Interim Report For The
Upper Mississippi River - Illinois Waterway System Navigation Study

Stranding Potential of Young Fishes Subjected to Simulated, Vessel-Induced Drawdown

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Stranding Potential of Young Fishes Subjected to Simulated, Vessel-Induced Drawdown

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Interim report

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Preface

The work reported herein was conducted as part of the Upper Mississippi River - Illinois Waterway (UMR-IWW) System Navigation Study. The information generated for this interim effort will be considered as part of the plan formulation process for the System Navigation Study.

The UMR-IWW System Navigation Study is being conducted by the U.S. Army Engineer Districts, Rock Island, St. Louis, and St. Paul, under the authority of Section 216 of the Flood Control Act of 1970. Commercial navigation traffic is increasing and, in consideration of existing system lock constraints, will result in traffic delays that will continue to grow in the future. The system navigation study scope is to examine the feasibility of navigation improvements to the Upper Mississippi River and Illinois Waterway to reduce delays to commercial navigation traffic. The study will determine the location and appropriate sequencing of potential navigation improvements on the system, prioritizing the improvements for the 50-year planning horizon from 2000 through 2050. The final product of the System Navigation Study is a Feasibility Report which is the decision document for processing to Congress.

At the time of publication of this report, Dr, Lewis E. Link, Jr. was Acting Director of ERDC, and COL Robin R. Cababa, EN, was Commander.

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1 Introduction

Water flow dynamics associated with moving commercial navigation vessels result in shoreline drawdown (water recedes from the shoreline) (Bhowmik, Miller, and Payne 1993). These brief dewatering periods generally last 2 to 3 min (Holland 1987). The magnitude of drawdown depends on vessel speed, submerged cross-sectional area of the vessel, and channel cross section. Shallow and constricted channels increase drawdown because flow in restricted channels is accelerated more than flow in unrestricted channels. If a vessel travels close to the riverbank, drawdown will be higher in the region between the vessel and bank than it would have been if the vessel was in the middle of the channel (Bouwmeester et al. 1977). Bhowmik, Demissie, and Guo (1981) measured vertical drawdown for 27 tow passage events during 1980 and 1981 on the Mississippi and Illinois Rivers. Drawdown elevation averaged 0.08 m (range 0.03 to 0.21 m) on the Illinois River for 19 events and 0.06 m (range 0.02 to 0.1 m) on the Mississippi River for 8 events.

Commercial vessel passage may strand young fishes during drawdown and subsequent dewatering of littoral areas (Holland and Sylvester 1983; Nielsen, Sheehan, and Orth 1986), but field observations of strandings are sparse. During the passing of a commercial vessel on the Illinois River, approximately 20 juvenile fish (species unknown) were observed to strand on the shoreline; the fish were stranded due to the combined effect of being pushed ashore by the initial surge wave and subsequent drawdown.[1] In the laboratory, Holland (1987) found that dewatering (2-min air exposure) did not cause mortality of walleye *Stizostedion vitreum vitreum* or northern pike *Esox lucius* eggs. However, significant mortality of larvae of both species occurred at dewatering frequencies of 1 and 3 h, the latter being equivalent to mean passage of eight tows per day. Holland (1987) used a flow-through aquarium system that prevented fish from moving out of the dewatered zone as water receded.

This laboratory study evaluates the response of young fishes to simulated, vessel-induced drawdown. One goal was to determine the proportion of susceptible larval and juvenile fish subject to stranding during simulated, shoreline drawdown. Facilitated by the use of fishes with different habitat tendencies (main channel versus shoreline) and body shapes, we also examined stranding potential between species to elucidate differences in vulnerability and behavioral adaptation. Stranding experiments were conducted with larval shovelnose sturgeon *Scaphirhynchus platorynchus,* paddlefish *Polyodon*

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[1] Personal communication, April 1998, D. Soong, Illinois State Water Survey, Springfield, IL.

spathula, and bigmouth buffalo *Ictiobus cyprinellus,* as well as with juvenile blue catfish *Ictalurus furcatus,* largemouth bass *Micropterus salmoides,* and bluegill *Lepomis macrochirus.* Species and life stages were chosen based on availability, susceptibility to vessel-induced drawdown, and ecology.

2   Methods

Fishes were obtained from Osage Catfisheries, Osage Beach, Missouri, and were maintained in a flow-through aquaculture facility at the U.S. Army Engineer Research and Development Center (ERDC). Fishes were fed Nutrafin Fry Food daily. Water temperature ranged from 19 to 22 ºC in holding tanks and stranding flume. Photoperiod in the facility approximated 12 h light:12 h dark. Shovelnose sturgeon (16.6 to 18.0 mm TL), paddlefish (13.9 to 16.8 mm TL), and bigmouth buffalo (8.4 to 10.8 mm TL) larvae were in the early post yolk sac phase during experiments; blue catfish (15.9 to 18.2 mm TL), bluegill (12.6 to 18.3 mm TL), and largemouth bass (21.2 to 24.7 mm TL) were early juveniles. Fishes were tested within 7 days after arrival to the laboratory.

Drawdown was simulated in a stranding flume having sand substrate and adjustable bank slopes (Figure 1). The flume was constructed of 1.2-cm-thick Plexiglas, and the stranding region was 1.6 m long, 0.6 m wide, with a maximum depth of 0.3 m. Sand was obtained from a local streambed (U. S. Standard Sieve classification was 108; silty sand, small: 81.1 percent sand, 18.9 percent silt). After setting a designated slope, the flume was filled and drained a minimum of 10 times before initiating experiments. This allowed sand to settle and pack, resembling a wave-swept shoreline. Smoothing with a block of wood maintained continuity and form of the sand surface, promoting consistency of the stranding region during the study. Light was evenly distributed throughout the flume to eliminate fish clustering as a result of phototaxis.

The flume was filled with dechlorinated tap water before each experiment. Ten fish of the same species were introduced in the center of the stranding region and allowed 15 min to habituate and disperse. A retaining screen of 500 μ mesh confined fish to the stranding region during habituation. A 7.62-cm ball valve in the drainage well floor enabled the flume to be completely drained at a designated rate. When the valve was opened to begin a stranding event, the retaining screen was carefully removed without disturbing the fish. A fish was considered stranded if it remained on the sand after complete dewatering. Fish that did not strand drifted into the drainage well and were collected in a 500 μ mesh net at the valve outflow. Individuals were used only once during the study.

The percent stranded was measured at three vertical drawdown rates (0.76 cm/s, 0.46 cm/s, and 0.21 cm/s) to simulate different passage events and two bank slopes (1:5 and 1:10) representing a steep and gradual bank line. Varying with the drawdown rate/slope combination, time elapsed until complete dewatering of the stranding surface ranged from 13 s (0.76 cm/s at 1:10) to 143 s (0.21 cm/s at 1:5). Maximum water depth of the stranding region at a slope of 1:5
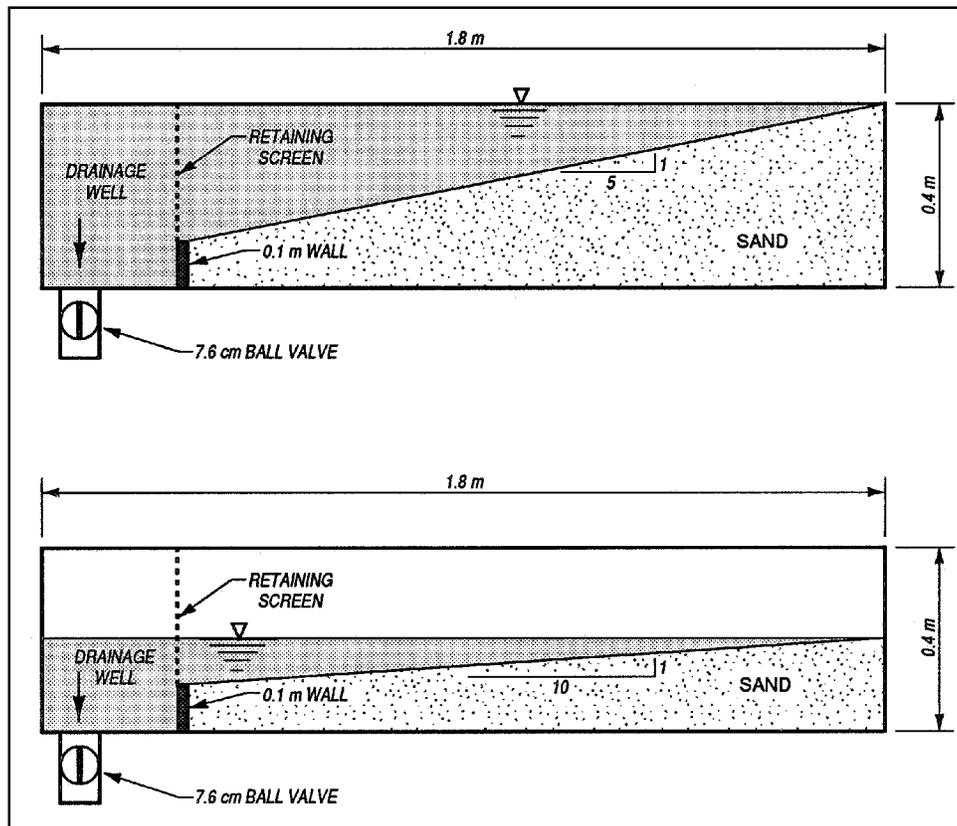
Figure 1.   Side view of stranding flume illustrating bank slopes of 1:5 and 1:10

and 1:10 was 0.3 m and 0.1 m, respectively. Water velocities were time-averaged throughout each stranding event and measured with a Marsh-McBirney electronic flowmeter. Mean water velocities (SD) in the flume were:

Drawdown (cm/s)	1:5 Slope (cm/s)	1:10 Slope (cm/s)
0.76	4.3 ± 2.4	7.7 ± 4.4
0.46	3.1 ± 1.8	5.0 ± 3.4
0.21	2.2 ± 1.8	2.4 ± 1.5

Data were analyzed with Statistica 4.2 (StatSoft Inc., Tulsa, OK). The general model was a (fixed effects) one-way or two-way analysis of variance (ANOVA) with drawdown, slope, and species as factors. Percent stranded was the dependent variable and arcsine-transformed values were used in all analyses (Zar 1984). Except for shovelnose sturgeon, drawdown rates were replicated a minimum of three times per species (10 fish per replicate). Due to fish availability (abundance and temporal constraints), only bigmouth buffalo, largemouth bass, and bluegill were tested at both slopes, resulting in an incomplete design. Therefore, each species was first analyzed separately to determine the effects of slope and/or drawdown rate on percent stranded (one-way or two-way ANOVA). Next, a one-way ANOVA was performed at each slope to examine species differences, and post hoc comparisons were examined with a Student-Newman-Keuls test (SNK). Differences were determined significant at $\underline{P} \leq 0.05$.

3 Results

There was no significant effect (all $\underline{P} > 0.1$) of drawdown rate or the interaction of drawdown rate and slope on percent stranded of any species (Tables 1 and 2). Percent stranded was significantly higher for largemouth bass (two-way ANOVA, $\underline{F}_{1,19} = 7.55$, $\underline{P} = 0.013$) at a slope of 1:10 than at a slope of 1:5. Conversely, percent stranded was significantly higher for bluegill (two-way ANOVA, $\underline{F}_{1,18} = 4.67$, $\underline{P} = 0.044$) at a slope of 1:5 than at a slope of 1:10. Bank slope had no effect on percent stranded in bigmouth buffalo (two-way ANOVA, $\underline{F}_{1,21} = 2.33$, $\underline{P} = 0.141$).

As percent stranded was independent of drawdown rate for all species, these data were pooled within a species to examine overall differences between species at each bank slope. A significant species effect was found at a slope of 1:5 (one-way ANOVA, $\underline{F}_{4,54} = 55.91$, $\underline{P} < 0.001$); shovelnose sturgeon had the highest stranding percentage (66.7 percent $\pm$ 16.32 SD), followed by paddlefish (38.0 percent $\pm$ 14.74 SD), bluegill (20.0 percent $\pm$ 17.32 SD), and bigmouth buffalo (2.2 percent $\pm$ 4.28 SD) (Table 1). Largemouth bass did not strand at a slope of 1:5. A significant species effect was found at a slope of 1:10 (one-way ANOVA, $\underline{F}_{3,50} = 8.83$, $\underline{P} < 0.001$); blue catfish had the highest stranding percentage (26.7 percent $\pm$ 19.15 SD), followed by largemouth bass (15.3 percent $\pm$ 20.31 SD) and bluegill (5.3 percent $\pm$ 8.34 SD). Bigmouth buffalo did not strand at a slope of 1:10 (Table 2). Interspecific comparisons of means using SNK showed that only bigmouth buffalo and largemouth bass had similar standing percentages at a slope of 1:5 (Table 1). At a slope of 1:10, standing percentages were significantly different among species, except for bluegill which were similar to bigmouth buffalo and largemouth bass (Table 2).

Table 1
Mean (±SD) Percent of Stranded Fish Species at Each Drawdown Rate When Slope Was 1:5

Species	Drawdown cm/s	N	Percent Stranded		Overall Mean
			Mean	SD	
Shovelnose Sturgeon	0.76	2	75.0	21.21	
	0.46	2	60.0	14.14	
	0.21	2	65.0	21.21	66.7[a]
Paddlefish	0.76	5	40.0	10.0	
	0.46	5	32.0	21.68	
	0.21	5	42.0	10.95	38.0[b]
Bigmouth Buffalo	0.76	6	3.3	5.16	
	0.46	6	3.3	5.16	
	0.21	6	0.0	0.0	2.2[c]
Largemouth Bass	0.76	3	0.0	0.0	
	0.46	4	0.0	0.0	
	0.21	4	0.0	0.0	0.0[c]
Bluegill	0.76	3	13.33	11.55	
	0.46	3	20.0	20.0	
	0.21	3	26.67	23.09	20.0[d]

Note: Number of replicates (N) per drawdown rate are stated, and the sample size for each replicate was 10 fish. Shared superscripts indicate that overall means were not significantly different among species using SNK. SD for overall means are given in the text.

Table 2
Mean (±SD) Percent of Stranded Fish Species at Each Drawdown Rate When Slope Was 1:10

| Species | Drawdown cm/s | N | Percent Stranded | | Overall Mean |
			Mean	SD	
Blue Catfish	0.76	5	26.0	27.02	
	0.46	5	26.0	13.42	
	0.21	5	28.0	19.24	26.7[a]
Bigmouth Buffalo	0.76	3	0.0	0.0	
	0.46	3	0.0	0.0	
	0.21	3	0.0	0.0	0.0[b]
Largemouth Bass	0.76	5	28.0	27.75	
	0.46	5	2.0	4.47	
	0.21	5	16.0	15.17	15.3[c]
Bluegill	0.76	5	6.0	5.48	
	0.46	5	6.0	13.42	
	0.21	5	4.0	5.48	5.3[bc]

Note: Number of replicates (N) per drawdown rate are stated, and the sample size for each replicate was 10 fish. Shared superscripts indicate that overall means were not significantly different among species using SNK. SD for overall means are given in the text.

4 Discussion

Larval fish that are confined and repeatedly exposed to the atmosphere, even for brief periods, can be injured or die (Holland 1987; Pearson et al. 1989). However, the behavioral response of larval fish to receding water may influence the level of stranding and mortality. In our study, fish species adapted to rearing in shallow, low-velocity, littoral zones (largemouth bass, bluegill, and bigmouth buffalo) were less vulnerable to stranding than larvae or juveniles that inhabit main or side channel habitats. Main channel larvae were positively rheotactic and more likely to swim toward the shoreline as water receded, compared to littoral larvae which ultimately exhibited negative rheotaxis or passively drifted to avoid stranding.

Shovelnose sturgeon and paddlefish larvae were highly vulnerable to stranding in our study, but they are usually found in main channel habitats (Wallus, Simon, and Yeager 1990). They are adapted to high velocity, currents, and turbulence (Payne, Kilgore, and Miller 1990; Killgore et al. 1998) and, based on observations in our stranding flume, are positively rheotactic with well-developed swimming capabilities. If these species/life stages comply with the general rule that sustained swimming speed is two to seven body lengths per second (Webb 1975), individuals in our study would have been capable of maintaining station during most drawdown events. Blue catfish juveniles, usually occurring in the bottom strata of side or main channel habitats (Simon, Kay, and Wallus 1998), periodically swam and made progress against the current but were usually able to avoid stranding at the last moment. Although young shovelnose sturgeon, paddlefish, and blue catfish are probably not found in shallow, shoreline areas at high frequencies (based on current knowledge), susceptible individuals are highly vulnerable to stranding during drawdown.

Relative to main channel larvae, stranding was low for species that typically inhabit shallow, low-velocity shorelines of navigable rivers. Bigmouth buffalo avoided stranding by passively drifting into the drainage well as water receded. On average, less than 20 percent (28 to 0 percent) of bluegill and largemouth bass juveniles stranded, and largemouth bass did not strand at a slope of 1:5. Whereas other species dispersed randomly during the habituation period, juvenile bluegill and largemouth bass aggregated. Therefore, when stranding occurred, it typically involved multiple individuals. The effect of bank slope on stranding was opposite in bluegill and largemouth bass (Tables 1 and 2) and may reflect subtle differences in habitat use. In a Kentucky stream, Floyd, Holt, and Kimbrook (1984) collected juvenile *Micropterus* spp. predominately near shallow vegetated shorelines, while young bluegill associated with undercut banks and structure. In the stranding flume, juvenile largemouth bass were often located in the shallowest

portion of the stranding region when the valve was opened. An affinity for shallower water and their larger body size relative to bluegill may have rendered largemouth bass more vulnerable to stranding at 1:10, because the substrate was exposed rapidly at this slope.

All species initially demonstrated positive rheotaxis and oriented against the current produced by opening the valve. However, shovelnose sturgeon and paddlefish actively swam and made progress against the current making them vulnerable to stranding. Also, shovelnose sturgeon tended to remain on the bottom which may have increased stranding potential. Juvenile bluegill and largemouth bass typically positioned the body parallel with the receding water edge, drifted, and avoided stranding by swimming to deeper water. In contrast to other species studied, bigmouth buffalo larvae were small-bodied and passively drifted away from the exposed surface as water receded. Our data, coupled with behavioral observations, suggest stranding may vary among species based on predominate microhabitat use (main channel versus littoral; pelagic versus benthic) and larval body morphology (large-bodied versus small-bodied).

The behavioral response of larval and juvenile fishes to a variable hydraulic regime must be considered when evaluating effects of vessel passage. Our results indicate that littoral fishes are not highly vulnerable to drawdown even when our vertical drawdown distance (0.3-m maximum) exceeded the maximum vertical distance of 0.21 m measured on the Illinois River (Bhowmik, Demissie, and Guo 1981). Though the modes of dispersal of littoral fishes are adaptive to fluctuating water levels, approximately 20 percent stranding per tow passage event of some species, depending on density and mortality rates, could be detrimental to year-class strength. Factors that may contribute to stranding during vessel passage such as the initial surge wave, subsequent wave action, substrate consistency (sand versus silt), and overall shoreline topography were beyond the scope of this study. Depending on vessel characteristics (relative position, size, speed, etc.), stranding potential may be higher in very low gradient shoreline areas within constricted river channels. Field studies of stranding during tow passage events are needed to ultimately determine the effects on early life stages of fishes.

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13. ABSTRACT *(Maximum 200 words)*

Early life stages of fish in the Mississippi River system may become stranded during shoreline drawdown, induced by the passage of commercial vessels. We examined the stranding of larval shovelnose sturgeon (*Scaphirhynchus platorynchus*), paddlefish (*Polyodon spathula*), and bigmouth buffalo (*Ictiobus cyprinellus*), and of juvenile blue catfish (*Ictalurus furcatus*), largemouth bass (*Micropterus salmoides*), and bluegill (*Lepomis macrochirus*) in a laboratory flume. Stranding was measured at three vertical drawdown rates (0.76, 0.46, and 0.21 cm/s) and two bank slopes (1:5 and 1:10). Blue catfish, shovelnose sturgeon, and paddlefish were not tested at both bank slopes. Suscepti-bility to stranding varied among species and was independent of drawdown rate. At a slope of 1:5, shovelnose sturgeon had the highest stranding percentage (66.7 percent), followed by paddlefish (38.0 percent), bluegill (20.0 percent), bigmouth buffalo (2.2 percent), and largemouth bass (0.0 percent). At 1:10, blue catfish had the highest stranding percentage (26.7 percent), followed by largemouth bass (15.3 percent), bluegill (5.3 percent), and bigmouth buffalo (0.0 percent). The likelihood of stranding was related to the behavioral response of fishes to receding water levels. Species that typically occur in littoral/backwater areas swam with the current or passively drifted, while the young of main channel fishes, such as sturgeon and paddlefish, exhibited positive rheotaxis and were more likely to become stranded.

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