

FINAL REPORT

To

Idaho Department of Fish and Game
Boise, ID

Ontogenetic Behavior and Dispersal of Kootenai River White Sturgeon
Early Life Intervals: A laboratory Study

Boyd Kynard and Erika Parker
U.S. Geological Survey, Leetown Science Center
S. O. Conte Anadromous Fish Research Center
Turners Falls, MA 01376
Phone: (413)986-3807, email:boyd_kynard@usgs.gov

10 March 2006

Synopsis

Laboratory studies on Kootenai sturgeon indicated the following conceptual model on dispersal style and habitat preference.

Early free embryos (day-0 hatchling to day 6 fish) are photonegative and have no preference for dark or white colored substrate. Hatchlings initiate a weak day and night downstream dispersal with fish swimming near the bottom but increasing their swimming height daily (mean, 38 cm high). When fish are not dispersing using swim-up and drift, they hide under cover.

Late free embryos (days 7–12 fish) gradually become photopositive and develop a weak preference for light-colored substrate. There is a trend with age for fish to leave cover and use open bottom. Fish continue a weak swim-up and drift dispersal, but move only at night. Daytime swimming height of late-embryos increases with age from <50 m to about 100 cm.

Fish develop into larvae and begin to forage after 230 CTU (day 13). With increasing age of larvae, fish leave cover and forage on the open bottom. Fish prefer bright habitat (strongly photopositive, weakly prefer white substrate). Larvae continue a weak mostly nocturnal dispersal with fish also dispersing in the daytime during the 21 day dispersal peak (days 21–42). Some late-larvae move weakly upstream in the day.

Juveniles continue a weak nocturnal dispersal to at least day 77 (4 September), when observations ended. The long dispersal suggests fish disperse until foraging ceases and they seek wintering habitat. Some juveniles move weakly upstream in the day, likely a foraging movement. During the day, most juveniles swim on or near the bottom with some fish swimming about 1 m above the bottom.

The weak, long dispersal style of Kootenai sturgeon should slowly move fish many kilometers downstream and distribute them far away from spawning sites. The dispersal style of Kootenai sturgeon is different from the dispersal style of white sturgeon populations in long rivers, like the Sacramento and Columbia rivers, and likely adapts slow-growing young Kootenai sturgeons to rearing in a short river with low food abundance.

Background

All sturgeons are highly migratory, thus to protect and manage the habitat and river reaches needed to complete the life cycle of any species of sturgeon, it is necessary to understand all migrations that occur during life history. Perhaps, the most difficult migration (or dispersal) to study, particularly for rare sturgeons like Kootenai River white sturgeon *Acipenser transmontanus* (hereafter, Kootenai sturgeon) is the dispersal of small early life intervals, which are transported downstream via water current from spawning areas to rearing areas. The lack and potential importance of this information for understanding the decline of Kootenai sturgeon was noted by Anders et al. (2002) and Paragamian and Beamesderfer (2004).

Laboratory studies on many sturgeon species provide the best information on the innate dispersal style and habitat preferences of post-hatching early life intervals (free embryos, larvae, and juveniles, e.g. ELS). These studies found all species have one or more downstream dispersals by ELS (Kynard & Horgan 2002; Kynard et al. 2002a, b; Zhuang et al. 2002 a, b; Kynard et al. 2003; Kynard & Parker 2004; Kynard & Parker 2005). The major factor determining year-class recruitment success is the survival of ELS (Parsley 2000, Gross et al. 2002, Kynard & Parker 2005, Kynard et al. in press). However, dispersal is poorly understood for most populations, particularly, how river conditions and behavioral preferences interact to influence dispersal distance.

Additional results from the previously cited laboratory studies on ELS provided information on the innate preferences for important habitat characteristics, i.e., habitat brightness (illumination intensity and substrate color), cover, and swimming height above the bottom. Information on habitat preference is useful for determining location of wild fish and information on swimming height helps estimate dispersal distance of wild fish.

Despite the decline of abundance in many white sturgeon populations, the ontogenetic behavior and dispersal of ELS of most populations is still poorly studied. An unpublished laboratory study provides the best information on the white sturgeon from the lower Columbia River population (Brannon et al. 1985¹). Hatchling free-embryos swam above the bottom into the water column (20 cm deep), an indication this life

¹ Brannon, E., S. Brewer, A. Setter, M. Miller, F. Utter & W. Hershberger. 1985. Columbia River white sturgeon (*Acipenser transmontanus*) early life history and genetics study. Final Rept. Bonneville Power Admin. Portland.

interval initiated a weak downstream dispersal. Then, free embryos hid under rocks until they developed into larvae on about day 11. Feeding larvae swam out from under rock cover and foraged on the bottom, but did not disperse. Observations ceased on day 20, less than one-half the number of days needed to complete larval development; thus, older larvae and early juveniles were not observed for dispersal. This study suggested that Columbia River white sturgeon ELS only have only one weak, short dispersal by swim-up free embryos.

A recent study on ontogenetic behavior of Sacramento River white sturgeon (Kynard & Parker 2005) used the same methods as the laboratory studies on sturgeons cited previously by these authors. Sacramento River white sturgeon ELS have two dispersal periods, i.e., an initial dispersal following hatching by free embryos and a second dispersal by early juveniles. The free-embryo dispersal is weak intensity with fish moving near the bottom for only a few days, much like the dispersal of Columbia River white sturgeon free embryos. The function of this dispersal in both rivers is likely to move fish away from the egg deposition area. The early juvenile dispersal is intense with fish swimming fast headfirst downstream at night for many days. The juvenile dispersal moves fish far downstream.

Intra-specific differences among populations have been found in Atlantic sturgeon *A. oxyrinchus*, shortnose sturgeon *A. brevirostrum*, and lake sturgeon *A. fulvescens* (Kynard and Parker 2004, Parker and Kynard unpubl. data, Kynard and Parker unpubl. data). Populations differed most for dispersal, with fish in some populations dispersing a short time (likely short distance), and fish in the other population dispersing for a long time (likely long distance). Thus, dispersal style of populations is highly adaptive and depends on specific selective factors in each river. The distance from spawning areas to ELS rearing areas, and the rearing environment quality, particularly the amount of forage, seem particularly important factors that affect dispersal style.

The goal of the present study was to study behavior and dispersal of Kootenai sturgeon ELS in the laboratory and to make a conceptual model of ontogenetic behavior, particularly dispersal and habitat preference. We generally used the same methods we have used for many years to study the ELS of sturgeon populations.

Methods

Laboratory methods generally follow those presented in Kynard and Parker (2005) for Sacramento River white sturgeon. We obtained fertilized eggs from the artificial spawning of one female and one male. Eggs were shipped to us (see Acknowledgements) and we received them on 15 June.

All rearing and experiments were done at facilities at the S.O. Conte Anadromous Fish Research Center. We used dechlorinated city water (Montague, MA) for all rearing and experiments. Temperature in rearing and test tanks was controlled and similar ($\pm 1^\circ\text{C}$). We maintained the natural photoperiod for the Turners Falls, MA location.

We reared eggs in a McDonald hatching jar and hatchling embryos swam from the hatching jar in over-flow water to 18-L circular rearing tanks supplied with bottom cover. We fed larvae a commercial food six–eight times daily using a timed feeder and also fed early larvae four times daily with live *Artemia* nauplii.

To link daily behavior and development, we scaled fish development to daily cumulative water temperature (CTU). We recorded temperature ($^\circ\text{C}$) every 2 hours and determined the mean daily temperature to the final day of observation. Daily temperatures were sequentially added to obtain the total cumulative temperature units (CTU) for each day. For example, day-0 fish accumulated 0 degree days of temperature, day-1 fish accumulated the mean temperature for day 0; day-2 fish accumulated the degree days of day 0 plus the temperature on day 1. The beginning time for the 24-h cycle used to calculate CTU was 2400 h (the estimated time of first hatching).

During development, we characterized the body color of life intervals using Hype's Color for Netscape v. 3. We examined stomach contents of embryos to determine the CTU when they began to feed (beginning of the larva interval), and we examined fins of larva to determine when the CTU when they developed the adult fin complement.

In all daily experiments, we mixed rearing tank water and haphazardly selected test fish, then after tests, returned test fish to the rearing tank. No individual was tested twice in a daily replicate, but there was a small chance a fish could be captured and used in other tests. The haphazard selection and capture process using a suction tube or small net provided a diverse group of test fish for daily experiments.

Swimming height above bottom

From day 0 to day 32, we daily tested 10 fish in a 150 cm high x 15 cm diameter vertical stream tube that simulated a vertical section of water with horizontal water flow, like in a natural stream (Figure 1a). Illumination level (top to bottom) was 300–50 lx to 30–5 lx depending on time of tests. Test time was the same each day (also similar illumination regime) and previous tests found no effect of illumination level on swimming height of ELS in the tube in the daytime.

During tests, we poured a single fish and water into the top of the introduction tube, which carried fish to the bottom. Fish had 1 min for acclimation, then at 5–6 min, we visually recorded swimming height of fish above the bottom each 10 s for 60 s (total measurements = 7) using a depth scale (1-cm marks with 0 = bottom) inscribed on the outside of the tube. We calculated the mean of the seven measurements for each fish and present the grand mean for 10 fish as a daily time series.

One-half of the tube's bottom was covered with two layers of gray rocks (5-cm diameter) to provide cover; the other one-half was open. During daily tests, we recorded the number of fish on the bottom in the rocks (cover), in the open, or in the water column.

We used a larger stream tube that was taller (175 cm high) and had a larger diameter (60 cm diameter) to observe mid-larvae to juveniles (days 42–79 fish). We placed six 10 cm diameter rocks on the bottom to provide cover. Each 3–4 days, we introduced five fish into the tank by pouring them from a 1 L bucket into the top of the tank. We allowed fish to acclimate for 1 hour, and then recorded swimming height as (1) on bottom, or (2) above bottom and measured distance to the nearest centimeter. For fish above the bottom, we characterized swimming as (1) in water column not facing the wall and with pectoral fin not touching wall, or (2) facing or appressed to wall. We observed each fish every 30 seconds for 5 minutes (total measurements = 7 per fish). The fish were not individually marked; so two observers worked together to make sure all fish were recorded each time. We did two replicates using this procedure each test day, changing the water in the tube between replicates to maintain temperature.

Dispersal and diel activity

We daily observed up- and downstream movement of 15 sturgeons (introduced as day-0 hatchlings) in an oval, endless stream tank colored light green-blue (Figure 1b). Dimension of the tank was 7.3 m circumference x 32 cm wide and water was 20 cm deep.

Underwater light intensity was 20 lx or less. The in- and outflow of water was 1-L min. Three rocks (each, 10–15 cm diameter) in each turn of the channel provided cover habitat (structure, low light, and a slow velocity). Current velocity was 3–9 cm/s (mean, 7 cm/s), which was sufficient to illicit the innate dispersal of fish, yet was slow enough so we could accurately view and count fish at night.

The same 15 fish were observed each hour, 24 hours/day from hatching (day 0) until fish were early juveniles (day 77). Fish could not be identified individually so we counted the number of fish passes around the tank at one site. We used a video camera and infrared (IR) light over the stream to observe fish (Figure 1b). White sturgeon do not see IR light until they are several months old or in the juvenile interval (Loew & Silliman 1993). Silver reflective tape covered surfaces in the video field-of-view to enhance observing the small fish at night. We recorded fish for 5 min per hour for 24 hours and reviewed videotapes counting the number of up and downstream fish passes for every other hour. We scaled the number of fish passes to the number of fish in the tank that day, usually 15, but sometimes 14, as fish that died were not replaced until after live observations (see habitat preference, below) were finished for the day.

Habitat preference

In the oval stream during five observation periods per day during daylight, we made visual point samples of the number of free embryos or larvae in four habitat types: on the bottom under rocks, on the bottom in the open, in the water column (>3 cm above the bottom), and at the water surface. We calculated the grand total of fish in each habitat type each day, converted this number to percent of total fish in each habitat type, and present the percent in each habitat type as a daily time series to day 20 (free embryo–early-larva stages).

Illumination and substrate color preference

We tested single fish each day (10 fish per day) for preference of illumination intensity and substrate color (bright vs. dark habitat). We used two 20-L rectangular glass tanks with overhead light provided by two 20-W fluorescent lights and black plastic placed around the tanks to exclude other light. We tested illumination preference using a tank with a black cover over one-half of the aquarium's top to divide the tank into equal areas of bottom illumination (8.2–3.0 lx) and dark (2.2–0 lx). The substrate tank gave fish

a choice of white vs. black substrate. The bottom of the substrate tank was clear glass, and under the glass, the bottom area was divided equally into a black and a white square. Underwater light intensity on the bottom was similar on both sides, e.g., 4.3–2.6 lx (white side) and 3.3–3.0 lx (black side). In both illumination and substrate tests, we reversed habitat position after each fish to prevent side bias.

During tests, we placed the fish at the water surface in the center of the aquarium. After 1-min acclimation, we visually recorded fish movement for 60 sec as a continuous time series of fish presence on each habitat type (for the illumination test – dark vs. illuminated, for substrate color test – white vs. black). We calculated the percent of time each fish spent in each habitat and the daily mean percent of time all fish spent in each habitat, and plotted the percent as a daily time series. We transformed the daily percentages on one of the two habitats to arcsine values and calculated binomial 95% confidence intervals to determine if the percent of time fish spent in the selected habitat was significant (confidence intervals that include 50% were not significant).

Results

CTU and body color

A summary of CTU, development stages of fish, and behavior of fish is shown in Table 1. Body and tail color of day-0 hatchlings was light gray (gray 81). On day 6, body color was still a light gray, but 3–4 mm of the tail tip was black, e.g., the black-tail phenotype. Older free embryos also had black-tails.

Fish developed into larvae on day 13 after 229.9 CTU. Body color of larvae was a medium gray (gray 51) and the posterior 7–8 mm of the body and tail was black. Body color of larvae gradually became darker (body of day 19 larvae was a dark gray 11), but the tail tip remained black. The tip of the tail remained black during the larva interval. The black-tail phenotype was most evident during the late-embryo and early-larva stages.

Larvae developed into juveniles on day 66 after 1265.5 CTU. Body color of most juveniles was a medium gray (gray 51) or dark gray (gray 11) except for the tail tip, which was still a faint black.

Not all fish developed into the black-tail phenotype. Some fish never developed a black tail and their bodies remained light gray (even lighter than same-age black-tail

morphs). The gray morph had normal eye color, not pink eyes, like an albino. Thus, we observed two body-color morphs (black-tail and gray).

Dispersal

We observed Kootenai sturgeon dispersal in the oval stream from 19 June (day-0 hatchling) to 4 September (day-77 juveniles). Review of video tapes found the following dispersal pattern: (1) days 0–6 early free embryos had a low intensity day and night dispersal (night peak) that decreased daily; (2) days 7–12 late free embryos hid under cover during the day, but continued a slowly increasing low intensity dispersal at night; (3) days 13–42 larvae had a slowly increasing dispersal intensity that peaked on days 21–42 with fish moving mostly at night but some fish dispersing in the day during days 24–40; (4) days 43–65 late larvae and days 66–78 early juveniles continued a low intensity dispersal, like early embryos (Figure 2a). The drive by ELS to move weakly downstream was strong; the only upstream movement was the weak movements by day-60 late-larvae and early-juveniles.

The level of daily activity (combined scaled numbers of day + night up- and downstream fish passes) increased with fish age (Figure 2b). The greatest level of activity was always at night, but during the dispersal peak of larvae by days 21–42 fish, day activity reached its highest point. Juveniles (days 66+ fish) showed a clear drive to move at night.

The number of fish that dispersed each day during the daytime was determined from point observations on 15 fish in the oval tank (Figure 3). When day 0–8 free embryos were dispersing, 5–65% of the 15 fish (e.g., 1–10 fish) were moving downstream. As fish developed into larvae, downstream movement of individuals was so slow that our short point observations could not determine the number of fish that was moving downstream. The larvae in Figure 3 that we observed swimming in the water column or at the surface (5–20% of the 15 fish) were likely the same fish the camera recorded as moving downstream.

Swimming height above the bottom

During daytime observations of fish in the small diameter 150-cm high swim tube, days 0–5 early free embryos (which were dispersing) swam slightly higher each day (daily mean range, 12–79 cm; overall daily mean, 37.7 cm; Figure 4). Days 6–11 free

embryos swam higher above the bottom in the day (daily mean range, 25–109 cm; overall daily mean, 67.8 cm).

Days 13–32 larvae, which mostly dispersed at night, swam a mean of 90–132 cm (overall mean, 111.5 cm) above the bottom in the day. During the period when the greatest number of larval fish passes occurred in the day (days 24–40 mid- and late-larvae), observations of swimming height during 3 days found fish swam 90–110 cm high (mean, 100.4 cm), similar to early larvae.

Fish in the small stream tube never exhibited frantic swimming indicative of escape behavior, e.g. fish orientation and swimming speed was similar to the fish in the oval tank that were not subject to stream tube tests. We switched to the larger stream tube on day 32 because fish were almost too large to fit into the small introduction tube in the small stream tube, not because their behavior appeared abnormal in the small stream tube.

Daytime observations on the group of five juveniles in the large stream tube found the swimming height of fish that swam in the water column (body not touching and at 90° to the wall and oriented into or with the current) decreased with age (Figure 5). Except for 3 days, when fish swam a mean of 90, 100, or 160 cm high, the mean daily swimming height of fish on 10 days was <70 m high. Observing individual fish found there were two types of fish: bottom fish (fish that swam on the bottom or appressed to the lower part of the tank side), and other fish (fish that swam on the bottom but also far above the bottom).

Illumination preference

There was a strong trend to strongly prefer illuminated habitat with increasing age of fish (Figure 6). Days 0–7 early free embryos preferred dark habitat except on day 4. Day-8 free embryos had no preference for illuminated or dark habitat. Days 9–12 late free embryos preferred illumination, like days 13–38 larvae, except on a few rare days.

Substrate color preference

Fish had a trend to weakly prefer white substrate with increasing fish age, but on most days, the preference was not significant (Figure 7). Days 0–12 free embryos had no consistent preference for black or white substrate. Usually fish had no significant preference, but on rare days, they preferred either the illuminated or dark sides. Days 13–38 larvae used white substrate more than black substrate, but the preference was weak

and not significant on all days.

Habitat use with age

There was a strong trend for decreasing use of bottom cover and an increasing use of open bottom with increasing fish age (Figure 3). Days 0–8 free embryos showed a decreasing frequency of fish dispersing and an increasing frequency of fish hiding in cover. As fish developed from late free embryos (days 9–12) to early-larvae on day 13, fish spent less time in cover and more time on the open bottom. The last larvae using cover was on day 18. After day 18, all larvae swam on the open bottom; zero larvae were in cover. A few larvae were swimming in the water column, likely dispersing.

We did not conduct any trials to determine preference by late-larvae or early-juveniles for cover vs. open habitat. However, both in the oval stream tank and during tests in the large stream tube, all fish swam actively in the open. No fish used large rock cover, although fish swam around and over rocks, none stopped and hid under rocks.

Aggregation

Because some fish swam in the water column and dispersed daily (Figure 2a, Figure 3), the numbers of fish that were stationary on the bottom in each section of the oval tank continually changed. This made it impossible for our point counts of fish in each tank section to reflect the number of stationary fish; thus, we could not determine if fish were non-randomly distributed, and possibly, were grouping socially. Fish accumulated in some sections of the stream more than at other sections, distributions likely due to accumulation of drifting food or preferred bottom velocity present in some sections.

Discussion

CTU and development

Sacramento River white sturgeon developed into larva after 178 CTU (Kynard and Parker 2005). Growth of Kootenai sturgeon was much slower, requiring 230 CTU to develop into larva. Sacramento River white sturgeon developed into juveniles on day 50 after 826 CTU, while the juvenile interval of Kootenai sturgeon began on day 66 after 1265 CTU. Although we fed ELS from both populations similarly, Kootenai sturgeon developed slower than Sacramento River white sturgeon.

Body color

During development, most Kootenai sturgeon developed into the black-tail phenotype

(black-tail morph) with a similar body and tail color as Sacramento River white sturgeon free embryos and larvae. In both populations, black-tail was darkest and most extensive during the larva interval, after fish left cover and began to forage on the open bottom. Kootenai sturgeon even retained a small black-tail tip as early juveniles. Kynard and Parker (2005) suggested the adaptive significance of black tail is related to predator avoidance, signaling con-specifics, or both.

The presence of two body color morphs (black tail and gray) in white sturgeon has not been documented previously. If the morphs are a genetic polymorphism, this suggests the evolution of two body-color morphs to avoid predators: a black-tail morph that uses wig-wag swimming with a black tail to evade the strike of predators, and a gray morph that uses camouflage to hide from predators. The body-color morphs need further study as they may provide clues to selective factors (predators?) on larvae in the river.

Conceptual model

The following conceptual model integrates data on Kootenai sturgeon development and behavior in Table 1. Early free embryos (day-0 hatchling to day 6) are photonegative and have no preference for substrate color. They initiate a weak day and night dispersal with fish swimming near the bottom (mean, 38 cm high). Swimming height increases daily. When fish are not dispersing using swim-up and drift, they use cover.

Late free embryos (days 7–12) gradually become photopositive (strong preference for illumination) and have a weak preference for white substrate. Fish leave cover and use the open bottom, and continue a weak swim-up and drift dispersal moving only at night. Daytime swimming height increases with age from <50 cm to about 100 cm.

Larvae initiate foraging after 230 CTU (day 13). With increasing age of larvae, fish use cover less and open bottom more, and prefer bright habitat (strongly prefer illumination, weakly use white substrate). Larva disperse mostly at night; however, during the dispersal peak (days 21–42), the greatest number of daytime fish passes also occurs.

Juveniles continue the weak nocturnal downstream dispersal. A weak upstream movement occurs in the daytime and is likely related to foraging. In the day, most juveniles swim on or near the bottom, but some fish swim about 1 m or higher.

Habitat preference

Free embryos preferred bottom cover for hiding when they were not dispersing. The preference was very strong with no fish on the open bottom away from cover in the day.

Larvae and juveniles did not use bottom cover during the day, which indicated wild fish forage on the open bottom and do not use cover in the day. Foraging larvae preferred a bright habitat during the day (illuminated and light-colored substrate), which has been linked to foraging by larvae using visual detection to capture evading prey, like large zooplankton (Kynard and Horgan 2002). The preference for bright habitat suggests Kootenai sturgeons use vision to capture active swimming prey in the day.

Vertical swimming height

We did not know fish were migrating at night and only observed fish in the day. For early free embryos dispersing day and night, our daytime observations may reflect the correct swimming height during dispersal (at least in the daytime). But for late embryos, larvae, and juveniles that dispersed mostly or entirely at night, daytime observations may not reflect swimming height. More study is needed to clarify this important behavior.

The trend by free embryos was to swim higher with age. As their swimming ability improved, early embryos swam higher each day, until they swam about 110 cm high (mean) as late free embryos and early larvae. Fish were not frantically swimming using an escape response and swimming appeared normal, with fish located away from the vertical wall, and not appressed to the wall. We did not record fish's body position in relation to the wall, but most were not touching the wall or facing the wall, e.g., using it like the bottom. The observations on free embryos, which have poorly developed eyes, suggest fish were swimming free in the water column and were unaffected by the vertical wall (a tank effect). The same observations apply to larva, which appeared to be swimming normally. However, the data on larvae from the small diameter stream tube should be taken as preliminary until more study is done on a possible tank effect.

Swimming height of late larvae and juveniles in the large stream tube found most fish swam on or near the bottom, but some fish swam about 100 cm high. Like larvae in the small stream tube, these fish appeared to be swimming normally, unaffected by the tank walls. Because all observations were done in the daytime, these observations may not reflect swimming height of fish dispersing at night.

Dispersal style

The dispersal style of Kootenai sturgeon, combined with the drifting of spawned eggs, seems likely to move ELS many kilometers downstream from a spawning site. Kootenai sturgeon dispersed weakly for at least 77 days (21 day peak during days 21–42). Observations ceased on 4 September (day 77) before juveniles ceased dispersing. Because juveniles continued to disperse as late as September, they may not stop until foraging ceases and fish seek wintering habitat.

The dispersal style of Kootenai sturgeon ELS is quite different from the dispersal style of Sacramento River white sturgeon that disperse weakly as early embryos, do not disperse as larvae, then strongly disperse as juveniles (Kynard & Parker 2005). The style of Kootenai sturgeon is also different from Columbia River white sturgeon that disperse weakly as early embryos, but do not disperse as larvae (Brannon et al. 1985¹). The initial weak dispersal of embryos of all three populations was similar, likely an adaptation to move hatchlings away from spawning sites to avoid predators. However, a strong dispersal, like the dispersal of Sacramento River sturgeon juveniles that moves fish far down the river, never occurred in Kootenai sturgeon. We predict a strong juvenile dispersal also occurs in white sturgeon in the Columbia River, another long river. The weak dispersal by all ELS of Kootenai sturgeon is very different than the two white sturgeon populations in long rivers and suggests a different rearing and foraging strategy.

Intense dispersal styles in which all dispersing fish begin and stop on or about the same day reflect a dispersal strategy to move fish to a discrete rearing reach (Kynard & Horgan 2002), and a weak, long dispersal style suggests there is no discrete rearing reach. A slow dispersal style of larvae and juveniles lasting 5 months was recently found during similar artificial stream studies with Suwanee River Gulf sturgeon *A. oxyrinchus desotoi* (Kynard and E. Parker 2004). In this case, field captures of year-0 juveniles by Ken Sulak et. al. (unpublished data) supported the laboratory results on dispersal. During the slow foraging dispersal of Gulf sturgeon, some fish moved downstream more than 100 km, but all stopped before reaching the estuary. The daily weak dispersal of Gulf sturgeon larvae and juveniles is likely an adaptation to low forage abundance (Kynard and Parker 2004). This dispersal style enables fish to slowly disperse and forage as they move downstream for months using a long river reach.

Kootenai sturgeon may also have evolved a weak, long dispersal in response to low

food abundance, but data are lacking on food or habitat abundance for ELS in the Kootenai River. Kootenai sturgeon ELS that are spawned at the present spawning sites at rkm 228–246 (Paragamian & Duehr 2005), likely rear in the long river reach that terminates at Kootenai Lake at rkm 120 (only 108 km from the lowermost spawning reach). Kootenai sturgeon likely stop before leaving the river and entering Kootenai Lake, but we have no data on this possibility.

The present results on dispersal style of Kootenai sturgeon ELS and the lack of recruitment of wild juveniles for many years, even following years with successful spawning, suggest that poor survival of ELS in the rearing reach is the cause of recruitment failure. It seems highly likely that ELS rear in the meandering reach upstream of Kootenai Lake, which has been highly modified (Anders et al. 2002). Also, anthropogenic impacts, like Libby Dam operations, that could affect river ecology and invertebrate production could be affecting Kootenai sturgeon habitat and forage. Perhaps, the native fish community in the rearing reach has also been modified by introduction of new predator or competitor fish species, which can cause the death of young life stages of isolated native fish populations (Kynard 1979).

Acknowledgments

We thank Bonneville Power Administration (U.S. Corps of Engineers) for funding; Vaughn Paragamian (Idaho Fish & Game Department) for information and coordination of the project; Bob Hallock (U.S. Fish & Wildlife Service) for information; and Sue Ireland (Kootenai Tribe of Idaho) for supplying fertilized eggs. Rachael Tyler assisted with data collection and fish care. Brian Kynard and Tim Parker provided diverse assistance and reviewed videotapes.

Literature Cited

- Anders, P. J., D. L. Richards, & M. S. Powell. 2002. The first endangered white sturgeon population: repercussions in an altered large river floodplain ecosystem. *American Fisheries Society Symposium* 28: 67–82.
- Gross, M. R., J. Repka, C. T. Robertson, D. H. Secor & W. V. Winkle. 2002. Sturgeon conservation: insights from elasticity analysis. *Amer. Fish. Soc. Symp.* 28: 13–30.
- Kynard, B. 1979. Population decline and change in frequencies of lateral plates in threespine sticklebacks (*Gasterosteus aculeatus*) *Copeia* 1979: 635–638.

- Kynard, B. & M. Horgan. 2002. Ontogenetic behavior and migration of Atlantic s sturgeon, *Acipenser oxyrinchus oxyrinchus*, and shortnose sturgeon, *A. brevirostrum*, with notes on social behavior. *Environ. Biology of Fishes* 63: 137–150.
- Kynard, B., E. Henyey & M. Horgan. 2002a. Ontogenetic behavior, migration, and social behavior of pallid sturgeon, *Scaphirhynchus albus*, and shovelnose sturgeon, *S. platyrhynchus*, with notes on the adaptive significance of body color. *Environ. Biology of Fishes* 63: 389–403.
- Kynard, B., P. Zhuang, T. Zhang & L. Zhang. 2002b. Ontogenetic behavior and migration of Volga River Russian sturgeon, *Acipenser gueldenstaedtii*, with a note on adaptive significance of body color. *Environ. Biology of Fishes* 65: 411–421.
- Kynard, B., P. Zhuang, T. Zhang & L. Zhang. 2003. Ontogenetic behavior and migration of Dabry's sturgeon, *Acipenser dabryanus*, from the Yangtze River with a note on body color. *Environ. Biology of Fishes* 66: 27–36.
- Kynard, B. & E. Parker. 2004. Ontogenetic behavior and migration of Gulf of Mexico sturgeon, *Acipenser oxyrinchus desotoi*, with notes on body color and development. *Environ. Biology of Fishes* 70: 43–55.
- Kynard, B., E. Parker & T. Parker. 2005. Behavior of early life intervals of Klamath River green sturgeon, *Acipenser medirostris*, with a note on body color. *Environ. Biology of Fishes* 72: 85–97.
- Kynard, B., & I. Parker. 2005. Ontogenetic behavior and dispersal of Sacramento River white sturgeon, *Acipenser transmontanus*, with a note on body color. *Environ. Biology of Fishes* 74: 19–30.
- Kynard, B., E. Parker, D. Pugh, & T. Parker. In press. Effect of water temperature, water velocity, and swimming height on dispersal distance of pallid sturgeon early life stages. *Scaphrhynchus Symposium*, St. Louis, MO.
- Loew, E.R. & A.J. Sillman. 1993. Age-related changes in the visual pigments of the white sturgeons (*Acipenser transmontanus*). *Can. J. Zool.* 71:1552-1557.
- Paragamian, V. L., & R. C. Beamesdefer. 2004. Dilemma on the Kootenai River —The risk of extinction or when does the hatchery become the best option? *American Fisheries Society Symposium* 44: 377–385.

- Paragamian, V. L. & J. P. Duehr. 2005. Variations in vertical location of Kootenai River white sturgeon during the prespawn and spawning periods. *Transactions of the American Fisheries Society* 134: 261–266.
- White, R. G., & R. G. Bramblett. 1993. The Yellowstone River: its fish and fisheries. Pages 396-414 *in* L. W. Hesse, C. B. Stalnaker, N. G. Benson, and J. R. Zuboy, editors. Restoration planning for the rivers of the Mississippi River ecosystem. Biological Report 19, National Biological Survey, Washington, D. C.
- Zhuang, P., B. Kynard, L. Zhang, T. Zhang & W. Cao. 2002a. Ontogenetic behavior and migration of Chinese sturgeon, *Acipenser sinensis*. *Environ. Biology of Fishes* 65: 83–97.
- Zhuang, P., B. Kynard, T. Zhang, L. Zhang & W. Cao. 2002b. Comparative ontogenetic behavior and migration of Kaluga, *Huso dauricus*, and Amur sturgeon, *Acipenser schrenckii*, from the Amur River. *Environ. Biology of Fishes* 66: 37–48.

Table 1.—Summary of CTU, development, and ontogenetic behaviors of Kootenai sturgeon early life stages observed in laboratory studies during 2005. Observations began on day 0 free embryos and ceased on day 77 juveniles.

Life stage	Day	CTU	Dispersal	Daytime swimming height (mean)	Illumination preference	White substrate preference	Cover preference
Early free embryo	0-6	00 – 104	Day-night & weak	38 cm	Avoid	No pref.	Strongly prefer
Late free embryo	7-12	122 – 211	Night & weak	75 cm	Avoid to prefer	Weakly prefer	Strongly prefer – weakly prefer
Early Larva	13 - 42	230– 785	Peak: night - day & weak	110 cm (days 13-32)	Prefer (days 13-38)	Weakly pref. (days 13-38)	Avoid (days 13-20)
Late Larva	43-65	805-1246	Night & weak	87 cm	??	??	Avoid
Early juvenile	66	1266	Night & weak	120 cm	??	??	Avoid
Early juvenile	70-77	1354-1505	Night & weak	74 cm	??	??	Avoid

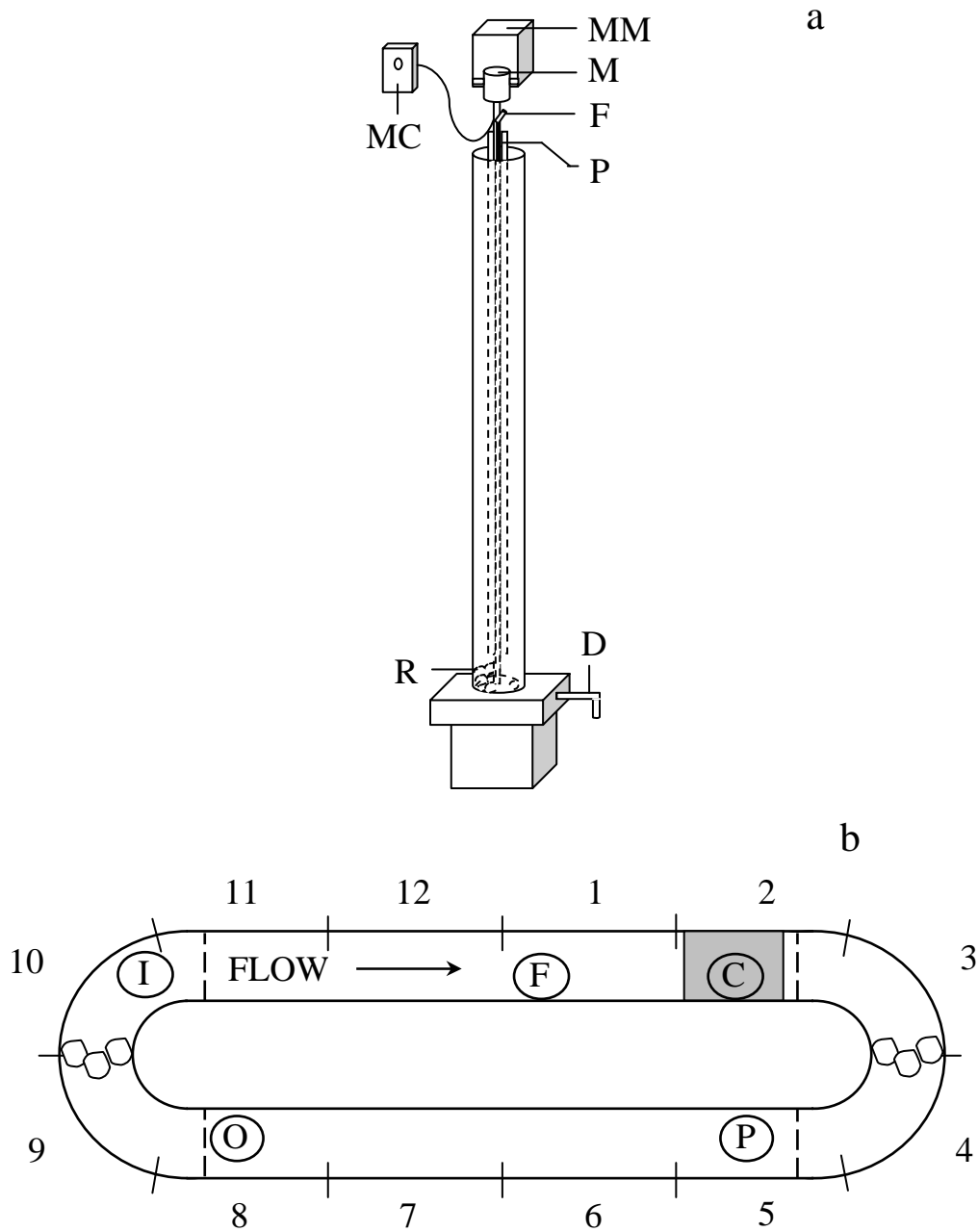


Figure 1. Panel a shows the stream tube (water depth, 150 cm; diameter, 15 cm) used to determine swimming height and cover use of white sturgeon. Key to components: M = motor, MM = motor mount, MC = motor control, F = fish introduction tube, P = paddlewheel, R = rocks, and D = drain. The rotating paddlewheel created a clockwise horizontal water current with a velocity of 2 cm s⁻¹. Panel b shows the oval stream (32 cm wide, 7.3 m in circumference, with water 20 cm deep) used to observe migration and habitat use. Three rocks at each end provided cover. The stream was marked into 12 sections, each 62 cm long. Mean bottom velocity was 3.5 cm s⁻¹ (range, 1–9 cm s⁻¹). The following notations show features: arrow = flow direction, I = water inflow, O = water outflow, P = submerged pump, F = feeder, C = video camera and infrared light, and shaded area = video field of view.

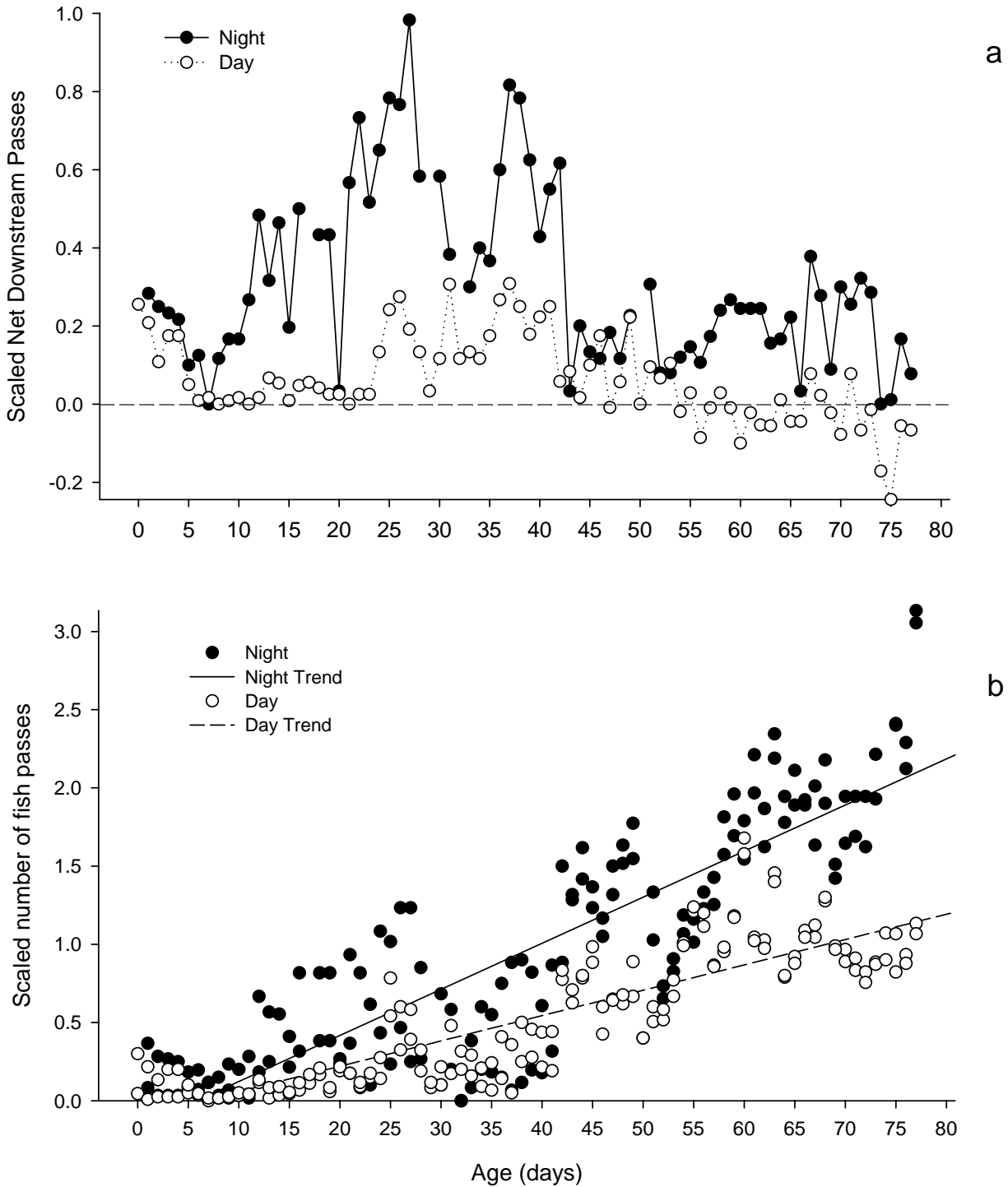


Figure 2. Graph of dispersal intensity and general activity in the oval stream tank over time. Panel a shows the scaled mean net number of downstream fish passes separated by day and night. Positive numbers of passes indicate downstream movement, whereas negative numbers indicate upstream movement. Panel b shows the scaled mean number of both up- and downstream fish passes (as a measure of activity) separated by day and night. Linear regression was used to plot trendlines for daytime and nighttime activity.

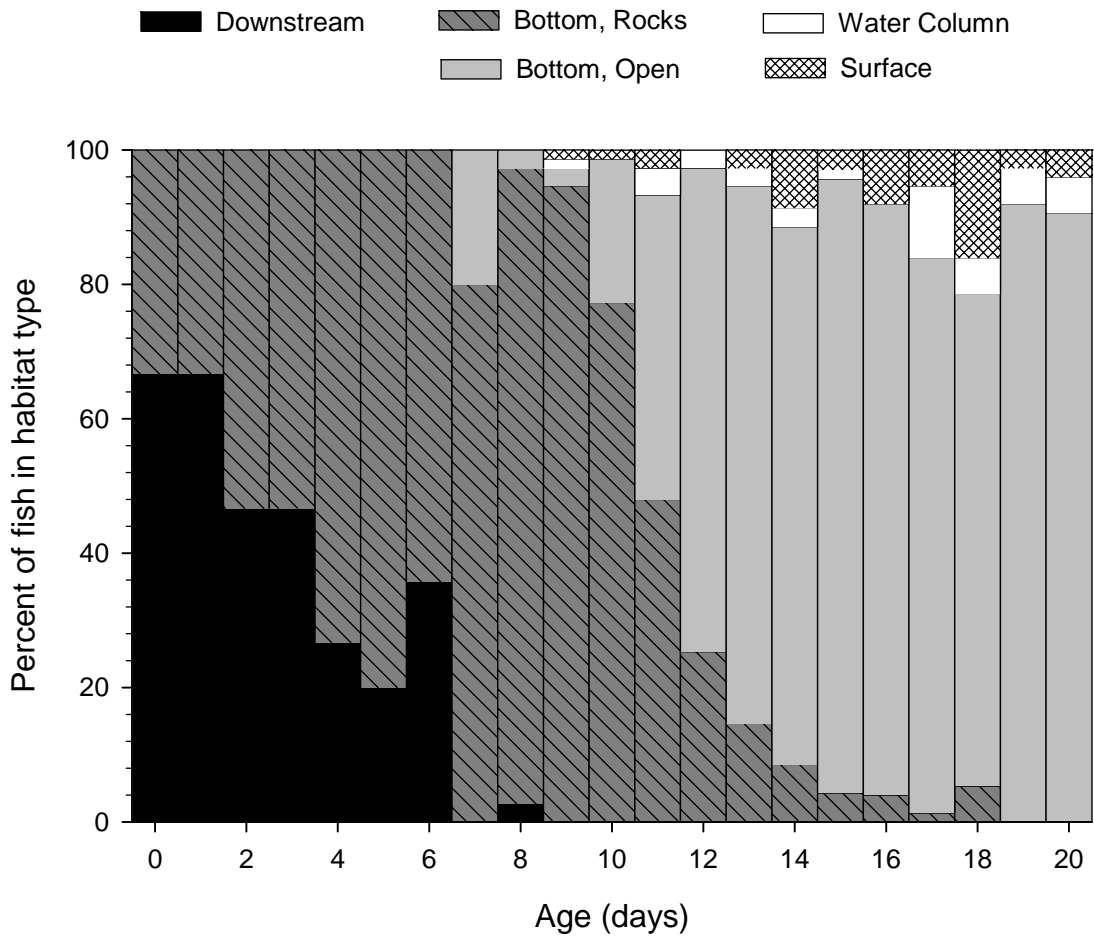


Figure 3. Percent of fish using four habitats (surface, water column, open bottom, and on the bottom under rocks) or moving downstream in the oval stream by age.

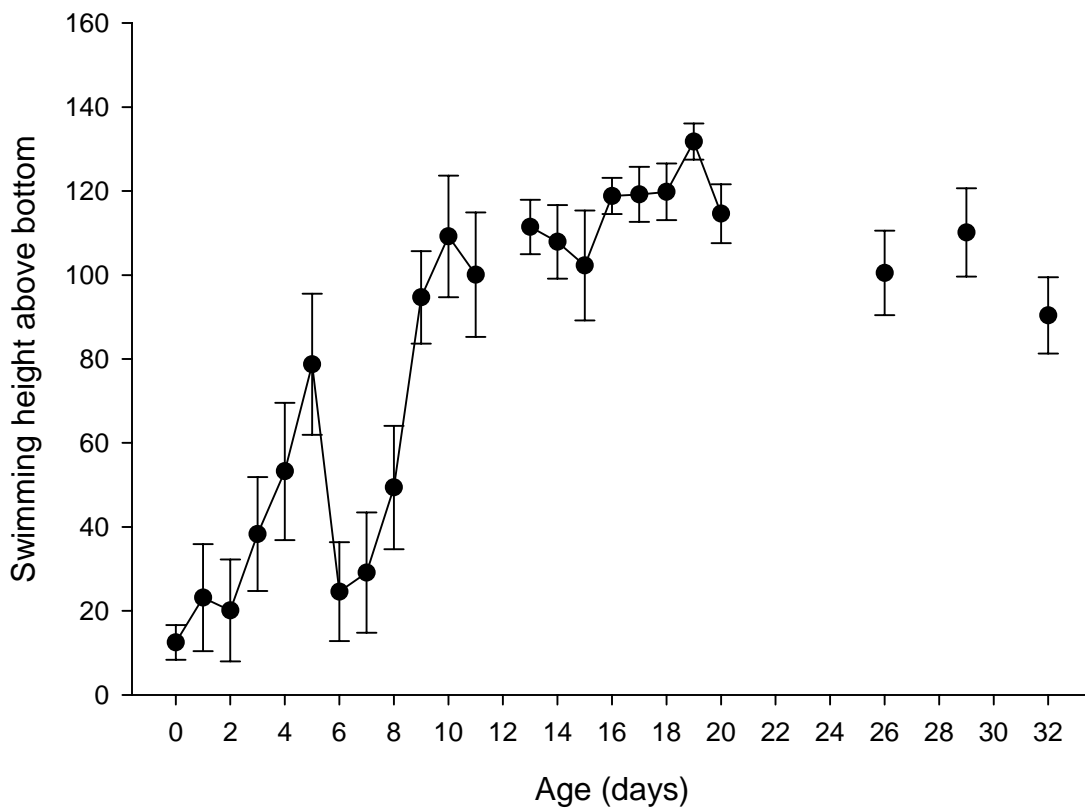


Figure 4. Mean (\pm 95% CI) swimming height above the bottom in the small (150 cm high x 15 cm diameter) stream tube.

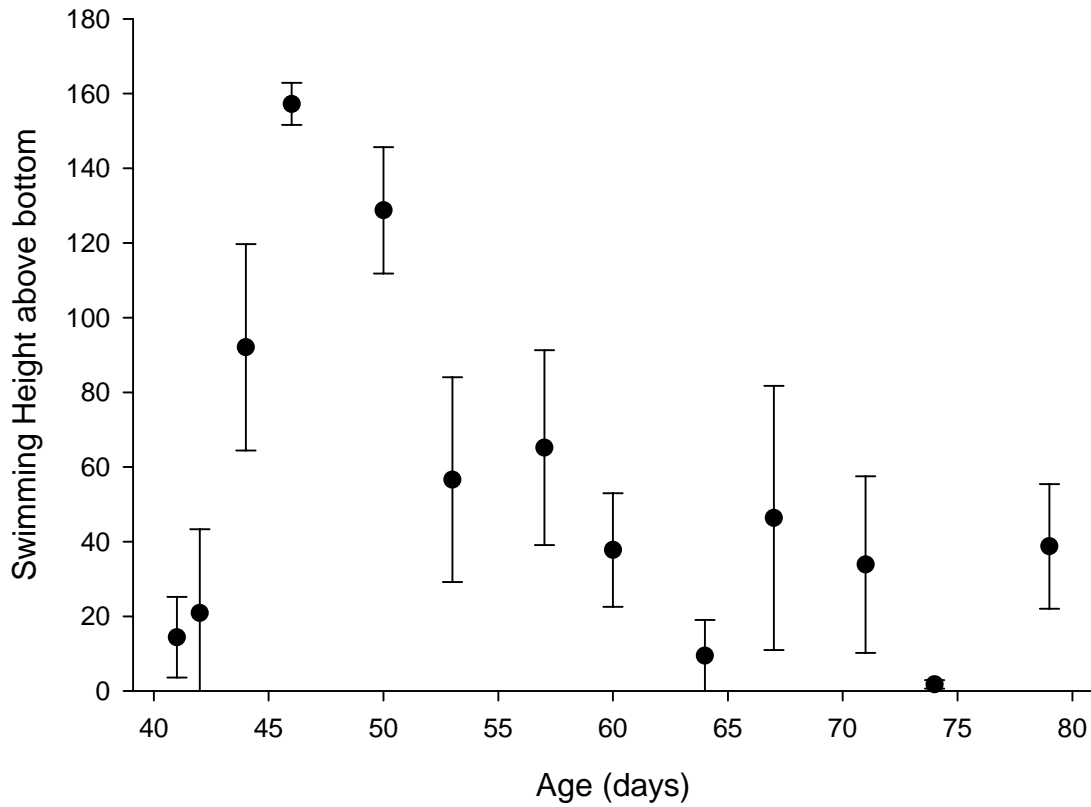


Figure 5. Mean (\pm 95% CI) swimming height above the bottom in the large (175 cm high x 60 cm diameter) stream tube. Only fish swimming in the water column and not in contact with the side of the tank are included. Because of this, different numbers of observations were used to calculate each daily mean, as follows: day 41 n=34, day 42 n=19, day 44 n= 32, day 46 n=56, day 50 n=42, day 53 n=18, day 57 n=35, day 60 n=47, day 64 n=49, day 67 n=16, day 71 n=35, day 74 n=53, and day 79 n=43.

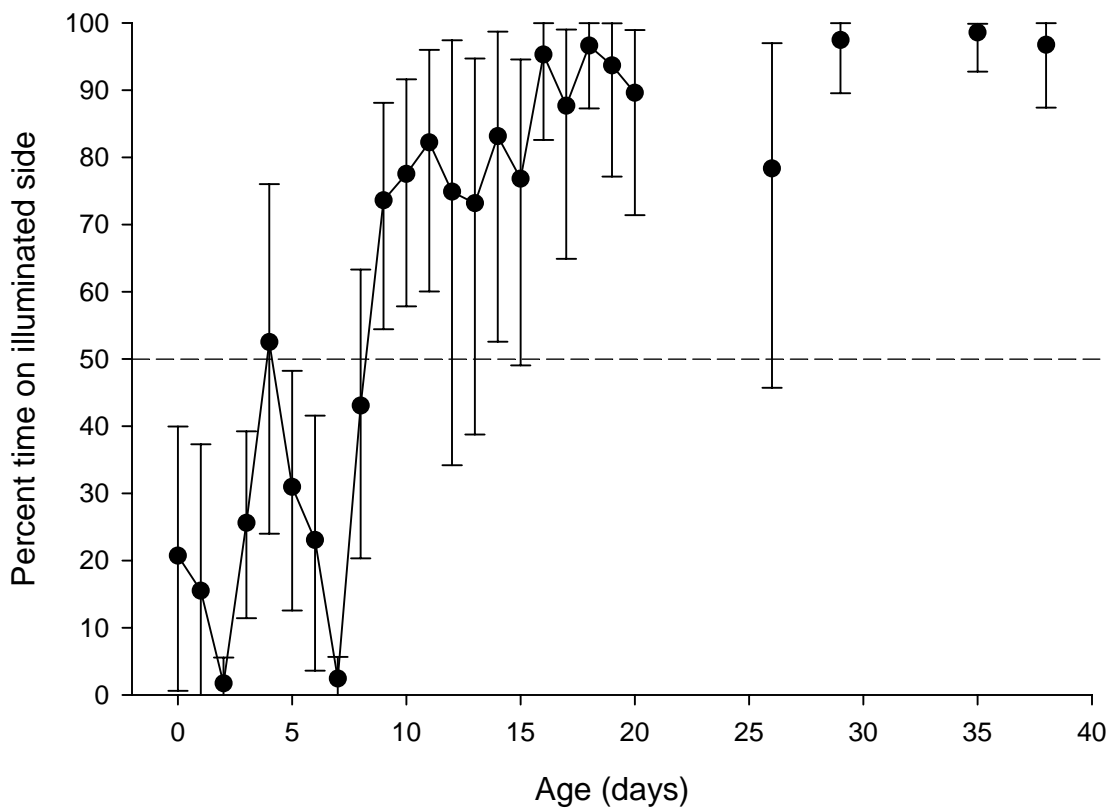


Figure 6. Means and 95% confidence intervals of percent time fish spent on illuminated side of illumination vs. darkness choice tank. If a confidence interval includes 50% (indicated by dashed line) preference is not significant.

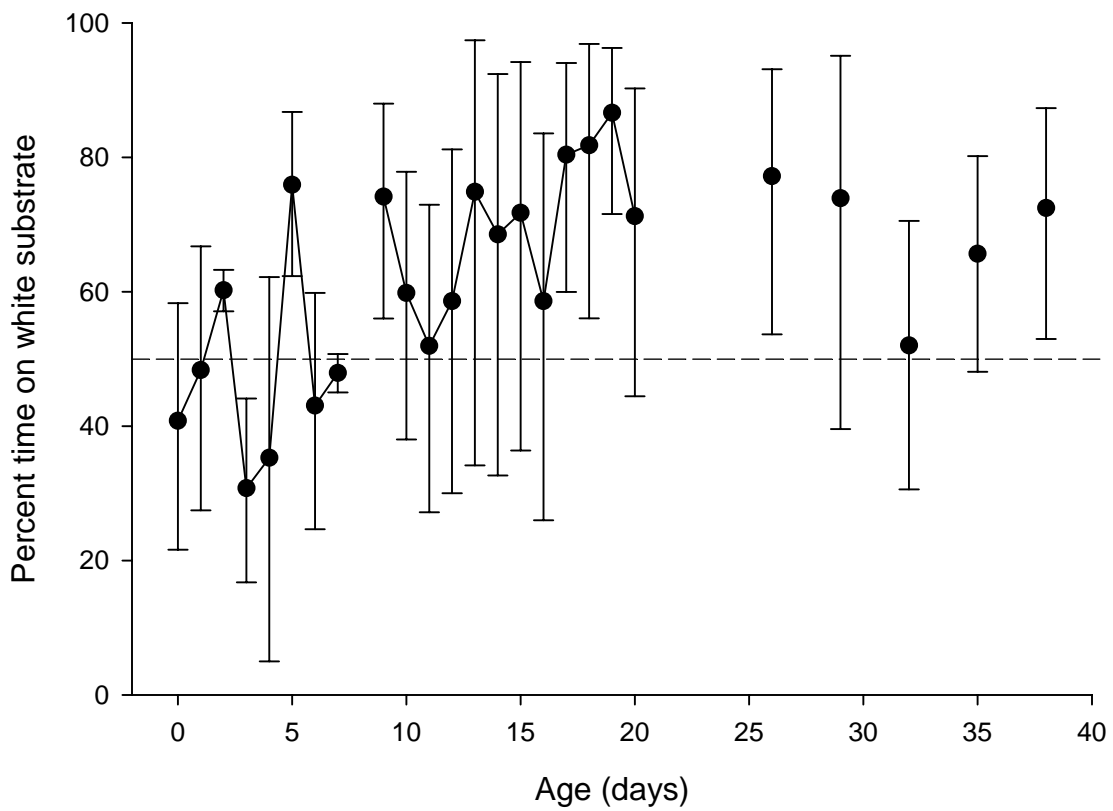


Figure 7. Means and 95% confidence intervals of percent time fish spent on white side of black vs. white substrate choice tank. If a confidence interval includes 50% (indicated by dashed line) preference is not significant.