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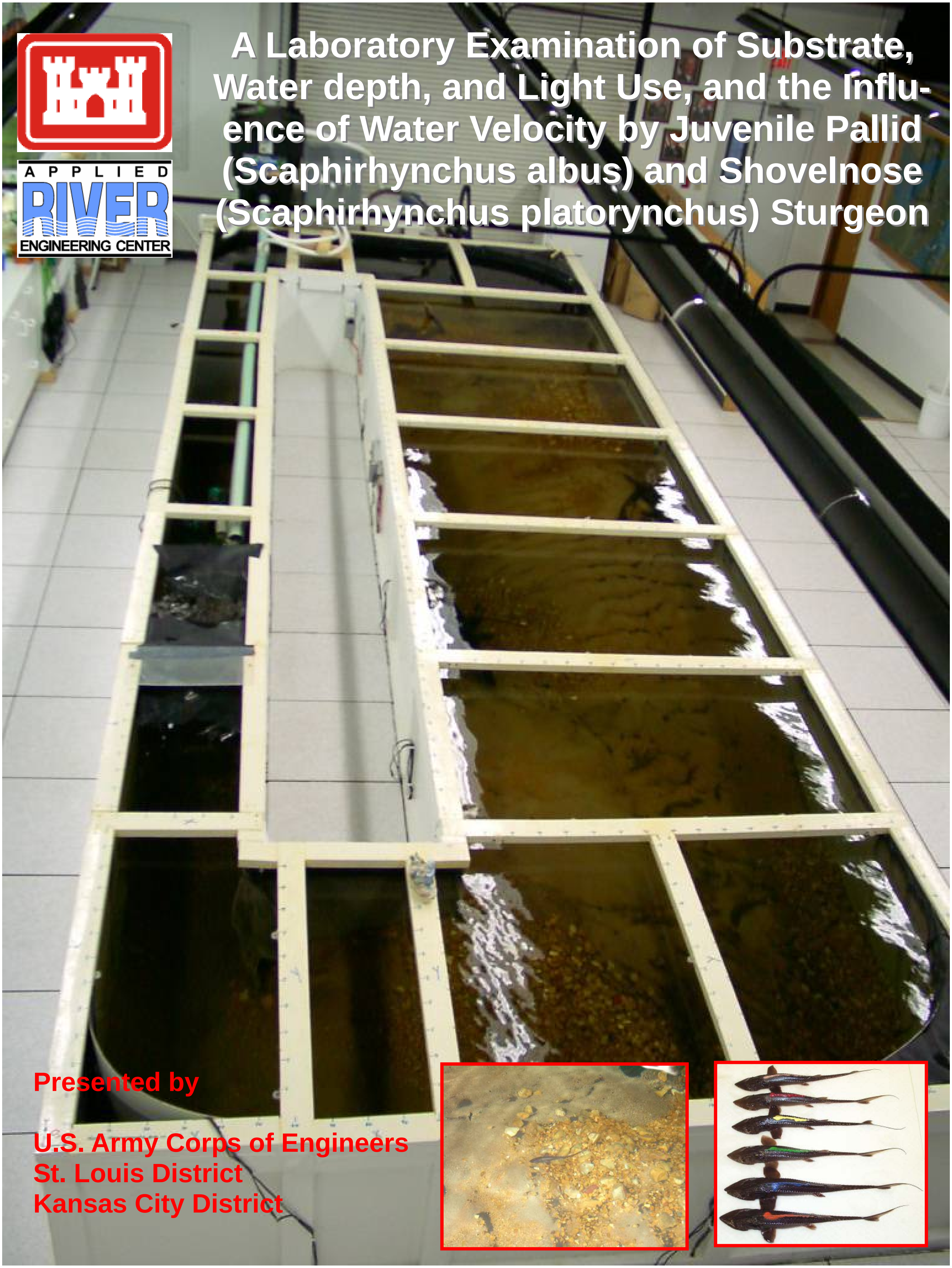

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A Laboratory Examination of Substrate, Water Depth, and Light Use, and the Influence of Water Velocity by Juvenile Pallid (*Scaphirhynchus albus*) and Shovelnose (*Scaphirhynchus platorynchus*) Sturgeon

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Abstract

We investigated the influence of substrate type, water depth, and light, on microhabitat selection in juvenile pallid (*Scaphirhynchus albus*) and shovelnose (*Scaphirhynchus platorynchus*) sturgeon at two water velocity levels. Individuals and groups of sturgeon were placed in a 315 cm by 835 cm (18,927 L; 5000 gal) elliptical flume, and their distributions were recorded every 10 minutes over a two hour period. Data were analyzed as contingency tables using an exact Kruskal-Wallace of two ordered multinomials to test for differences in distributions. Overall, individuals and groups used sand significantly more and gravel significantly less than expected ($P < 0.0001$ all cases). Use of sand/gravel mixture and woody structure was not significantly different than expected. Water depth was categorized into shallow, medium, and deep areas based on equal interval distributions. Individuals and groups all used deep areas significantly more, and medium and shallow areas less than expected based on availability ($P < 0.0001$ all cases), with the exception of individual shovelnose, in which case the use of medium depth areas was not significantly different than expected ($P = 0.1642$). Light was categorized into very light, light, dark, and very dark areas. Individuals and groups all used very dark areas significantly more than expected based on availability ($P < 0.0001$ all cases). Use of dark areas by individual shovelnose ($P = 0.0013$), groups of pallids ($P = 0.0446$), and groups of shovelnose ($P <0.0001$) was significantly more than expected based on availability. Proportional availability and use of dark areas did not differ significantly in individual pallids ($P = 0.0839$) and mixed species groups ($P = 0.7707$). All used light areas significantly less than expected ($P < 0.0001$ all cases). Additionally, individual shovelnose ($P < 0.0001$), groups of pallids ($P < 0.0001$), and mixed species groups ($P <0.0001$) all used very light areas significantly less than expected ($P < 0.0001$ all cases). Use of very light areas by individual pallids ($P = 0.5026$), and groups of shovelnose ($P = 0.3547$) did not differ significantly from availability. This study is the first investigation of juvenile pallid and shovelnose sturgeon habitat selection in a large-scale artificial stream system. Field studies of microhabitat selection by juvenile pallid and shovelnose sturgeon should be carried out to substantiate the results of this study, and to identify critical habitat for recovery and management of sturgeon species. Proper management of the species likely requires river improvements that provide sturgeon with access to a broad range of habitat conditions over time, including system-wide habitat diversity; natural variation in flow, velocity, temperature, and turbidity; high water quality; a broad prey base; and free-flowing sections which provide suitable spawning and rearing sites.

Introduction

The pallid sturgeon (*Scaphirhynchus albus*) may be close to extinction, which prompted the U.S. Fish and Wildlife Service to list it as an endangered species in 1990 pursuant to the Endangered Species Act of 1973 as amended (16 USC 1531-1543). Historically, the range of pallid sturgeon likely encompassed the Yellowstone River from the confluence of the Bighorn River to the confluence of the Missouri River; the Missouri River from Great Falls, Montana to the confluence of the Mississippi River; and the Mississippi River from the confluence of the Missouri River to the Gulf of Mexico (Bailey and Cross 1954, National Paddlefish and Sturgeon Steering Committee 1992). Forbes and Richardson (1905) and Bailey and Cross (1954) suggest that pallid sturgeon were never common. Today, pallid sturgeons are scarce in the upper Missouri River above Ft. Peck Reservoir; scarce in the Missouri and lower Yellowstone Rivers between Ft. Peck Dam and Lake Sakakawea; very scarce in the other Missouri River reservoir reaches; scarce in the Missouri River downstream of Gavins Point Dam; scarce but slightly more common in the Mississippi and Atchafalaya Rivers; absent from other tributaries. (USFWS 1998). Shovelnose sturgeon, which are sympatric with pallids over their entire range, also occur in most of the larger tributaries as well (Bailey and Cross 1954, Lee et al. 1980, Keenlyne 1997, Bramblett and White 2001).

Because pallid sturgeon are so rare, little is known about their life history and habitat requirements. Adult pallid sturgeon, like shovelnose sturgeon, inhabit comparatively large flowing rivers, but pallid sturgeon occur over a narrower range of conditions. They are postulated to prefer greater turbidity (Bailey and Cross 1954, Lee et al., 1980), finer substrates, and deeper, wider channels; and they are more likely than shovelnose sturgeon to occur in sinuous reaches and near long-established islands and alluvial bars (Bramblett 1996). Despite intense sampling efforts by fisheries personnel (Clancey 1991, Hrabik pers comm.), field collections of young sturgeons are rare. Bottom trawling on the sand flats of the Mississippi River has only recently resulted in the collection of juvenile pallid and shovelnose (5.0-21.0 cm), primarily in main channel border areas where sand troughs were usually present in the general capture locations (Adams et al. 2003).

Consequently, the microhabitat used by juvenile pallid sturgeons has not been described, and little is known about the habitat requirements and ecology of any young North American sturgeon species (Chan et al. 1997). The acquisition of sound scientific information regarding life history and habitat requirements of all life stages was identified as a national research priority, being deemed essential to the formulation of recovery and management plans for the pallid sturgeon (Kallemeyn 1983, Dryer and Sandoval 1993). Additionally, a 1997 survey of biologists working on North American sturgeon noted a lack of knowledge about the biology and life history of the pallid sturgeon and a need for additional research (Beamesderfer and Farr 1997).

Unfortunately, the difficulties of studying the life history and population dynamics of sturgeon in the field are enormous (Ragotzkie 1985, Gilbraith et al. 1988). Parsley et al., (1993) suggest that additional information on juvenile sturgeon habitat preferences for velocities and substrates may best be obtained through laboratory studies, while Chan et al. (1997) proposed that laboratory studies of microhabitat selection should be carried out to identify habitat critical for the recovery and management of sturgeon species until appropriate field studies can be executed. Thus, the St. Louis District of the United States Army Corps of Engineers conducted a laboratory study to investigate the influence of substrate type, water depth, light, and relative water velocity on the habitat selection of juvenile pallid and shovelnose (*Scaphirhynchus platorynchus*) sturgeon. Habitat selection was examined in pallid and shovelnose individuals, as well as intra- and inter-specific groups, since both intra- and inter-specific dynamics may influence habitat selection (Matheson and Brooks 1983). Protection of endangered species must involve identifying their essential habitat requirements. Only then can a direct, targeted attempt be made to protect the remaining natural habitat or to restore or develop new areas of suitable habitat.

Methods and Materials

Flume Design — A 315 cm by 835 cm (18,927 L; 5000 gal) elliptical flume (Figure 1) was used to quantify the distribution of individuals and groups of juvenile pallid and shovelnose sturgeon in relation to substrate type, water depth, light, and relative water velocity. The flume consisted of a 16 cm (6") thick concrete bottom with 2 cm (3/4") plywood sides supported by a 5 x 10 cm (2" X 4")

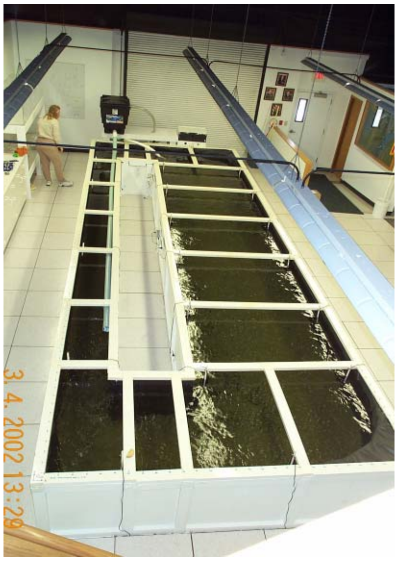

Figure 1. The approximate 18,927 L (5000 gal) elliptical flume.

wooden frame. The perimeter of the flume was also supported by a raised flooring system. The flume was lined with 45 mil Firestone PondGuard (Ethylene Propylene Diene Monomer) and underlain with Geo-Pad, a polypropylene nonwoven needle-punched fabric (www.pondsuppliesrus.com). Commercially obtained clean sand and gravel lined the flume bottom. Water filtration and low velocity (LV) circulation was accomplished using 254 liter per minute (Lpm) (4000 gallon per hour; gph) wet/dry Green Machine mechanical and biological canister filter (GM6000; www.pondsuppliesrus.com) supplied with an in-line 1/8 horse power (hp) PerformancePro Artesian pump (A1/8-35; www.pondsuppliesrus.com). The water intakes and outtakes of the filtration system were designed to distribute flow proportionally over the entire flume. A sump pump (Water Ace 3/4 HP Submersible Sewage Pump, 227 Lpm / 3600 gph) was placed in a partitioned off section of the flume in order to increase flow during high velocity (HV) trials.

Grid system — A data reference grid consisting of a coordinate system was established by a simple surveying method. Once the axis was determined, incremental measurements of 10 cm (3.9 in) were marked on the rails of the flume to assist in determining the x and y-coordinates. The z-coordinate was determined as needed by gently setting a measuring rod on the substrate and measuring the distance off the bottom at which the fish was swimming.

Bathymetry — Bathymetry was plotted using the above mentioned surveying method. The grid placed on the rails of the flume was used to establish survey lines. The bathymetry was measured by placing the surveying rod on the surface of the sediment at set intervals and recording the readings. The number of intervals necessary was determined by visually examining the complexity of the flume bed and increasing the measurements taken in areas of increased complexity. Bathymetry measurements were taken before the research began, as bed conditions were not changed during this experiment (Figure 2).

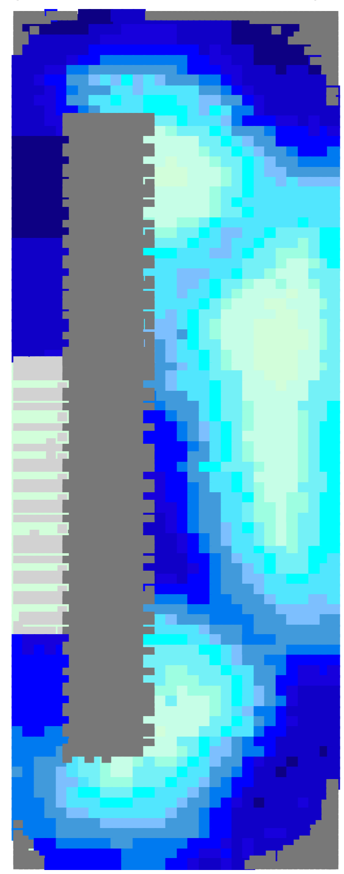

Figure 2. Gradient of water depth distribution within the flume. Lighter areas are shallower, darker areas are deeper.

Light — Ambient room light provided by fluorescent fixtures remained constant during the trials. Light measurements (lux) were taken along the flume bed every 5 cm throughout the flume using a modified water resistant Extech model 401025 light meter. For analytical purposes, measurements were categorized into four levels based on natural breaks in the data (ArcView GIS 3.3, Environmental Systems Research Institute, Inc. (ESRI), Redlands, CA) (Figure 3).

Figure 3. Gradient of light distribution within the flume at the substrate surface. Lighter areas have more light, darker areas have less light.

Water velocity — Water velocity ranged from 0 cm/s to 33 cm/s, and was measured as a quantitative variable using a SonTek/YSI FlowTracker handheld acoustic Doppler velocity meter (SonTek/YSI Inc., San Diego, CA). The device collects velocity readings at a single point if the velocity is within the range of 0.001 m/s (0.1 cm/s, 0.003 ft/s) to 5 m/s (500 cm/s, 16 ft/s). For analytical purposes, water velocity measurements were categorized into two levels. During the low velocity trials, the sump pump was off, and minimal flow was provided by the filtration system only. During high velocity studies, the sump pump was turned on in addition to the filtration system.

Fish — Juvenile pallid sturgeon were obtained from Garrison Dam National Fish Hatchery, Riverdale, North Dakota on 14 August and 11 September 2002. Shovelnose sturgeon were obtained from Bozeman Fish Technology Center, Bozeman, Montana on 11 September 2002. Upon arrival, the fish were transferred into two 340-L (90 gal) partitioned acrylic aquariums filled with dechlorinated tap water (Figure 4). Fish used in trials ranged in size from 27-200 mm. Average fish size during trials was 133 mm (± 30 mm, N = 311). Water circulated through the aquariums was obtained from the flume. Thus, water conditions in the holding tanks and the experimental unit were

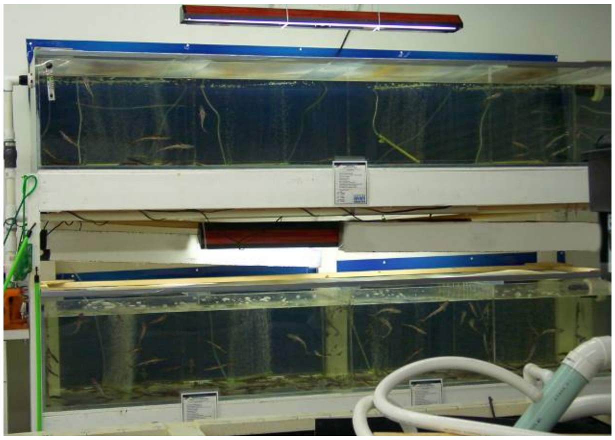

Figure 4. Partitioned 340-L (90 gal) acrylic sturgeon holding tanks.

nearly identical. Water quality was tested once per week, and maintained as follows: temperature approximately 21-22ºC, dissolved oxygen > 6.0 mg/L, pH 7.0, nitrite < 0.2 ppm, and ammonia < 0.0125 ppm.

Experimental Design — Organisms experience the environment in terms of a combination of features simultaneously. In order to determine the substrate type, water depth, light, and relative water velocity inclinations of young pallid and shovelnose sturgeon, 102 (total) replicates of the following experiment were conducted at both low and high velocities using (1) an individual pallid sturgeon (15 trials each), (2) a group of six pallid sturgeon (7 trials each), (3) an individual shovelnose sturgeon (15 trials each), (4) a group of six shovelnose sturgeon (7 trials each), and (5) a mixed species group of three pallid and three shovelnose sturgeon (7 trials each). Trials were conducted from 9 September 2002 to 28 March 2003 between 0700 and 1600 hours. The fish were marked, placed in the flume (starting location was randomly generated) (Figure 5), and allowed to acclimate for 30 minutes (Chan et al. 1997). Following the acclimation period, the specific location of each individual was recorded every 10

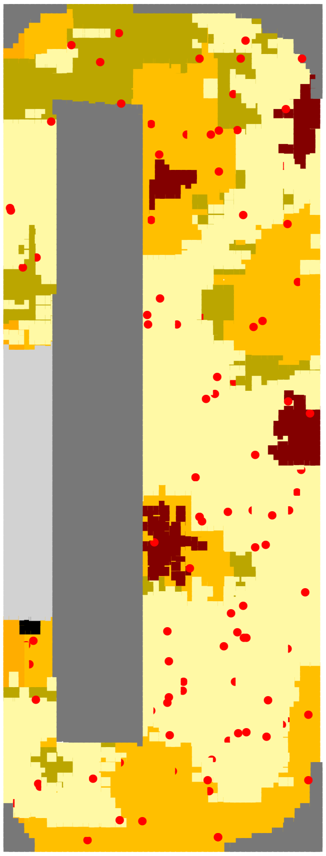

Figure 5. Distribution of randomly generated starting points for all 103 trials.

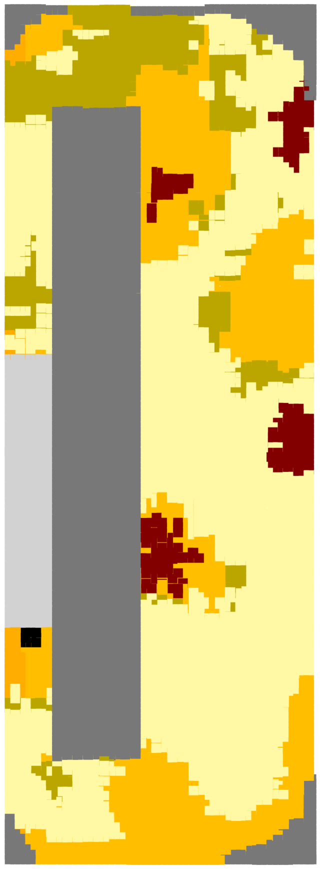

Figure 6 Distribution of substrate within the flume.

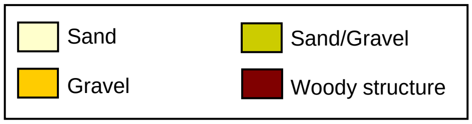

Figure 7. Woody structure placed in the flume.

minutes for a period of two hours (13 point samples per individual). Individuals were not disturbed during the sampling period. Some individuals were used in two trials.

Figure 8. Sturgeon were anaesthetized with MS 222, and marked with a mixture of cyanoacrylate (Super/ Krazy glue) and fingernail polish for identification purposes.

The flume substrate consisted of sand or gravel or a sand/gravel mixture to replicate conditions that occur in the middle Mississippi River. Bottom contours were designed to include each substrate at shallow, medium, and deep water depths (Figure 6). Four bundles of driftwood obtained from the bank of the Mississippi River were also placed in the flume over sand and gravel (Figure 7). At each observation time, each fish's location was referenced using the grid system and in relation to the surrounding habitat. Behavior (swimming, resting) was also noted.

Fish Marking — Immediately prior to the marking procedure, fish were anaesthetized with tricaine methanesulfonate (MS 222; 50 mg/L). Once anaesthetized, the slime coating along a portion of the dorsal surface was removed with a cotton swab, and a mixture of cyanoacrylate (Super/Krazy glue) and fingernail polish was applied (Figure 8). Individuals were allowed to recover for approximately 15 minutes before being placed in the flume for acclimation and subsequent use in trials. Fish for each trial were marked with a different color to aid observers in easily distinguishing between pallids and shovelnose, and to permit simple visual tracking of individuals over the two-hour sampling period. Prior observations demonstrated that the marking did not alter fish behavior. The paint was peeled off by hand at the completion of the trial to allow the slime coat to recover.

Data Analyses — Data were analyzed as contingency tables using an exact Kruskal-Wallace of two ordered multinomials to test for differences in distributions (e.g., low vs. high velocity, single pallids vs. single shovelnose at low velocity, habitat occupancy by single pallids vs. habitat availability as estimated using GIS data, etc.). The difference between the two populations at each level of the multinomial table was analyzed as the differences between binomial proportions using asymptotic tests, except when the numerator was small (<10). All analyses were carried out using StatXact 6.0 (Cytel,

Table 1. Percent substrate availability and use by individual pallid and individual shovelnose sturgeon.

	Sand				Gravel				Sand & Gravel				Woody Structure			
	Avail-able	Use			Avail-able	Use			Avail-able	Use			Avail-able	Use		
		All	LV	HV		All	LV	HV		All	LV	HV		All	LV	HV
Pallids	52.50	77.66	77.27	78.06	30.03	5.33	7.07	3.57	13.51	13.45	10.61	16.33	3.96	3.55	5.05	2.04
Shovel-nose		67.62	76.14	58.96		13.47	12.50	14.45		13.18	7.95	18.50		5.73	3.41	8.09

All—LV and HV trials combined; LV – Low velocity; HV – high velocity

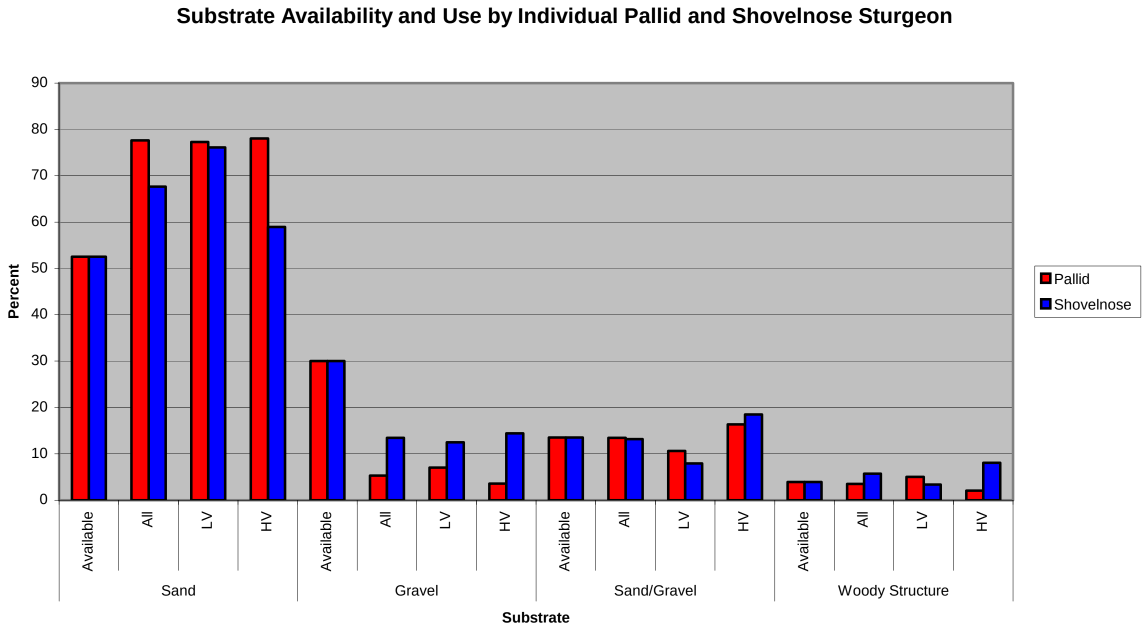

Figure 9. Percent of substrate availability and use by individual pallid and shovelnose sturgeon during low velocity (LV) and high velocity (HV) trials.

Cambridge, MA). Significance was determined at P < 0.05.

Results

Substrate — The relative areas of available substrate for all trials were 52.5% sand, 30.0% gravel, 13.5% sand/gravel mixture, and 3.9% woody structure (Figure 6). Individual pallids did not use the substrate in proportion to its availability (Table 1, Figure 9). Sand was used significantly more than expected (P < 0.0001) and gravel was used significantly less (P < 0.0001). Use of the sand/gravel mixture (P = 0.059) and woody structure (P = 0.099) were not significantly different than expected.

Like individual pallids, individual shovelnose used sand more than expected (P < 0.0001), and gravel less than expected (P < 0.0001) based on availability. Use of sand/gravel mixture (P = 0.862) and woody structure (P = 0.117) were not significantly different than availability (Table 1, Figure 9).

Groups of pallid sturgeon, groups of shovelnose sturgeon, and mixed species groups all used

Table 2. Percent substrate availability and use by groups of pallids, groups of shovelnose, and mixed-species groups.

	Sand				Gravel				Sand & Gravel				Woody Structure			
	Avail-able	Use			Avail-able	Use			Avail-able	Use			Avail-able	Use		
		All	LV	HV		All	LV	HV		All	LV	HV		All	LV	HV
Pallids	52.50	68.63	67.13	70.50	30.03	9.68	14.63	3.50	13.51	21.69	18.24	26.00	3.96	0.00	0.00	0.00
Shovel-nose		59.31	53.55	63.81		14.35	23.23	7.43		25.59	22.00	28.38		0.75	1.22	0.38
Mixed		65.04	65.87	63.70		7.24	10.16	2.51		27.38	23.55	33.56		0.35	0.42	0.23

LV – Low velocity, HV – high velocity

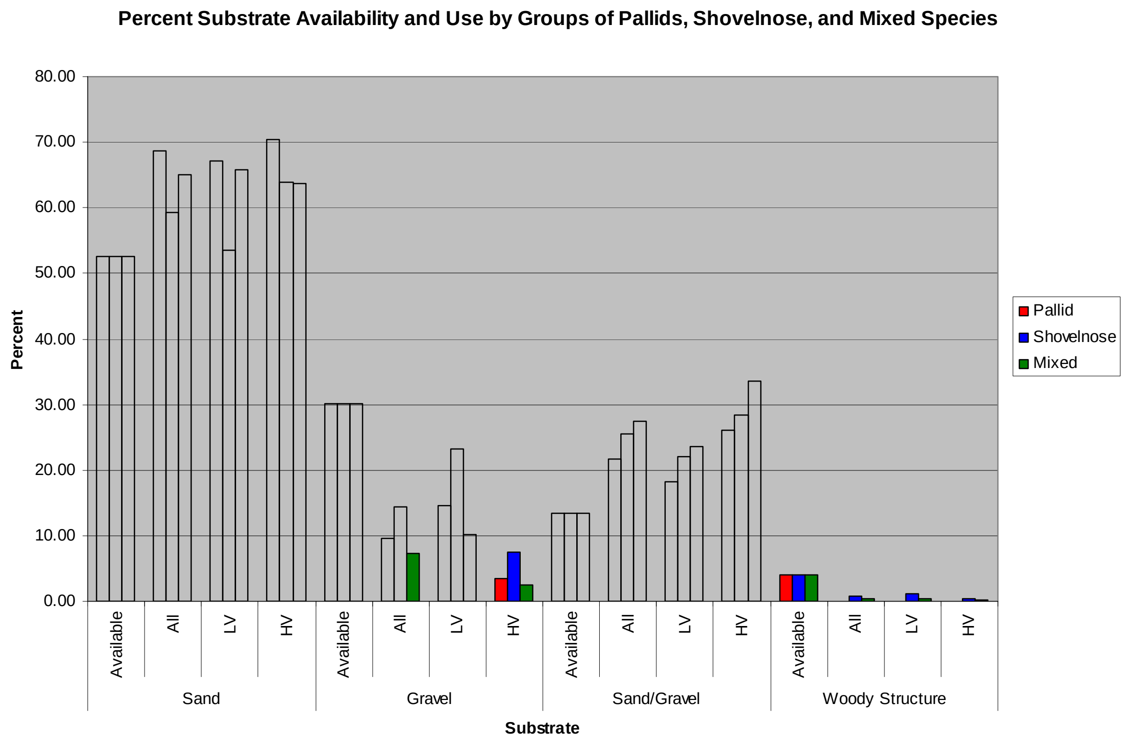

Figure 10. Percent of substrate availability and use by groups of pallids, groups of shovelnose, and mixed species groups during low velocity (LV) and high velocity (HV) trials.

sand (P = 0.005, P = 0.0001, P <0.0001) and sand/gravel (P < 0.0001, P < 0.0001, P <0.0001) more than anticipated, and gravel (P < 0.0001, P < 0.0001, P < 0.0001) and woody structure (P < 0.0001, P < 0.0001, P < 0.0001) less than anticipated. Use of sand (P = 0.623), sand/gravel (P = 0.060), and woody structure (P = 0.526) by pallids and shovelnose in mixed groups did not differ significantly. Gravel was used significantly more by shovelnose than pallids in mixed groups (P = 0.027) (Table 2, Figure 10).

Influence of Velocity on Substrate Use — Overall, the use of substrate at low velocity and high velocity did not significantly differ in individual pallids (P = 0.884), groups of pallids (P = 0.961), groups of shovelnose (P = 0.095), or mixed species groups (P = 0.095). However, individual shovelnose did show a significant difference in use overall in relation to velocity (P = 0.0003). They used sand significantly more at low velocity (P = 0.0006), and sand/gravel significantly more at high velocity (P = 0.004). There was no significant difference in the use of gravel (P = 0.594) or woody

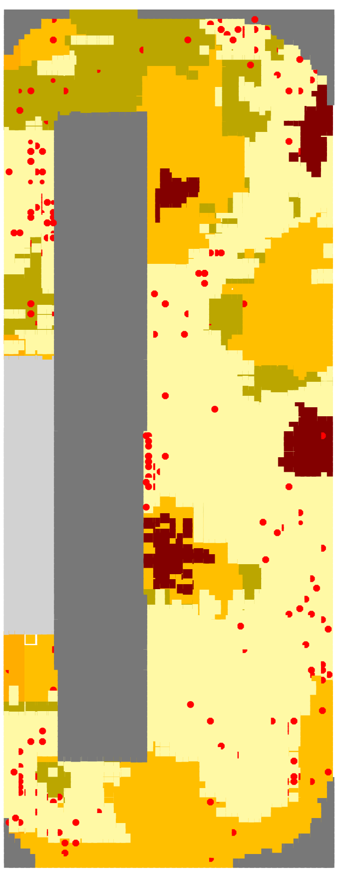

Figure 11. Distribution of substrate within the flume, and location of individual juvenile pallid sturgeon during low velocity trials. Refer to Figure 5 for legend.

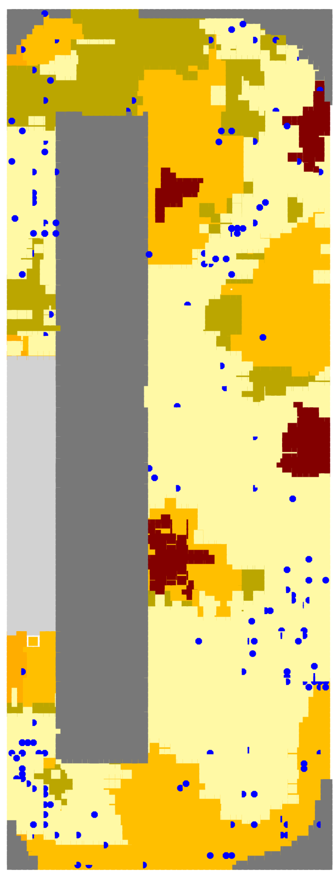

Figure 12. Distribution of substrate within the flume, and location of individual juvenile shovelnose sturgeon during low velocity trials. Refer to Figure 5 for legend.

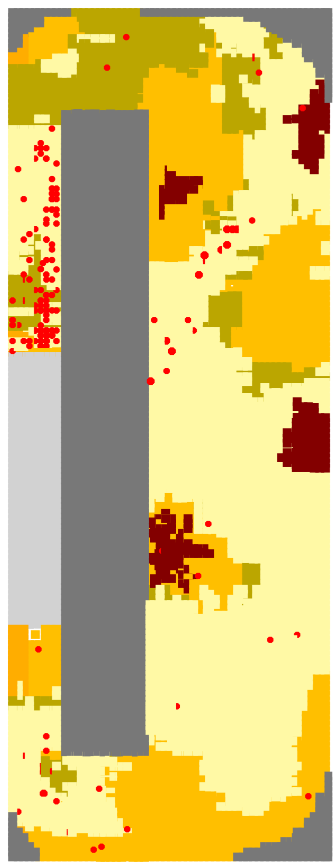

Figure 13. Distribution of substrate within the flume, and location of individual juvenile pallid sturgeon during high velocity trials. Refer to Figure 5 for legend.

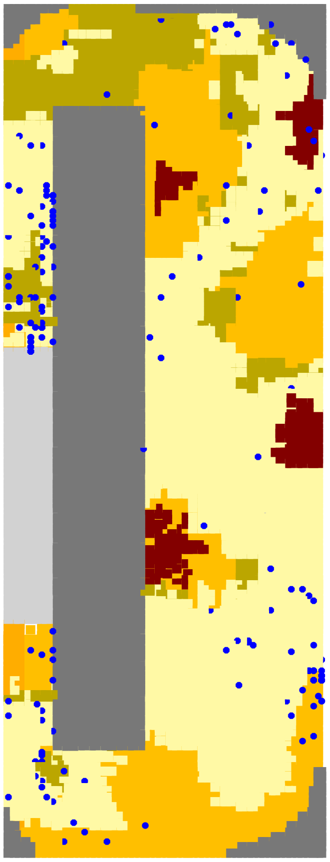

Figure 14. Distribution of substrate within the flume, and location of individual juvenile shovelnose sturgeon during high velocity trials. Refer to Figure 5 for legend.

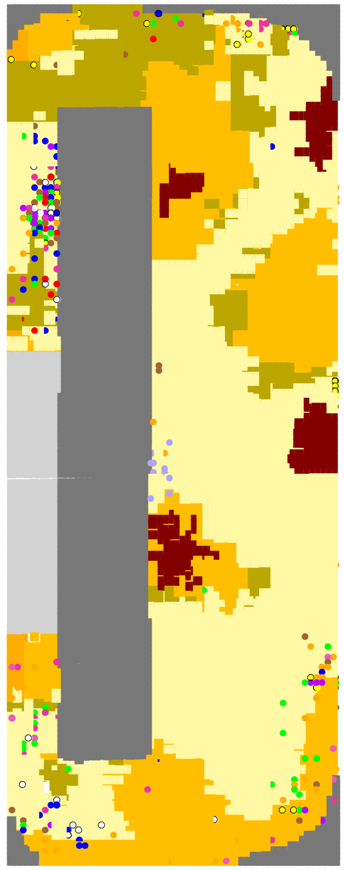

Figure 15. Distribution of substrate within the flume, and location of groups of juvenile pallid sturgeon during low velocity trials. Refer to Figure 5 for legend.

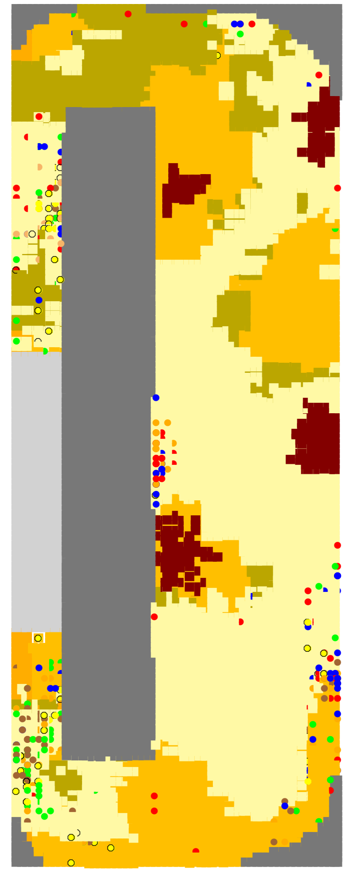

Figure 16. Distribution of substrate within the flume, and location of groups of juvenile shovelnose sturgeon during low velocity trials. Refer to Figure 5 for legend.

structure (P = 0.065) at low velocity versus high velocity by individual shovelnose (Tables 1-2, Figures 9-21).

Species Comparisons and Substrate Use —

Individual Pallids and Individual Shovelnose — Individual pallids and individual shovelnose do not differ in their use of substrate at low velocity (overall, P = 0.990; sand, P = 0.795; gravel, P = 0.076; sand/gravel, P = 0.379; woody structure, P = 0.579) (Table 1, Figures 9, 11-12).

However, individual pallids and individual shovelnose do differ in their use of substrate at high velocity (P = 0.0003). At high velocity, sand was used significantly more by pallids than by shovelnose (P = 0.0001), gravel was used significantly more by shovelnose than pallids (P = 0.0002), sand/gravel use did not differ significantly (P = 0.583), and shovelnose used woody structure significantly more than pallids (P = 0.007) (Table 1, Figures 9, 13-14).

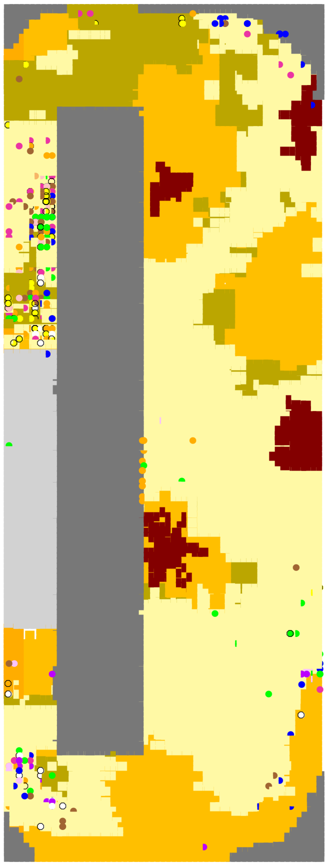

Figure 17. Distribution of substrate within the flume, and location of groups of juvenile pallid sturgeon during high velocity trials. Refer to Figure 5 for legend.

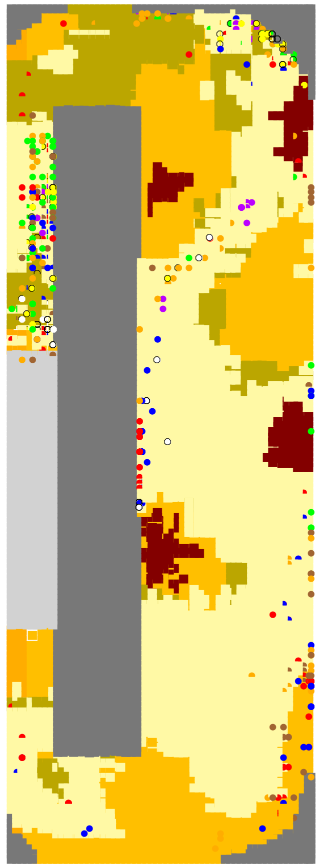

Figure 18. Distribution of substrate within the flume, and location of groups of juvenile shovelnose sturgeon during high velocity trials. Refer to Figure 5 for legend.

Individual Pallids and Groups of Pallids — Individual pallids and groups of pallids differed in their use of substrate at low velocity (P = 0.037). Individual pallids used sand (P = 0.008) and woody structure (P < 0.0001) more than groups of pallids, but used gravel (P = 0.007) and sand/ gravel (P = 0.013) less (Tables 1-2, Figures 9-11, 15).

Overall, individual pallids and groups of pallids did not differ significantly in their use of substrate at high velocity (P = 0.059). However, single pallids used sand/gravel (P = 0.008) more and woody structure (P = 0.0085) less than groups of pallids. Use of sand (P = 0.051) and gravel (P = 0.992) did not differ significantly (Tables 1-2, Figures 9-10, 13, 17).

Individual Shovelnose and Groups of Shovelnose — Individual shovelnose and groups of shovelnose differed in their use of substrate at low velocity (P = 0.000). Single shovelnose used sand more than groups of shovelnose (P<0.0001), while groups tended to use gravel (P = 0.003) and sand/ gravel (P < 0.0001) more than single shovelnose. Use of woody structure did not differ significantly between trials of single and group shovelnose (P = 0.103) (Tables 1-2, Figures 9-10, 12, 16).

Overall, use of substrate by individual shovelnose and groups of shovelnose did not differ significantly at high velocity (P = 0.256). However, gravel (P = 0.006) and woody structure (P < 0.0001) were used significantly more by individual shovelnose, while sand/gravel (P = 0.010) was used significantly more by groups of shovelnose. Use of sand did not differ significantly between trials of

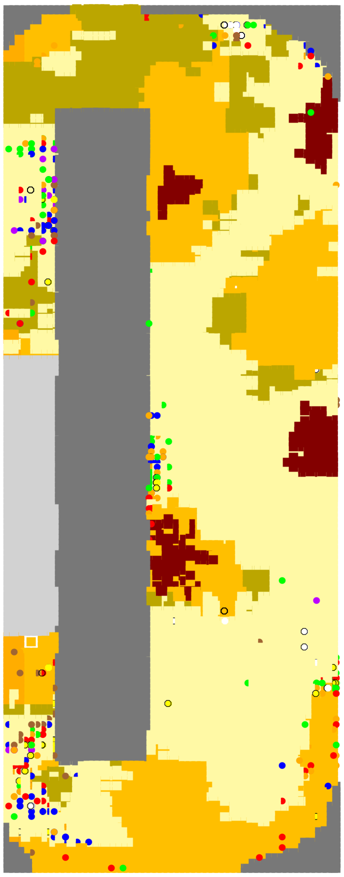

Figure 19. Distribution of substrate within the flume, and location of mixed groups of juvenile pallid and shovelnose sturgeon during low velocity trials. Refer to Figure 5 for legend.

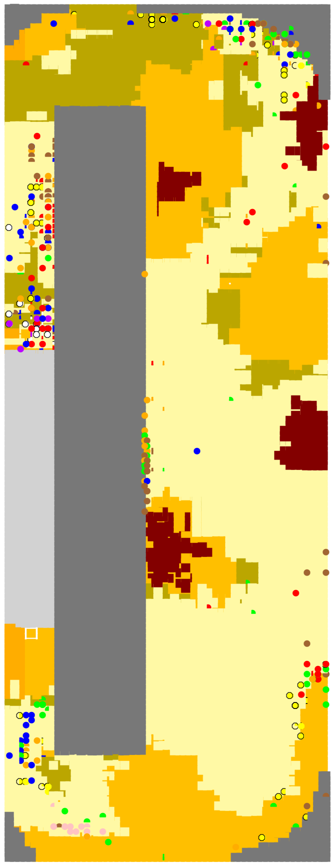

Figure 20. Distribution of substrate within the flume, and location of mixed groups of juvenile pallid and shovelnose sturgeon during high velocity trials. Refer to Figure 5 for legend.

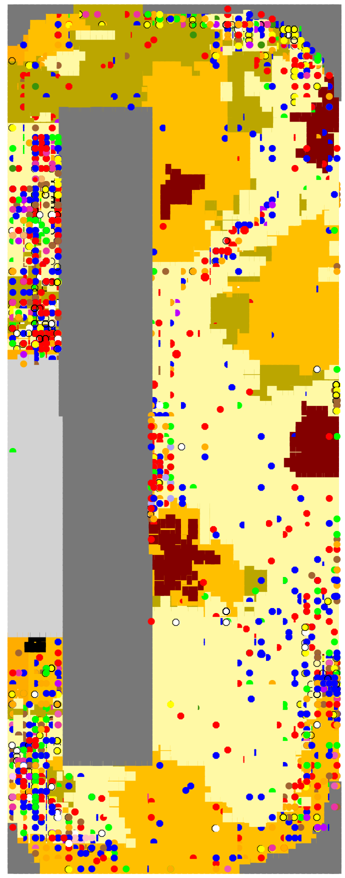

Figure 21. Distribution of substrate within the flume, and location of juvenile pallid and shovelnose sturgeon (all trials). Refer to Figure 5 for legend.

individuals and groups of shovelnose (P = 0.253). (Tables 1-2, Figures 9-10, 14, 18)

Groups of Pallids and Groups of Shovelnose — Groups of pallids and groups of shovelnose differ in their use of substrate at low velocity (P = 0.0001). Pallids use sand significantly more than shovelnose (P < 0.0001), but use gravel (P = 0.0005) and woody structure (P = 0.013) significantly less. There was no significant difference in the use of sand/gravel mixture between the two groups at low velocity (P = 0.157) (Table 2, Figures 10, 15-16).

Overall, groups of pallids and groups of shovelnose do not differ in their use of substrate at high velocity (P = 0.059). However, groups of pallids use sand (P = 0.032) significantly more and gravel (P = 0.011) significantly less than groups of shovelnose. There was no significant difference in the use of sand/gravel (P = 0.421) or woody structure (P = 0.299) between the groups at high velocity (Table 2,

Table 3. Percent water depth availability and use by individual pallid and individual shovelnose sturgeon.

	Shallow (27-49 cm deep)				Medium (50-72 cm deep)				Deep (73-93 cm deep)			
	Avail-able	Use			Avail-able	Use			Avail-able	Use		
		All	LV	HV		All	LV	HV		All	LV	HV
Pallids	25.97	2.28	4.04	0.51	38.60	21.32	29.80	12.76	35.43	76.40	66.16	86.73
Shovelnose		2.87	2.84	2.89		34.67	44.89	24.28		62.46	52.27	72.83

LV – Low velocity, HV – high velocity

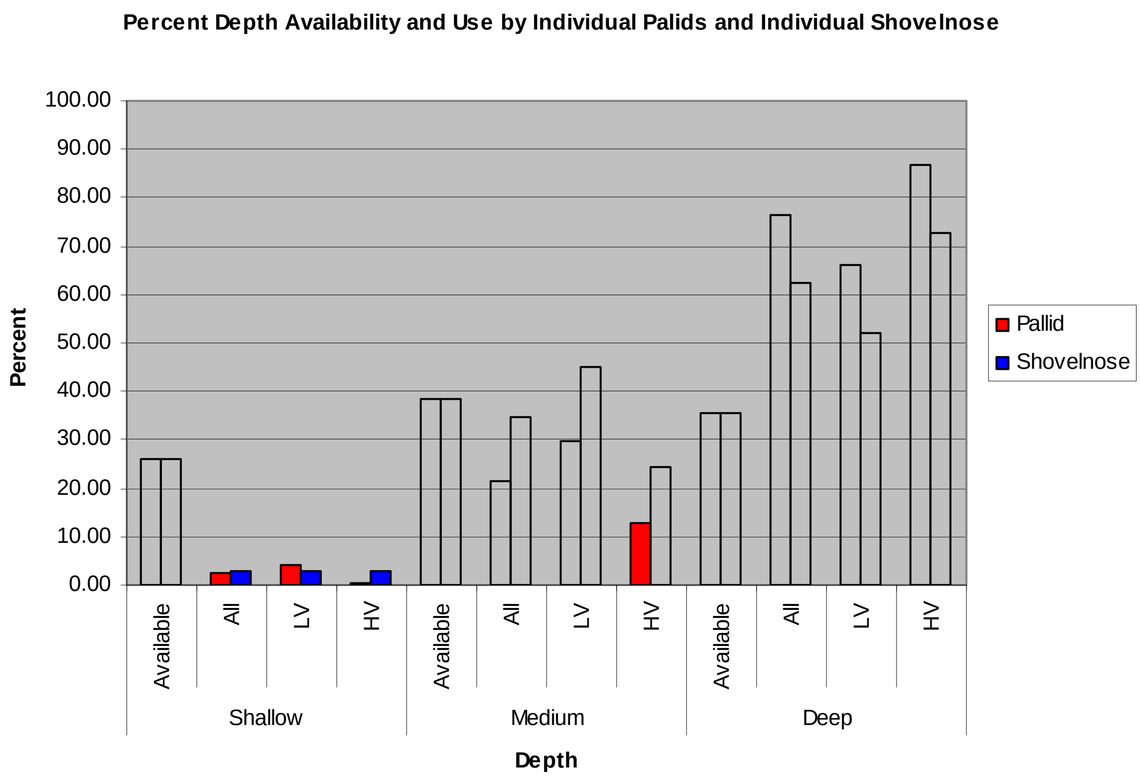

Figure 22. Percent water depth availability and use by individual pallids and individual shovelnose during low velocity (LV) and high velocity (HV) trials.

Figures 10, 17-18).

Pallids and Shovelnose in Mixed Groups — Pallids and shovelnose in mixed groups did not differ in their use of sand (P = 0.806), gravel (P = 0.069), sand/gravel (P = 0.364), or woody structure (P = 0.596) at low velocity (overall P = 0.882) (Table 2, Figures 10, 19). Similarly at high velocity, pallids and shovelnose in mixed groups did not differ significantly in their use of sand (P = 0.314), gravel (P = 0.807), sand/gravel (P = 0.296), or woody structure (P = 0.397) (overall P = 0.359) (Table 2, Figures 10,

Table 4. Percent water depth availability and use by groups of pallids, groups of shovelnose, and mixed-species

	Shallow (27-49 cm deep)				Medium (50-72 cm deep)				Deep (73-93 cm deep)			
	Avail-able	Use			Avail-able	Use			Avail-able	Use		
		All	LV	HV		All	LV	HV		All	LV	HV
Pallids	25.97	1.11	2.00	0.00	38.60	16.57	17.64	15.25	35.43	82.31	80.36	84.75
Shovel nose		2.19	3.42	0.95		21.40	26.41	16.38		76.42	70.17	82.67
Mixed		0.17	0.14	0.23		16.74	20.73	10.27		83.09	79.13	89.50

LV – Low velocity, HV – high velocity

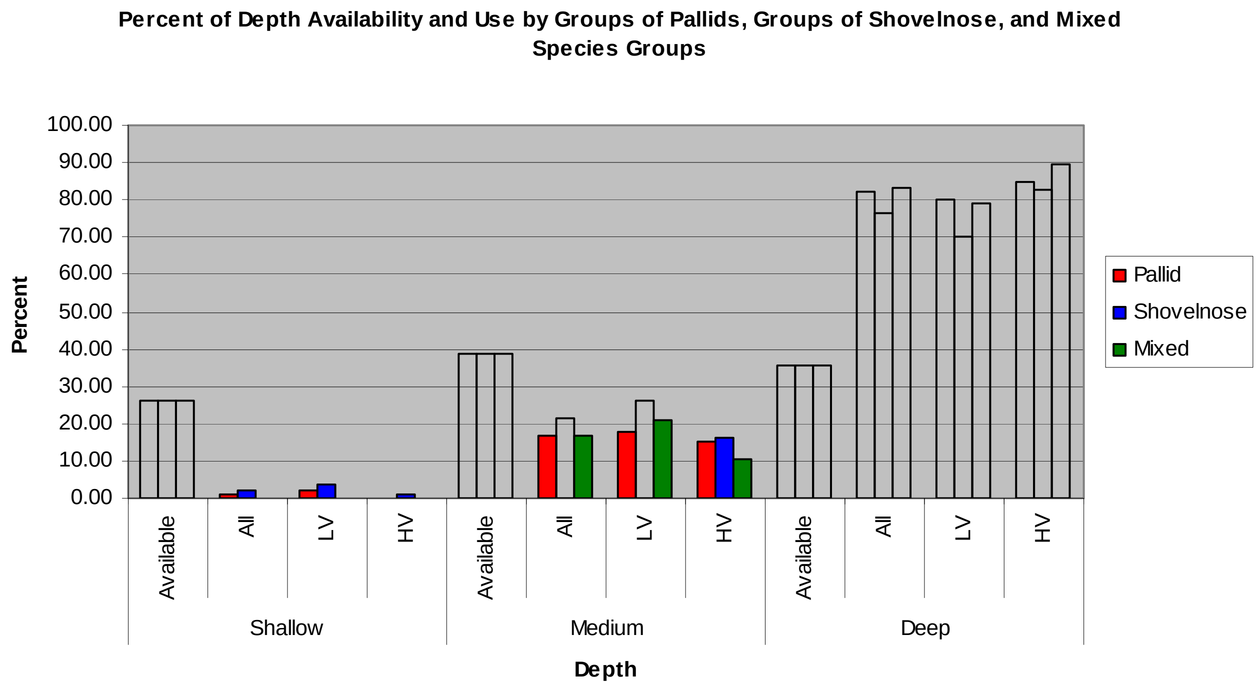

Figure 23. Percent of water depth availability and use by groups of pallids, groups of shovelnose, and mixed species groups during low velocity (LV) and high velocity (HV) trials.

20). Figure 21 shows the distribution of substrate within the flume, and the location of juvenile pallid and shovelnose sturgeon for all trials.

Water depth — For data analysis, water depth was categorized into three groups. Shallow areas, which comprised 25.97% of available habitat, had water depths ranging from 27 to 49 cm; medium areas varied from 50 to 72 cm deep, and comprised 38.60% of available habitat; and deep areas had a water depth of 73 to 93 cm deep, and comprised 35.43% of available habitat (Table 3,

Figure 22). Individual pallids, individual shovelnose, groups of pallids, groups of shovelnose, and mixed species groups did not use water depth in proportion to its availability (P < 0.0001 all cases). All used deep areas significantly more, and medium and shallow areas less than expected based on availability (P < 0.0001 all cases), with the exception of individual shovelnose, in which case the use of medium depth areas was not significantly different than expected (P = 0.164). Furthermore, use of water depth categories by pallids and shovelnose in mixed species groups did not differ significantly for any category (deep, P = 0.299; medium, P = 0.377; shallow P = 0.526) (Tables 3-4, Figures 22-23).

Influence of Velocity on Water Depth Use — Individual pallids (P = 0.000), individual shovelnose (P = 0.0002), and mixed species groups (P = 0.000) all used water depth differently during low velocity and high velocity trials. Individual pallids used deep areas more at high velocity than at low velocity (P < 0.0001), whereas medium (P =< 0.0001) and shallow (P = 0.019) areas are used more at

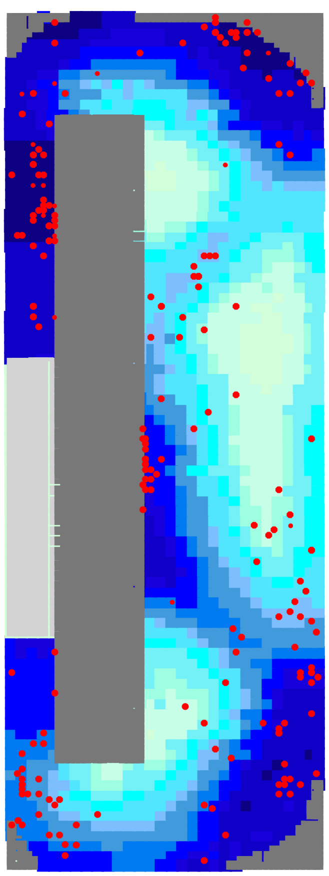

Figure 24. Distribution of water depth habitat within the flume, and location of individual juvenile pallid sturgeon during low velocity trials. Refer to Figure 6 for legend.

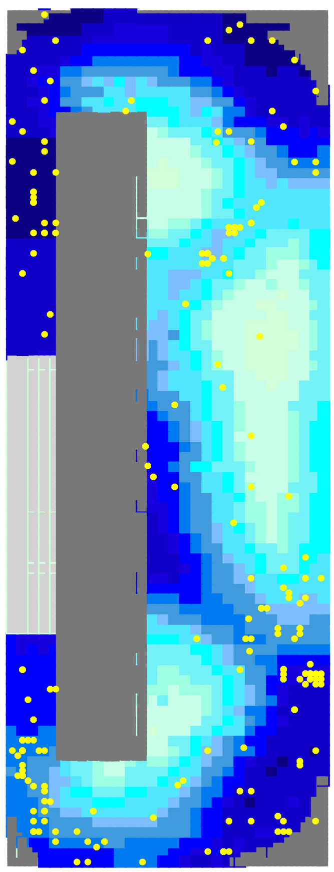

Figure 25. Distribution of water depth habitat within the flume, and location of individual juvenile shovelnose sturgeon during low velocity trials.

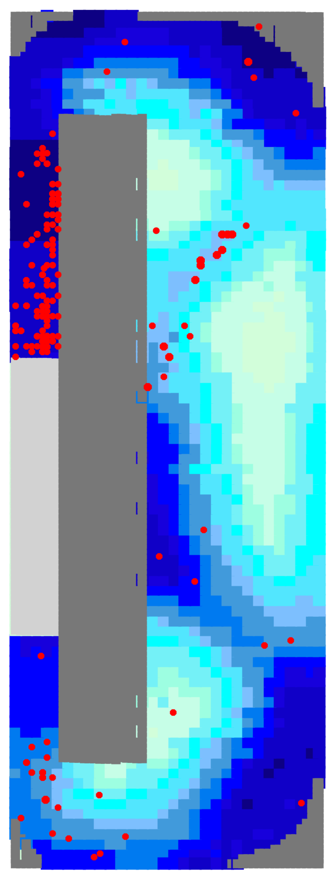

Figure 26. Distribution of water depth habitat within the flume, and location of individual juvenile pallid sturgeon during high velocity trials.

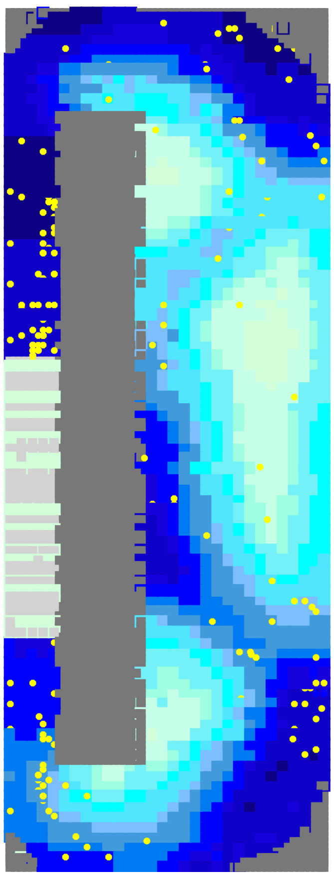

Figure 27. Distribution of water depth habitat within the flume, and location of individual juvenile shovelnose sturgeon during high velocity trials.

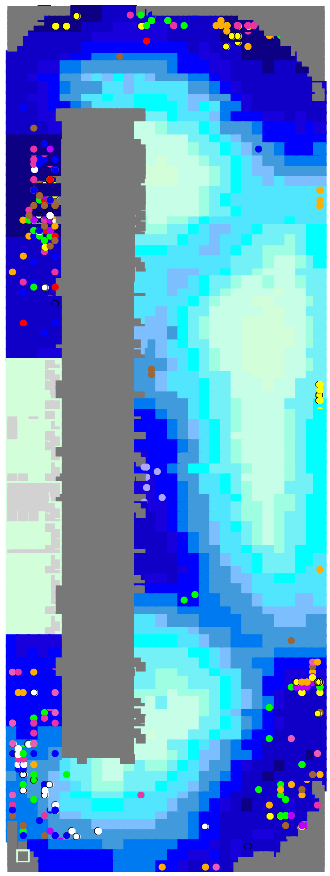

Figure 28. Distribution of water depth habitat within the flume, and location of groups of juvenile pallid sturgeon during low velocity trials.

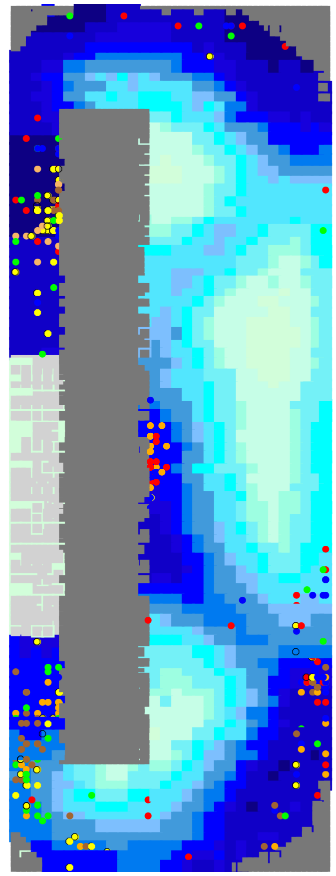

Figure 29. Distribution of water depth habitat within the flume, and location of groups of juvenile shovelnose sturgeon during low velocity trials.

low velocity than high velocity. Individual shovelnose used deep areas significantly more (P = 0.0001), and medium areas significantly less (P = 0.0001) at high velocity than at low velocity. There was no significant difference in the use of shallow areas at low velocity versus high velocity in trials with individual shovelnose (P = 0.978). Use of water depth did not differ during low velocity and high velocity trials for groups of pallids (P = 0.064), with the exception of shallow areas (P = 0.004), which were used to a very small extent during low velocity trials, but not at all during high velocity trials (Deep, P = 0.087; Medium P = 0.339). The trend in use of water depth category by groups of shovelnose remains the same at low velocity and high velocity. However, deeper areas are used even more at high velocity than low velocity (P <0.0001), while medium (P = 0.0002) and shallow (P = 0.009) areas are used less. At low velocity, deep areas were used more (P = 0.0001), while at high velocity medium depth areas were

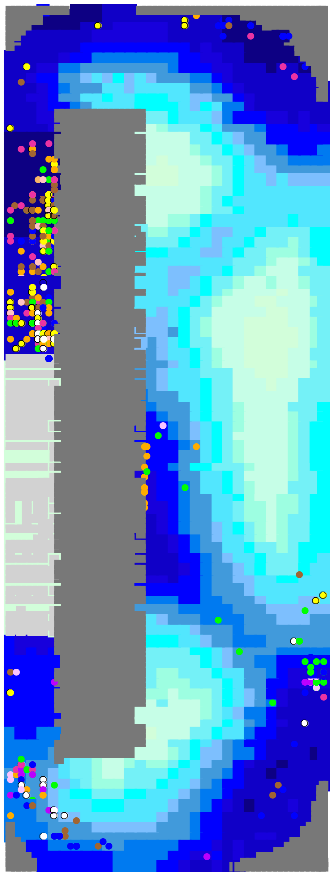

Figure 30. Distribution of water depth habitat within the flume, and location of groups of juvenile pallid sturgeon during high velocity trials.

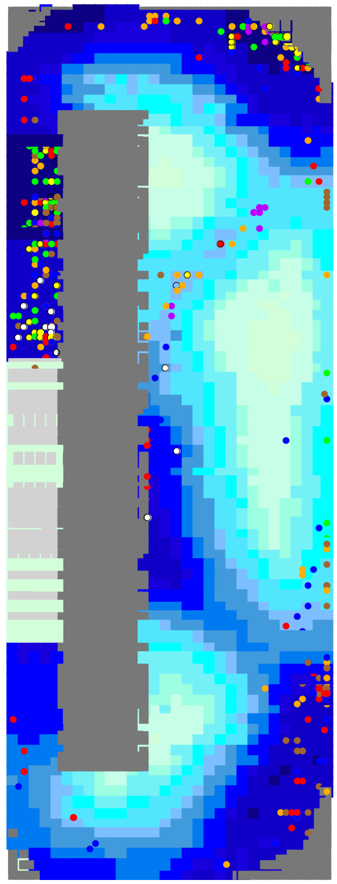

Figure 31. Distribution of water depth habitat within the flume, and location of groups of juvenile shovelnose sturgeon during high velocity trials.

used more (P < 0.0001). There was no significant difference in the use of shallow areas in relation to velocity (P = 0.823) (Tables 3-4, Figures 22-34).

Species Comparisons and Use of Water Depth —

Individual Pallids and Individual Shovelnose — Individual pallids and individual shovelnose differed in their use of water depth at low velocity (P = 0.013). Pallids used deep areas more than shovelnose at low velocity (P = 0.006), while shovelnose used medium depth areas more than pallids at low velocity (P = 0.003). Use of shallow areas (P = 0.584) at low velocity did not differ significantly between individual pallids and individual shovelnose (Table 3, Figures 22, 24-25).

Individual pallids and individual shovelnose differed in their use of water depth at high velocity (P = 0.0008). Pallids used deep areas more than shovelnose at high velocity (P = 0.0008), while shovelnose used medium depth areas more than pallids at high velocity (P = 0.004). Use of shallow areas (P = 0.095) at high velocity did not differ significantly between individual pallids and individual shovelnose (Table 3, Figures 22, 26-27).

Individual Pallids and Groups of Pallids — Individual pallids and groups of pallids differed in their use of water depth at low velocity (P = 0.0001). Groups of pallids used deep areas more than individuals (P =0.0001), while individuals used medium areas more (P = 0.0004). Use of shallow areas during low velocity trials was not significantly different between individuals and groups of pallids (P =

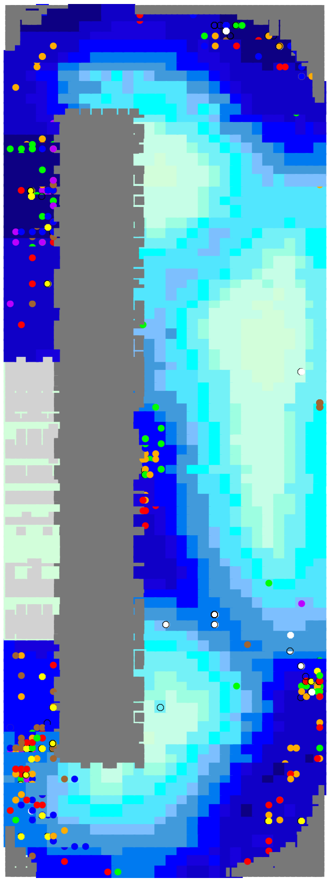

Figure 32. Distribution of water depth habitat within the flume, and location of mixed groups of juvenile pallid and shovelnose sturgeon during low velocity trials. Refer to Figure 2 for legend.

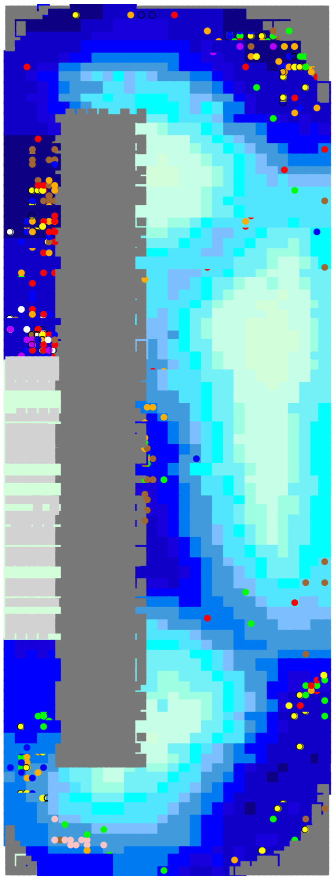

Figure 33. Distribution of water depth habitat within the flume, and location of mixed groups of juvenile pallid and shovelnose sturgeon during high velocity trials. Refer to Figure 2 for leg-

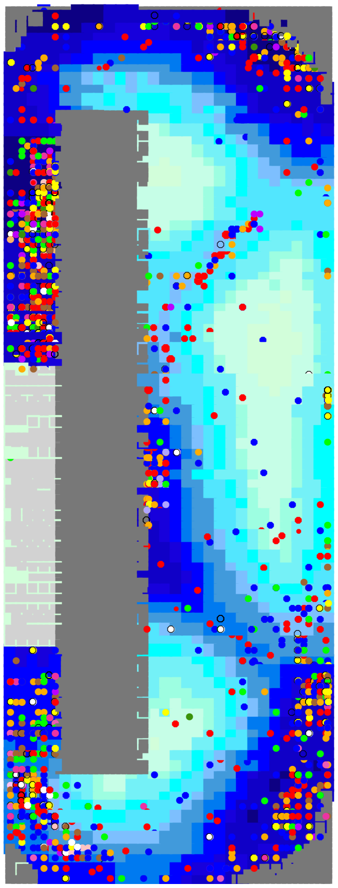

Figure 34. Distribution of water depth within the flume, and location of juvenile pallid and shovelnose sturgeon (all trials). Refer to Figure 2 for legend.

0.247) (Tables 3-4, Figures 22-24, 28).

During high velocity trials, individual pallids and groups of pallids did not differ significantly in their use of shallow water (P = 0.690), medium-depth water (P = 0.416), or deep water (P = 0.519). Thus, there was no significant difference in use of water depth between individual pallids and groups of pallids during high velocity trials overall (P = 0.534) (Tables 3-4, Figures 22-23, 26, 30).

Individual Shovelnose and Groups of Shovelnose — Individual shovelnose and groups of shovelnose differ in their use of water depth at low velocity (P = 0.0000). Groups of shovelnose (P <0.0001) used deep areas more than individuals, while individuals used medium areas more (P <0.0001). Use of shallow areas during low velocity trials were not significantly different between individuals and groups of shovelnose (P = 0.860) (Tables 3-4, Figures 22-23, 25, 29).

Table 5. Percent light availability and use by individual pallid and individual shovelnose sturgeon.

	Very Light (374-510 lux)				Light (274-373 lux)				Dark (157-273 lux)				Very Dark (14-156 lux)			
	Avail-able	Use			Avail-able	Use			Avail-able	Use			Avail-able	Use		
		All	LV	HV		All	LV	HV		All	LV	HV		All	LV	HV
Pallids	17.79	2.28	4.04	0.51	31.74	9.90	15.66	4.08	29.72	25.63	37.88	13.27	20.75	62.18	42.42	82.14
Shovel nose		4.01	6.82	1.16		15.19	20.45	9.83		37.82	36.93	38.73		42.98	35.80	50.29

LV – Low velocity, HV – high velocity

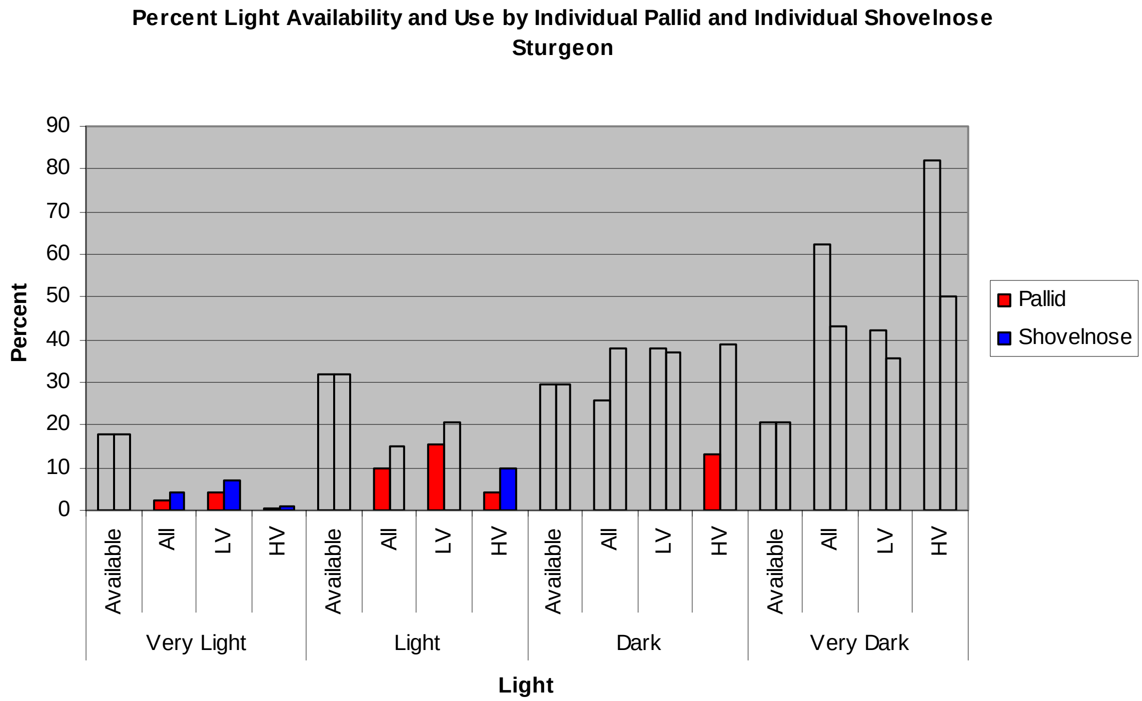

Figure 35. Percent of light availability and use by individual pallid and shovelnose sturgeon during low velocity (LV) and high velocity (HV) trials.

Individual shovelnose and groups of shovelnose differ in their use of water depth at high velocity (P = 0.004). Groups of shovelnose (P = 0.005) used deep areas more than individuals, while individuals used medium areas more (P < 0.02). Use of shallow areas during high velocity trials were not significantly different between individuals and groups of shovelnose (P = 0.087) (Tables 3-4, Figures 22-23, 27, 31).

Groups of Pallids and Groups of Shovelnose — Groups of pallids and groups of shovelnose

Table 6. Light availability and use by groups of pallid, groups of shovelnose, and mixed-species sturgeon groups.

	Very Light (374-510 lux)				**Light (274-373 lux)**				**Dark (157-273 lux)**				**Very Dark (14-156 lux)**			
	Avail-able	Use			Avail-able	Use			Avail-able	Use			Avail-able	Use		
		All	LV	HV		All	LV	HV		All	LV	HV		All	LV	HV
Pallids	17.79	0.00	0.00	0.00	31.74	3.34	3.81	2.75	29.72	26.47	30.06	22.00	20.75	70.19	66.13	75.25
Shovel		1.39	0.98	1.71		8.89	11.25	7.05		40.36	42.79	38.48		49.36	44.99	52.76
Mixed		0.44	0.56	0.23		4.01	4.23	3.65		29.29	30.04	28.08		66.26	65.16	68.08

LV – Low velocity, HV – high velocity

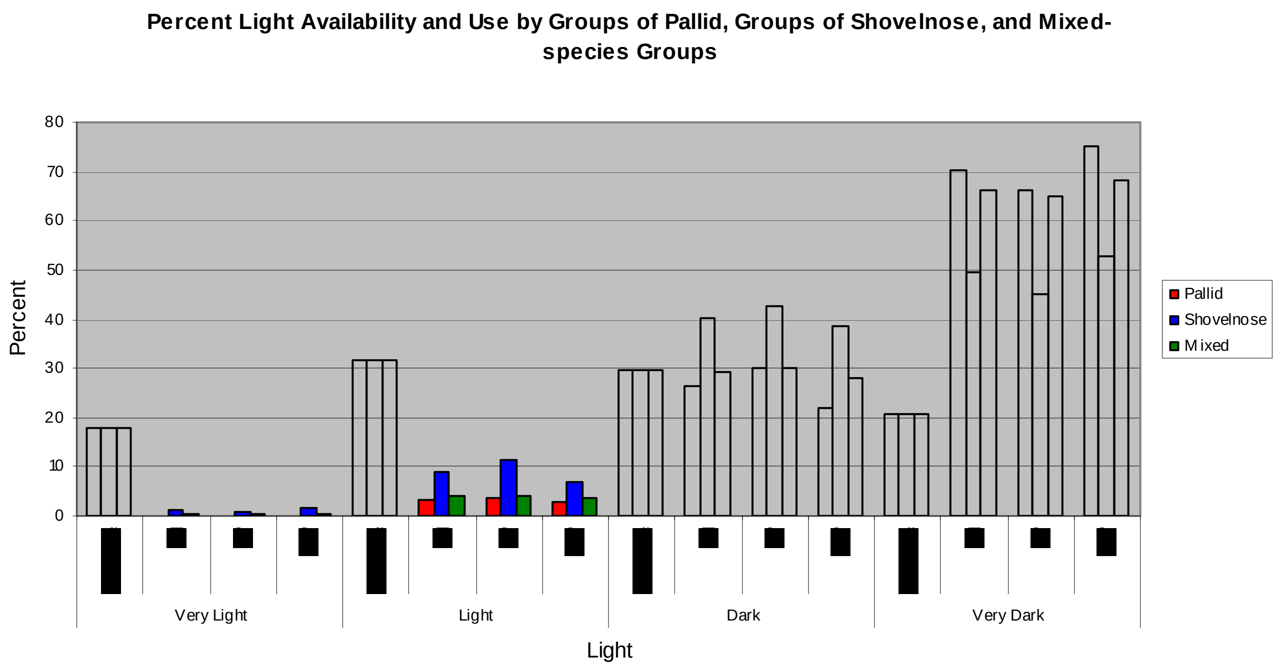

Figure 36. Percent of light availability and use by groups of pallids, groups of shovelnose, and mixed species groups during low velocity (LV) and high velocity (HV) trials.

differed in their use of water depth at low velocity (P = 0.0005). Groups of pallids used deep (P = 0.0004) areas significantly more than groups of shovelnose, and used medium depth (P = 0.001) areas significantly less than shovelnose. There was no significant difference in the use of shallow areas between the two groups at low velocity (P = 0.185) (Table 4, Figures 23, 28-29).

Groups of pallids and groups of shovelnose did not differ in their use of water depth at high velocity (P = 0.358; Deep, P = 0.397; Medium, P = 0.641; Shallow, P = 0.053) (Table 4, Figures 23, 30-31).

Pallids and Shovelnose in Mixed Groups — Pallids and shovelnose in mixed groups did not differ in their use of water depth at low velocity (P = 0.817). (Deep, P = 0.798; medium, P = 0.862; shallow, P = 0.581) (Table 4, Figures 23, 32).

Pallids and shovelnose in mixed groups did not differ in their use of water depth at high velocity (P = 0.694). (Deep, P = 0.058; medium, P = 0.845; shallow, P = 0.397) (Table 4, Figures 23, 33).

Figure 34 shows the distribution of water depth within the flume, and the location of juvenile pallid and shovelnose sturgeon for all trials.

Light — For purposes of statistical analysis, light levels were categorized into four groups (Figure 3). Very light areas ranged from 374-510 lux (17.8%); light areas varied from 274-373 lux (31.74%), dark areas varied from 157-273 lux (29.7%), and very dark areas extended from 14-156 lux (20.8%). Individual pallids, individual shovelnose, groups of pallids, groups of shovelnose, and mixed

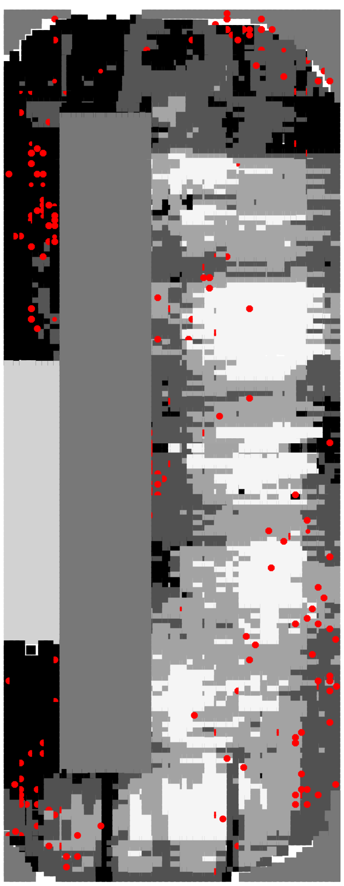

Figure 37. Distribution of light levels within the flume, and location of individual juvenile pallid sturgeon during low velocity trials. Refer to Figure 3 for legend.

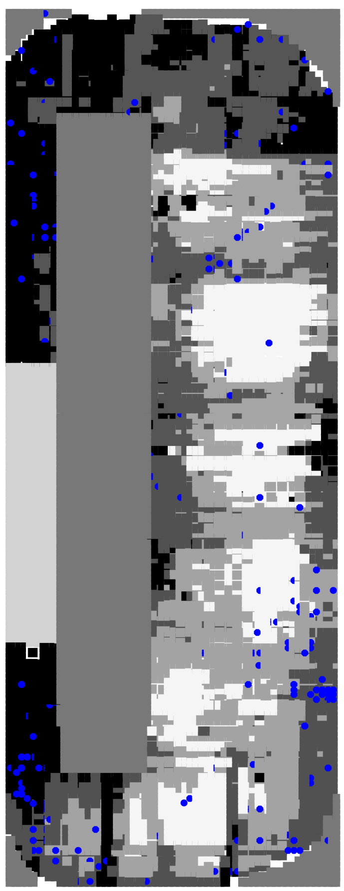

Figure 38. Distribution of light level categories within the flume, and location of individual juvenile shovelnose sturgeon during low velocity trials. Refer to Figure 3 for legend.

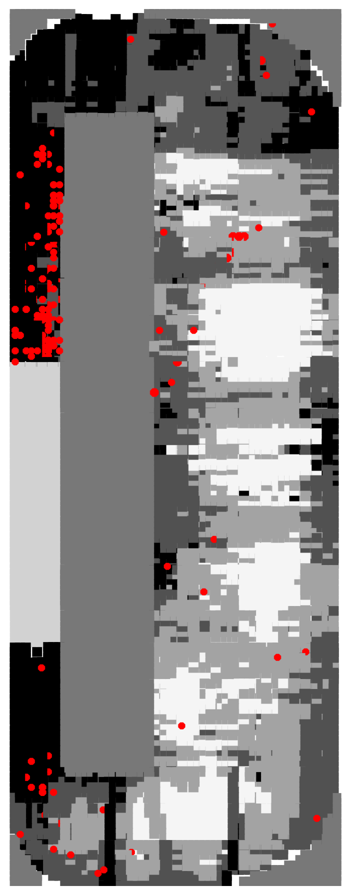

Figure 39. Distribution of light level categories within the flume, and location of individual juvenile pallid sturgeon during high velocity trials. Refer to Figure 3 for legend.

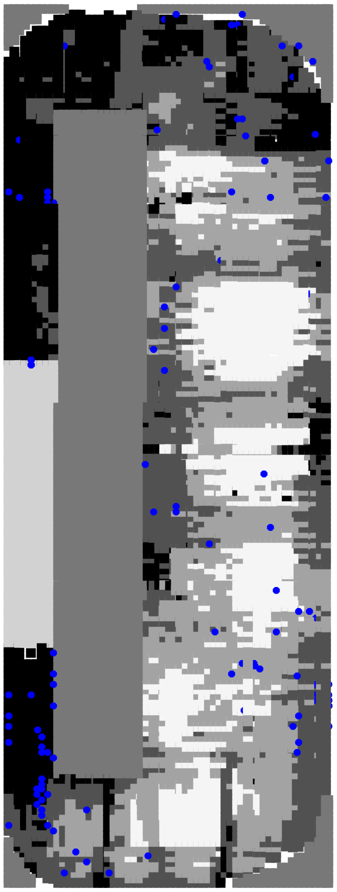

Figure 40. Distribution of light level categories within the flume, and location of individual juvenile shove1ose sturgeon during high velocity trials. Refer to Figure 3 for legend.

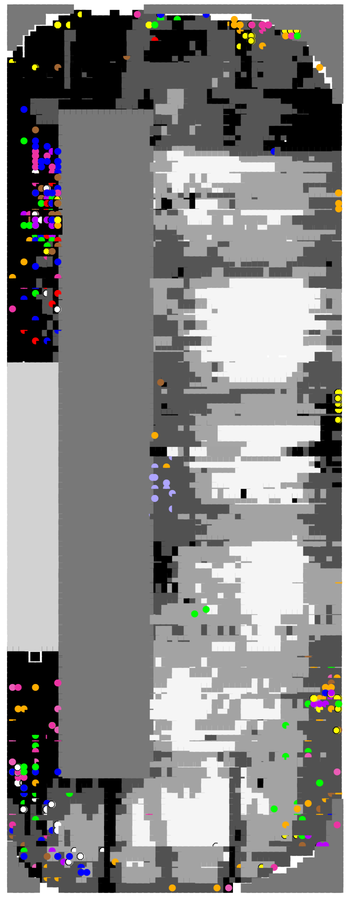

Figure 41. Distribution of light level categories within the flume, and location of groups of juvenile pallid sturgeon during low velocity trials. Refer to Figure 3 for legend.

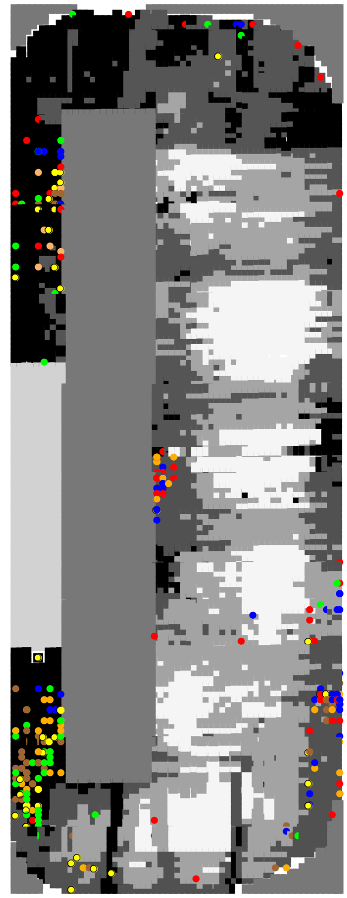

Figure 42. Distribution of light level categories within the flume, and location of groups of juvenile shovelnose sturgeon during low velocity trials. Refer to Figure 3 for legend.

species groups did not use light in proportion to its availability ($P < 0.0001$ all cases). All used very dark areas significantly more than expected based on availability ($P < 0.0001$ all cases). Use of dark areas by individual shovelnose ($P = 0.001$), groups of pallids ($P = 0.045$), and groups of shovelnose ($P < 0.0001$) was significantly more than expected based on availability. Proportional availability and use of dark areas did not differ significantly in individual pallids ($P = 0.084$) and mixed species groups ($P = 0.771$). All used light areas significantly less than expected ($P < 0.0001$ all cases). Additionally, individual shovelnose ($P < 0.0001$), groups of pallids ($P < 0.0001$), and mixed species groups ($P < 0.0001$) all used very light areas significantly less than expected ($P < 0.0001$ all cases). Use of very light areas by individual pallids ($P = 0.503$), and groups of shovelnose ($P = 0.355$) did not differ significantly from availability (Tables 5-6, Figures 35-36).

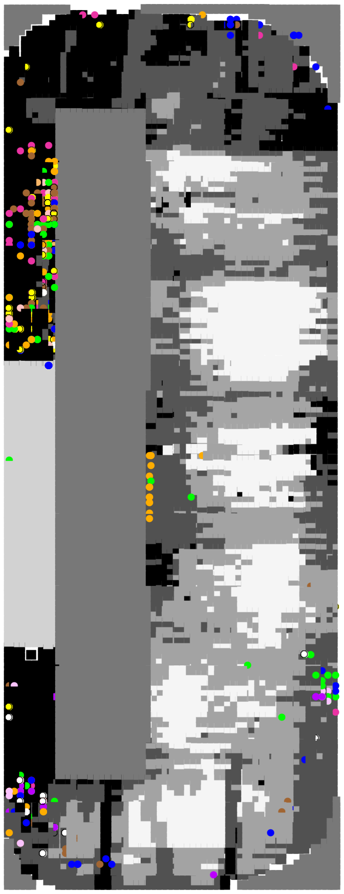

Figure 43. Distribution of light level categories within the flume, and location of groups of juvenile pallid sturgeon during high velocity trials. Refer to Figure 3 for legend.

Figure 44. Distribution of light level categories within the flume, and location of groups of juvenile shovelnose sturgeon during high velocity trials. Refer to Figure 3 for legend.

Influence of Velocity on Light Use — Light level is used differently at low velocity and high velocity by individual pallids (P = 0.0000), individual shovelnose (P = 0.0001), groups of pallids (P = 0.004), and groups of shovelnose (P = 0.012). In individual pallids, very dark areas were used significantly more during high velocity trials (P < 0.0001), while dark (P < 0.0001), light (P = 0.0001), and very light (P = 0.019) were used significantly more during low than high velocity trials. Individual shovelnose used very dark areas significantly more during high velocity trials (P = 0.006), while light (P = 0.006), and very light (P = 0.007) areas were used significantly more during low velocity trials than high velocity trials. There was no significant difference in the use of dark areas (P = 0.729) during low velocity versus high velocity trials of individual shovelnose sturgeon. Very dark areas were used significantly more by groups of pallids during high velocity than low velocity trials (P = 0.003), and dark areas were used significantly more during low velocity than high velocity trials (P = 0.007). Use of light and very light areas did not differ among low velocity and high velocity trials. In groups of shovelnose, use of very dark areas increases at high velocity (P = 0.018), while use of light areas decreases (P = 0.025). There is no significant difference in the use of dark (P = 0.183) or very light (P = 0.364) areas at low velocity and high velocity. Mixed species groups did not use light differently at low

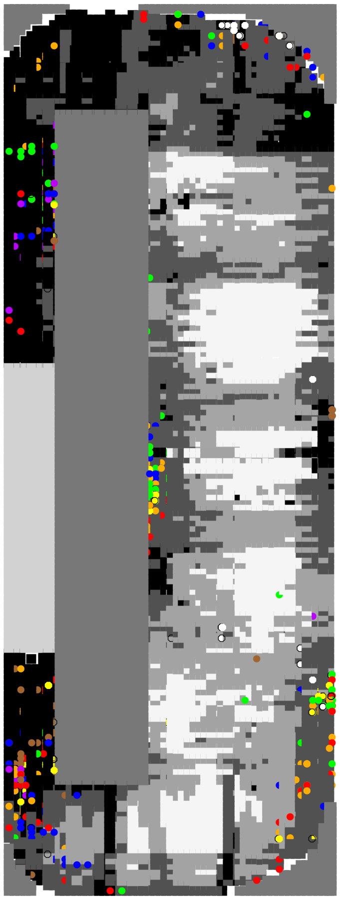

Figure 45. Distribution of light level categories within the flume, and location of mixed groups of juvenile pallid and shovelnose sturgeon during low velocity trials. Refer to Figure 3 for legend.

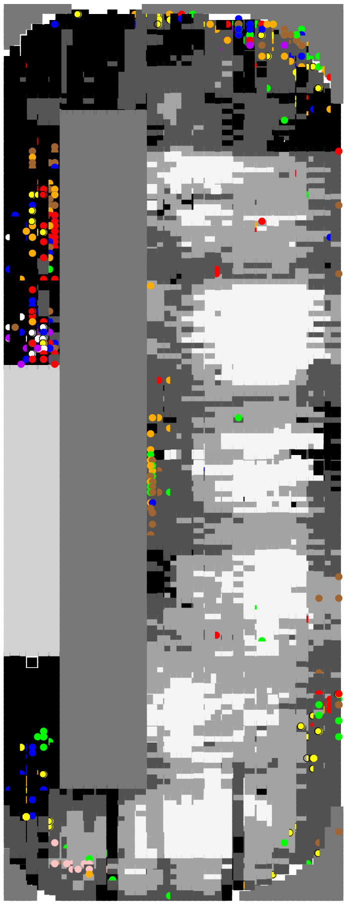

Figure 46. Distribution of light level categories within the flume, and location of mixed groups of juvenile pallid and shovelnose sturgeon during high velocity trials. Refer to Figure 3 for legend.

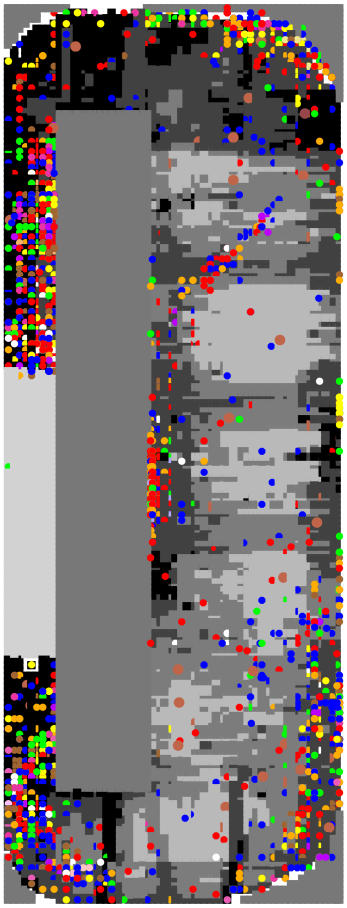

Figure 47. Distribution of light level categories within the flume, and location of juvenile pallid and shovelnose sturgeon (all trials). Refer to figure 3 for legend.

velocity and high velocity (P = 0.289). (Very dark, P = 0.317; dark, P = 0.4789, light, P = 0.628; very light, P = 0.475) (Tables, 5-6, Figures 35-47).

Species Comparisons and Use of Light —

Individual Pallids and Individual Shovelnose — Use of light levels did not differ significantly between individual pallids and individual shovelnose during low velocity trials (P = 0.077; very dark, P = 0.190; dark, P = 0.850; light, P = 0.227; very dark, P = 0.233). Both species used very dark and dark areas more than light and very light areas (Table 5, Figures 35, 37-38).

Individual pallids and individual shovelnose differed in their use of light at high velocity (P = 0.0000). Pallids used very dark (P <0.0001) areas significantly more than shovelnose, while shovelnose used dark (P <0.0001) and light (P = 0.031) areas significantly more than pallids during high velocity trials. There was no significant difference in the use of very light areas during HV trials of individuals (P = 0.612) (Table 5, Figures 35, 39-40).

Individual Pallids and Groups of Pallids — Individual pallids and groups of pallids differed in their use of light at low velocity (P = 0.0000). Single pallids used very dark (P < 0.0001) areas less; and dark (P = 0.047), light (P < 0.0001), and very light (P < 0.0001) areas more than groups of pallids (Tables 5-6, Figures 35-36, 37, 41).

Overall, individual pallids and groups of pallids did not differ significantly in their use of light at high velocity (P = 0.090). However, groups of pallids did use dark (P = 0.011) areas significantly more than single pallids. Use of very dark (P = 0.059), light (P = 0.415), and very light (P = 0.298) did not differ significantly (Tables 5-6, Figures 35-36, 39, 43).

Individual Shovelnose and Groups of Shovelnose — Individual shovelnose and groups of shovelnose differ in their use of light at low velocity (P = 0.0007). Groups of shovelnose (P < 0.039) used very dark areas more than individuals, while individuals used light (P = 0.003) and very light (P = 0.0002) areas more. Use of dark areas during low velocity trials were not significantly different between individuals and groups of shovelnose (P = 0.187) (Tables 5-6, Figures 35-36, 38, 42).

Individual shovelnose and groups of shovelnose did not differ in their use of light at high velocity (P = 0.487). Very dark (P = 0.572), dark (P = 0.953), light (P = 0.235), very light (P = 0.952) (Tables 5-6, Figures 35-36, 40, 44).

Groups of Pallids and Groups of Shovelnose — Groups of pallids and groups of shovelnose differed in their use of light at low velocity (P = 0.0000). Pallids used very dark areas (P < 0.0001) more than shovelnose, but used dark (P < 0.0001), light (P < 0.0001), and very light (P = 0.030) areas significantly less (Table 6, Figures 36, 41-42).

Groups of pallids and groups of shovelnose differ in their use of light at high velocity (P = 0.0000). Pallids used very dark areas (P < 0.0001) more than shovelnose, but used dark (P < 0.0001), light (P = 0.004), and very light (P = 0.007) areas less (Table 6, Figures 36, 43-44).

Pallids and Shovelnose in Mixed Groups — Overall, pallids and shovelnose in mixed groups did not differ in their use of light at low velocity (P = 0.955). When light categories were examined individually, the only category in which use differed significantly between pallids and shovelnose at low velocity was light (P = 0.016), which was used more by shovelnose than pallids. There was no significant difference in the use of very dark (P = 0.726), dark (P = 0.219), or very light (P = 0.272) categories (Table 6, Figures 36, 45).

Pallids and shovelnose in mixed groups differed in their use of light at high velocity (P = 0.027). Shovelnose used dark areas more than pallids at high velocity (P = 0.006). Use of the other categories of light did not differ significantly between species in mixed groups (Very dark, P = 0.170; light, P = 0.425; very light, P = 0.700) (Table 6, Figure 36, 46). Figure 47 shows the distribution of light levels in the flume and the location of juvenile pallid and shovelnose sturgeon for all trials.

Fish Size— Fish size was not found to significantly influence selection of substrate, water depth, or light levels.

Discussion

Results indicated that juvenile pallid and shovelnose sturgeon exhibited obvious partiality in habitat selection. Habitat selection takes into account the availability of the habitat and then compares availability with the amount of use each habitat receives. Habitats that are selected against (used significantly less than expected based on availability) may represent areas that are undesired,

Table 7. Summary of overall habitat selection by juvenile pallid and shovelnose sturgeon.

Habitat	Velocity	Individual Pallids	Individual Shovelnose	Group Pallids	Group Shovelnose	Mixed Group
Sand	All	+	+	+	+	+
Gravel	All	-	-	-	-	-
Sand/Gravel	All	=	=	+	+	+
Woody Structure	All	=	=	-	-	-
Shallow	All	-	-	-	-	-
Medium	All	-	=	-	-	-
Deep	All	+	+	+	+	+
Very light	All	-	-	-	-	-
Light	All	-	-	-	-	-
Dark	All	=	+	+	+	=
Very dark	All	+	+	+	+	+

+ Habitat selected for; - Habitat selected against; = No selection preference unavailable, or simply used less frequently. Habitats that are selected for (used significantly more than expected based on availability) may represent areas preferred by or important to pallid or shovelnose sturgeon. The significant difference between the patterns of availability and usage implies that the distributions were in all probability due to deliberate selection by pallids and shovelnose rather than due to random starting position or water circulation patterns in the flume.

Overall, selection for sandy, deep, very dark or dark habitat was found for individuals and groups of both species (Table 7). Not surprisingly, this corresponds to the habitat where pallid and shovelnose sturgeon are found most often in natural settings (Bramblett 1996, Hurley et al., 2004). Pallid and shovelnose sturgeon are not generally found in lake or backwater areas (Curtis 1990, Erickson 1992), and sand is the predominant substrate in the middle Mississippi River. In all cases, sand was used more by pallids than by shovelnose, while shovelnose used gravel more than pallids. This supports the long held view that pallids prefer finer substrates than shovelnose sturgeon (Bramblett 1996). However, neither species used gravel in a proportion greater than its availability. The selection against gravel may be due to a preference for the finer substrate, or an aversion to some other feature of the gravel. However, if the gravel was objectionable for some reason other than its size, it is expected that the sturgeon would not have selected for the sand/gravel mixture (Tables 1-2, Figures 9-10). Additionally, in these trials, we frequently observed sturgeon on sand substrate resting against an adjacent gravel area of higher relief. Unfortunately, this was not a documented habitat type in our study, and its possible importance only became apparent after repeated observations during the course of our investigation. This habitat, which has an abrupt change in relief, may correlate to troughs present on sand flats in the Mississippi River where juvenile pallid and shovelnose were recently collected (Adams et al. 2003).

Surprisingly, woody structure was not selected for by individuals or groups of either species. It was used randomly by pallid and shovelnose individuals, and selected against by all groups. Association with cover has been noted to be important for other fish species for a variety of potential reasons including forage fish attraction, predation advantage, protection from predation, (Bevelhimer 1996), and in providing refuge from strong currents. While sturgeon in this experiment were not exposed to predators or prey, one would expect them to utilize the structures as advantageous positions nevertheless. However, because these individuals were hatchery reared, they may not have become skilled at predation or predator avoidance behaviors. Additionally, it is possible that the woody structure did not provide velocity breaks as anticipated, or that velocity levels within the flume were not high enough to cause the sturgeon to seek such refuge. Furthermore, some aspect of the wood itself may have been objectionable, although we did not test this.

Sturgeon were rarely observed to rest in shallow water areas of the flume. Quite frequently they were found in the deepest portions, which would correspond to the main channel thalweg in rivers. Pallids used the deep areas more than the shovelnose, while the shovelnose used the medium areas more. This supports some field studies which found that adult pallid sturgeon occupy faster currents and are more abundant in swift, channel habitats than shovelnose sturgeon (Forbes and Richardson 1905, Carlson et al. 1985). However, the interpretation of adult and juvenile pallid and shovelnose sturgeon capture data in the field can be hindered by uncertainty in identification, and problems associated with measuring the focal point velocity in large turbid rivers (Adams et al. 2003). Additionally, adults of both species are also known to use relatively low velocity areas associated with dike fields, sand bars, and islands (Carlson et al. 1985, Hurley et al. 1987, 1999, Bramblett 1996, Curtis et al. 1997, Adams et al. 2003). Recent collections of juvenile pallid and shovelnose sturgeon have occurred in main channel border areas where velocities ranged from 20 to 80 cm/s and sand troughs were usually present (Adams et al. 2003). According to Adams et al. (1999), juvenile pallid sturgeon have the capability of occupying habitat that contains water velocities ranging from 15-30 cm/sec for extended periods depending on body size. Thus, juveniles may have the ability to use the main channel thalweg under certain conditions. Furthermore, sand troughs have also been suggested as velocity shelters for sturgeons and other benthic fishes present in the main channel of large rivers (Baker et al. 1991, Adams et al. 1999).

Sturgeon selected for dark and very dark areas, and either selected against or showed random distribution patterns for light and very light areas (Tables 5-6, Figures 35-36). This pattern of distribution is likely correlated with the fact that the deepest areas of the flume were often the darkest. Pallids used the very dark areas more than the shovelnose, while the shovelnose used the dark, light, and very light areas more than pallids. However, approximately nine areas within the flume categorized as very dark were not used frequently (Figure 47). Four of these areas contained woody structure, and the others contained gravel or sand/gravel mixture (Figures 3, 6). Both woody structure and gravel were either selected against or used randomly (Table 7), and their occurrence in these areas apparently overshadowed the appeal of very dark habitat.

In group trials, individuals often clustered in groups of two or three. In mixed species groups, this clustering did not appear to be species-related. We did not attempt to document this behavior in this experiment, therefore further investigation would be necessary to determine its relevance.

This study is the first investigation of juvenile pallid and shovelnose sturgeon habitat selection in a small-scale artificial stream system. Future studies which tease apart the influence of light and water depth, and studies which include the effects of predation, competition, foraging, temperature, and turbidity are encouraged. Additionally, field studies of micro– and macro-habitat selection by juvenile pallid and shovelnose sturgeon should be carried out to substantiate the results of this study, as well as to identify critical habitat for recovery and management of sturgeon species. The habitat conditions selected by juvenile sturgeon in this study: deep, dark, sandy areas, are not in short supply in the Missouri and Mississippi river systems, yet the sturgeon are. It is likely that the unique features of large river habitats in concert with sturgeon life history characteristics require that researchers use a much broader definition of habitat than is typically applied to fishes when alternatives for habitat restoration are considered (Beamsderfer and Farr 1997). Fish habitats are frequently defined in terms of site-specific conditions including water depth, velocity, temperature, substrate, and cover. However, proper management of sturgeon species likely requires that their habitat be defined in terms of system-wide conditions. Thus, river system modifications that provide sturgeon with access to a broad range of habitat conditions over time, including system-wide habitat diversity; natural variation in flow, velocity, temperature, and turbidity; high water quality; a broad prey base; and free-flowing sections which provide suitable spawning and rearing sites should be encouraged (Beamsderfer and Farr 1997).

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References

Adams, S.R., G.L. Adams, and G.R. Parsons. 2003. Critical swimming speed and behavior of juvenile shovelnose sturgeon and pallid sturgeon. Transactions of the American Fisheries Society 132: 392-397.

Adams, S.R.. J.J. Hoover, and K.J. Killgore. 1999. Swimming endurance of juvenile pallids sturgeon, *Scaphirhynchus albus*. Copeia. 1999(3): 802-807.

Baker, J.A, K.J. Killgore, and R.L. Kasul. 1991. Aquatic habitats and fish communities in the lower Mississippi River. Reviews in Aquatic Sciences 3:313-356.

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

Beamesderfer, R.C.P., and R.A. Farr. 1997. Alternatives for the protection and restoration of sturgeon and their habitat. Environmental Biology of Fishes 48:407-417.

Bevelhimer, M.S. 1996. Relative importance of temperature, food, and physical structure to habitat choice by smallmouth bass in laboratory experiments. Transactions of the American Fisheries Society 125:274-283.

Bramblett, R.G. 1996. Habitats and Movements of Pallid and Shovelnose Sturgeon in the Yellowstone and Missouri Rivers, Montana and North Dakota. Ph.D. Dissertation, Montana State University, Bozeman, Montana.

Bramblett, R.G., and R.G. White. 2001. Habitat use and movement of pallid and shovelnose sturgeon in the Yellowstone and Missouri rivers in Montana and North Dakota. Transactions of the American Fisheries Society 130: 1006-1025.

Carlson, D.M. W.L. Pflieger, L. Trial, and P.S. Haverland. 1985. Distribution, biology, and hybridization of *Scaphirhynchus albus* and *S. platorhynchus* in the Missouri and Mississippi Rivers. Environmental Biology of Fishes 14:51-59.

Chan, M.D., E.D. Dibble, and K.J. Kilgore. 1997. A laboratory examination of water velocity and substrate preference of age-0 gulf sturgeon. Transactions of the American Fisheries Society 126:330-333.

Clancey, P. 1991. Paddlefish and pallid sturgeon spawning habitat study in the area of the Altamont gas transmission company's proposed pipeline crossing of the wild and scenic Missouri River. Montana Department of Fish Wildlife and Parks.

Curtis, G.L. 1990. Habitat use by shovelnose sturgeon in Pool 13, upper Mississippi River, Iowa Master's thesis. Iowa State University, Ames.

Curtis, G.L., J.S. Ramsey, and D.L. Scarnecchia. 1997. Habitat use and movements of shovelnose sturgeon in pool 13 of the upper Mississippi River during extreme low flow conditions. Environmental Biology of Fishes 50:175-182.

Dryer, M.P., and A.J. Sandoval. 1993. Recovery Plan for the Pallid Sturgeon (*Scaphirhynchus albus*). USFWS, Bismarck, ND.

Erickson, J.D. 1992. Habitat selection and movement of pallid sturgeon in Lake Sharpe, South Dakota. Master's thesis. South Dakota State University, Brookings.

Forbes, S.A., and R.E. Richardson. 1905. On a new shovelnose sturgeon from the Mississippi River. State Laboratory of Natural History Bulletin 7(4):37-44.

Gilbraith, D.M., et al. 1988. Preliminary Report on the Pallid Sturgeon, *Scaphirhynchus albus*, a candidate endangered species. Brookings, SD: Cooperative Fish and Wildlife Research Unit, USFWS and Department of Wildlife and Fisheries Sciences, South Dakota State University.

Hurley, K.L. 1999. Habitat Use, Selection, and Movement of Middle Mississippi River Pallid Sturgeon and Validity of Pallid Sturgeon Age Estimates from Pectoral Fin Rays. M.S. Thesis. Southern Illinois University, Carbondale.

Hurley, S.T., W.A. Hubert, and J.G. Nickum. 1987. Habitat and movements of shovelnose sturgeon in the upper Mississippi River. Transactions of the American Fisheries Society 116:655-662.

Hurley, K.L., R.J. Sheehan, R.C. Heidinger, P.S. Wills, and B. Clevenstine. 2004. Habitat use by middle Mississippi River pallid sturgeon. Transactions of the American Fisheries Society 133:1033-1041.

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

Keenlyne, K.D. 1997. Life history and status of the shovelnose sturgeon, S*caphirhynchus platorynchus*. Environmental Biology of Fishes 48:291-298.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. 1980. Atlas of North American Freshwater Fishes. North Carolina State Museum of Natural history. North Carolina. Biological Survey Publication No. 1980-12:867 pp.

Matheson, R.E., Jr., and G.R. Brooks, Jr. 1983. Habitat segregation between *Cottus bairdi* and *Cottus girardi*: an example of complex inter- and intraspecific resource partitioning. American Midland Naturalist 110:165-176.

National Paddlefish and Sturgeon Steering Committee. 1992. Framework for the Management of Conservation of Paddlefish and Sturgeon Species in the United States. U.S. Fish and Wildlife Service, Washington, D.C. 12 pp. + App.

Parsley, M.J., L.G. Beckman, and G.T. McCabe. 1993. Spawning and rearing habitat use by white sturgeons in the Columbia River downstream from McNary Dam. Transactions of the American Fisheries Society 122:217-227.

Ragotzkie, R.A. 1985. Introduction to a Symposium on the Biology and Management of Sturgeons. Environmental Biology of Fishes 14:9-10.

U.S. Fish and Wildlife Service. 1998. Endangered Species Facts**,** Pallid Sturgeon (*Scaphirhynchus albus*). http://midwest.fws.gov/Endangered/fishes/palld_fc.html.