flow with either a fast current regime (two tanks, mean, 23.4 cm/s) or a slow regime (two tanks, mean, 16.9 cm/s) did not have a behavioral dispersal. A few fish moved downstream during two weak peaks: early-free embryos seeking cover (and slow velocity) and late-free embryos likely affected by development. The strong dispersal by early-larvae was greatly affected by velocity regime. Early-larvae in fast velocity initiated dispersal earlier, with greater intensity, and the dispersal lasted longer than in slow velocity (14 d vs. 11 d). A velocity trigger for dispersal response by early-larvae may exist: ≥ 16.9 -cm/s velocity triggers the response by most larvae, but 7 cm/s does not. Downstream movement of late-larvae and early-juveniles was similar with small to moderate peaks in intensity in both velocity regimes and most fish used edge, not channel or eddy habitat.

A passive drift model, using conservative estimates for all factors, estimated the strong early-larval dispersal could move fish downstream ≥ 90 km to the lower river, even to Kootenai Lake. Foraging behavior and use of current in artificial streams by larvae and juveniles suggest rearing habitat is the lower river, not the lake. Most of the river's length downstream from the spawning reach only provides dispersing larvae daytime foraging resources and a passage route to the lower river. Because larvae can reach the lower river using only the dispersal by early-larvae, the weak-moderate downstream movement by older larvae and juveniles in artificial streams may reflect another function other than dispersal.

Both years-0 and 1 juveniles preferred dark habitat during wintering: dark substrate color and no illumination. However, juveniles differed for preference of substrate size: year-0 fish preferred small substrate and year-1 fish preferred large substrate. This difference suggests the two groups are spatially segregated during winter.

The number of early-larvae swimming above the bottom in 16.9 or 23.4-cm/s velocity regimes was not sensitive to a doubling of the number of downstream fish passes during the peak larval dispersal. Monitoring the downstream movement of fish is the most sensitive measure of dispersal by larvae.

Background

Damming and river alterations can disrupt the life history of sturgeons by causing changes that deleteriously affect spawning success, survival of early life intervals, or both. Although some aspects of spawning by Kootenai River white sturgeon (hereafter, Kootenai sturgeon) *Acipenser transmontanus* are understood, there is a poor understanding of the dispersal and habitat needs of early life stages (ELS), i.e., eggs, free embryos (hereafter, embryos), larvae, and year-0 juveniles. The years of successful spawning by Kootenai sturgeon in the river between Kootenai Lake and Libby Dam (Paragamian & Beamesderfer 2004) should have resulted in juvenile recruitment. Apparently there is a bottle-neck in survival of ELS because recruitment has failed for many years (Anders et al. 2002, Koch et al. 2005). This suggests a mismatch between the present egg–juvenile rearing environments available and their habitat preference which evolved to maximize fitness.

Basic information on the innate behavior of ELS can help managers determine if there is a mismatch between ELS life history and the present rearing environment, and also, can identify the environmental factor(s) that are important. Unfortunately, even capturing a few wild ELS to study basic aspects of dispersal and habitat selection in a river is very difficult, expensive, and not practical if ELS are rare, like Kootenai sturgeon. Because of the difficulty of studying ELS in rivers, the only practical approach to revealing their innate behavior is to study their behavior in artificial streams. Comparative studies on ELS dispersal and habitat preference of North American, Asian and European sturgeon species have resulted in developing useful methods for studying behavior and downstream movements of young sturgeons in artificial streams (Kynard & Horgan 2002; Kynard et al. 2002a,b; 2003, 2005; Kynard & Parker 2004, 2005; Zhuang et al. 2002a,b).

Research using an artificial stream in common-garden experiments that compared behavior of ELS between populations of the same species revealed differences between river populations, particularly for dispersal. Within white sturgeon, the dispersal style of Sacramento River white sturgeon is quite different from Kootenai sturgeon (Kynard & Parker 2005, Kynard & Parker 2006, present study).

Kootenai sturgeon ELS observed in an artificial stream with a slow velocity

regime (mean, 7 cm/s; range, 3–9 cm/s) moved downstream with weak to moderate intensity during all life intervals (Kynard & Parker 2006). Embryos moved downstream weakly for several days, then hid under cover, and finally moved downstream weakly again (two small movement peaks). Early- and mid-larvae dispersed moderately during days 10–43 with a peak at day 28, then weakly as late-larvae and early-juveniles. The slow downstream movement suggested fish continue to move downstream until they stop and enter the wintering phase in fall. The diel pattern of dispersal changed during development with embryos moving day and night, but larvae moving mostly or only at night depending on the stage of development. The 2005 study suggested wild Kootenai sturgeon ELS have a slow dispersal style that requires a long river reach for rearing during the first summer and fall of life.

Comparative studies on the behavior of ELS of different sturgeon species used a common stream environment and a slow velocity regime (mean, 7 cm/s). These common methods were necessary for a broad comparison among species. However, the specific effects of riverine factors like temperature (Parker & Kynard unpubl. data) or velocity on dispersal are only just beginning to be studied. Observations by Brannon et al. (1985) on Columbia River white sturgeon ELS in artificial streams suggested a positive relationship between water velocity and the number of fish swimming above the bottom, which was used as an indication of dispersal. A higher percent of embryos and early larvae swam above the bottom when water velocity was fast (mean, 8 cm/s) than when velocity was slow (mean, 2 cm/s). Brannon et al. also found that embryos in the fast velocity regime ceased swim-up behavior after day 1, whereas those in slow velocity showed swim-up behavior for up to 3 days. Thus, fast water speed appeared to shorten duration of movement by embryos.

Drift distance of pallid sturgeon *Scaphirhynchus albus* embryos was estimated using ontogenetic dispersal characteristics in an artificial stream, swimming height of fish observed in a vertical stream tank, and a conservative estimate of bottom water velocity (Kynard et al. In Press). This study and analysis found that recruitment failure of one population of Missouri River pallid sturgeon is likely caused by dispersing embryos that drift into the headwaters of a reservoir and die because of the altered rearing habitat. We used the same techniques to estimate the distance Kootenai sturgeon could move

downstream from the spawning reach. Identifying the rearing reach of Kootenai sturgeon larvae and juveniles is critical to future field studies on habitat availability during rearing and wintering.

Habitat preference of wintering year-0 juvenile Kootenai white sturgeon has not been studied. Wintering is a period of great physiological and energetic stress that usually lasts at least for 5–6 months for most sturgeons, so young sturgeons likely have evolved a survival strategy that includes strong wintering habitat preferences (Kynard et al. 2005). Wintering Sacramento River white sturgeon year-0 juveniles observed in an artificial stream preferred cobble, not sand substrate, and a moderate water velocity >20 cm/s (Parker et al. unpubl. data). In addition, wintering year-0 juveniles of some species are photonegative and active only at night, i.e., green sturgeon *A. medirostris* (Kynard et al. 2005). Field studies on substrate use during summer by stocked cultured Kootenai sturgeon juveniles several years old found they used mostly sand (Young & Scarnecchia 2005). However, no data are available on the innate substrate preference of wintering juveniles of any age. Understanding habitat preferences is the key to evaluating the impact of anthropogenic habitat changes.

The present research on Kootenai sturgeon used artificial stream tanks to: (1) determine the effect of two velocity regimes on dispersal duration, intensity, and percent of embryos and larvae swimming above the bottom, (2) gather preliminary data on daytime habitat use of channel, edge, and eddy by ELS, (3) estimate the drift distance of each life interval, (4) determine habitat preference of wintering years-0 and 1 juveniles for dark vs. white substrate color and for substrate size (roughness), and (5) determine 24-h preference of dark vs. illuminated habitat of wintering years-0 and 1 juveniles. Dispersal studies contribute to the model of dispersal distance, habitat use, and identifying dispersal strategy. Information on habitat preference assists managers understand habitat needs of young sturgeons during foraging and wintering.

Methods

General rearing procedures

We received fertilized eggs on 27 June 2006 and reared them in a flow-through McDonald hatching jar. After eggs hatched on 4 July 2006, we transferred about 1,000 hatchling embryos (day-0 fish) to a stream tank for rearing. This tank is identical to the

slow velocity test tank we used to observe fish dispersal. We reared fish in this artificial stream so, if a fish died in a test stream, we could replace it with a fish also reared in a stream tank. Larvae were fed commercially available food in an automatic feeder six times/d and frozen Cyclop-eeze (Argent Chemical Labs) three times daily.

We used the number of days post-hatching to characterize age of fish, not the number of days post-fertilization, because we did not know how early egg-rearing conditions (particularly water temperature) varied during shipping before we receive the eggs. We used de-chlorinated city water (Montague, MA) for rearing and experiments. Temperature in both situations was the same ($\pm 1^\circ\text{C}$). We maintained the natural photoperiod for Turners Falls, MA, latitude location (42.6°N).

Objective 1. Determine the effect of water velocity on dispersal duration, dispersal intensity, and percent of fish swimming above the bottom. Determine habitat use of embryos and larvae. Estimate dispersal distance.

Artificial stream tanks.—We conducted tests in four 1.5 m diameter identical circular stream tanks with a blue bottom (Hype’s Color, dark turquoise 0 206 209; Figure 1). Two tanks had a fast mean channel velocity of 23.4 cm/s (range, 7–40 cm/s) and two tanks had a slower mean channel velocity of 16.9 cm/s (range, 7–30 cm/s; Table 1). Mean velocities in the edge and eddy habitats in fast and slow tanks were similar (Table 1). Channel velocities presented fish with exposure to much higher velocity regimes than tests in 2005 where the mean channel velocity was 7 cm/s (Kynard & Parker 2006). Our previous tests in these stream tanks with shortnose sturgeon *A. brevirostrum* embryos, which are a dark gray color like Kootnenai sturgeon, found that about 20 cm/s was the fastest water velocity at which we could see the small fish on nighttime videotapes monitoring downstream movement. Thus, the fast velocity regime in the present study was as fast as we could record fish passes on videotape.

Each tank had a circular insert placed offset from the center of the tank to create two major velocity habitats (channel and eddy) and an edge or transition habitat between the two major habitats (Figure 1). To enlarge eddy habitat and create an eddy that even the weakest swimming embryo or larva could use to remain out of the current if they lacked the drive to move downstream, we placed walls at the up- and downstream ends of the eddy. Fish with a behavioral drive to move downstream had the channel flow in

which they could consummate their drive; fish that lacked a downstream movement drive had a large eddy and edge habitat, so they could remain out of the flow. We placed eight cobble-size rocks (8–10 cm diameter) in the eddy to provide cover for fish (Figure 1).

Water depth in stream tanks was 30 cm, except in the video viewing area where the ramp reduced depth to 13.5 cm and brought fish close to the camera. Each tank was covered with a fine-mesh netting to exclude insects and aerial debris. The entire test system was built outside on a platform and protected from weather by a tent, which only allowed diffuse illumination into the tank bottom.

The water system for the four test tanks was a constant circulating system. Water constantly drained from a head tank to each test tank and overflowed into a common drain tank, where the water was pumped through a chiller-heat pump and back to the head tank. The chiller-heat pump within the water system maintained the same water temperature in all tanks. Individual pumps at each of the tanks provided the water velocity regime. In the two slow velocity tanks, a submersible pump inside the circular insert pumped water through an outlet in the ramp (Figure 1). Large pumps for fast velocity tanks were located outside and underneath each tank and circulated water from the test tank insert area into the test arena through an outlet pipe in the ramp.

Water temperature during experiments attempted to duplicate the general rise in temperature of the Kootenai River during spawning to ELS rearing in summer. Temperature during embryo rearing was 14°C; temperature during larval rearing was 16°C.

We characterized the hydraulic environment in one slow and one fast velocity tank by measuring velocity at six stations along eight radians of the tank, four radians between the two barrier walls creating the eddy, two radians just upstream of the upstream wall, and two radians just downstream of the downstream wall. These radians encompassed the areas that larvae and juveniles used most. We measured only bottom velocity (5 cm above the bottom) because fish were always on the bottom except when moving downstream.

Observations on fish.— To view fish moving downstream in the ramp area of each tank, we placed a color video camera with two 60-W yellow lights (to see fish at night) over the viewing area in each tank (Figure 1). We noted the behavior of fish when we used

red lights or yellow lights and could find no difference on the videotape review, so we used yellow lights to reduce the attraction of nocturnal flying bugs. To better see the small fish at night, we covered the walls in the camera viewing area with silver reflective tape and painted the ramp white.

We continued to observe fish until 4 d after morphological examination showed that they had developed into juveniles. We observed 10 fish in each tank counting and replacing dead fish every other day (to minimize disturbance) with same-age fish from the rearing tank.

Data collection and analysis.— In 2005, Kootenai sturgeon moved downstream day and night (nocturnal peak) as embryos, but moved downstream only at night as larvae (Kynard and Parker 2006). Thus, monitoring nocturnal dispersal should provide a good measure of daily dispersal intensity and dispersal duration (start and end by fish in both velocity regimes). To reduce data to a manageable level, we recorded fish downstream movement only at night at four time intervals (2200, 0000, 0200, and 0400 h). During each observation period, the video camera observed fish for 5 min (total, 20 min/d).

We reviewed tapes from the four time periods each day to determine the net number (mean) of downstream fish passes (mean number of downstream fish passes – mean number of upstream fish passes = net mean number of downstream fish passes). We used a one-way repeated measures ANOVA to compare the mean number of fish passes within and between velocity treatments (2 replicate tanks combined). We present the data as a daily time series of the net mean number of downstream fish passes.

To determine the percent of fish swimming above the bottom in each of the four test tanks, we made visual point samples two times for 10 d from days 0–20). Sampling provided observations on free embryos for 6 d and observations on larvae for 4 d. We used two-sample *t*-tests to compare the slow and fast velocity treatments for mean daily percent of fish swimming above the bottom.

Embryo use of eddy vs. channel habitats in fast vs. slow velocity regimes was determined every day, but for clarity, because there was little variation between days, we only plotted the data for every other day. We sampled habitat use every third day for larvae (12 d) until they were 43 d old. On an observation day, we observed fish twice daily in one slow and in one fast velocity tank by visually counting the number of fish (of

10 total fish) in eddy habitat. We used these observations to calculate the daily percent of fish in the eddy (number fish in eddy divided by 10 times 100) and compared the mean daily number of swimming fish in slow and fast tanks using two-sample *t*-tests. We also gathered visual information on daytime use of channel, edge, and eddy habitat by late-larvae (days 42–44 and day 51) and early-juveniles (days 64–66, days 70–73 and day 74) in both fast and slow velocity regimes. We compared velocity regimes for the mean percent use of the three habitats by larvae and juveniles using a one way ANOVA.

Estimate of drift distance.—To estimate dispersal distance by life interval, we used information on the daily downstream movement during ontogenetic development gathered from fish observed in artificial streams in the present study and by Kynard & Parker (2006). We used dispersal timing and duration data (begin and end dates) from the present study (two fast velocity artificial stream tanks). Kynard & Parker (2006) found dispersal of early-larvae was mostly nocturnal, although some early- and mid-larvae moved in the day. To be conservative, we omitted all daytime hours of downstream movement and only used hours of darkness for dispersal dates obtained from the Naval Observatory. We did not estimate actual bottom velocities fish used during downstream movement, but instead, used a mean bottom velocity of 20 cm/s, which was similar to the velocity in our two fast velocity artificial streams. Thus, we felt confident that the dispersal timing and behavior of fish we used was correct for that velocity regime. We used a passive drift model (fish move at the speed of water) because early-larvae in artificial streams reflected this drift pattern.

Objective 2. Study winter habitat of year-0 juveniles and yearlings: identify preference for substrate color and size; preference for dark vs. illuminated habitat.

Test stream tank and the test environment.— We conducted tests in a rectangular tank (240 cm x 70 cm with 15 cm deep water; Figure 2). Water velocity was similar and about 6 cm/s (range 0–9 cm/s) across the width of the tank. Water flow was needed to provide an orientation flow.

Before testing fish, we reared years-0 and 1 juveniles in separate tanks supplied with ambient Connecticut River water during winter, 2006–2007. Water temperature was 2.0–5.5 °C in both rearing and test tanks while observing fish.

Photoperiod during rearing and tests was natural for this latitude. Lighting above both rearing and test tanks was controlled by a timer which turned lights off at sunset and on at sunrise. After lights were turned off in the evening and before lights were turned on in the morning, ambient light entered through windows in the laboratory, giving the fish a natural twilight period. In the test tank, illumination intensity (lx) was regulated by an overhead florescent light in the visible wavelength. Light intensity was low, about 40 lx. We did not know the light intensity on the bottom of the Kootenai River let alone the light level in sturgeon wintering areas. We selected 40 lx because the light level in juvenile wintering areas of Connecticut River shortnose sturgeon is about 100 lx and the Kootenai River appeared less clear in winter than the Connecticut River (B.K., personal observation).

Observations on fish.—A video camera with IR light was placed over the tank to observe fish day and night. A light meter measured light level (lux) each 15 min on the bottom in the center of the tank. This system was previously used to examine wintering habitat preference and activity of green sturgeon in this same stream tank (Kynard et al. 2005). In substrate-color tests, one-half the length of the bottom was colored black and one-half was colored white. We conducted tank side-bias tests with both year-0 juveniles and year-1 juveniles and found no bias so we did not reverse test substrates during replicates. Tests and replicates follow: year-0 juveniles (eight fish/replicate and three replicates) and year-1 juveniles (six fish/ replicate and four replicates) for a total of 24 of either juvenile group per substrate test.

We captured fish randomly from the rearing tank, placed them in a small bucket, and introduced them into the center of the tank at the interface of the substrate types. We introduced fish into the test tank in the afternoon and observed fish with the overhead video camera for 24 h. We sub-sampled the videotape and visually determined the number of fish on each substrate type for 5 min/h (a point sample each minute for a total of 6 point samples/h) obtaining 6 day and 6 night samples. This ratio of day:night samples was determined by the natural pattern, which was 12 h of light and 12 h of darkness. We calculated 95% confidence intervals around the mean percent of fish occupying each habitat during the day and during the night. If the confidence interval did not include 50%, we considered the preference to be statistically significant.

In substrate-type tests, fish had a choice of two substrates that differed for roughness: small gravel (mean, 3.2 mm; range 2.0–5.1 mm) and small pebble (mean, 30.0 mm; range, 19.0–41.5 mm). Size of each substrate was determined by randomly selecting 10 rocks, measuring their greatest length, and calculating the mean of all measurements. Color of the two substrates (Hype's Color Scale) was a similar light color: gravel was a Wheat 3 (205 186 150) and pebble was a Tan 3 (205 133 63). The two substrates were placed into the tank like the black and white substrate, i.e., each covered ½ of the length of the bottom. We tested year-0 juveniles for choice of substrate in three replicates (eight fish/replicate) and tested yearlings in four replicates (six fish/replicate). We determined substrate choice of each life stage using the same techniques and analysis used for substrate color.

We measured preference for dark vs. illuminated habitat in the same tank used for substrate choice tests, but the bottom was a uniform white color and was smooth. The same tank and techniques were used to study this behavior of green sturgeon (Kynard et al. 2005). We covered one-half of the tank top with black plastic to create a tank with one-half illuminated bottom (40 lx) and one-half dark (0 lx under the cover). Bottom light intensity (lux) was recorded each 15 min by the meter on the illuminated side. During four 24-h replicates with year-0 juveniles (8 fish/replicate, 32 total fish) and six 24-h replicates using yearlings (5 fish/replicate, 25 fish total), we monitored fish use of the illuminated side for 5 min/h using the camera and IR light. We reviewed tapes and counted the number of fish on the illuminated side each 5 min/h and calculated the mean number on the illuminated side for each hour of the test period. The data were presented as a 24-h time series of mean number of years 0 and 1 juveniles on the illuminated side along with the mean hourly light intensity.

Results

Development

Using presence of food in stomachs of some fish, but mainly the switch in behavior from non-dispersal to a strong dispersal, we estimated the embryo interval was days 0–11 and the larva interval began on day 12 (170 CTU). We used the same two characters to estimate a CTU of 220 when embryos developed into larvae in 2005 and began dispersing. The difference in the estimated number of days (and CTU) to develop

into larvae between the two years was partly due to the colder rearing temperature used in 2006, but mostly to the uncertainty of the day in 2005 when the moderate larval dispersal began. The day larval dispersal began in 2006 was much more obvious than in 2005 (Figure 3). Developing into larvae is a process requiring days and some fish were foraging when dispersal began, but not all early dispersing fish were foraging. Thus, we relied mainly on the day the major dispersal began (and confirmatory examination of some fish foraging) to separate embryo from larva intervals in this behavioral study.

Based on morphological examination of fin rays, larvae had developed into juveniles by day 60 (940 CTU). A CTU of 805 occurred on day 52, when the low to moderate dispersal by larvae ended in 2005. Although we proposed ending observations on dispersal at 805 CTU in 2006, we continued observation on dispersal until fish were early juveniles on day 64 (1,000 CTU) to confirm in a second year that the juvenile life interval continues to disperse.

Effect of slow vs. fast velocity regimes on downstream movement

Embryos.—Downstream movement by embryos was weak and of similar duration in both velocity regimes (Figure 3). Also, in both regimes, movement pattern was similar with an initial small peak (particularly at night), a gradual daily decline to zero by day 3, a second small peak on day 6, then a decline to zero by day 10. Velocity regime had little effect on intensity or duration of downstream movement.

During the first one-half of the embryo interval, the number of downstream fish passes was similar in fast or slow velocity regimes (Figure 3). However, during the second one-half, more downstream fish passes occurred in the fast regime.

Larvae.—Velocity regime greatly affected dispersal by larvae (Figure 3). Early-larvae in fast velocity tanks initiated an intense dispersal from days 13–26 (14 d) with a peak at days 17–19, then dispersal declined to a low level by day 27. Larvae in the slower velocity tanks initiated dispersal during days 15–25 (11 days) and the peak was slightly less intense, but it still lasted 4 d. The mean number of downstream fish passes during days 13–26 in fast vs. slow velocity tanks was not quite significantly different at $\alpha = 0.05$ (t -test, $p = 0.053$), but the trend was strong. After either peak, dispersal gradually decreased daily to day 27. Duration of the peak dispersal was 22% longer in the fast velocity regime; thus, in the faster velocity regime, the peak was greater in intensity and

duration. After the short intense dispersal by early-larvae, dispersal intensity of mid- and late-larvae in both velocity regimes was similar with low to moderate small peaks and valleys.

Juveniles.—Dispersal intensity of early-juveniles in the slow and fast velocity regimes was similar (Figure 3). The dispersal peaks and valleys of late-larvae and early-juveniles in fast and slow velocity treatments were similar, indicating velocity regime had little effect on dispersal. However, the common peaks and valleys in both regimes suggest a common factor or factors caused the slight increases or decreases in dispersal intensity. Examination of our activities during fish care did not reveal any relationship with the peaks and valleys in dispersal intensity. We do not know what caused this phenomenon; perhaps it was related to development.

Duration of dispersal was not affected by fast or slow velocity regimes (Figure 3). Some early-juveniles in both velocity regimes were moving downstream when observations ceased on day 64.

Effect of velocity regime on percent of fish swimming above the bottom

Embryos.—During the embryo interval, the mean percent of fish swimming above the bottom in fast and slow velocity tanks was highly variable, although there was a slight trend for more fish to swim above the bottom in the fast velocity regime (Figure 4). On most days, 18–40% of the embryos in either regime were swimming above the bottom, indicating no strong effect of velocity regime. There was no difference in the mean percent of embryos swimming above the bottom between fast vs. slow velocity tanks (*t*-test, $p = 0.24$).

Larvae.—During the early-larval period (days 12–16) when peak dispersal had begun (Figure 2), the percent of fish swimming above the bottom was at the same level as for late-embryos (Figure 4). However, observations on day 20 found the highest percent swimming above the bottom in both slow (60%) and fast velocity (80%) tanks. The mean percent of fish swimming above the bottom in fast vs. slow velocity tanks was not different (*t*-test, $p = 0.23$). Unfortunately, we did not realize the dispersal was peaking during this period until reviewing videotapes, so except for day 20, we missed observing fish swimming above the bottom during the dispersal peak.

Use of channel vs. eddy

Embryos.—The only day when the number of embryos in the eddy was different between slow and fast velocity tanks was day 0 ($p < 0.03$), when a low percent of fish in the fast velocity tanks were in the eddy (Figure 5). This suggests that the higher velocity regime kept more new embryos in the current that were searching for slow velocity and cover. Most embryos (73–100 %) during all days in both velocity regimes were in eddy and cover habitat, not in channel flow (Figure 5).

Larvae.—During the peak dispersal by early-larvae in fast velocity tanks on days 13–26 (14 d; Figure 2), the percent of fish in the eddy gradually decreased to 30% and the percent decreased to 41% in slow velocity tanks (Figure 5). Data are missing for days 17–19 during the peak, but the percent in the eddy was lowest on day 20, a day of peak dispersal in both velocity regimes. This result supports the idea that the peak number of downstream fish passes was caused by additional fish leaving the eddy and entering channel flow. After the peak dispersal ended, the pattern of eddy use by mid- to late-larvae generally had a similar pattern of high or low use in both slow and fast velocity tanks (Figure 5) as expected because the peaks and valleys of dispersal intensity were similar in both velocity regimes (Figure 2). About 70–80% of these life stages were in the eddy in either velocity regime.

Late-larvae & juveniles.—A significantly higher number of late-larvae were in edge habitat in both fast and slow velocity regimes. In the fast velocity regime, the mean number of late-larvae observed (day and night observations combined) in each habitat follows: channel – 1.6 fish, edge – 6.9 fish, and eddy – 1.2 fish ($p < 0.001$). In the slow velocity regime, the mean number of late-larvae in each habitat follows: channel – 1.0 fish, edge – 6.9 fish, and eddy – 1.5 fish ($p < 0.001$). The percent of fish in edge habitat was strikingly similar between fast and slow velocity tanks during the day and night: fast tank – day = 66.5% and night = 79%; slow tank – day = 65.8% and night = 78.5%. Thus, there was a trend for a higher percent of fish to use edge habitat at night in both velocity regimes. For early-juveniles in the fast velocity regime observed only in the day, the mean number of fish in each habitat follows: channel – 0.16 fish, edge – 9.04 fish, and eddy – 0.12 ($p = 0.001$). Like late-larvae, most juveniles also used edge habitat.

Estimate of drift distance.—The estimated drift distance by life interval follows. Most eggs likely remain at or just downstream of the spawning area. Some embryos move

downstream a short distance seeking cover, or in response to development, but the distance moved will likely be short (< 1 km), if cover is available. The 14-d mostly nocturnal dispersal of early-larvae that occurs in mid- to late-July occurs when there is about 9 h/d of darkness; thus, fish move downstream for about 126 h at night (14 d x 9h = 126 h). Fish drifting passively in 20-cm/s velocity could drift about 12 m/min or 720 m/h; thus, during the 14-d peak, fish in 20-cm/s velocity drifting only at night could move about 90.7 km downstream (126 h x 720 m/h drift = 90.7 km). The low to moderate intensity, mostly nocturnal downstream movement by older larvae and early-juveniles continued until at least day 64 (August and early September) for an additional minimum of 36 d (mean, 10 h of darkness each day). If we assume that some fish move downstream each hour of darkness, this long period could move fish an additional 259.2 km (36 d x 10 h/d = 360 h; 360 h x 720 m/h drift = 259.2 km). The total estimated total distance moved for early-larvae plus older larvae and early-juveniles would be about 350 km. There is about 110 km from spawning areas to Kootenai Lake, so it seems that early-larval fish alone could move downstream to the lower river, or even to Kootenai Lake. Even at a much slower bottom velocity than 20 cm/s, the dispersal of Kootenai sturgeon could result in larvae moving to the lower river. Although the estimated drift distance could be refined using actual bottom velocities along the dispersal route, it seems unlikely this would change the major conclusion of the present analysis.

Wintering behavior

Preference for dark vs. light colored bottom.—Year-0 juveniles preferred black bottom during three 24-h tests (Table 2). Fish were introduced into the tank in the late-afternoon and preferred black during all three night periods. On day-1 tests, some fish moved off the dark color onto the white color and did not move back. Video tape review found few fish moved about the tank in the day, so after introduction, the most important color preference was done in the first hour at dusk and fish just remained on that color. A 24-h test was not necessary to determine substrate color preference.

Year-1 juveniles also preferred a black-colored bottom color (Table 3). During 4 d of tests, fish preferred black color during all day and night periods except for day-1 night (no preference) and day-4 night (prefer white). Test fish moved minimally during the day except when reorienting headfirst into the current. During dawn and dusk

periods, there was an increased movement by many fish. During the night, most fish were active traveling from one side of the tank to the other regardless of black or white substrate color.

Preference for small gravel vs. small pebble.—Year-0 juveniles had no strong preference for either 3-mm diameter small gravel or 30-mm diameter small pebble substrate (Table 2). Fish had the greatest preference for a smaller substrate size (night of day 2; night and day of day 3).

Year-1 juveniles preferred small pebbles with significant preference on the day and night of days 3–4 and during the daytime of day 1 (Table 3). These preliminary results suggest years-0 may prefer smaller substrate size than year-1 juveniles.

Preference for dark vs. illuminated habitat.—Years-0 and 1 juveniles strongly preferred dark habitat (Tables 2, 3). Although both have a black body color, year-0 juveniles had a stronger preference for dark habitat than year-1 juveniles.

Fish moved around most at night, and with few exceptions, laid immobile on substrate in the day. Thus, after introduction during the first afternoon and night, fish moved into the dark habitat. Once there, few left and moved onto the illuminated side, day or night. Interestingly, with both years-0 and 1 juveniles, there was increased movement along the edge between the illuminated side and the covered side during dawn, dusk and night periods by a few fish in each age group. Fish swam along the edge between the two habitats, but rarely entered the illuminated side. This movement suggested fish detected illumination, but most avoided entering it.

Years-0 and 1 juveniles had a strong preference for dark habitat (Figure 6). At night when both sides of the tank were dark, 17.2% of year-0 juveniles were on the illuminated side vs. 56.7% of year-1 juveniles, a highly significant difference (two sample *t*-test, $p < 0.001$). During the day, 15.8% of year-0 juveniles were on the illuminated side vs. 31.5% of year-1 juveniles, also a significant difference (two sample *t*-test, $p < 0.001$). These results suggest that both groups preferred dark habitat in the day, and year-0 fish avoided the illuminated side more than year-1 fish. However, at night when fish were moving around and both sides of the tank were in the dark, year-1 juveniles were evenly distributed on both sides, but year-0 juveniles had a low percent of fish on the uncovered side (illuminated side) in the day and at night. This result suggests

an unknown factor affected use of the uncovered side at night by year-0 fish. While the two sides of the tank were very similar for velocity regime and side-bias tests found no side preference by either juvenile group, we did not eliminate small differences in velocity in the tank. Perhaps, most year-0 fish were selecting very small velocity microhabitats on the covered side of the tank soon after introduction and remaining there, mostly immobile day and night.

Discussion

Dispersal and water velocity

We have observed downstream movement of Kootenai sturgeon in three velocity regimes, i.e., mean channel velocities of 7 cm/s in 2005 and 16.9 and 23.4 cm/s in 2006; Kynard & Parker 2006, present study). All tanks provided fish with slow and fast velocities and bottom cover (rocks), with the 7-cm/s regime having the slowest velocity and least amount of cover. Fish with a behavioral drive to move downstream could do so and fish without a strong dispersal drive could remain in slow velocity areas with cover. Although the tank with the slowest velocity differed in several physical ways (shallower, oval shape, longer circumference) from the two higher velocity tanks, we do not believe these differences likely effected downstream movement of fish. The following reviews the effects of velocity regime (7 cm/s in 2005; 16.9 and 23.4 cm/s in the present tests) and habitat on downstream movement of embryos, larvae, and juveniles.

Embryos.—There was a weak two-peak downstream movement of Kootenai sturgeon embryos in all velocity regimes. Downstream movement of embryos was always weak, and consisted of an initial peak for a few days after hatching, a gradual daily decrease to zero, then a second peak by late-embryos. The first peak after hatching was likely due to a few fish seeking and not finding or remaining in cover and slow velocity. The second peak by late-embryos in all three velocity regimes suggests a developmental, not an environmental cause.

Sacramento River white sturgeon observed in the same 7-cm/s velocity regime with the same rock cover found cover quickly, but some continued to move downstream for 1–2 d after hatching. Late-embryos did not have a second peak, so they only had an initial weak downstream movement peak after hatching instead of the two-peak pattern of Kootenai sturgeon (Kynard & Parker 2005, 2006). These embryos were well hidden,

remained concealed, and were very difficult to find and count. When rocks were removed to count fish, they quickly relocated cover and did not move downstream but for one or two loops of the tank before they reentered rock cover. Thus, Sacramento River embryos at all stages of development found quickly and remained well-hidden in rock cover in the 7-cm/s regime. Additionally, shortnose sturgeon embryos are also photonegative, like Sacramento River and Kootenai white sturgeons (Kynard & Horgan 2002, Kynard & Parker 2005, 2006), and they are also able to quickly find and remain in rock cover in the 7-cm/s velocity tank. Kootenai sturgeon embryos seem less able to find and remain in cover than embryos of either Sacramento River white sturgeon or Connecticut River shortnose sturgeon.

The environment (velocity, amount of cover, or both) may affect the intensity of the second downstream movement by late-embryos. In the 7-cm/s velocity regime, the second peak was much more intense than the second peak in the two faster velocities. In this environment with a slower velocity and small amount of cover, there was an increased downstream movement by late-embryos. This result was different from that of Brannon et al. (1985), who found a higher percent of embryos swimming above the bottom in fast velocity compared to slow velocity. However, it is difficult to compare our results with those of Brannon et al. because they used very slow velocity regimes (2 cm/s = slow and 8 cm/s = fast). Downstream movement of late-embryos was slightly more intense in 23.4 compared to 16.9-cm/s velocity in our study, suggesting a small increase in movement by late-embryos at the higher velocity (a result predicted by the Brannon et al. study).

Kynard & Parker (2006) observed embryos in a 7-cm/s velocity regime and characterized the downstream movement of Kootenai sturgeon embryos as a weak dispersal. They made a similar conclusion about the 2-d movement of Sacramento River white sturgeon embryos (Kynard & Parker 2005). However, in the two faster velocity regimes in 2006, almost all Kootenai sturgeon embryos remained in eddy and cover habitat. This strong seeking of cover and slow velocity is consistent with the strong photonegative behavior of embryos from both populations (Kynard & Parker 2005, 2006). In summary, we conclude that our characterization of downstream movement by Sacramento and Kootenai sturgeon embryos as a dispersal was incorrect. There is some

downstream movement in our experimental tanks as there will be in rivers, but after early-embryos find cover and slow velocity, most downstream movement should cease. The high percent of Kootenai sturgeon embryos in eddy and cover habitat in the two fast velocity regimes and the low percent (36 %) of days 0–1 embryos in rock cover in the 7-cm/s velocity regime suggests that downstream movement by embryos slow velocity regime was higher because they continued to search for cover with low velocity habitat. Thus, although the second-peak pattern seems related to development, the ability of late-embryos to find and remain in a suitable environment may affect the intensity of downstream movement.

Observation of strongly dispersing pallid sturgeon embryos in the same artificial streams as those used to study Kootenai sturgeon in 2006, except with 17.3 or 21.1 cm/s mean channel velocities and a slightly smaller eddy and less rocks, found no relationship between water speed and dispersal timing, intensity, or duration (Kynard et al. In Press). Non-dispersing Kootenai sturgeon embryos observed over a wide range of channel velocities (7 to 23.4 cm/s) also found no effect of velocity regime, except possibly on the intensity of the second peak by late-embryos. Results of studies on embryos of two sturgeon genera suggest velocity has little affect on downstream movement of early- or mid-embryos, probably because of their poor swimming ability and lack of development. While it is possible that a higher velocity regime could evoke more swim-up and drift behavior in early- and mid-embryos of Kootenai sturgeon, we think this unlikely if the key is poor development and fish have a strong preference for cover with slow velocity.

Larvae.— Velocity had a strong effect on dispersal timing, intensity, and duration. Larvae in 7-cm/s velocity continued a weak peak (peak, 1 pass/5 min) during a long period of days 21–42 (Kynard and Parker 2006). In contrast, at either the 16.9 or 23.4 cm/s velocity regimes, there was an intense (but shorter) peak by early–larvae that ceased by day 27. At the highest velocity regime, the dispersal peak was 3 d earlier, more intense, and lasted slightly longer (14 d compared to 11 d), suggesting an increase in dispersal response by more fish at the faster velocity. The differences in dispersal between larvae in 7 cm/s velocity and the faster regimes used in the present study suggest there is a threshold velocity needed to trigger larval dispersal: 7 cm/s is an insufficient trigger for most larvae, 16.9 cm/s velocity triggers most larvae, and 23.4 cm/s triggers

slightly more larvae.

After the peak dispersal by early-larvae, mid-larvae in 7-cm/s velocity continued to disperse at a moderate intensity for many days. This was very different from either 16.9 or 23.4 cm/s velocity regimes where the early-larva peak gradually declined daily to near zero and mid-larvae continued a low to moderate dispersal with peaks and valleys. Thus, cessation of the larval peak dispersal was delayed about 15 d by the slow velocity regime of 7 cm/s. None of the velocity regimes tested had much effect on the low to moderate intensity dispersal by late-larvae, i.e., there were small peaks and valleys of intensity in all three regimes.

Juveniles.—Velocity did not have any obvious effect on dispersal of early-juveniles in 7, 16.9, or 23.4-cm/s velocity regimes. Juveniles spent most of the day in edge habitat, not in the channel or eddy. They faced upstream and held position in the edge or swam short distances upstream apparently seeking to position themselves for food to drift to them.

Higher velocity.—Would a higher mean bottom velocity regime, like 30 cm/s, affect dispersal characteristics? The available data suggest the life stage that would most likely be affected would be early-larvae and their peak dispersal. An increased velocity could result in a slightly higher peak in intensity, as more larvae were triggered to disperse. Based on the strength of peak larval dispersal at 23.4-cm/s velocity, which produced a strong response by larvae (82% swimming above the bottom and a low of 35% in the eddy), a higher velocity regime would likely result in a small increase in peak intensity. There would not likely be a change in peak dispersal duration, which was similar in both 16.9 and 23.4-cm/s velocity regimes. Initiation timing could not change much, because at 23.4 cm/s, a high percent of fish (70–80%) were dispersing as they developed into larvae and this timing could not be much earlier, as it is determined by development. The dispersal studies in 2005 and 2006 indicated a velocity regime > 23.4 cm/s would likely cause little change in downstream movement characteristics of embryos, late-larvae, or early-juveniles.

Percent of fish swimming above the bottom as a measure of dispersal

For embryos, the percent of fish swimming above the bottom seems as good a measure of downstream movement as the number of fish passes per unit of time. The weak early and late peaks during embryo movement, as measured by the number of

downstream fish passes, was also reflected in the percent of embryos swimming above the bottom in either the 23.4 or 16.9-cm/s velocity regimes.

However, on days 14 and 16, when the larval peak dispersal was well-established in both velocity regime (23.4 and 16.9 cm/s) as measured by increasing downstream fish passes, the increased dispersal was not reflected by corresponding increases in the percent of fish swimming above the bottom. Observations on the percent of larvae swimming above the bottom missed the initiation of the major dispersal event of this life interval. The available data indicate that monitoring the actual downstream movement of fish results in the best measure of larval (and likely, juvenile) dispersal.

Wintering behavior

Preliminary results indicated year-0 juveniles prefer a smaller substrate size than year-1 juveniles. Future tests will refine the substrate size preferred by each group of juveniles. A different preference for substrate size could result in spatial segregation during the winter and minimize interaction between these two groups.

Years-0 and 1 juveniles preferred dark substrate and habitat with no light, even more than green sturgeon (Kynard et al. 2005). This common preference for dark habitat suggests both groups of juveniles are in deep water with no illumination.

We do not know the body color of wild years-0 and 1 juveniles. If they have a black body, like artificially-reared fish do, then a preference for dark substrate and dark habitat would provide excellent camouflage and protection from visual predators. If wild fish are not black, but are lighter in color like older juveniles, then the preference for black substrate likely reflects an attempt to match body color with the surrounding color. There are light and dark morphs in any group of larval Kootenai sturgeons and the number of light-colored morphs is high as larva and low as juveniles. In the future, we will separate and rear these light morphs, determine their survival or conversion during ontogeny to dark morphs, and try to have enough to conduct habitat color preference tests to test the hypothesis that body color determines bottom color preference.

Preliminary observations before habitat substrate trials began indicated year-0 juveniles were extremely sensitive to water velocity. Many fish selected the lowest velocity available with some fish aggregating together in small eddy areas. This slow velocity is likely only available in the river in very deep areas.

Management implications

Dispersal distance.—All studies indicated Kootenai sturgeon embryos are strongly photonegative and seek slow velocity and cover (Kynard & Parker 2006, present study). Thus, most embryos should be at or just downstream of egg deposition sites in rocky cover and their drift distance should be insignificant compared to larvae. Rocky substrate provides attachment and protection for eggs, and after embryos hatch, rocks provide cover and protection for embryos during development and absorption of the yolk-sac. Thus, a preference by females for rocky spawning substrate likely evolved because it is important for survival of two life intervals: eggs and embryos. If eggs are spawned on sand (a smooth substrate without crevices and cover), then even if a few eggs survive and develop into embryos, the hatchling embryos will not be in preferred cover habitat and would have to move downstream and search widely for cover.

The long downstream movement of larvae and early-juveniles in three artificial stream environments suggest wild Kootenai sturgeon larvae and early-juveniles have a strong dispersal drive that could move fish far downstream from a spawning reach. Diel activity by larvae and juveniles in the artificial stream (Kynard & Parker 2006) suggested wild fish mostly forage in the day and disperse downstream at night, a pattern commonly found in dispersing larvae of other sturgeons (Kynard & Horgan 2002, Kynard & Parker 2004). This pattern was also found in the early-juvenile dispersal of Sacramento River white sturgeon (Kynard & Parker 2005). However, some Kootenai sturgeon larvae moved downstream during the day, particularly during the peak dispersal by early-larvae, suggesting the dispersal drive is so strong that it replaces the drive in many fish to forage in the day.

To understand dispersal of any life interval of sturgeon, it is helpful to identify if there is a spatial goal, i.e., are fish moving to a particular rearing reach? For example, for Connecticut River shortnose sturgeon larvae, the spatial goal is to move a short distance (< 20 km) during a few days to a rearing area where they remain during the summer, fall, and winter; and for Hudson River *A. oxyrinchus* larvae, the goal is to move downstream many kilometers during about 12 d, but cease before entering saltwater until they have developed salinity tolerance (Kynard & Horgan 2002).

Our use of a passive drift model is supported by observations on body orientation

of early-larvae, almost all of which were oriented head upstream and drifting with the current. This body orientation is typical of dispersing larvae (Kynard & Horgan 2002). Older larvae and juveniles were mixed for body orientation, with some fish oriented head upstream and others oriented head downstream and actively swimming downstream, like Sacramento River white sturgeon juveniles during dispersal (Kynard & Parker 2005). The passive drift model is a conservative estimate of movement distance by early-larvae because it ignores the daytime dispersal of many fish (Kynard & Parker 2006). The bottom velocity we used in the model was reasonable, perhaps even low, and the estimate could be improved with actual bottom velocities. It seems unlikely this would change the basic conclusion: larvae have a dispersal style that takes them to the lower river.

For the drift model, we assumed that the swimming height of early-larvae was near the bottom (within 50 cm) like photopositive dispersing larvae of other sturgeon species (Kynard & Horgan 2002). Data on this behavior of Kootenai sturgeon has been hard to obtain. Kootenai sturgeon seem very sensitive to handling, tanks, or both. For example, highly photonegative Kootenai sturgeon embryos did not quickly enter and remain in cover in the vertical stream tank like other sturgeons (Kynard & Horgan 2002, Kynard & Parker 2004). Further, although larvae are good swimmers, able to quickly swim 100 cm above the bottom as early-larvae and their swimming seemed normal (Kynard & Parker 2006), we were not sure their swimming was not affected by handling or the small diameter tank. Some sturgeon are sensitive to the short-term tests we did with Kootenai sturgeon in our small diameter vertical stream tank. Fish swam far above the bottom, a situation requiring many hours of acclimation before pallid sturgeon revealed their swimming height (Kynard & Parker In Press). Thus, we did not use the 100-cm swimming height of larvae in Kynard & Parker (2006) in the drift model because we were not sure it was a good estimate of swimming height of wild larvae. If larvae disperse 100 cm above the bottom, the velocity used by dispersing larvae would likely be faster than the mean 20 cm/s velocity in the model. All observations on early-larvae in stream tanks indicated fish were bottom-oriented, not at the surface attempting to swim higher.

The drift model indicates early-larvae could move to the lower river near Kootenai Lake or to the lake, and that older larvae and juveniles could move much

farther. Even at a much slower bottom velocity than the 20 cm/s we used in the model, the continuing drive of Kootenai sturgeon to move downstream could result in larvae moving downstream to the lower river or lake. Late-larvae and juveniles in all artificial streams used the moderate current of edge habitat and not the slow–zero velocity in the eddy. They also held position in edge current, and like many riverine fish, seemed waiting for food to drift to them. This foraging style and habitat use suggests larvae and juveniles rear in the river, not in the lake.

If the dispersal by early-larvae of Kootenai sturgeon has a spatial destination, i.e., a lower river reach near the lake, and early-larvae can move to this reach with a short duration movement, why do older fish continue a weak–moderate downstream movement in artificial streams? In our studies on dispersal of other North American sturgeons, dispersal by larvae ceased after a certain number of days, suggesting timing was genetically coded. The intense night, and even some daytime, downstream movement by early-larvae strongly suggests fish are programmed to quickly move to the rearing reach. If this scenario is correct, then the weak downstream movement by older fish seems unnecessary and is difficult to interpret. Perhaps, the movement indicates that fish continue to move downstream and do not stop in the lower river. We think this is unlikely unless there was a historical selective advantage (reduced predation, more forage, or both) to larvae and juveniles that rear in the lake, rather than in the river. We do not have information to evaluate this possibility. Perhaps, older fish continue to disperse weakly in the artificial stream because they did not receive the appropriate cue(s) from the natural environment needed to trigger dispersal cessation. We think this unlikely because larvae of other sturgeons cease dispersal in artificial streams (Kynard & Horgan 2002). Finally, perhaps older fish are not moving downstream in response to a dispersal drive, but instead the movement has another function. Perhaps, a fish density–food abundance relationship exists that we have not seen in other populations, but which is important in the Kootenai River. In this case, fish at a higher than natural density in the artificial streams may continue to weakly move downstream searching for additional habitat, forage, or both. Individuals in some sturgeon populations interact strongly during competition for food, even evolving a size-related dominance hierarchy (Kynard & Horgan 2002). If the forage base for larvae is low in the Kootenai River, perhaps

Kootenai sturgeon evolved behaviors to reduce competition for food.

All data indicate the lower river near the lake is the likely spatial goal of dispersal by Kootenai sturgeon early-larvae. The drift model indicates larvae should be able to travel the distance to the lower river. If the lower river has been altered so that it no longer provides suitable rearing habitat for Kootenai sturgeon larvae and juveniles, the reach will need to be restored to make it useful for sturgeon restoration.

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Table 1. Velocity measurements in one fast and one slow velocity stream tank used for dispersal tests of Kootenai sturgeon. All measurements were taken 5 cm above the bottom along eight radii from the outer wall to the center of the tank. Three habitat designations based on velocity are shown.

Velocity Regime	Habitat	Transect								Row Mean	Habitat Mean
		1	2	3	4	5	6	7	8		
Fast	Channel	36	40	24	26	31	31	31	29	31.0	23.4
		21	17	7	14	21	21	13	12	15.8	
	Edge	16	13	3	6	8	10	4	6	8.3	
		11	10	0	2	2	2	1	0	3.5	
	Eddy	10	1	2	2	-2	-1	-4	1.1	4.3	
		10	-3	0	1	-1	-1		1.0		
				-3	-3	-2			-2.7	-0.8	
Slow	Channel	22	30	22	20	22	26	26	21	23.6	16.9
		9	17	7	5	10	15	9	9	10.1	
	Edge	7	14	2	2	3	5	7	5	5.6	
		6	12	0	1	0	2	4	2	3.4	
	Eddy	9	1	1	2	0	2	0	2.1	3.7	
				0	0	1	0	-2		-0.2	
				0	-2	0			-0.7	-0.4	

Table 2. Preference of year-0 juvenile Kootenai sturgeon for (A) substrate size (small, 3.2 mm vs. large, 30.0 mm), (B) substrate color (white vs. black), and (C) illumination (light, 40 lux vs. dark, 0 lux). Numbers in A, B, and C are mean time on small substrate, white substrate, or illuminated side. A significant preference for each choice test is indicated, and if there is no significant preference, "none" is used. We considered preference to be significant if the 95% confidence interval of time in habitat did not include 50%.

		Test Group			
		1	2	3	
(A) <u>Substrate Size</u>	Night	None	Small	Small	
		53.2	80.7	72.5	
	Day	Large	None	Small	
		25.0	47.6	62.5	
			Test Group		
			1	2	3
(B) <u>Substrate Color</u>	Night	Black	Black	Black	
		33.7	33.1	26.1	
	Day	None	Black	Black	
		51.1	37.3	25.0	
		Test Group			
		1	2	3	
(C) <u>Illumination</u>	Night	Dark	Dark	Dark	
		28.1	5.0	18.9	
	Day	Dark	Dark	Dark	
		27.2	5.4	14.9	

Table 3. Preference of year-1 juvenile Kootenai sturgeon for (A) substrate size (small, 3.2 mm vs. large, 30.0 mm), (B) substrate color (white vs. black), and (C) illumination (light, 40 lux vs. dark, 0 lux). Numbers in A, B, and C are mean time on small substrate, white substrate, or illuminated side. A significant preference for each choice test is indicated, and if there is no significant preference, "none" is used. We considered preference to be significant if the 95% confidence interval of time in habitat did not include 50%.

		Test Group			
		1	2	3	4
(A) <u>Substrate Size</u>	Night	None	None	Large	Large
		41.1	57.3	27.8	36.8
	Day	Large	None	Large	Large
		30.7	50.1	30.1	27.9
		Test Group			
		1	2	3	4
(B) <u>Substrate Color</u>	Night	None	Black	Black	White
		47.2	32.3	30.4	65.2
	Day	Black	Black	Black	Black
		34.8	34.8	37.5	44.0
		Test Group			
		1	2	3	4
(C) <u>Illumination</u>	Night	Dark	None	Light	None
		39.3	50.4	93.5	50.3
	Day	Dark	Dark	None	Dark
		19.3	33.6	56.3	18.1

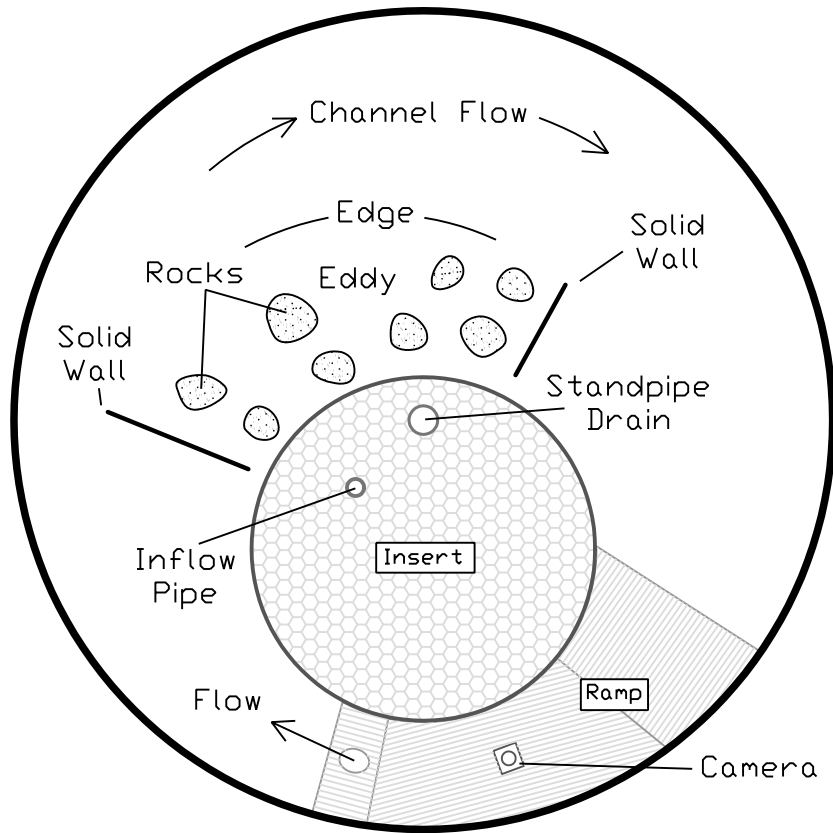


Figure 1. Plan view of the artificial stream tanks used to observe dispersal and habitat use.

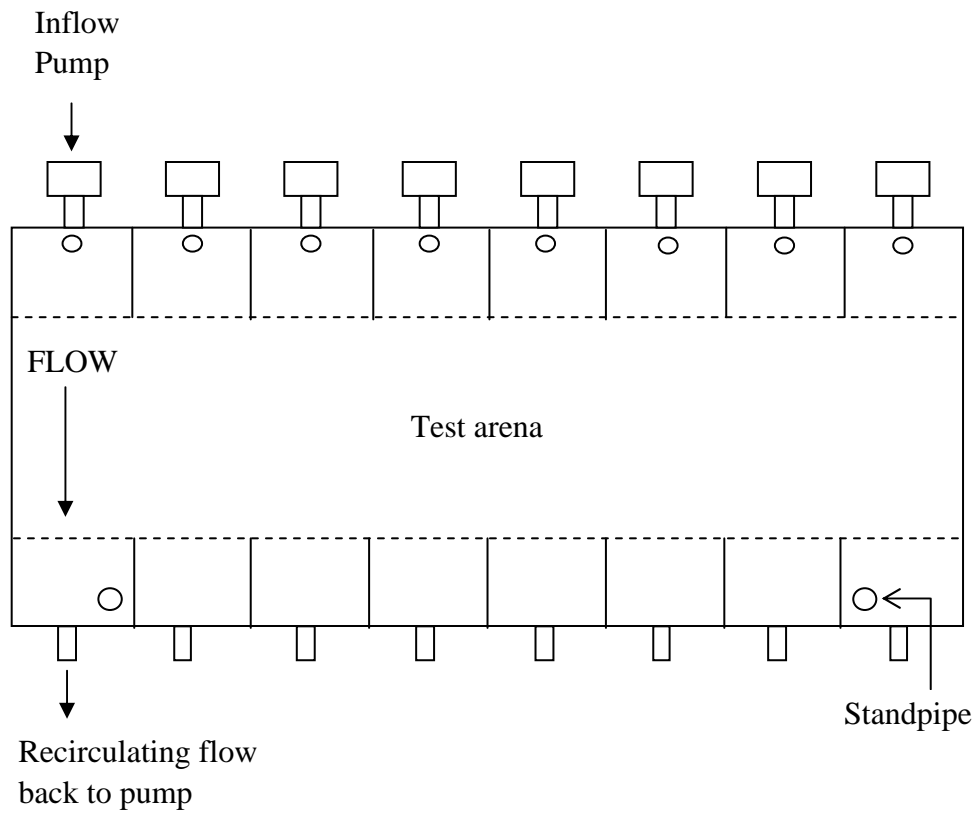


Figure 2. Diagram of rectangular tank used for winter habitat selection tests of year 0 and year-1 Kootenai sturgeon. The tank was 2.4 m long and 1.2 m wide with a water depth of 15 cm. The test arena was 2.4 m long and 0.7 m wide.

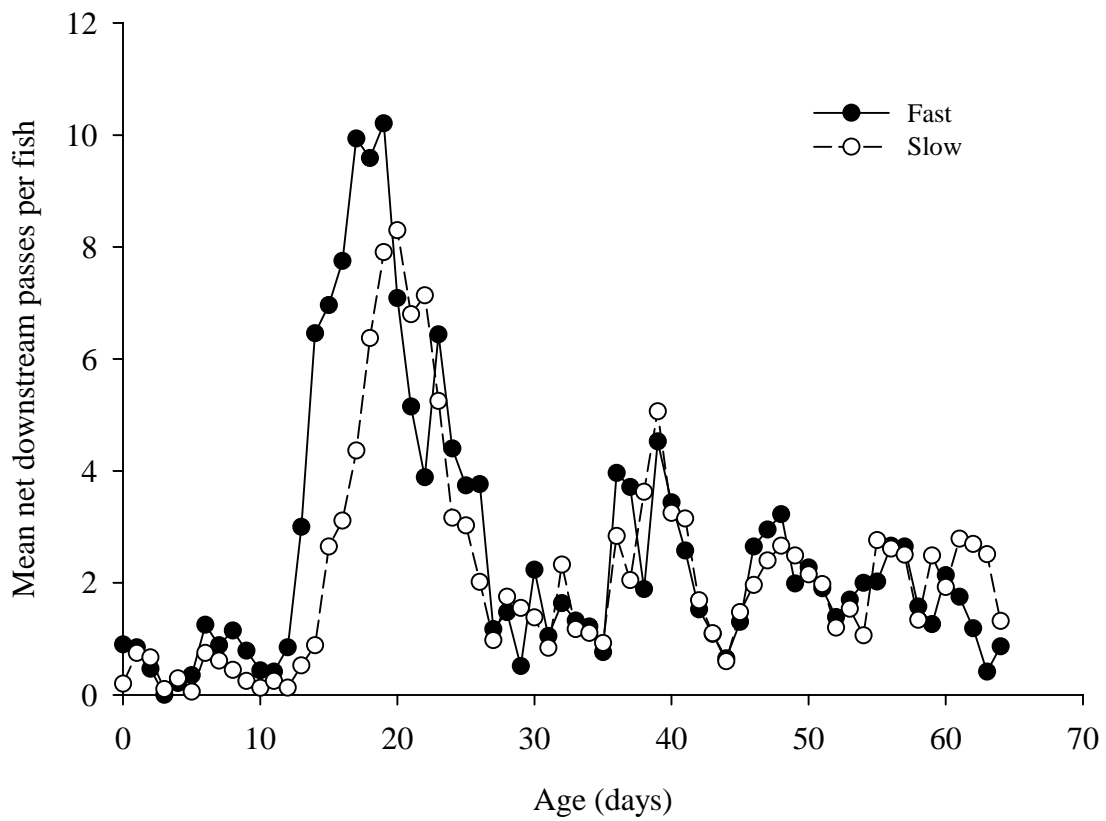


Figure 3. Graph of mean net downstream passes of Kootenai sturgeon in fast and slow velocity stream tanks.

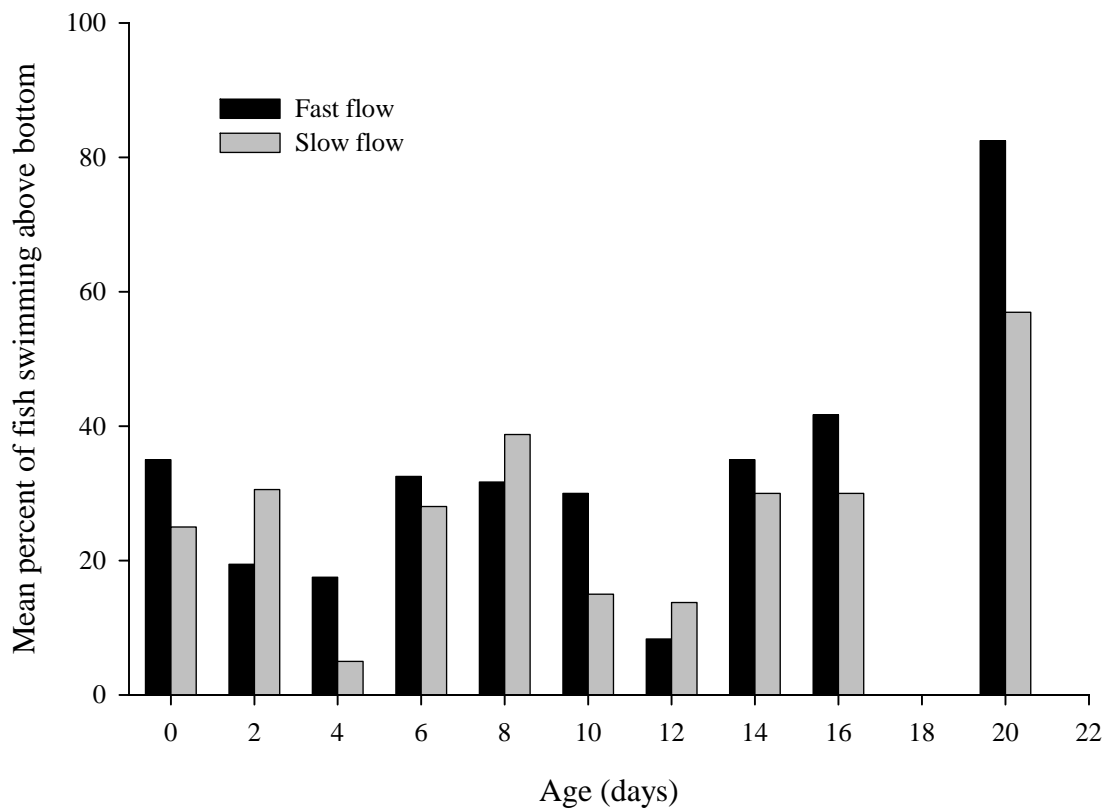


Figure 4. Mean percent of time Kootenai sturgeon spent swimming above the bottom in fast and slow velocity stream tanks.

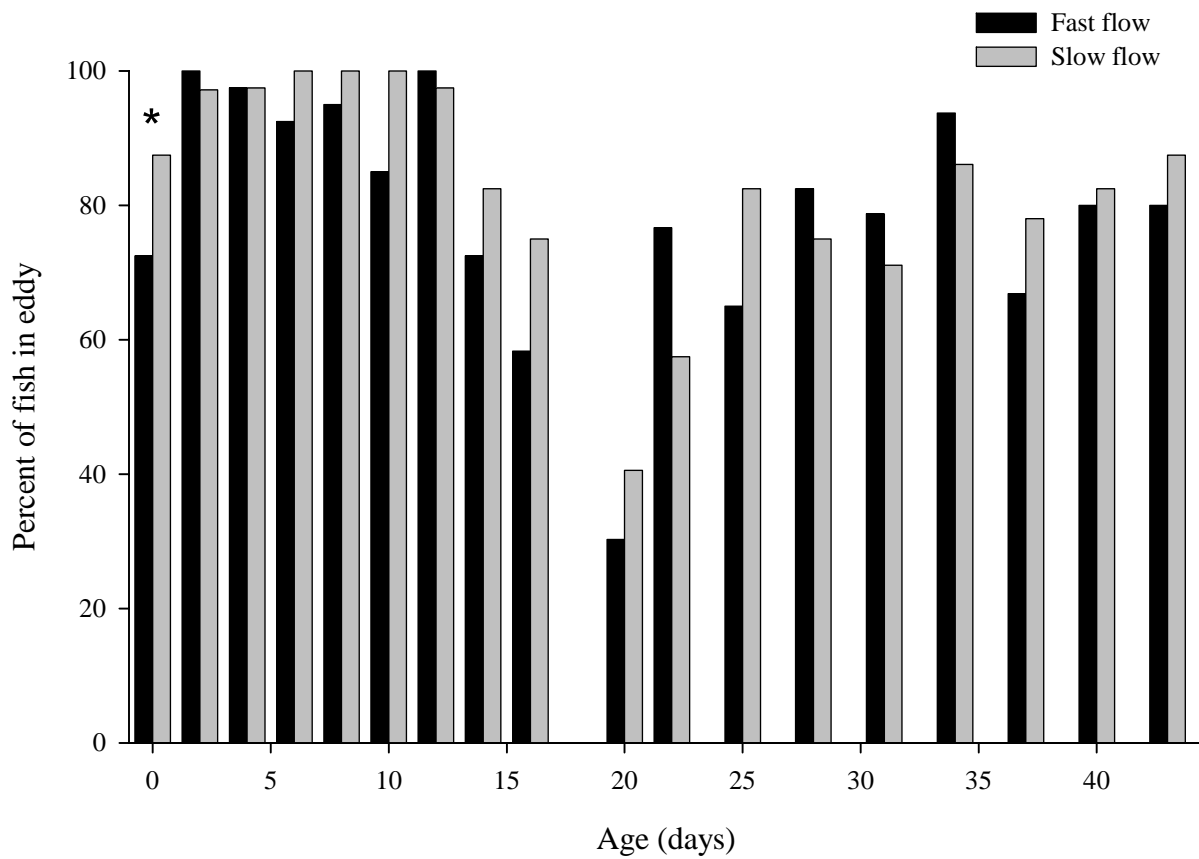


Figure 5. Mean percent of time Kootenai sturgeon spent in the eddy in fast and slow velocity stream tanks. A significant difference in fish behavior between velocity regimes is indicated by an asterisk.

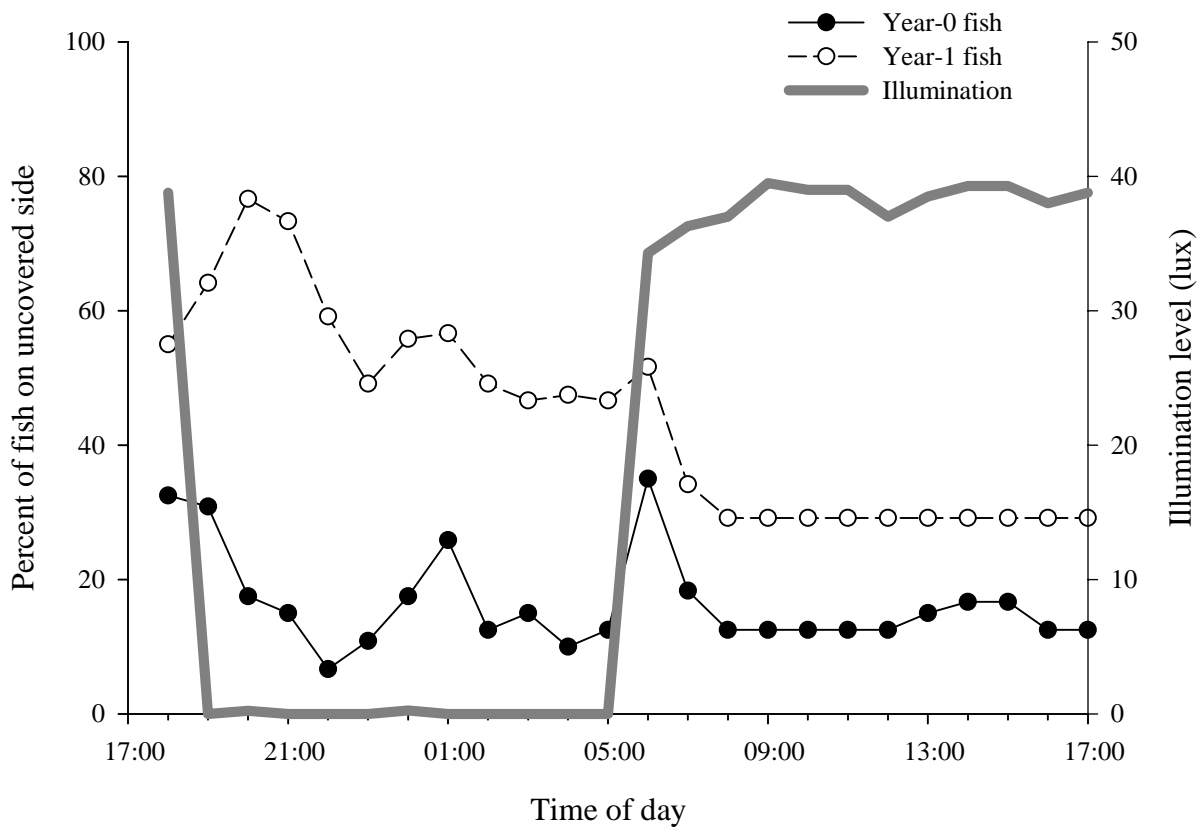


Figure 6. Graph of mean percent of fish (all trials averaged) on the uncovered (illuminated) side of the rectangular test tank and illumination levels in the tank for 24 hours.