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Guidance of Yearling Shortnose and Pallid Sturgeon Using Vertical Bar Rack and Louver Arrays

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Abstract.—Some populations of shortnose sturgeon *Acipenser brevirostrum* and pallid sturgeon *Scaphirhynchus albus* have been divided by hydroelectric dams, and migration downstream past the dams likely continues. No protection for downstream migrants is presently available, and the behavior of sturgeon to guidance structures has not been studied. We conducted experiments in a 5.4-m-long × 1.5-m-wide flume with a water depth of 37 cm to determine the guidance efficiency and behavior of yearling shortnose and pallid sturgeon to two guidance structures, a bar rack and a louver array. We tested one vertical bar rack configuration with slats spaced 3.9 cm apart (clear spacing). The bar rack slats were oriented directly into the approach flow, and the row of slats was oriented at a 45° angle to the flow. We tested two louver array configurations, one with slats spaced 3.9 cm apart and one with slats spaced 9.0 cm apart (clear spacing). Louver slats were oriented at a 90° angle to the flow, and the row of slats was oriented at a 20° angle to the approach flow. Mean approach velocity to both structures was 31–34 cm/s. Eighteen shortnose sturgeon tagged with passive integrated transponders were tested once in each configuration; 24–38 pallid sturgeon were tested in each configuration. Shortnose sturgeon showed some behavioral differences due to experience with the bar rack, but experience did not affect the percent guided. Both sturgeon species were guided efficiently by the louver array (96–100%) but less efficiently by the bar rack (58–80%). Shortnose sturgeon were more likely to contact the bar rack at night than during the day ($P = 0.01$) and at night were more likely to contact the bar rack than the louver array ($P = 0.006$). Bar racks guided fewer individuals at night than during the day. For pallid sturgeon, the percentages guided by day and night were 80 and 58, respectively; for shortnose sturgeon, the percentages were 80 and 67. Both species used vision to avoid structures because both increased contact with structures at night. Shortnose sturgeon were superior to pallid sturgeon at swimming off the bottom and avoiding structures.

Riverine sturgeon populations are often divided by dams into upstream and downstream segments (pallid sturgeon *Scaphirhynchus albus* [USFWS 1992], lake sturgeon *Acipenser fulvescens* [Auer 1996], and shortnose sturgeon *A. brevirostrum* [Kynard 1997]). The full impact of segmentation is not well understood, but a functional natural population can only be restored when the upstream and downstream segments are reconnected by facilitation of migration past dams. Although some study of upstream passage for sturgeon has been done (Warren and Beckman 1993; Kynard 1998), we could find no study of methods for protecting downstream migrants. This study investigates guidance of downstream-moving juvenile pallid and shortnose sturgeon.

Shortnose sturgeon are found in many rivers along the Atlantic coast, but only two dam-locked populations may remain: one in the Santee River–Cooper River system, South Carolina, divided by Wilson and Pinopolis dams, and one in the Connecticut River, Massachusetts, divided by Holyoke Dam (Kynard 1997). Damming has also divided populations of the endangered pallid sturgeon in the Missouri and Mississippi rivers, creating upstream and downstream population segments with a one-way flow of individuals (sturgeon can move downstream but not the reverse [USFWS 1992]). Recent studies of Connecticut River shortnose sturgeon found that juveniles and adults maintained natural upstream and downstream migration patterns in spite of more than 150 years of population segmentation by Holyoke Dam. When adults migrated downstream past the dam, about 50% were entrained, and 100% of the entrained sturgeon were killed passing through a Kaplan turbine at Hadley Falls Station (Kynard et al. 1999). Although no studies have examined turbine-related mortality of yearling sturgeon, mortality at Hadley Falls Station could be similar to the 11.3% found for channel catfish *Ictalurus punctatus* (me-

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dian total length [TL] range, 170–277 mm) that passed through a Kaplan turbine (EPRI 1992) because they are similar to our sturgeon species in size and in hardiness during handling.

Recent behavioral studies of shortnose and pallid sturgeon (hereafter sturgeon) early-life stages in oval endless channels found that both species have a two-step downstream migration. After hatching, the first migration is short, lasting only a few days (B. Kynard and M. Horgan, unpublished data; B. Kynard, E. Henyey, and M. Horgan, unpublished data). In rivers, this migration would move sturgeon from the spawning site to the nursery area. Other experiments found that yearlings resumed downstream migration and that migration lasted for months (B. Kynard and E. Henyey, unpublished data). Thus, laboratory studies indicate that yearlings migrate downstream throughout the population's range. If these laboratory results correctly reflect migrations of wild juveniles, then the yearling stage is the earliest life stage likely to encounter dams during downstream migration. Understanding the life history is critical for developing fish passage because it provides information on migrant size and migration timing (Kynard 1993).

The most reliable protection for downstream-migrating small fish at water intakes is provided by physical barriers such as screens, bar racks, and louvers. (Taft and Mussalli 1978; Ruggles 1990; EPRI 1992). These structures are often placed upstream of a water intake to intercept and guide downstream-migrant fish to a bypass. Unfortunately, none of the many experimental studies and site evaluations on fish guidance have included sturgeon (EPRI 1986, 1992), which are different from most teleost fish species tested in guidance studies. Sturgeon are benthic and, compared with most teleost fishes, have limited eyesight and are weak swimmers. A heterocercal tail produces 18% less thrust than a symmetrical teleost tail, and a sturgeon's rough body has about 3.5 times more drag than a trout species body per unit surface area (Webb 1986). These morphological characteristics result in a reduced swimming performance especially at burst speeds (less than 30 s endurance [EPRI 1986]). Observations of shortnose sturgeon in experimental flumes suggested that juveniles might be guided by physical barriers in moderate-to-low water velocities in which the burst-swimming speed was not needed to avoid a structure.

Two physical barriers commonly used to guide small, surface-oriented anadromous migrants in the northeastern United States are angled bar racks and louver arrays (Odeh and Orvis 1998). Both are placed diagonally upstream of a turbine intake across the fish's approach route to intercept and guide downstream migrants to a bypass entrance. Angled bar racks are composed of a row of metal slats, often spaced 2.5 cm apart (clear spacing); the leading edge of the bars is oriented into the approach water flow, and the entire array is positioned at an angle of 45° or less to flow (Figure 1). The slats may be positioned vertically or sloped downstream at about 45°, as is done in the northeast United States, where the recommended maximum approach velocity is about 60 cm/s for juvenile anadromous migrants (Odeh and Orvis 1998). A bar rack functions mainly as a physical barrier to large fish, allowing small fish to pass between the bars; however, some small fish avoid passing through the rack and are guided to the bypass (EPRI 1986). Behavior of fish at bar racks is poorly understood. A louver array is a line of evenly spaced vertical slats each oriented 90° to the flow; the entire array is positioned at an 11–20° angle to flow (EPRI 1986; Figure 1). Slats are usually 2.5 cm apart (clear spacing) for guiding small fish, but spacing distance varies widely during application. Louver arrays create a sweeping zone of flow along the leading edge of the array that is a behavioral barrier to fish. The sweeping zone is created by water forced to change direction 90° by the louver slats. Fish avoid this flow by orienting upstream and parallel to the zone and the louver array rather than to the main current and gradually moving downstream to a bypass (EPRI 1986). The response of fish to louvers is related to species, size of the fish, and light intensity. For example, adult American shad *Alosa sapidissima* respond to louvers as a physical barrier in the day, when fish can see the barrier, and as a behavioral barrier at night, when vision is ineffective (Kynard and Buerkett 1997).

We conducted experiments to determine the comparative behavior and guidance efficiency of yearling shortnose and pallid sturgeon at bar rack and louver arrays. Body shapes of the two species encompass the two body types of North American sturgeon, and observing both species using the same structures could provide a useful comparison. We evaluated guidance efficiency of the two sturgeon species by the use of arrays with spacing wide enough to allow fish to pass through the slats. This allowed us to examine differences in the behavior of sturgeon that were guided and those that were not guided.

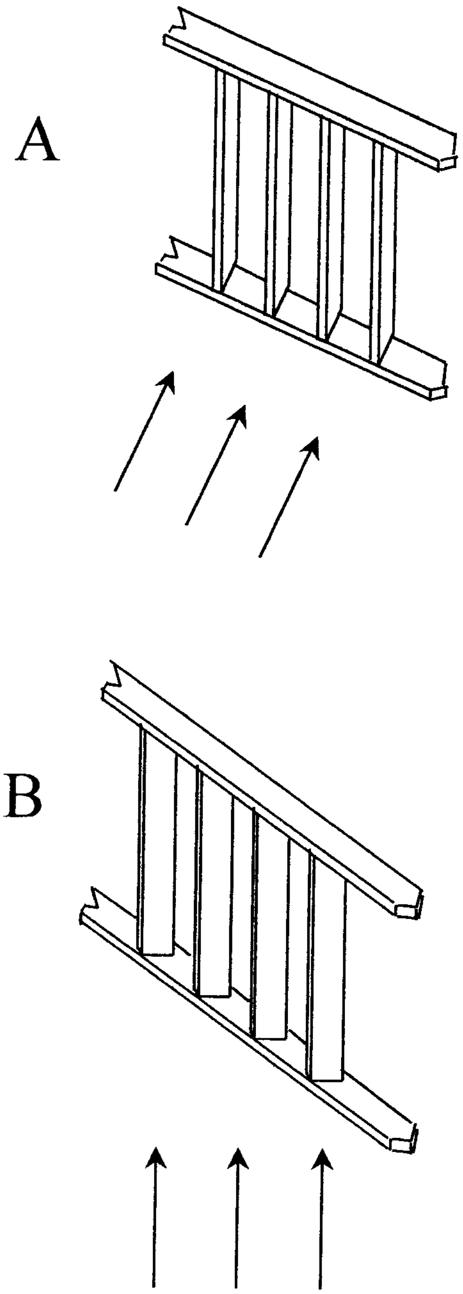

FIGURE 1.—Drawings of the **(A)** bar rack and **(B)** louver arrays. The direction of the approach flow is indicated by arrows. Slats of the bar rack are oriented directly (0°) into the approach flow, and slats of the louver are oriented at 90° to the approach flow.

Methods

Test fish.—Shortnose and pallid sturgeon were hatched in May and June 1997, respectively, reared for 1 year, and tested as yearlings. Shortnose sturgeon yearlings were produced by spawning two males with one female (Connecticut River stock); pallid sturgeon (a cross of Missouri River and Yellowstone River fish) were reared for 3 months and provided to us by the Gavins Point National Fish Hatchery (U.S. Fish and Wildlife Service). Both species were reared at the S. O. Conte Anadromous Fish Research Center and held in 1.5-m-diameter circular tanks with flow-through water of ambient temperature from the Connecticut River before and during testing. Sizes (TL) of test fish were as follows (mean, SD, and range): shortnose sturgeon (275, 26, and 238–315 mm) and pallid sturgeon (216, 23, and 174–273 mm). The total length of pallid sturgeon was exaggerated because the filamentous end of the caudal fin added an average of 15 mm to the length (by use of the caudal fork as a reference point).

Downstream guidance systems.—We constructed an experimental flume at the S. O. Conte Anadromous Fish Research Center. The rectangular flume (5.4 m long × 1.5 m wide; Figure 2) was provided with a partially recirculating water supply from the Connecticut River. Water depth was set by stop logs at a shallow level (36.5–37.5 cm) after preliminary tests showed that sturgeon stayed on or near the bottom. An approach velocity in the flume of about 35 cm/s was chosen because it was within the sturgeon's prolonged swimming range and preliminary tests showed that sturgeon could easily maneuver and hold position in areas with the fastest current. Test fish were restricted to the test flume area with plastic-coated wire mesh. The flume bottom was painted white to contrast with fish color and facilitate visual observations. The bypass entrance was 0.5 m wide and against the wall; the guidance structures angled diagonally from the bypass entrance to the opposite flume wall (Figure 2).

The bar rack array was oriented at a 45° angle to flow, and the louver array was at a 20° angle to flow. Thus, the louver was 1.5 m longer than the bar rack to cover the distance from the wall to the bypass entrance (Figure 2). Guidance structures were constructed of wood, and slats of both structures were 7.8 cm wide and 1.2 cm thick. We tested one bar rack slat-spacing configuration (3.9-cm clear spacing) and two louver slat-spacing configurations (3.9- and 9.0-cm clear spacing). We did

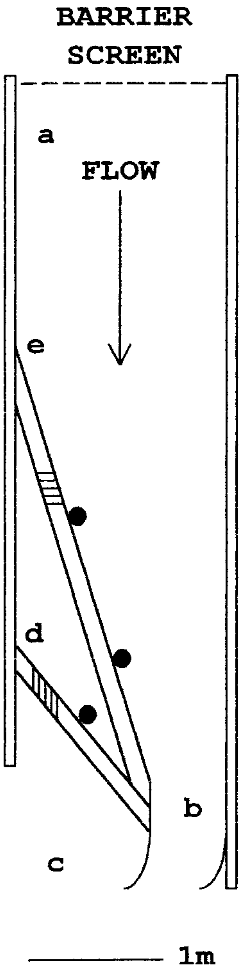

FIGURE 2.—Plan view of the guidance test flume. Configurations of the bar rack (d) and louver array (e) are both shown, but only one was tested at a time. We tested one bar rack array, with 3.9-cm slat spacing, and two louver arrays, with 3.9- and 9.0-cm slat spacing. Filled circles show the locations of video cameras; a = site of fish introduction, b = bypass exit, and c = downstream capture area.

not use the small spacing typical of many applications because we wanted to give our large fish the opportunity to be guided or not, i.e., to pass through the slats. We did not want to test guidance versus impingement (fish impaled on a structure). Bar rack slats were oriented parallel to flow so that water freely passed between them with little disturbance; for louvers, slats were oriented perpendicular to flow to create a sweeping flow along the leading upstream edge of the slats.

We characterized water velocity in the test area by measuring velocity with a Marsh-McBirney velocity meter at two depths (3 cm above the bottom and at 0.6 × the total depth) in the approach area to the structures, at 17 cm upstream from the structures, along the guidance structures, and at the bypass entrance (Table 1). The approach velocity in the open flume area was generally uniform across the flume but somewhat lower near the exit wall. Velocity 17 cm upstream from the structure (about one body length of test fish) was similar for all structural types. Velocities at the leading edge of the structure and at the bypass entrance were slightly lower for the bar rack than for louver arrays. Consistent flows were maintained among days by the use of a stop log overflow system.

We mounted one (bar rack) or two (louver) Sony HVM-332 video cameras above the guidance structures (Figure 2). Cameras were aimed straight down on the entire structure, the exit, and the flume area wall to wall. The guidance structure area was covered with a large tarp to intercept direct sunlight over the observation area. At night, one or two red floodlights illuminated the flume with red light so that we could observe fish with video. We did not observe any attraction or repellence of fish in response to the red light during trials.

Procedures and evaluation.—We tested the following four configurations with both sturgeon species: bar rack, day and night (9−28 July 1998); louver with 3.9-cm spacing, night only (4−5 August 1998); and louver with 9.0-cm spacing, night only (11−12 August 1998). We did not test louvers during the day to minimize testing of the small group of shortnose sturgeon ($N = 18$). We expected louvers to provide better guidance than bar racks; therefore, we decided to test louvers under less favorable conditions to present a more conservative comparison. Additionally, both species show greater nocturnal movement as yearlings (B. Kynard and E. Henyey, unpublished data), so night is most likely when guidance of wild yearlings is needed. Water temperature ranged from 21.0°C to 25.5°C during tests.

Each shortnose sturgeon individual was tested in all four configurations, whereas individual pallid sturgeon were tested in one bar rack and one louver configuration at most. Shortnose sturgeon ($N = 18$) were individually marked with passive integrated transponder (PIT) tags. To detect effects of experience on guidance behavior, we tested one-half of the shortnose sturgeon first with the bar rack at night, and the other one-half were tested first with the bar rack during the day. Subsequently, we retested each group of nine shortnose sturgeon with the bar rack during the alternate time

TABLE 1.—Mean water velocity (range) measured throughout the experimental flume in cm/s. Water velocity was measured 3 cm from the bottom and at 0.6 × depth at each location. The number of locations where velocity was measured is denoted *N*. Measurement locations (Flume area) were along the upstream edge of the guidance device (leading edge), 17 cm upstream of the leading edge (17 cm up), regularly spaced in the bypass entrance (bypass entrance), and at intersections of regularly spaced grid lines throughout the remainder of the flume upstream of the bypass entrance (approach).

			Water velocity	
Configuration	Flume area	*N*	Bottom	0.6 × depth
Bar rack	Approach	23	35 (16–61)	29 (11–54)
	17 cm up	10	30 (25–35)	29 (25–39)
	Leading edge	10	29 (22–48)	28 (23–37)
	Bypass entrance	6	19 (11–27)	23 (14–31)
Louver, 3.9 cm	Approach	21	33 (12–59)	28 (12–53)
	17 cm up	14	33 (30–37)	34 (28–40)
	Leading edge	14	35 (32–37)	40 (35–42)
	Bypass entrance	6	22 (11–41)	32 (22–55)
Louver, 9.0 cm	Approach	21	30 (15–56)	25 (10–50)
	17 cm up	14	31 (23–35)	34 (32–38)
	Leading edge	14	35 (27–38)	38 (35–41)
	Bypass entrance	6	26 (13–47)	33 (20–56)

period. Pallid sturgeon (24–38 individuals per configuration) were not individually marked, and test fish were removed from a holding tank with more than 100 individuals; separate recovery tanks were used posttesting to prevent individuals from being retested. After each test, fish were measured for TL, and shortnose sturgeon were checked for PIT tag number.

An observer introduced one test fish at the upstream end of the flume (Figure 2) by lowering the fish in a bucket into the water and tipping the bucket so that the fish could swim out. Each fish was observed for 10 min or until it completed downstream passage (through the bypass entrance or through the guidance structure). Passage results were classified by visual observation, and by the use of the videotapes, we scored body orientation approaching and at a structure and fish contact with a structure. We define the following terms: (1) passed downstream refers to the fish moving downstream either through the bypass entrance or through the slats of the guidance structure during the 10-min period; (2) contact refers to the fish coming into physical contact with the slats of the guidance structure; and (3) guided refers to the fish leaving the flume through the bypass entrance.

We statistically evaluated the numbers of sturgeon that passed downstream, contacted the structure, and were guided under different conditions by use of chi-square tests (1 df). The following comparisons were of interest for both species: day and night bar rack, bar rack and louver (we used night bar rack and 9.0 cm louver array for a conservative comparison between the two types of structures), and headfirst and tailfirst approaches. We also compared the results of naive and experienced shortnose sturgeon with the bar rack. As we have low power to find significant differences given the sample sizes of shortnose sturgeon in particular, we evaluate statistical significance at $P = 0.10$ and accept a 10% chance of a type I error. Larger sample sizes would have greatly enhanced the study; however, as is often the case with studies of endangered species, we were limited in the number of fish that were available.

Results

Sturgeon of both species remained on or near the bottom of the flume. Pallid sturgeon could hold a position on the smooth bottom better than shortnose sturgeon because of their flattened broad head and large pectoral fins, adaptations for holding bottom position in high velocities (Moyle and Cech 1988). Shortnose sturgeon were larger and more likely to be in control when swimming off the bottom than were pallid sturgeon. A small number of fish temporarily caught pectoral fins in seams of the flume; these were excluded from analyses. We noted no injury or mortality during the trials. Most pallid sturgeon passed downstream during the 10-min trial (range, 60–92%; Table 2). Pallid sturgeon were more likely to pass downstream with the bar rack during the day than at night ($P = 0.085$), and they were more likely to pass downstream with louvers than with the bar rack at night ($P = 0.010$). Many pallid sturgeon came into contact with the structures (range, 54–63%) but showed no differences among trials (Table 2). Pal-

TABLE 2.—Results of guidance tests with shortnose and pallid sturgeon.

Test	Number tested	Number passed downstream (% of total)	Number in contact with device (% of total)	Number guided (% of those that passed downstream)
Shortnose sturgeon				
Bar rack				
Day	17	10 (59)	7 (41)	8 (80)
Night	18	12 (67)	15 (83)	8 (67)
Louver (night)				
5.1 cm	18	9 (50)	9 (50)	9 (100)
10.2 cm	18	9 (50)	7 (39)	9 (100)
Pallid sturgeon				
Bar rack				
Day	37	30 (81)	20 (54)	24 (80)
Night	20	12 (60)	12 (60)	7 (58)
Louver (night)				
5.1 cm	24	22 (92)	15 (63)	22 (100)
10.2 cm	25	23 (92)	15 (60)	22 (96)

lid sturgeon were more likely to contact the bar rack at night when approaching headfirst ($P = 0.068$), but there was no difference with orientation during the day.

Guidance by louvers with both 3.9- and 9.0-cm slat spacing was effective; only one pallid sturgeon passed through the louver slats. Of those fish that passed downstream in 10 min, 96–100% of pallid sturgeon were guided to the bypass entrance (Table 2). Bar racks, however, were less effective than louvers for guiding pallid sturgeon ($P = 0.007$; 58–80% guided; Table 2). There was a strong effect of orientation on bar rack guidance. Pallid sturgeon were less likely to be guided (more likely to pass through the slats) if they approached the bar rack headfirst than if they approached tailfirst during the day ($P = 0.019$) and at night ($P = 0.004$). Fish size may have been a factor in guidance. All pallid sturgeon (day and night) that passed through the bar rack slats were 174–213 mm in TL, whereas pallid sturgeon 216–273 mm in TL were guided. However, the sole pallid sturgeon that passed through louver slats was relatively large, 229 mm in TL.

Shortnose sturgeon showed no difference in tendency to pass downstream with configuration (range, 50–67%; Table 2). Shortnose sturgeon were more likely to contact the bar rack at night than during the day ($P = 0.010$) and were also more likely to contact the bar rack than the louver ($P = 0.006$). During the day, shortnose sturgeon that approached the bar rack headfirst were more likely to contact it than were those that approached tailfirst ($P = 0.023$), but there was no difference by orientation at night. Also, shortnose sturgeon were more likely to contact the 3.9-cm louver when approaching headfirst than when approaching tailfirst ($P = 0.091$).

All shortnose sturgeon that passed downstream of louvers were guided through the exit (Table 2). Guidance was lower with the bar rack ($P = 0.054$; 67–80% guided). There was no effect of orientation on guidance for shortnose sturgeon. Unlike pallid sturgeon, both small and large shortnose sturgeon passed through bar rack slats day and night.

Naive shortnose sturgeon showed some behavioral differences from shortnose sturgeon that had experienced the bar rack (Table 3). In day trials, naive fish were more likely to pass downstream than were fish that had already been tested at night ($P = 0.092$), and naive fish were more likely to contact the bar rack ($P = 0.024$). In night trials, naive fish did not differ from experienced fish in

TABLE 3.—Effects of experience for shortnose sturgeon tests with the bar rack. For comparisons between experienced and naive fish, $P < 0.10$* and $P < 0.05$**.

Test	Fish tested first	Number passed downstream/total	Number with contact/total	Number guided/ number passed downstream
Day	Day (naive)	7/9*	6/9**	5/7
	Night (experienced)	3/8	1/8	3/3
Night	Night (naive)	5/9	9/9*	3/5
	Day (experienced)	7/9	6/9	5/7

TABLE 4.—Effects of orientation on encounter with guidance device. In the last three columns, the first number refers to fish oriented head first, the second to fish oriented tail first. In comparisons, $P < 0.10$* and $P < 0.05$**.

Test	Number	Contact with device (% of total)	Guided (% of those that passed downstream)
Shortnose sturgeon			
Bar rack			
Day	3, 14	100, 29**	67, 86
Night	5, 13	100, 77	50, 75
Louver (night)			
5.1 cm	6, 10	83, 40*	100, 100
10.2 cm	6, 9	33, 56	100, 100
Pallid sturgeon			
Bar rack			
Day	10, 24	70, 50	60, 95**
Night	4, 16	100, 50*	0, 88**
Louver (night)			
5.1 cm	10, 14	70, 57	100, 100
10.2 cm	12, 13	58, 62	100, 92

passing downstream; however, naive fish were more likely to contact the bar rack at night than were experienced fish ($P = 0.058$). We found no effect of experience on the percent guided ($P > 0.30$; Table 3).

The two species of sturgeon oriented differently as they moved along the face of the bar rack or louver array, and this affected the numbers of each that contacted the structure and were guided (Table 4). Generally, fewer shortnose sturgeon moved downstream headfirst than did pallid sturgeon. Individuals of both species usually started at the bar rack oriented parallel to the approach flow. After holding position, fish moved down along the bar rack either while facing directly into the approach flow or while attempting to hold position at an angle to the approach flow. In both cases, the current moved sturgeon downstream, and they often contacted the slats. Individuals of both species that were oriented head downstream when they encountered the bar rack tended to contact the slats more than did sturgeon moving tailfirst, and for pallid sturgeon, the individuals oriented headfirst were guided less well than were tailfirst individuals ($P = 0.05$; Table 4). After contacting the bar rack slats, sturgeon either passed through the slats or turned and burst swam upstream. Conversely, when either species encountered the sweeping flow along the leading edge of the louver array, they responded by orienting headfirst into this flow, not into the approach flow. Both species moved upstream along the face of the louver array while oriented parallel to the array. Shortnose sturgeon moved downstream along the louvers by swimming head downstream and parallel to the louver. However, pallid sturgeon seemed too weak to maintain this orientation, and they moved downstream along the louver with head upstream while gradually being pushed downstream by the sweeping flow. Individuals of both species that swam headfirst downstream had a higher probability of contacting a structure, particularly the bar rack (headfirst, 70–100%; tailfirst, 29–77%), and individuals moving downstream tailfirst were guided better at the bar rack (headfirst, 0–67%; tailfirst, 75–95%; Table 4).

Discussion

The experiments found some interesting comparative behavioral and guidance results between the two sturgeon species, but many questions remain. The approach velocity of 31–34 cm/s used in the tests was within the prolonged swimming mode (30-s to 200-min endurance) of the juvenile pallid sturgeon we used (Adams et al. 1999). Additionally, individuals of both species easily swam short distances upstream into the fastest available velocity (40–60 cm/s). However, the velocity at hydroelectric project intakes may be much faster, and additional tests are needed at higher velocities. Also, our arrays were short, and full-scale arrays would be longer, giving sturgeon additional opportunity to encounter the structure. Guidance efficiency could decrease with increased exposure to any array, particularly with increased length of a bar rack with slats through which a sturgeon could pass. Finally, we do not know whether the red light affected the ability of either species to see a structure at night. Yearling and older white sturgeon *A. transmontanus* can see in the red and infrared spectrum (Loew and Sillman 1993; Sillman et al. 1999), so yearling shortnose and pallid sturgeon may also have this visual capability. However, we did not observe any avoidance movements of sturgeon during night trials that indicated that they were responding to the red light. We also did not observe a strong response of sturgeon in holding tanks to either white or red light at night. Fewer individuals of both species were guided, and more individuals made contact with the bar rack at night than during the day (Tables 2, 4), so even if the red light enabled fish to see a structure at night, their responses in darkness and in red light may not be different.

There could also be differences in the guidance and behavioral response of both sturgeon species to louvers or bar racks with characteristics different from those of ours. Differences in sturgeon guidance due to bar rack configuration, not louvers, seem most likely. We tested vertical bar racks at 3.9-cm clear spacing, through which unguided fish could pass. However, bar racks that slope downstream and that have 2.5-cm clear spacing between bars are mostly used in the northeastern United States (Odeh and Orvis 1998). Our observations suggest that the initial response of sturgeon approaching any bar rack configuration is likely to be similar—avoidance, if they can detect it in time. The unguided sturgeon in our study that passed through the bar slats could have been impinged if bars were spaced only 2.5 cm apart. Most of our impinged sturgeon could not escape from the bar rack, even in a velocity of 30 cm/s, and in a velocity of 60 cm/s, they would likely remain impinged. We believe that it is unlikely that a bar rack that slopes downstream would have made much difference in guiding sturgeon, but this possibility should be examined further.

Both species of sturgeon responded to the louver flow regimen with avoidance and orientation similar to that observed in other species of fish. For example, other fish studied include juveniles of the Sacramento River fish community (Bates and Vinsonhaler 1957), fry and smolts of Pacific salmon *Oncorhynchus* spp. and Atlantic salmon *Salmo salar* (Ruggles and Ryan 1964; Ducharme 1972), and adult American shad (Kynard and Buerkett 1997). Although differences in the response of fishes to louvers are related to age (size) and species, the common avoidance response of most fish predicts that louver arrays will protect many species of fish. If the goal of fish guidance is to protect a riverine fish community, then identification of a common avoidance response by many species of fish to louvers should provide a powerful tool for fish protection.

Although both sturgeon species showed avoidance behavior (body position and orientation) to the louver arrays similar to that of other species, some sturgeon responded by stopping and resting at the junction of the channel bottom and guidance structure. These fish held position for 1−10 min. Further research is needed on the design of the junction between the guidance structure and channel bottom for bottom-oriented fish like sturgeon. Although this area may be used by sturgeon in laboratory tests, in actual practice at dams, this area is probably filled with a great amount of debris that could compromise the function of any guidance structure. This suggests the need for fish-friendly turbines to protect all species of riverine fish.

Approach velocity could affect the sturgeon species differently. When pallid sturgeon left the bottom, their large dorso-ventrally flattened head and tendency to swim head downstream often resulted in a loss of swimming control and impingement on the bar rack, but not on the louvers. Their swimming ability was optimum when they were on the bottom and reduced when in the water column, possibly a problem when pallid sturgeon are guided with a bar rack. Shortnose sturgeon had a different body morphology, were larger, swam almost continually, and were better able to avoid being impinged on slats. They controlled their body orientation well, swam strongly in the water column, and should be more easily guided by bar racks.

In the northeastern United States, an approach velocity maximum of 60 cm/s is often prescribed at bar racks for surface-oriented juvenile anadromous migrants (Odeh and Orvis 1998). No accepted standard is available for benthic fish. We wanted to test sturgeon at this higher velocity, but we were not able to obtain the higher velocity with our system. We speculate that at 60 cm/s, guidance of pallid sturgeon probably could decrease further, whereas guidance of the stronger swimming shortnose sturgeon might not change. Although there is a clear relationship of decreasing guidance by louver arrays for small fish of less than 40-mm body length as approach velocity increases, there is no clear relationship for decreasing guidance of larger fish (salmonid smolts) and increasing approach velocity (EPRI 1986). Yearlings of most sturgeon species are large enough to have a relationship to approach velocity similar to that of salmonid smolts. Within the approach velocity range of 40–109 cm/s, the guidance of Pacific salmon smolts by louvers was unchanged (Ruggles and Ryan 1964). It is important to determine whether a high level of guidance of yearling sturgeon can be obtained over a wide range of velocities.

Floating louver arrays are used frequently in the northeastern United States to guide surface-oriented juvenile anadromous migrants (Ruggles 1990; Odeh and Orvis 1998), but these arrays do not extend to the river bottom, and their evaluations have provided no information on the potential guidance of bottom fish like sturgeon. Also, there is no information on the vertical distribution of sturgeon (juvenile or adult) during downstream migration or near dams. If migrants are surface-oriented, then at least one juvenile or adult shortnose sturgeon should have been intercepted and guided by the Holyoke Canal louver system, which extends to one-half the 5-m water depth (Ruggles 1990). This louver array was evaluated extensively for years during migration periods of anadromous fish (and coincidentally of shortnose sturgeon [Kynard et al. 1999]), but no sturgeon was diverted.

We cannot compare our results with other studies on sturgeon guidance because none was found in the literature. However, the louver guidance efficiency of white catfish *Ameiurus catus* and striped bass *Morone saxatilis* at the Tracy Pumping Station, Tracy, California, fish similar in size to our sturgeon, is available (Hallock 1968). White catfish were observed in a louver array with a 2.5-cm clear opening between slats, slats at a 90° angle to flow, an array at a 15° angle to flow, and an approach water velocity of 47–117 cm/s. Catfish of 100–300-mm TL were guided efficiently (more than 90%) as were striped bass of 70–300-mm TL (99–100% efficiency). This guidance efficiency is similar to the guidance for both sturgeon species in our louver tests.

The first documented test of bar racks (positioned vertically, not angled or sloped downstream) for guiding fish was done by Bates and Vinsonhaler (1957). They changed the slat position in a louver array from a 90° angle to flow to a 0° angle (parallel to flow). Guidance of small fish (most less than 40 mm in TL) went from 90% or more with the louver array to zero with the bar rack (0°) configuration. Unfortunately, no data on the guidance of large fish (longer than 100 mm in TL) were recorded for the bar rack configuration.

Whether bar racks can be made as efficient as louvers is not known, but maybe they can be improved. Both structural arrays guide sturgeon, but guidance efficiency was higher with the louver array. A main reason for this difference may be that louvers provide a warning stimuli to approaching sturgeon (sweeping flow and maybe sound from entrained air), whereas our bar rack had no sweeping flow and no warning stimuli. Changing the angle of the bar rack slats to be more perpendicular to the approach flow (more louver-like) could provide a sweeping-type flow with a warning stimuli and improve guidance. Also, adding physical stimuli (particularly sound) to bar racks in the form of a rattling device along the bar rack may warn fish and increase the response time that fish have between detection of a barrier (stimulus) and elicitation of avoidance (response). Techniques to make bar racks more detectable by approaching fish have not been investigated, but this seems to be a potentially valuable direction for fish protection research.

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