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A laboratory examination of substrate, water depth, and light use at two water velocity levels by individual juvenile pallid (*Scaphirhynchus albus*) and shovelnose (*Scaphirhynchus platorynchus*) sturgeon

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Summary

We investigated the influence of substrate type, water depth, light, and relative water velocity on microhabitat selection in juvenile pallid (*Scaphirhynchus albus*) and shovelnose (*Scaphirhynchus platorynchus*) sturgeon. Individual sturgeon were placed in an 18 927 L elliptical flume, and their location was recorded after a 2-h period. Data were analyzed using exact chi-square goodness of fit tests and exact tests of independence. Both sturgeon species used substrate, depth, and light in similar proportions. (all comparisons; $P > 0.05$). Specifically, pallid and shovelnose sturgeon did not use substrate in proportion to its availability (pallid: $P = 0.0026$; shovelnose: $P = 0.0199$). Each species used sand substrate more and gravel substrate less than expected based on availability. Additionally, neither species used woody structure. Both species used deep areas in greater proportion than availability while shallow areas were used less than expected based on availability (pallid; $P < 0.0001$; shovelnose; $P = 0.0335$). Pallid and shovelnose sturgeon used very dark areas in greater proportion than expected based on availability; however, very light areas were used in lower proportion than expected ($P < 0.0001$). Overall, neither species changed their use of habitat in relation to a change in water velocity (pallid, all comparisons $P > 0.05$; shovelnose, all comparisons $P > 0.05$). 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. Due to the extensive range, longevity, and migratory behavior of these fishes, proper management 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; free-flowing river sections which provide suitable spawning and rearing sites, as well as protection from recreational and commercial harvesting.

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). Forbes and Richardson (1905) and Bailey and Cross (1954) suggest that pallid sturgeon were never common. However, pallid sturgeon are currently scarce in many areas where they historically occurred (Bailey and Cross, 1954; National Paddlefish and Sturgeon Steering Committee (NPSSC), 1992; U.S. Fish and Wildlife Service, 1998). Shovelnose sturgeon (*Scaphirhynchus platorynchus*) 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 middle 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 present (Hrabik pers. comm.; C. Wrasse pers. comm.).

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 on 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 also 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, we conducted a laboratory study to investigate the influence of substrate type, water depth, light, and relative water velocity on the habitat selection of individual juvenile pallid and shovelnose sturgeon. Group interactions were not evaluated in this study as both intra- and inter-specific dynamics may influence the selection of habitat (Matheson and Brooks, 1983).

Protection of endangered species and their associated sibling 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.

Materials and methods

An approximate 18 927 L elliptical flume (285 cm by 835 cm) was used to quantify the distribution of individual juvenile pallid and shovelnose sturgeon in relation to substrate type, water depth, and light at two water velocity levels. 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. Four bundles of driftwood obtained from the bank of the Mississippi River were also placed in the flume over sand (deep and shallow) and gravel (deep and shallow). Water filtration and low velocity (LV) circulation was accomplished using a 254 liter per minute (Lpm) wet/dry Green Machine mechanical and biological canister filter (GM6000; http://www.pondsuppliesrus.com) supplied with an in-line 1/8 horse power (hp) PerformancePro Artesian pump (A1/8-35; http://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) was placed in a partitioned off section of the flume in order to increase flow during high velocity (HV) trials. A reference grid consisting of a 10 cm XYZ coordinate system was established by a simple surveying method and marked on the flume frame in order to establish fish locations. Bathymetry was plotted by placing the surveying rod on the surface of flume bed at set intervals and recording the water depth readings. Bathymetry measurements were taken before the trials began, as bed conditions were not changed during this experiment. 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, light measurements were categorized into four levels based on natural breaks in the data (ArcView GIS 3.3, ESRI, CA, USA). Water velocity ranged from 0 to 33 cm s^{-1}, and was measured as a quantitative variable using a SonTek/YSI FlowTracker handheld acoustic Doppler velocity meter (SonTek/YSI Inc., CA, USA). For analytical purposes, water velocity measurements were categorized into two levels. During the LV trials, the sump pump was off, and minimal flow was provided by the filtration system only. During HV studies, the sump pump was turned on in addition to the filtration system pump.

Juvenile pallid sturgeon were obtained from Garrison Dam National Fish Hatchery, Riverdale, North Dakota on 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 partitioned Plexiglas aquariums filled with dechlorinated tap water. Fish used in trials ranged in size from 27 to 200 mm total length (TL; not including filament). Average fish TL during trials was 133 mm. Water circulated through the aquariums was obtained from the flume. Thus, water conditions in the aquariums and the flume were nearly identical. Water quality was tested once per week, and maintained as follows: water temperature 21–22°C, dissolved oxygen > 6.0 mg L^{-1}, pH 7.0, nitrite < 0.2 mg L^{-1}, and ammonia < 0.0125 mg L^{-1}. In order to determine the substrate type, water depth, light, and relative water velocity inclinations of young pallid and shovelnose sturgeon, 59 (total) replicates of the following experiment were conducted at both low and high velocities using (i) an individual pallid sturgeon (31 trials each); and (ii) an individual shovelnose sturgeon (28 trials each). Trials were conducted from 9 September 2002 to 26 March 2003 between 07.00 and 16.00 hours. New recruits were used for each trial. The fish were marked, placed in the flume (starting location was randomly generated), and allowed to acclimate for 30 min (Chan et al., 1997). Following the acclimation period, the location of each individual was recorded after a 2-h period. Individuals were not disturbed during the sampling period. Data were analyzed using exact chi-square tests of goodness of fit and tests of independence to determine relative use of the associated habitat types to availability. All analyses were carried out using SAS Version 9.1 (SAS Institute Inc., Gary, NC, USA). Significance was determined at $P < 0.05$.

Results

The relative areas of available substrate for all trials were 52.50% sand, 30.03% gravel, 13.51% sand/gravel mixture, and 3.96% woody structure (Fig. 1). Overall, individual pallid and shovelnose sturgeon used substrate in similar proportions during all trials ($\chi^2 = 4.9436$, d.f. = 2, $P = 0.0844$). Substrate was used disproportionate to availability for pallid ($\chi^2 = 15.9982$, d.f. = 3, $P = 0.0026$) and shovelnose sturgeon ($\chi^2 = 10.1142$, d.f. = 3, $P = 0.0199$). Both species used sand more than expected based on availability while the sand/gravel mixture was used disproportionally less than expected (Fig. 1). Gravel was rarely used (pallid n = 0; shovelnose n = 3) while woody structure was never used during these trials (both species, n = 0). Overall, the use of substrate at LV and HV did not differ significantly in pallids ($\chi^2 = 0.6751$, d.f. = 2, $P = 0.4113$), or shovelnose sturgeon ($\chi^2 = 0.7315$, d.f. = 2, $P = 0.3864$). Figure 2 shows the distribution of the different substrates in the flume, as well as the location of the sturgeon. The light yellow areas indicate sand, the orange-ish areas denote gravel, the tan-ish areas imply a sand-gravel mixture, and the brown areas designate woody structure. The dark gray areas are the flume outline and the light gray area is a screened off area of the flume where the water pump was located. The red dots represent pallid sturgeon; the green dots represent shovelnose sturgeon.

For data analysis, water depth was categorized into three levels. 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 73–93 cm deep, and comprised 35.43% of available habitat

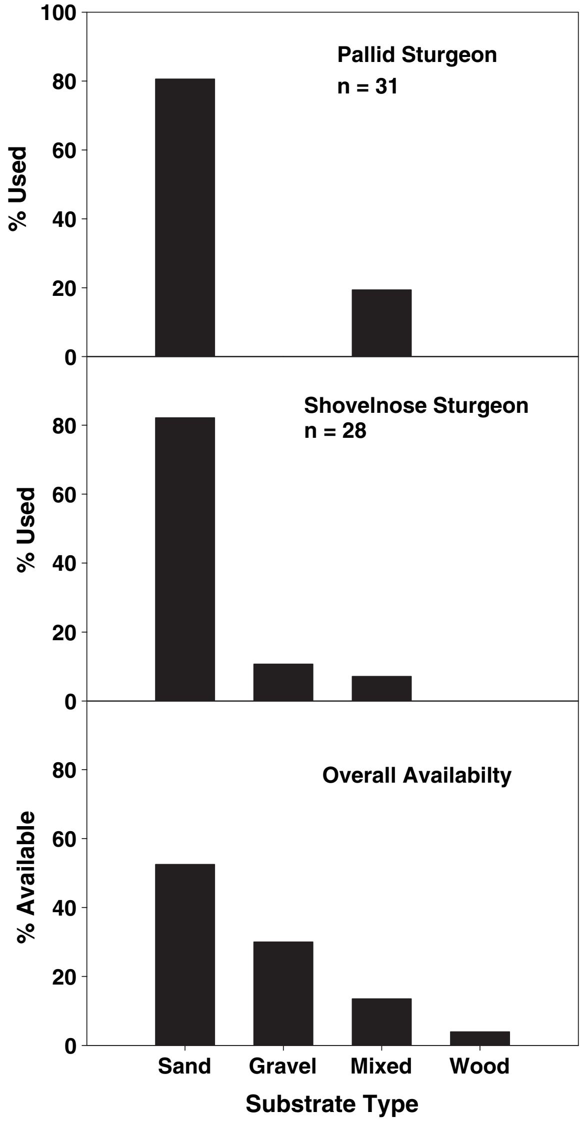

Fig. 1. Percent of use and availability for sand (Sand), gravel (Gravel), sand and gravel (Mixed), and Woody structure (Wood) by individual pallid and shovelnose sturgeon during all trials

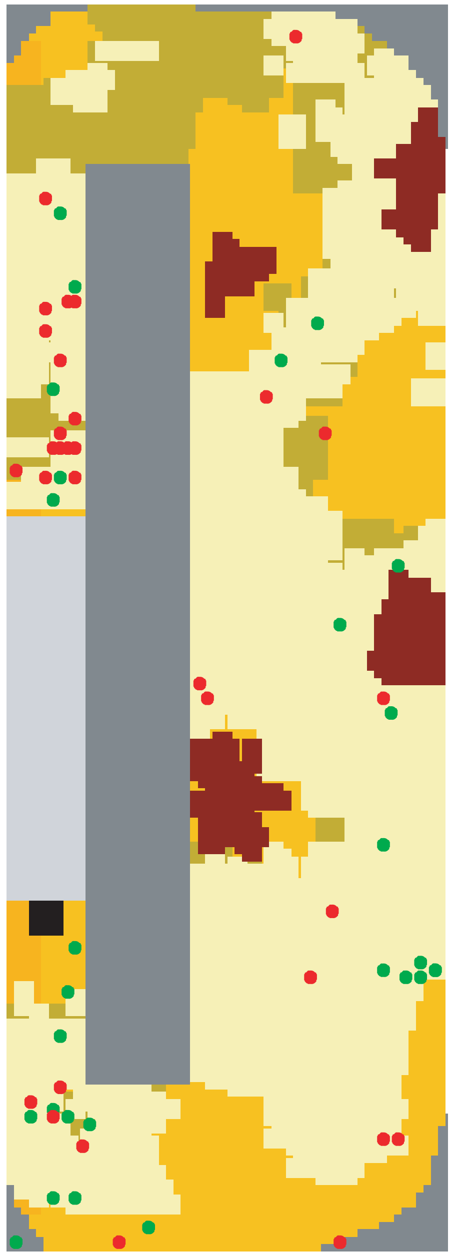

Fig. 2. Distribution of the different substrates in the flume, and location of sturgeon during all trials. Light yellow areas indicate sand, orange-ish areas denote gravel, tan-ish areas imply sand–gravel mixture, brown areas designate woody structure. Dark gray areas are the flume outline, light gray area is a screened off area of the flume where the water pump was located. Red dots represent pallid sturgeon, green dots represent shovelnose sturgeon

(Fig. 3). Pallid sturgeon used water depth in similar proportions to shovelnose sturgeon (χ^2 = 0.7840, d.f. = 2, P = 0.6757) during all trials. Neither species used water depth in proportion to availability (pallid, χ^2 = 14.9972, d.f. = 2, P = 0.0006; shovelnose χ^2 = 6.5376, d.f. = 2, P = 0.0381). Both pallid and shovelnose sturgeon used deep areas in higher proportion than availability and medium and shallow areas less than expected based on availability (Fig. 2). Further, pallids (χ^2 = 1.9773, d.f. = 2, P = 0.3721) and shovelnose (χ^2 = 1.4479, d.f. = 2, P = 0.4848), used water depth similarly during LV and HV trials. Figure 4 shows the distribution of the water depth in the flume, as well as the location of the sturgeon. The transition from lighter to darker colors indicates the transition from shallower to deeper water levels. The dark gray areas are the flume outline and the light gray area is a screened off area of the flume where the water pump was located. The red dots represent pallid sturgeon; the green dots represent shovelnose sturgeon.

For purposes of statistical analysis, light levels were categorized into four groups. Very light areas ranged from 374 to 510 lux (17.79%); light areas varied from 274 to 373 lux (31.74%), dark areas varied from 157 to 273 lux (29.72%), and very dark areas extended from 14 to 156 lux (20.75%) (Fig. 5). The sturgeon species used lighted areas in similar proportions during this evaluation (χ^2 = 1.6326, d.f. = 3, P = 0.6520). Pallids and shovelnose did not use light in proportion to its availability (pallids, χ^2 = 17.1840, d.f. = 3, P = 0.0006; shovelnose, χ^2 = 8.0037, d.f. = 3, P = 0.0459). All sturgeon used very dark and dark areas more than expected based on availability; however very light and light areas were used disproportionally less than expected based on availability (Fig. 5). Light levels were not used differently at LV and HV by pallids (χ^2 = 6.6413, d.f. = 3, P = 0.0843), or shovelnose (χ^2 = 5.2415, d.f. = 3, P = 0.1549). Figure 6 shows the distribution of the light

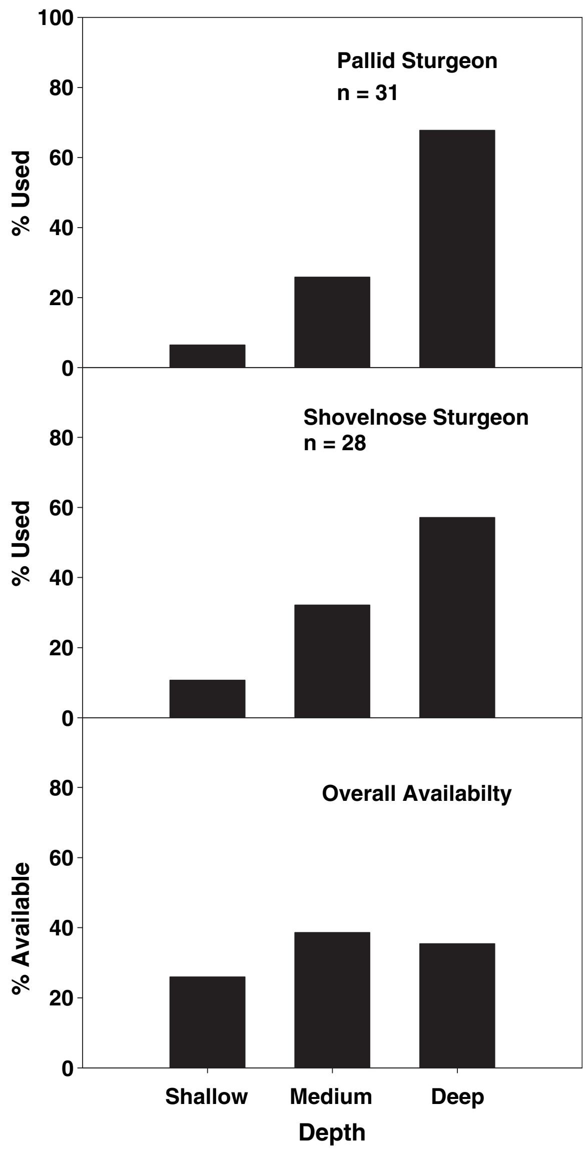

Fig. 3. Percent of use and availability for shallow water depth (Shallow), moderate water depth (Medium), and deep water depths (Deep) by individual pallid and shovelnose sturgeon during all trials

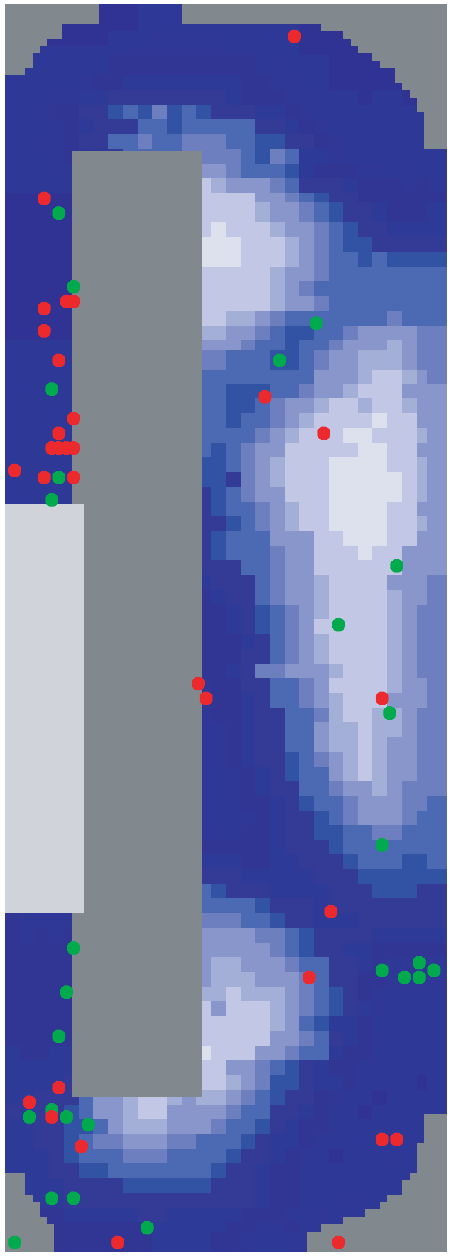

Fig. 4. Distribution of water depth in the flume, and location of sturgeon during all trials. The transition from lighter to darker colors indicates transition from shallower to deeper water levels. Dark gray areas are the flume outline and the light gray area is a screened off area of the flume where the water pump was located. Red dots represent pallid sturgeon, green dots represent shovelnose sturgeon

levels in the flume, as well as the location of the sturgeon. The transition from lighter to darker colors indicates the transition from lighter to darker areas. The dark gray areas are the flume outline and the light gray rectangular area is a screened off section of the flume where the water pump was located. The red dots represent pallid sturgeon; the green dots represent shovelnose sturgeon.

Discussion

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 less than expected based on availability) may represent areas that are undesired, unavailable, or simply used less frequently. Habitats that are selected for (used more than expected based on availability) may represent areas preferred by or important to pallid or shovelnose sturgeon. Our results indicated that juvenile pallid and shovelnose sturgeon exhibited obvious partiality in habitat selection. The 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 of both species. This corresponds to the habitat where pallid and shovelnose sturgeon are found most often in natural settings (Bramblett, 1996; Hurley et al., 2004). In all cases, sand was used similarly by pallids and shovelnose. Although neither species used gravel in a proportion greater than its availability, shovelnose did use gravel occasionally. This does not support the long held view that pallids prefer finer substrates than shovelnose sturgeon (Bramblett, 1996), at least in our captive non-feeding juveniles.

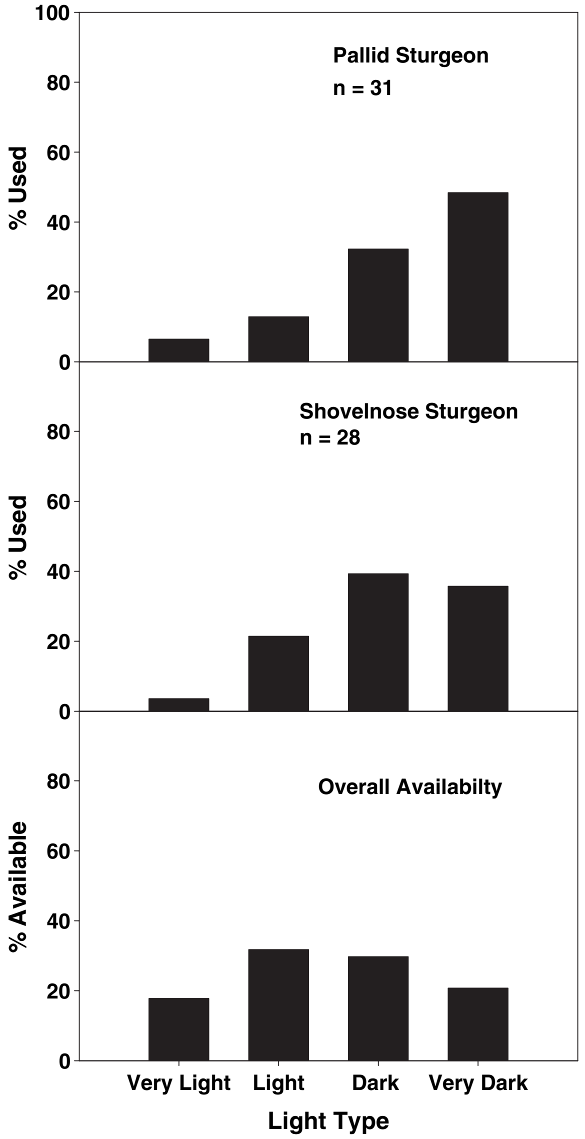

Fig. 5. Percent of use and availability for high light intensity (Very Light), moderate light intensity (Light), low light intensity (Dark), and extremely low light intensity (Very Dark) by individual pallid and shovelnose sturgeon during all trials

The selection against gravel in this study may be due to a preference for the finer substrate, or an aversion to some other feature of the gravel. In spite of this, we frequently observed sturgeon on sand substrate resting directly against an adjacent gravel area of higher relief. Unfortunately, this was not a documented habitat type in our study, and its possible significance only became apparent after repeated observations during the course of our investigation. This area, which has an abrupt change in relief, may relate to troughs present on sand flats in the Mississippi River where juvenile pallid and shovelnose were recently collected (R. Hrabik pers. comm.; C. Wrasse pers. comm.).

Woody structure was not selected for by individuals of either species. Contrary to our results, 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. However, because these individuals were hatchery reared, they may not have become skilled at predation or predator avoidance behaviors.

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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 in shallow water areas of the flume. Instead, they were found in the deepest portions. Forbes and Richardson (1905) and Carlson et al. (1985) both report that adult pallid sturgeon occupy faster currents and are more abundant in swift, channel habitats than shovelnose sturgeon. Again, our study did not indicate a difference between the species. This may be due to the fact that the flume was not deep enough for such a difference to be expressed, or that such an expression does not occur in captive juveniles. Additionally, 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 LV areas associated with dike fields, sand bars, and islands (Carlson et al., 1985; Hurley et al., 1987; Bramblett, 1996; Curtis et al., 1997; Hurley, 1999; Adams et al., 2003). Recent field collections of juvenile pallid and shovelnose sturgeon have occurred in main channel border areas where velocities ranged from 20 to 80 cm s^{-1} and sand troughs were usually present (Hrabik pers. comm.; C. Wrasse pers. comm.; Allen pers. obs.). According to Adams et al. (1999), juvenile pallid sturgeon have the capability of occupying habitat that contains water velocities ranging from 15 to 30 cm s^{-1} 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; C. Wrasse pers. comm.).

Sturgeon selected for dark and very dark areas, and against light and very light areas. This pattern of distribution is likely correlated with the fact that the deepest areas of the flume were often the darkest. However, approximately nine areas within the flume categorized as very dark were not used frequently. Four of these areas contained woody structure, and the others contained gravel or sand/gravel mixture. Both woody structure and gravel were generally selected against, and their occurrence in these areas apparently outweighed the appeal of very dark habitat.

This study is the first investigation of juvenile pallid and shovelnose sturgeon habitat selection in a small-scale artificial stream system. Future studies which uncouple 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 (Beamesderfer and Farr, 1997). Fish habitats are frequently defined in terms of site-specific conditions including water depth, velocity, temperature, substrate, and cover. However, due to the extensive range, longevity, and migratory behavior of these fishes, 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 river sections which provide suitable spawning and rearing sites (Beamesderfer and Farr, 1997); as well as protection from recreational and commercial harvesting, should be encouraged.

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