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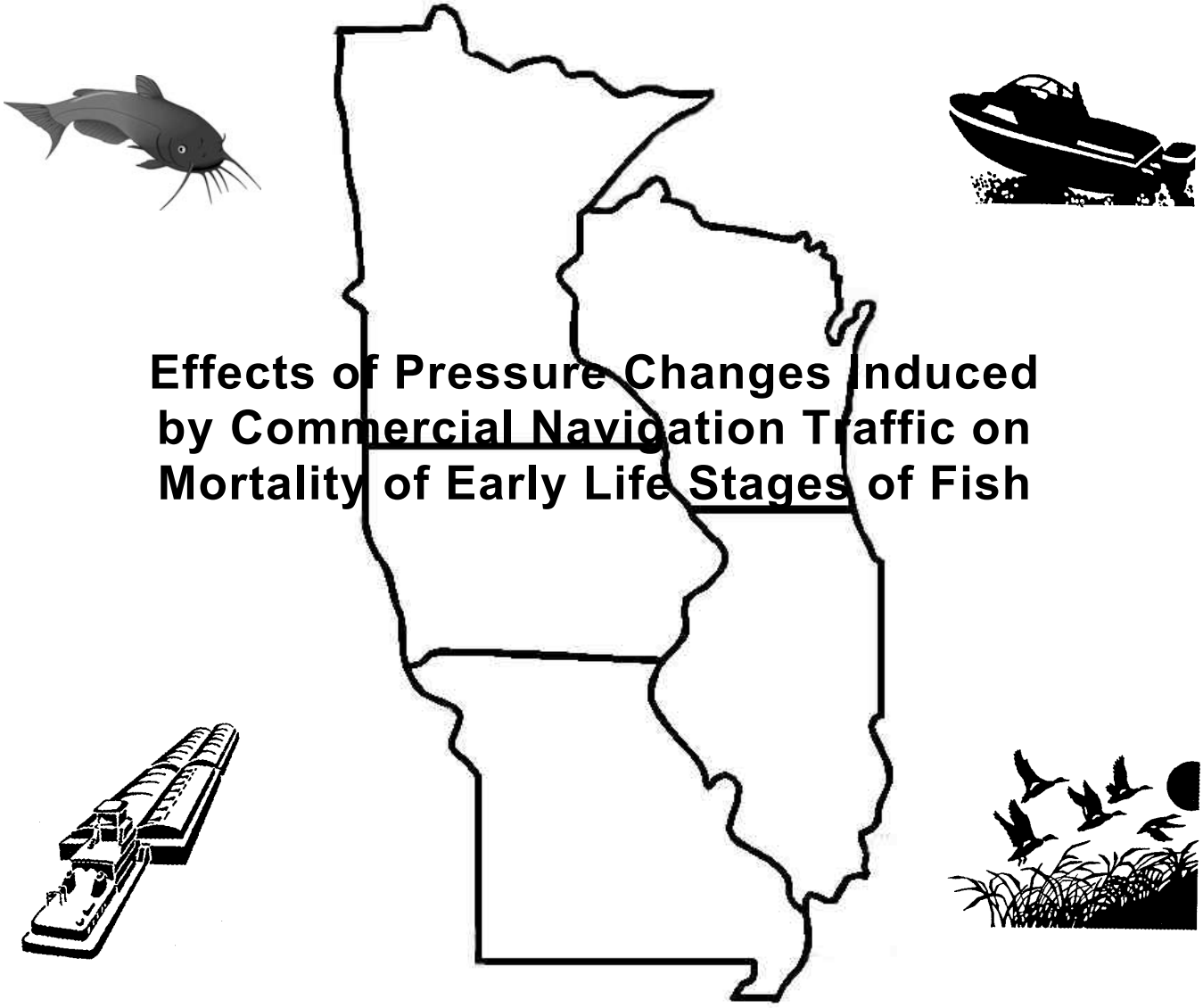
Interim Report For The Upper Mississippi River - Illinois Waterway System Navigation Study



Effects of Pressure Changes Induced by Commercial Navigation Traffic on Mortality of Early Life Stages of Fish

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Effects of Pressure Changes Induced by Commercial Navigation Traffic on Mortality of Early Life Stages of Fish

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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 of 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 will be a Feasibility Report, which will be the decision document for processing to Congress.

The work was performed by personnel of the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, and the U.S. Army Engineer District, St. Louis (MVS). This report was written by Dr. Thomas Keevin, MVS, Mr. Reid Adams, and Dr. John Killogore, Environmental Laboratory (EL), ERDC. Dr. John Keeley was Acting Director, EL.

Members of the staff of the Instrumentation Service Division, ERDC, designed and built the pressure vessel system. Mr. Wallace Guy wrote the computer operating program for the pressure vessel. Ms. Angie Haggard provided assistance in the laboratory. Fish were obtained from Osage Catfisheries, Osage Beach, Missouri, and walleye larvae were supplied by the Iowa Department of Natural Resources. Mr. David Schaeffer provided statistical assistance and reviewed a draft of this paper. Permission was granted by the Chief of Engineers to publish this document.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL James S. Weller, EN, was Commander.

1 Introduction

Commercial navigation traffic is responsible for rapid mixing of the water column (Stefan and Riley 1985). Early life stages of fish can be drawn from the surface and transported to the river bottom, resulting in increased ambient pressure, or drawn from the river bottom and moved to the surface, resulting in decreased ambient pressure. Since early life stages of fish have poor swimming capability and are fragile, they are vulnerable to rapid changes in ambient hydrodynamic pressure resulting from vertical movement within the water column (Hickey 1979; Pearson et al. 1989).

It has been suggested that towboat traffic may be responsible for larval fish mortality (Holland and Sylvester 1983; Nielsen, Sheehan, and Orth 1986). However, field evidence of direct mortality of larval fish is inconclusive because of difficulties in sampling small organisms in turbulent waters behind towboats, and also because sampling alone causes mortality. Holland (1986) studied the effects of barge traffic on fish eggs and larvae in the main channel of the upper Mississippi River. Significant mortality, based on oil globule disruption, was observed in freshwater drum *Aplodinotus grunniens* eggs but not in larval fish species collected after tow passage. Algae-filled ichthyoplankton samples prevented separation of live and dead larvae; consequently, captured larvae were preserved and examined later for signs of damage. Odom, Orth, and Nielsen (1992) studied barge-associated mortality of larval fish in the Winfield Pool, Kanawha River, West Virginia. Percentages of live larvae in samples taken before and after barge passage did not differ significantly. Laboratory studies have evaluated individual physical forces resulting from tow traffic that have the potential to cause mortality, including shear, turbulence, and shoreline dewatering (Adams et al. 1999; Holland 1987; Killgore, Miller, and Conley 1987; Morgan et al. 1976; Payne, Killgore, and Miller 1990). However, pressure has not been evaluated separately.

Teleosts have functional swim bladders as larvae, but the bladder must be filled by gulping air at the time the yolk-sac is lost (Lagler et al. 1977). Physoclistous fishes (swim bladder attached to the circulatory system allowing slow change in bladder pressure) have a pneumatic duct during their earliest stages which is subsequently lost (Lagler et al. 1977). Thus, vertical displacement in the water column will change the water pressure and affect the volume of gas in the swim bladder of larval and juvenile fishes.

If fish are rapidly moved from the bottom to the surface, the swim bladder may overinflate if gas cannot be reabsorbed or vented. Severe depressurization

may cause the bladder to burst. Pressurization will occur if fish are moved from the surface to the bottom, causing the bladder to deflate. Reinflation of the bladder will depend on behavoral response (e.g., regulping air) or rate of gas secretion into the bladder. For Atlantic herring *Clupea harengus* larvae, gas flows from the bulla to the swimbladder in approximately 30 sec (Blaxter and Hoss 1979), but this adaptation is unknown for Mississippi River fishes. Consequently, vessel-induced injury or mortality of young fishes caused by disruption of the swim bladder is speculative, but rapid changes in hydrostatic pressure have been linked to mortality of some larvae during simulated power plant entrainment (Hoss and Blaxter 1979).

A controlled laboratory study was conducted to evaluate mortality of larval fish resulting from simulated pressure changes due to water column mixing within the barge wake and the propeller wash behind towboats. Mortality of five species of fish, bigmouth buffalo *Ictiobus cyprinellus*, blue catfish *Ictalurus furcatus*, bluegill *Lepomis macrochirus*,largemouth bass *Micropterus salmoides*, and walleye *Stizostedion vitreum,* was measured. Largemouth bass and bluegills were early juveniles; bigmouth buffalo, blue catfish, and walleye were larvae.

2 Methods

Fish were obtained from a commercial hatchery and held in circulating holding tanks prior to experiments. Larvae were in the early postyolk sac phase, total lengths ranged from 7.5 to 24.2 mm (Table 1). Largemouth bass were obtained as early juveniles, ranging in size from 16.9 to 29 mm. Bluegills ranged from late larvae to early juvenile phase, juveniles having fully differentiated fins. Fish were fed Nutrafin Fry Food, *ad labitum*. Temperature of the aquaculture facilities was 20 to 22.5 ºC. Photoperiod was approximately 12 hr light, 12 hr dark.

Table 1
Mean and Range of Total Length, mm, for Species Tested (N=50)

Species	Mean	Range	S.D.
Bigmouth buffalo	10.8	7.9 – 12.6	0.93
Blue catfish	16.2	14.4 – 17.8	0.73
Bluegill	15.7	10.7 – 24.2	3.01
Largemouth bass	23.2	16.9 – 29.0	3.21
Walleye	9.2	7.5 – 10.1	0.59

The pressure vessel consisted of a steel cylinder rated to 689.6-kPa gage pressure with internal measurements of 42.5 cm in length and 30.3 cm in diameter, having a volume of 30,645 cm^3. Pressure was supplied by a compressor with gage pressure output of 100 psi (690 kPa). Pressure was regulated using a Bellofram Corporation 0- to 120-psi (0- to 827.5-kPa gage pressure) pressure regulator controlled by a Bellofram Corporation I-P current-to-pressure module. The module received input from a National Instruments Corporation analog-to-digital card No. AT-MIO16F-5. A 486 DX, 33 Mhz computer supplied instructions to operate pressure changes. The system was calibrated prior to use and produced pressure changes identical to the instructions.

Three pressure change regimes were created to simulate fish entrainment and vertical displacement within the propeller wash behind towboats. All pressure measurements are reported in absolute pressure (gage pressure + atmospheric pressure, 101.3 kPa STP) unless otherwise stated.

a. Cycle 1 - Pressure was gradually raised to 446.1 kPa over 1 hr, held for 30 min, and returned to atmospheric pressure in 5 sec.

b. Cycle 2 - Pressure was raised to 446.1 kPa within 5 sec, held for 10 sec, and returned to atmospheric pressure in 5 sec.

c. Cycle 3 - Pressure was raised to 446.1 kPa within 5 sec, held for 30 min, and returned to atmospheric pressure in 5 sec.

Cycle 1 simulated rapid depressurization of depth- acclimated fish from entrainment in towboat propwash, drawing larvae and juveniles from the river bottom and moving them to the surface in 5 sec. The 1-hr gradual pressure increase and 30-min holding time were used to acclimate fish to pressures experienced at a depth of 35.2 m, followed by a return to atmospheric pressure (surface) in 5 sec. Cycle 2 simulated rapid water column mixing and entrainment of surface-acclimated fish to pressures experienced at a depth of 35.2 m and rapid transport back to the surface. Cycle 3 simulated rapid transport of fish from surface waters to pressures experienced at 35.2 m for 30 min and rapid depressurization transport to the surface.

Fish were removed from their holding tanks using a roasting baster and placed in a 4-ℓ plastic bucket. The opening was covered with 500-µ nylon mesh and the bucket was placed in the pressure vessel. Special care was taken to remove all air bubbles from the holding bucket.

Fifty fish, replicated twice, were used for each experimental (pressure cycle) and control treatment, for a total sample size of 100 fish per treatment. With the exception of applying pressure, handling and time in pressure vessel were the same for control and experimental fishes. After each treatment, larval fish were removed from the bucket using a roasting baster and placed in a 15-cm-diam petri dish. Largemouth bass, bluegill, and walleye were placed in aerated 4-ℓ buckets. Observations of mortality were made at 1, 4, and 8 hr. Dead specimens had no heart beat. All individuals were preserved in 5 percent buffered formalin, and total lengths of 50 individuals were later obtained.

A Fisher exact test (Agresti 1990; Mehta and Patel 1995) was used for testing the equality of two binomial proportions (control dead vs exposed dead) for each exposure time period within each cycle tested. Failure to reject the null hypothesis (control mortality = exposed mortality) was accepted at $P \geq 0.05$.

3 Results

Mortality of both experimental and control larval fish was low for each species tested (Table 2). Cycle 1 mortality at 8 hr, the longest mortality observation time period, was 1 percent for bigmouth buffalo and blue catfish, 3 percent for bluegill, and 1 percent for walleye. Control mortality was 0 percent for bigmouth buffalo and blue catfish, 8 percent for bluegill, and 5 percent for walleye. Cycle 2 mortality at 8 hr was 3 percent for bigmouth buffalo, 5 percent for bluegill, and 10 percent for walleye. Control mortality was 1 percent for bigmouth buffalo and bluegill and 10 percent for walleye. There was no mortality in the blue catfish Cycle 2 experimental or control groups. Cycle 3 mortality at 8 hr was 1 percent for bigmouth buffalo, 0 percent for blue catfish, 7 percent for bluegill, and 6 percent for walleye. Control mortality was 0, 0, 4, and 5 percent, respectively. There was no mortality for any pressure cycle in both the experimental and control groups for juvenile largemouth bass.

All statistical tests on Cycles 1, 2, and 3 had probabilities of rejecting the null hypothesis > 0.1. There was no statistical evidence that the mortality rates for fish exposed to the three pressure cycles, simulating rapid changes in ambient hydrostatic pressure resulting from vertical movement of fish within the water column, were larger than for control animals. When sampling from a binomial distribution, if no events (mortality) occur, this does not mean that the proportion of events in the population is zero (Louis 1981). Rather, it sets an upper confidence bound on the number of deaths that could be observed in some future experiment. For example, there were 0/100 dead bluegill at 1 hr in Cycle 3. The upper 95 percent bound for the proportion dead in a future sample is 3.0, and the upper 99^{th} percentile for the number dead is 4.61. At 4 hr, there was one control death, and at 8 hr there were four control deaths. The latter is between the 95^{th} and 99^{th} percentiles estimated at 1 hr. Therefore, in evaluating these studies, a finding of zero deaths in the control does not mean that no deaths occured in the control population, but that no deaths were observed in the sample(s). A simple method for determining if an experimental treatment increased the mortality is to determine if the number dead exceed the 95^{th} or 99^{th} percentiles of the control distribution (Louis 1981).

Table 2
Cumulative Mortality of Experimental and Control Fish at 1-, 4-, and 8-hr Postexposure to Three Pressure Change Regimes (N=100)

	Cumulative Percent Mortality		
	1 hr	4 hr	8 hr
Bigmouth buffalo			
Cycle 1	0	0	1
Control	0	0	0
Cycle 2	0	0	3
Control	0	1	1
Cycle 3	1	1	1
Control	0	0	0
Blue catfish			
Cycle 1	0	0	1
Control	0	0	0
Cycle 2	0	0	0
Control	0	0	0
Cycle 3	0	0	0
Control	0	0	0
Bluegill			
Cycle 1	0	0	3
Control	0	1	8
Cycle 2	0	4	5
Control	0	0	1
Cycle 3	0	3	7
Control	0	1	4
Largemouth bass			
Cycle 1	0	0	0
Control	0	0	0
Cycle 2	0	0	0
Control	0	0	0
Cycle 3	0	0	0
Control	0	0	0
Walleye			
Cycle 1	0	1	1
Control	0	0	5
Cycle 2	1	8	10
Control	0	4	10
Cycle 3	0	4	6
Control	1	1	5

4 Discussion

A pressure change from 101.3 kPa (atmospheric) to 446.1 kPa, the maximum pressure differential tested, is equivalent to movement of larvae from surface waters to a depth of 35.2 m, resulting in an increased ambient pressure of 344.8 kPa (Table 3). The reverse movement of fish, from a depth of 35.2 m to the surface, represents a 344.8-kPa decrease in ambient pressure. The rapid increase or decrease of 344.8 kPa in 5 sec simulated a pressure change of 69 kPa sec^{-1}. A pressure change of 69 kPa/sec is equivalent to a vertical rate of 7 m of water column displacement per second. The maximum pressure-depth change tested did not cause significant mortality of larval or juvenile test species.

A 2.7-m-deep navigation channel is maintained by the U.S. Army Corps of Engineers in the Upper Mississippi River. The potential change in relative pressure as a result of towboat related mixing in a 2.7-m-deep channel is approximately $\pm$26.5 kPa. This value is far below the maximum pressure changes tested, indicating that pressure changes related to the rapid mixing of the water column behind towboats is not a mortality factor for these species and life stages. Higher flows and the resulting deeper depths of up to 10 m on the Upper Mississippi River are still less than one-third of the pressure change tested.

The results of this study compare with other studies which have found minimal effects of moderate pressure changes on larval fish. Beck, Poje, and Waller (1975) conducted a study exposing eggs and larvae of striped bass *Morone saxatilis* to numerous combinations of both low and high pressures to determine the role of hydrostatic pressure changes in fish mortality at a pumped-storage plant. Exposure of various egg and larval stages to subatmospheric pressure (44 kPa) resulted in a few additional deaths relative to controls. Similarly, exposure to even more extreme pressure ranges (14 kPa, followed by a return to atmospheric pressure, followed by exposure to 3,317 kPa) caused little differential mortality in these early life stages. Hoss and Blaxter (1979) exposed larval Atlantic herring *Clupea harengus* from 11 to 39 mm to both acclimation and rapid pressure increases to 5 atmospheres (506.5 kPa), followed by rapid decompression to simulate passage through the cooling water of a thermal power station. There was no evidence of increased mortality in larvae up to about 20 mm. Pressure-exposed larvae at a length of about 25 to 29 mm showed increased mortality over controls; still larger larvae did not. Blaxter and Hoss (1979) found rupturing of the pro-otic membrane of Atlantic herring when hydrostatic pressure was rapidly increased from 1 to 3 atmospheres (101.3 to 306.9 kPa) in 12- to 15-cm-long fish. Smaller juveniles and larvae were much

Table 3
Pressures (kPa) Experienced by Larval Fish with Depth, m

Depth, m	Absolute Pressure, kPa, @ STP
0	101.3
2.7[1]	127.8
3.0	130.7
5.0	150.3
10.0[2]	199.3
20.0	297.3
30.0	395.3
35.2[3]	446.1
40.0	493.3

[1] A 2.7-m navigation channel is maintained by the U.S. Army Corps of Engineers.
[2] A depth of 10 m is a typical maximum depth on the Upper Mississippi River.
[3] A depth of 35.2 m is equivalent to the largest pressure tested during this study.

less at risk. Bishai (1961) found that newly hatched herring larvae (6 to 8 mm long without bulla or swimbladder) could live at pressures as high as 5 atmospheres (506.5 kPa) and were not harmed by decompression. Kedl and Coutant (1976) passed larval bluegill *Lepomis macrochirus*, common carp *Cyprinus carpio*, white bass *Morone chrysops*, and striped bass through a simulated power plant condenser, which exposed the organism to turbulence, shear forces, and pressures ranging from about 50 to 200 kPa. Little or no mortality was observed. Ginn, Poje, and O'Connor (1978) could find no harmful effects of subatmospheric pressures as low as 53 kPa on common carp *Cyprinus carpio* larvae during passage through a simulated power plant condenser tube.

Based on the results of this study and other published studies with a variety of fish species and early life stages, it appears that the range of pressure changes experienced by early life stages during towboat mixing of the water column will not result in significant mortality.

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13. ABSTRACT ***(Maximum 200 words)***

Mortality of early life stages of fish was measured in a pressure vessel to simulate pressure changes associated with entrainment in the propwash of the towboat and subsequent vertical displacement within the water column. Mortality was measured for three pressure regimes for five fish species: larval bigmouth buffalo *Ictiobus cyprinellus,* larval blue catfish *Ictalurus furcatus,* larval walleye *Stizostedion vitreum*, early juvenile bluegill *Lepomis macrochirus*, and early juvenile largemouth bass *Micropterus salmoides*. The maximum pressure change tested, 344.8 kPa, equivalent to a 35.2-m displacement of fish within the water column, did not cause significant mortality of larvae or juveniles. Since 35.2 m exceeds depths in the Upper Mississippi River navigation channel, the range of pressure changes that could be experienced by early life stages during towboat mixing of the water column will not result in significant mortality.

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