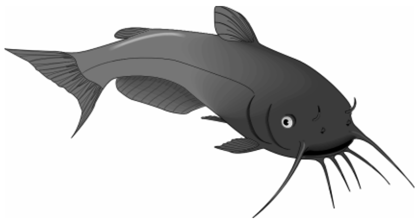
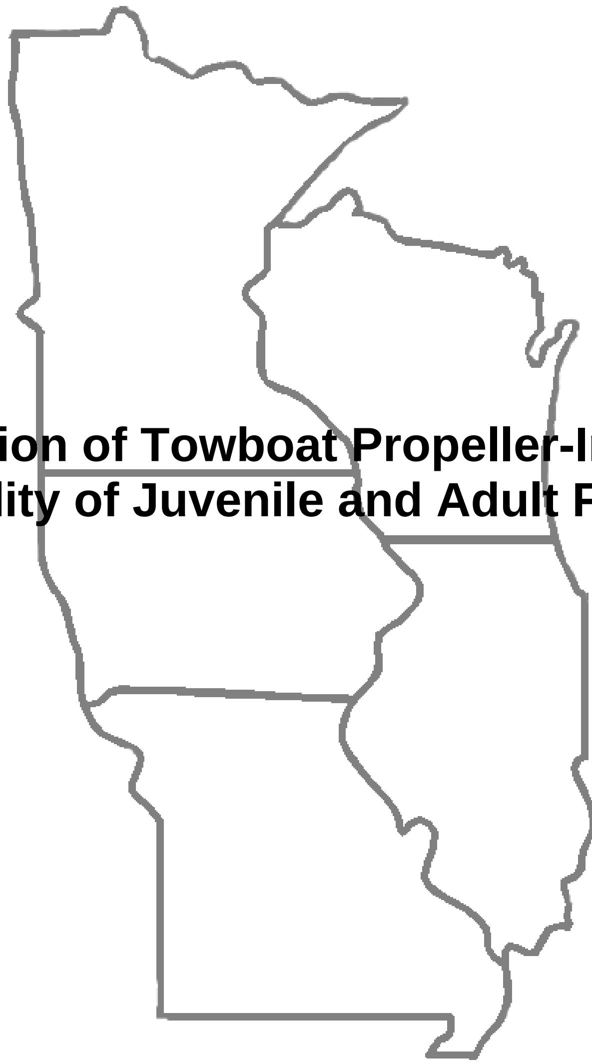
ENV Report 56

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





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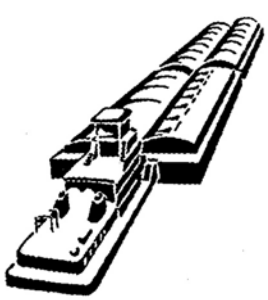

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Rock Island District
St. Louis District
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Evaluation of Towboat Propeller-Induced Mortality of Juvenile and Adult Fishes

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ABSTRACT: The number and species of fish potentially entrained through an operating towboat propeller were determined in Pool 26, Mississippi River and lower Illinois River. Fish were collected with a specially designed net deployed from a twin-screw river towboat to filter the propeller wash while withstanding turbulent forces. A total of 139, 10-min trawls were taken during four seasonal sampling periods. The mean (±SE) speed (km/h) and distance (km) traveled per trawl were 7.7 ± 0.1 and 0.82 ± 0.01, respectively. A total of 4,567 individuals, comprised of 15 species, were collected. *Clupeidae* was the dominant family, and gizzard shad (*Dorosoma cepedianum)* was the dominant species (96 percent of total catch) collected. Catches were highest in the summer, particularly in the Illinois River (13.8 ± 4.3 and 132.7 ± 44.8 fish/km in Pool 26 and Illinois River, respectively). The most common visible injuries were decapitation (80.2 percent) and ventral laceration from the anal fin to the spinal column (11.0 percent). With one exception, all injured or killed fish had visible net marks on their bodies. A 400-mm TL skipjack herring (*Alosa chrysochloris)* was decapitated, and the skull was partially crushed, suggesting it had been struck by the rotating propeller. The entrainment mortality rate is equivalent to 0.01 fish/km of towboat travel. Mortality rate of all killed or injured fish, including obvious net-induced injuries, was 0.5 and 1.0 fish/km of towboat travel for Pool 26 and Illinois River, respectively. Gizzard shad comprised the majority of dead fish, and mortality was highest during the summer sampling period. Towboat propeller mortality of juvenile and adult pelagic fish in Pool 26, Mississippi River and the lower Illinois River was low. Additional studies—using larger tows (i.e., number of barges to increase resistance) in smaller navigable channels and a smaller mesh size to avoid entrapment of fish in the webbing—are recommended to evaluate system-wide effects of mortality caused by towboat propeller entrainment.

Contents

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 report 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 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 UMR – IWW 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.

This study was conducted in the Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. The work was conducted under the direction of Dr. Edwin A. Theriot, Director, EL.

The report was written by Dr. Jack Killgore and Ms. Catherine Murphy, EL; Mr. Douglas Wolff, Elliott Bay Design Group, Seattle, WA; and Dr. Thomas Keevin, U.S. Army Engineer District, St. Louis.

Messrs. Steven George and Bradley Lewis, EL, assisted in all phases of the field study. Mr. Wendy Taylor, National Oceanic and Atmospheric Administration (NOAA), Pascagoula, MS, designed and constructed the net with assistance from Messrs. John Watson and Jack Forrester, also with NOAA. Mr. Kel Shurden, Captain Bob Nally, and Mr. Alton Walters, all of the U.S. Army Corps of Engineers, Vicksburg District, were responsible for the success in the initial deployment of the net from the Corps of Engineers towboat *Benyaurd*. Dr. Steve Maynord, Coastal and Hydraulics Laboratory, ERDC, provided technical expertise on hydraulic patterns associated with towboat propellers. Mr. Raymond Hopkins, Archer-Daniels-Midland Corporation, provided assistance in leasing the *Cooperative Venture* for this study. Captain Rennie Kienitz, Pilot John Walker, Chief Engineer Craig Guthrie, and cook Ann Brown, all with the *Cooperative Venture*, provided invaluable assistance during all

phases of the study. Dr. Jim Thomerson, retired Emeritus professor, Southern Illinois University, provided technical reviews.

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

1 Introduction

Most river towboat propellers are greater than 2.4 m in diameter and create major turbulent hydraulic forces in navigable waterways. Jet velocities from a propeller can exceed 6 m/sec (Maynord 1999), entraining high volumes of water and possibly organisms in the vicinity of the sailing line which cannot avoid the low-pressure area immediately in front of the propellers. Fish entrained through a towboat propeller can be struck by the blade and are subjected to rapid changes in pressure, shear stress, and turbulence (Cada 1990). Larval fish are susceptible to propeller entrainment, and up to 40 percent mortality has been reported for some riverine species (Killgore et al. 2001). Field investigations of direct injury and mortality of juvenile and adults from propellers, however, are inconclusive because of the difficulty and danger posed by sampling behind towboats in navigable waterways (Gutreuter et al. 2003; Odom et al. 1992).

Towboat traffic may increase as navigation improvements are implemented in the nation's waterways, with a concomitant potential increase in fish entrainment and mortality. Navigation channels have been poorly studied ecologically (Baker et al. 1991), but recent evidence indicates that main channel environments are used by a variety of species ranging from single-season users to permanent residents (Dettmers et al. 2001). However, quantifying effects of towboat propellers on this diverse group of fishes is technically and logistically challenging. In addition, capturing a wounded or dead fish with conventional trawls by trawling directly behind a moving towboat seems to be a rare event (Gutreuter et al. 2003).

The authors of this study pursued the possibility of developing a method to filter only the propwash to increase probability of capture and obtain potential mortality estimates. A net was specially-designed and constructed by NOAA (Harvesting Systems and Engineering Branch, Pascagoula, MS) to filter only towboat propwash while withstanding strong hydraulic forces created by the rudders and rotating propellers (Figure 1).

Net material was knotless Dyneema® webbing and Amsteel Blue Spectra® rope, both having the highest fiber strengths of any commercially-available material. Knotless netting presented a cleaner flow profile, reducing hydrodynamic drag thus probably reducing abrasion damage to captured fish. The feasibility of deploying the net from an operating towboat directly behind the propellers was evaluated in the Mississippi River using three empty barges and the Corps of Engineers' Motor Vessel *Benyaurd*, a twin-screw 4,300 horsepower towboat. The net performed well at all speeds and steering patterns, indicating

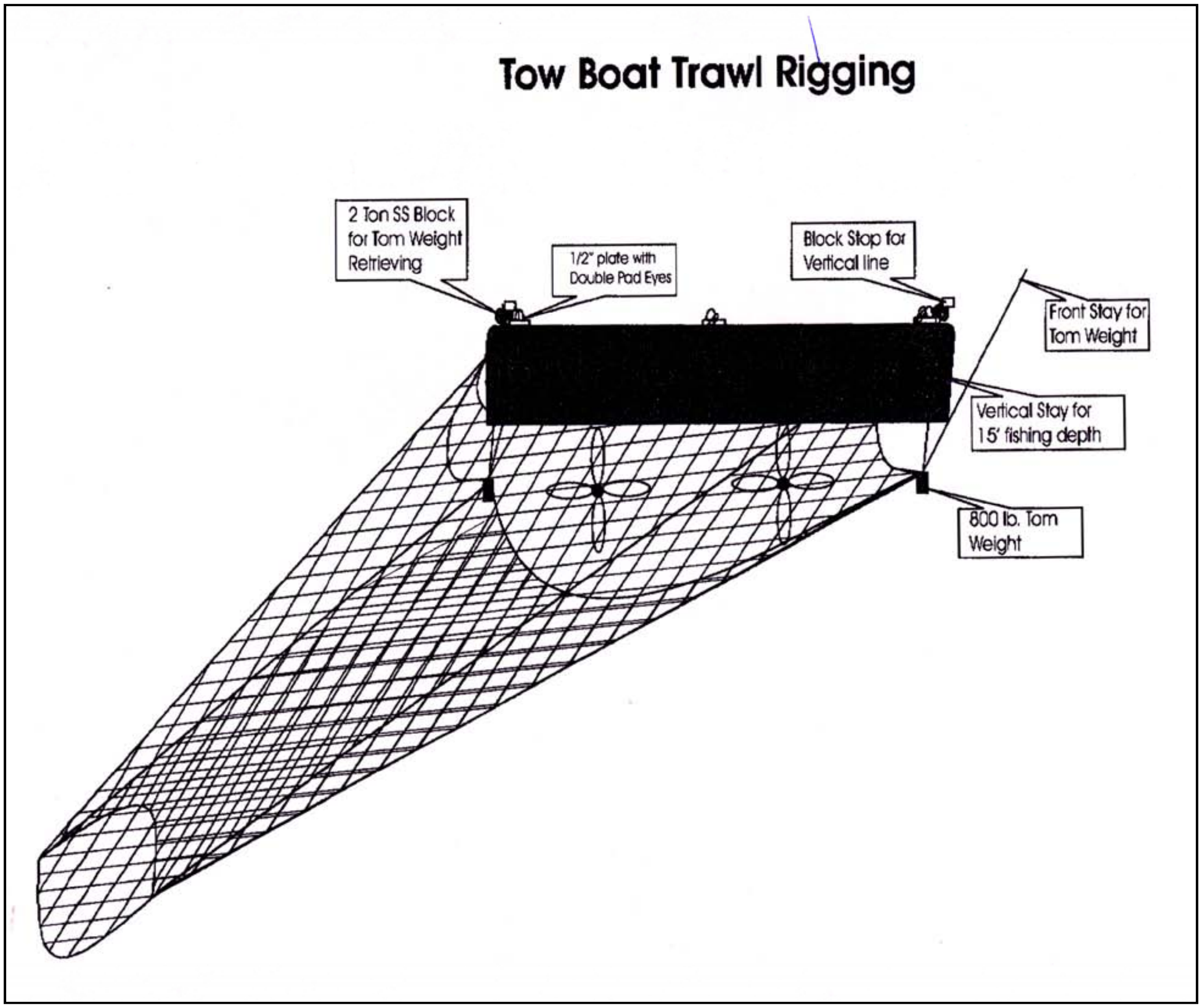

Figure 1. Schematic of the net and trawling gantry deployed from the towboat to filter propwash and entrained fish

that it was feasible to trawl directly behind an operating towboat. Consequently, an expanded field study was conducted in Pool 26, Mississippi River and the lower reach of the Illinois River to quantify the number and species of fish entrained through operating towboat propellers. This method will be used in the Upper Mississippi – Illinois Waterway Navigation Improvement study to estimate seasonal, propeller-induced mortality rates of juvenile and adult fish in the project area under different navigation traffic scenarios.

2 Methods

Pool 26 of the Upper Mississippi River and the lower reach of the Illinois River were sampled seasonally during 2002-2003 using a net specifically designed to filter only the propeller wash. Pool 26 was divided into the upper reach (river km 367 to 388), middle reach (rkm 343 to 366), and lower reach (rkm 323-365). The lower Illinois River was sampled from rkm 0 (Grafton, IL) to rkm 14. A three-barge wide arrangement, all empty, was used to create one type of a worst-case hydraulic pattern around the propellers of the moving towboat (pers. com., Steve Maynord, U.S. Army Engineer Research and Development Center, Vicksburg, MS). A light load would be less likely to displace a fish away from the vessel compared to a towboat pushing fully-loaded barges with greater draft. The towboat was moving upstream (upbound) during all sampling, except during the initial summer sample when some downstream (down-bound) samples were taken. Emphasis on upbound towboats focused on worst-case conditions since they require greater horsepower and entrain greater volumes of water. All samples were taken in daylight for safety considerations, except during the summer when crepuscular samples were taken in the Illinois River.

The net was deployed from the twin-screw towboat *Cooperative Venture*, built in 1976 by St. Louis Ship; the official number is 577069. The *Cooperative Venture*, a typical-sized towboat operating in the Upper Mississippi River, has a length of 51 m, beam width of 12 m, hull depth of 3.3 m, and a draft of 2.6 m. It has two main engines (Electro Motive Diesel 16-model 6450E6), each rated 1,500 horsepower at 850 revolutions per minute with a reduction gear ratio of 4.80:1 ahead, 4.562:1 astern. The towboat has four-blade, open-wheel (no propulsion nozzles) propellers measuring 2.6-m diameter x 2.4-m pitch, inboard turning at top. Propeller shafts are parallel to vessel baseline, resulting in a nearly horizontal propeller wake flow. The two steering rudders, one each aft of the propellers, are 3.3 m long x 2.5 m high; the four flanking rudders, forward of the propellers, are each 2.3 m long x 2.3 m high.

The net used to filter the propeller wash was designed and built by National Oceanic and Atmospheric Administration (NOAA), Pascagoula, MS. The net was constructed of 2.54-square cm (5.1-cm stretched diagonally) webbing. It measured 9.1 m wide at the mouth (head and foot rope), which was the width of the towboat transom, and was 36.6 m long with a 6.1 m long codend. After completing the first seasonal sample, the original net was slightly modified by the addition of a 4.9 m section in the codend and a 4.9 m section in the middle portion of the net to possibly reduce net impingement.

The top line (head rope) was shackled to padeyes on the corners and center line of the towboat transom. To maintain opening of the net while underway, a 363-kg Tom (i.e., bottom) weight was secured to the outboard ends of the footrope using steel chains attached to deck-mounted winches. Trawl blocks were hung from gallows-type padeyes welded to the transom corners. The Tom weights and chain hung below these blocks, which were the turning point for the trawl wire to go forward to the deck-mounted winches. Trawl winches were Dayton model 4Z327B, 115 VAC, 6 amp, with a 570:1 gear ratio. Each winch was bolted to a length of channel iron that was welded to the deck and oriented to align with the trawl block. A two-part haul-in system was arranged. Winches had adequate power for hoisting the Tom weights; however, hoist speed was marginally adequate. Winches were furnished with a clutch and free-fall option to rapidly lower the weights. To facilitate correct setup of the trawl net, connections and shackles were color-coded. Once set, the top of the net skimmed the water surface and the bottom of the net was set at approximately 2.6 m below the water surface, sampling virtually all of the water going through or adjacent to the propellers. While underway, the warps or lines attached to the Tom weights from the deck winches were approximately at a 90 degree angle relative to the long axis of the towboat, further indicating that the footrope was in-line with the bottom of the propeller blades.

To deploy the net from the towboat, a trailing boat would receive the codend from the crew, and slowly backup while the crew manually lowered the net over the transom and into the water. The crew made a special effort to grind smooth a number of rough edges on which the trawl net had regularly snagged. The towboat would remain stationary during deployment, which took approximately 20 minutes, but the pilot would occasionally engage the gears for 5-10 seconds to maintain an upstream orientation. However, the front of the net was deployed last, thus eliminating the possibility of incidental catch during deployment.

Each sample consisted of a 10-minute trawl and three to five replicate samples were taken in each reach. In the Illinois River, samples were taken the same day, whereas two days were required to complete Pool 26 samples. At the end of each timed trawl, the towboat pilot idled the vessel's engines, and the crew of the trailing boat checked the codend for fish. Fish were identified to species, measured (TL), and examined for injuries. Injuries were categorized according to position and type of wound, and condition of fins. Criteria were also established to identify age of wounds based on signs of clotting, and, if a fish was dead, the time of death. Red gills and clear eyes indicated very recent death. Length, location of river sites sampled, and vessel speed relative to earth were determined using GPS and navigation charts. In addition, ambient surface water velocity was measured with a Marsh-McBirney flow meter, and surface water quality was recorded using a HydroLab.

Catch rates were expressed three ways to accommodate future comparison of our data with other published reports on fish abundance in navigable waterways: volumetric (number per 1,000 m^3), distance traveled (number per km of towboat travel), and areal (number per ha). The volume of water filtered by the net was calculated based on a modification in Maynord (1999). Analysis of Variance (ANOVA) and the Student-Newman-Keuls (SNK) mean comparison test were used to evaluate significant differences of locational and seasonal catches (SAS Institute, Inc. 1999).

3 Results

Sampling periods encompassed the range of water temperatures that typically occur in the study area: summer (24-25 ºC), autumn (8-9 ºC), winter (0.5 ºC), and spring (17 ºC). Dissolved oxygen was greater than 7 mg/l during all sampling periods, and turbidity never exceeded 60 NTU. Mean (±SE) water velocity (cm/sec) was greater in Pool 26 (71 ± 3.6) than in the lower Illinois River (25 ± 0.8). The highest water velocity measured during the study (181 cm/sec) was in the upper reach of Pool 26 during spring.

A total of 139, 10-minute trawls were taken during the four sampling seasons (107 in Pool 26, 32 in the Illinois River). The three reaches in Pool 26 and the Illinois River were sampled in summer and autumn. However, only the lower and upper reaches of Pool 26 were sampled in winter (due to ice formation in the Illinois and middle reach of Pool 26) and spring (due to equipment problems).

Most trawls were upbound (n = 118), but during the summer and autumn sampling periods, 17 downbound samples were taken in Pool 26 and 4 in the Illinois River. Sampling was conducted during daylight, except in autumn when eight crepuscular trawls were completed. The mean (±SE) speed (kmh) and distance (km) traveled per trawl were 7.7 ± 0.1 and 0.82 ± 0.01, respectively, and these values did not appreciably vary between upbound and downbound tows. However, the engine (and therefore propeller) revolutions per minute were greater for upbound (123 ± 2) than downbound (84 ± 1) tows, and consequently, the average volume of water filtered through the nets (m^3) for each 10-min tow was also greater for upbound ($2.6 \times 10^4 \pm 0.4 \times 103^3$) than downbound tows ($1.7 \times 10^4 \pm 0.3 \times 10^3$).

A total of 4,567 individuals comprised of 15 species was collected (Table 1). *Clupeidae* was the dominant family, and gizzard shad (*Dorosoma cepedianum*) was the dominant species (96 percent of total catch). Skipjack herring (*Alosa chrysochloris*) represented 2.7 percent of the catch, and other species were less than 1 percent. Six species were collected in the Illinois River only and five species were collected in Pool 26 only (Table 1). In addition to the 15 species collected in normal trawling operations, single individuals of shortnose gar (*Lepisosteus platostomus*) and brown trout (*Salmo trutta*) were removed from the net after trawling was completed during the spring sampling period. These fish became lodged in the middle portion of the net and never entered the codend. Therefore, we were unable to determine during which trawl they were collected. Both individuals were released alive with no apparent injuries and were not used in subsequent analyses.

Table 1
Number of Individual Fish Collected in Towboat Trawl Samples by Species, Location, and Season in the Mississippi River (MS) Pool 26 and Illinois River, 2002-2003 (Upbound and downbound tows are included)

	Mississippi River Pool 26												Illinois River		All Tows
	Upper				Middle				Lower						
Scientific Name	**Sept**	**Nov**	**Jan**	**May**	**Sept**	**Nov**	**Jan**	**May**	**Sept**	**Nov**	**Jan**	**May**	**Sept**	**Nov**	
Family Acipenseridae															
Scaphirhynchus platorynchus			1												1
Family Hiodontidae															
Hiodon alosoides													1		1
H. tergisus			1		1										2
Family Clupeidae															
Alosa chyrochloris	2	1			12	1			19				79	9	123
Dorosoma cepedianum	32	13		1	530	3		1	146			18	1,285	2,350	4,379
D. petenense													14	12	26
Family Cyprinidae															
Aristichthys nobilis													1		1
Cyprinus carpio			1												1
Hypophthalmichthys molitrix													1		1
Family Catostomidae															
Ictiobus niger													1		1
I. bubalus												1			1
Family Ictaluridae															
Ictalurus punctatus															1
Family Moronidae															
Morone chrysops	1				1								11	1	14
Family Centrarchidae															
Lepomis machrochirus												1			1
Family Sciaenidae															
Aplodinotus grunniens					11			1				1	1		14
Total number of species	3	2	3	1	5	2	0	2	2	0	0	4	9	5	15
Total number of individuals	35	14	3	1	555	4	0	2	165	0	0	21	1,394	2,373	4,567
Sample size	18	9	8	2	13	7	0	8	18	8	8	8	8	24	139

Catch rate (fish/km of towboat travel) was not significantly different between upbound and downbound trawls made during the summer in Pool 26 (ANOVA: $F = 0.85$, $df = 1,48$; $P < 0.36$) and during autumn in the Illinois River ($F = 0.57$, $df = 1,22$; $P < 0.46$). However, mean catch (±SE) was higher for upbound than downbound trawls in both Pool 26 (13.8 ± 4.4 vs. 7.9 ± 3.0) and Illinois River (28.1 ± 14.7 vs. 3.6 ± 3.4). Because volume of water filtered, propeller RPM, and mean catch were substantially different between upbound and downbound trawls, and only a relatively small number of trawls were taken downbound, subsequent analysis was based solely on upbound trawls.

In Pool 26, where sampling occurred during all four seasons, fish/km of towboat travel was positively correlated (Pearson correlation coefficient = 0.56, $n = 89$; $p < 0.001$) with water temperature. The SNK test indicated that only mean summer catches were significantly ($P < 0.05$) higher (13.8 ± 4.3) among seasons. However, autumn and spring catches were similar (mean = 0.6 and 1.1, respectively), and except for three adult fish collected below Lock and Dam 25 during winter (common carp *Cyprinus carpio*, mooneye *Hiodon tergisus*, and shovelnose sturgeon *Scaphirhynchus platorynchus*), all of which were not injured, no fish were collected at water temperatures less than 1 °C. There were no significant differences in catch rates between summer and autumn in the Illinois River, although mean summer catches were substantially higher (132.7 ± 44.8 fish/km) than those of autumn (89.9 ± 63.3 fish/km).

Fish/km of towboat travel was significantly higher in the Illinois River (102.2 ± 46.6) than in Pool 26 (5.3 ± 1.7) for all seasons combined ($F = 13.9$, $df = 1,117$; $P < 0.001$). One reason for this difference was the high concentration of gizzard shad at the Grafton Ferry crossing on the Illinois River. During one trawl in autumn, 1,624 gizzard shad were collected, which was orders of magnitude greater than other trawl samples. In addition, autumn catch rates in the Illinois River were significantly ($F = 6.3$, $df = 1,18$; $P < 0.03$) higher during crepuscular sampling (66.2 ± 31.0) than day sampling (0.5 ± 0.3). This latter comparison did not include the disproportionably higher catch of gizzard shad at Grafton Ferry. In Pool 26, SNK test indicated that catch rates were significantly higher in the middle reach (15.1 ± 5.6) than the lower (2.0 ± 0.7) and upper (0.9 ± 0.2) reaches for all seasons combined. However, there was a significant ($P < 0.001$) interaction between reach and season due to higher catches in the summer.

Of the 15 species collected during the study, three species—skipjack herring, gizzard shad, and freshwater drum *Aplodinotus grunniens*—comprised of 107 individuals exhibited injuries or were dead upon collection (Table 2). All injured or killed fish were preserved and forensically examined in the laboratory. The most common visible injuries were decapitated (80.2 percent) and ventral laceration from the anal fin to the spinal column (11.0 percent). Other injuries included lateral contusions, amputated peduncle and caudal fin, and amputated operculum. One 160 mm TL gizzard shad was torn in half, and the only injured freshwater drum (148 mm TL) was decapitated. Except for one 400 mm TL skipjack herring, all injured or killed fish had visible net marks on their body. The skipjack herring was decapitated, and the skull was partially crushed suggesting it was struck by the rotating propeller.

Table 2
Mean (±SE) Catch of Fish Collected Alive and Dead in Pool 26, Mississippi River (n = 90) and Lower Illinois River (n = 28) for Upbound Tows

	Pool 26, Mississippi River						Lower Illinois River					
	No/1,000 m^3		No/km		No/ha		No/1,000 m^3		No/km		No/ha	
Species	**Alive**	**Dead**	**Alive**	**Dead**	**Alive**	**Dead**	**Alive**	**Dead**	**Alive**	**Dead**	**Alive**	**Dead**
Skipjack Herring	0.01 (0.00)	<0.01	0.2 (0.05)	0.1 (0.0)	<0.1	<0.1	0.13 (0.05)	0.01 (0.00)	2.2 (0.9)	0.1 (0.1)	0.4 (0.2)	<0.1
Gizzard shad	0.22 (0.08)	0.02 (0.01)	4.5 (1.6)	0.4 (0.1)	0.8 (0.3)	0.1 (0.0)	6.42 (3.28)	0.05 (0.02)	97.7 (46.1)	0.8 (0.3)	17.5 (8.3)	0.2 (0.1)
Freshwater drum	<0.01	<0.01	0.1 (0.1)	<0.1	<0.1	<0.1	<0.01	0.00	<0.1	0.0	<0.1	0.0
All Species	0.23 (0.08)	0.03 (0.01)	4.8 (1.6)	0.5 (0.1)	0.9 (0.3)	0.1 (0.02)	6.63 (3.31)	0.06 (0.02)	101.2 (46.5)	1.0 (0.4)	18.1 (8.3)	0.2 (0.1)

Only one (400 mm TL skipjack herring) of 4,567 fish collected during the study could be identified as being directly killed by the propeller, which is equivalent to 0.01 fish/km of towboat travel. Net-induced injuries were obvious for all other dead fish. Mortality rate of all killed or injured fish, including obvious net-induced injuries, was 0.5 and 1.0 fish/km of towboat travel for Pool 26 and the Illinois River, respectively (Table 2). Gizzard shad comprised the majority of dead fish, and mortality was highest during the summer sampling period.

Length-dependent injuries likely related to net impingement are indicated for gizzard shad (Figure 2). Total length of gizzard shad ranged from 71 to 368 mm (median=120 mm). The number of decapitated gizzard shad was greatest for the smallest size group (<125 mm) collected during the study, but rapidly decreased for larger fish. The heads of injured fish, still attached to the body, were often caught in the webbing and would become detached during removal from the codend. Body width is greatest immediately posterior to the head, and this was the location of net impingement for the smaller size class. Maximum body depth of gizzard shad <125 mm TL collected during the study ranged from 20 to 30 mm, making them susceptible to impingement in nets constructed of 25-mm mesh.

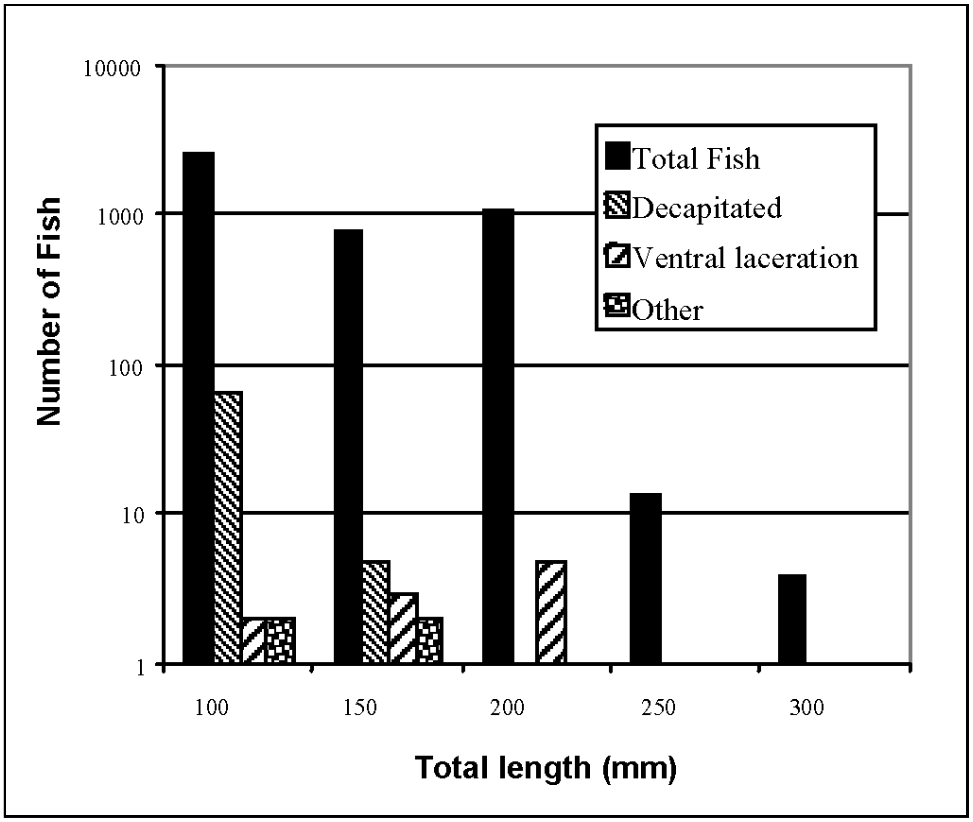

Figure 2. Size distribution (midpoint of class interval) of all gizzard shad (*Dorosoma cepedianum*) and those with visible injuries likely caused by net impingement determined from trawls deployed behind a tow-boat in the Pool 26, Mississippi River and the lower Illinois River

4 Discussion

Our sampling indicates that gizzard shad are the main inhabitants of the navigation channel in Pool 26, Mississippi River and the lower Illinois River susceptible to propeller entrainment. Gizzard shad abundance in the navigation channel peaks during the summer, declines during autumn, and is virtually absent during winter. An anomaly was the disproportionately high abundance of gizzard shad at the Grafton Ferry crossing during autumn. Gizzard shad may prefer ferry crossings for several reasons. First, ferry boats resuspend sediments that can be ingested by foraging gizzard shad. Second, ferry crossings are usually deep, and in the Illinois River, velocities are lower than in shallower reaches. Thus, deep slackwater periodically disturbed by towboat propellers would be an optimal foraging area for gizzard shad. Seagulls, hawks, and eagles were concentrated at the Grafton Ferry Crossing, foraging on shad as the ferry crossed the river. The upwelling of water from turbulent propeller action probably moves gizzard shad close to the surface making them more vulnerable to bird predation.

Other species that occur in the navigation channel were considerably less abundant, and consequently, less likely to become entrained in the propeller wash. Pelagic species would be more susceptible to propeller entrainment than benthic fish, but skipjack herring was the only other pelagic species collected in moderate abundance. Dettmers et al. (2001) reported relatively high abundances of smallmouth buffalo, channel catfish, and freshwater drum using benthic trawls. In our study, however, benthic species were rarely collected, and those that were did not display propeller-type injuries. Differences in species composition and catch rates between the studies can be attributed to different collecting techniques.

Our study suggests that instantaneous mortality of fish entrained through towboat propellers is minimal in Pool 26 and the lower Illinois River, and only gizzard shad appear to be susceptible to entrainment in any measurable number. The only other study that measured juvenile and adult fish mortality rates was reported in Gutreuter et al. (2003), which collected fish by trawling behind towboats. This study estimated gizzard shad mortality rates of 2.52 fish/km of towboat travel (80 percent confidence interval, 1.00-6.09) compared to 0.8 fish/km determined in our study when including net-damaged fish. Estimates for skipjack herring (0.1 fish/km) were similar between the studies. However, Gutreuter et al. (2003) also reported towboat entrainment mortality for smallmouth buffalo and shovelnose sturgeon. We also captured these species, but with the exception of one smallmouth buffalo with frayed fins, they were uninjured and released alive.

A number of similar-sized shad (approximately 100 mm total length) had injuries apparently caused by the net, including mesh-imprinted markings and decapitation from the head being caught in the webbing. The length of the net was maximized to the extent possible to avoid net-induced injuries, but the extremely high jet velocities from the propellers (>6 m/sec, Maynord 1999) and the upstream movement of the vessel has the potential to impinge captured fish against the net. We observed numerous small gizzard shad with their heads caught in the webbing during retrieval of the codend. Decapitated gizzard shad were not apparent for larger individuals whose body depths exceeded the net mesh size. Delayed mortality, which was not measured in our study, is also a possibility. Separating injuries sustained from the propeller and the net is problematic when estimating mortality rates. We cannot discount the probability that decapitated or mesh-imprinted gizzard shad were killed by the propeller and then impinged on the net causing additional injury or markings on the body. Therefore, the mean entrainment mortality of upbound tows in our study ranged from 0.01 fish/km of towboat travel (n = 90, Pool 26), assuming that the single skipjack herring collected in Pool 26 directly struck by the propeller represented the only death, to 1.0 fish/km when including net-induced injuries for all samples and locations (n = 118).

Annual entrainment mortality of gizzard shad can be estimated from extant data. In Pool 26, the maximum mortality rate for gizzard shad in our study was 0.5 fish/km of towboat travel, and, assuming an average of 3.1×10^5 km of towboat travel per year (Gutreuter et al. 2003), approximately 1.6×10^5 gizzard shad are killed per year by towboat propellers or net impingement. Gutreuter et al. (2003) reported 1.5×10^7 gizzard shad in Pool 26; therefore, using our estimates which include fish with net injuries, less than 1 percent of the gizzard shad population is potentially killed by towboat propellers. Seasonal mortality rates were not considered in these estimates; however, based on our sampling, pelagic fish species were most abundant in the warmer months and absent in the channel during winter when water temperatures drop below 1 ºC. Thus, as water temperatures increase, the potential of fish subjected to propeller entrainment also increases.

Although entrainment mortality was negligible in Pool 26, it was slightly higher in the Illinois River where the channel is narrower. This suggests that pelagic fish inhabiting smaller navigation channels are more susceptible to entrainment because they may be more concentrated and confined. However, effects of propeller entrainment mortality on the population density of gizzard shad are unlikely, due to their high standing crops and reproductive potential in navigable channels. Larger, benthic species were not directly injured by the propeller during our study, but we cannot assume that towboats operating during spring spawning movements, night movements through the channel, or low water during the summer and fall months, particularly in smaller channels, will not entrain benthic species. If benthic or other pelagic species with relatively low standing crops or low recruitment potential (e.g., mooneye, shovelnose sturgeon) were entrained and killed by the propeller, effects on population size would be greater. Further studies in small, shallow navigation channels are needed to identify the risk of entraining benthic species.

Our study demonstrated that a net deployed from an operating towboat is a feasible method to estimate propeller entrainment rates in navigable waterways. The net can withstand extremely high velocities and turbulence, it can be adjusted to filter only the propwash during different operating conditions, and the trawling equipment (gallows and winches) is relatively simple to set up on the towboat. Most fish apparently pass through the propellers without being struck and then become entrained in upwelling turbulent water. However, these results are based on a limited daytime study in two reaches of the Upper Mississippi River. In addition to night sampling, greater geographical coverage is required to evaluate system-wide effects of towboat propeller entrainment using a larger number of tows to increase resistance and higher engine speeds, and smaller mesh to avoid entrapment of fish in the webbing.

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14. ABSTRACT

The number and species of fish potentially entrained through an operating towboat propeller were determined in Pool 26, Mississippi River and lower Illinois River. Fish were collected with a specially designed net deployed from a twin-screw river towboat to filter the propeller wash while withstanding turbulent forces. A total of 139, 10-min trawls were taken during four seasonal sampling periods. The mean (±SE) speed (km/h) and distance (km) traveled per trawl were 7.7 ± 0.1 and 0.82 ± 0.01, respectively. A total of 4,567 individuals, comprised of 15 species, were collected. *Clupeidae* was the dominant family, and gizzard shad (*Dorosoma cepedianum)* was the dominant species (96 percent of total catch) collected. Catches were highest in the summer, particularly in the Illinois River (13.8 ± 4.3 and 132.7 ± 44.8 fish/km in Pool 26 and Illinois River, respectively). The most common visible injuries were decapitation (80.2 percent) and ventral laceration from the anal fin to the spinal column (11.0 percent). With one exception, all injured or killed fish had visible net marks on their bodies. A 400-mm TL skipjack herring (*Alosa chrysochloris)* was decapitated, and the skull was partially crushed, suggesting it had been struck by the rotating propeller. The entrainment mortality rate is equivalent to 0.01 fish/km of towboat travel. Mortality rate of all killed or injured fish, including obvious net-induced injuries, was 0.5 and 1.0 fish/km of towboat travel for Pool 26 and Illinois River, respectively. Gizzard shad comprised the majority of dead fish,

(Continued)

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14. Abstract (Concluded)

and mortality was highest during the summer sampling period. Towboat propeller mortality of juvenile and adult pelagic fish in Pool 26, Mississippi River and the lower Illinois River was low. Additional studies—using larger tows (i.e., number of barges to increase resistance) in smaller navigable channels and a smaller mesh size to avoid entrapment of fish in the webbing—are recommended to evaluate system-wide effects of mortality caused by towboat propeller entrainment.