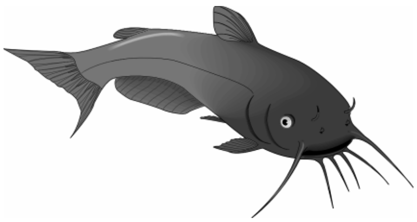
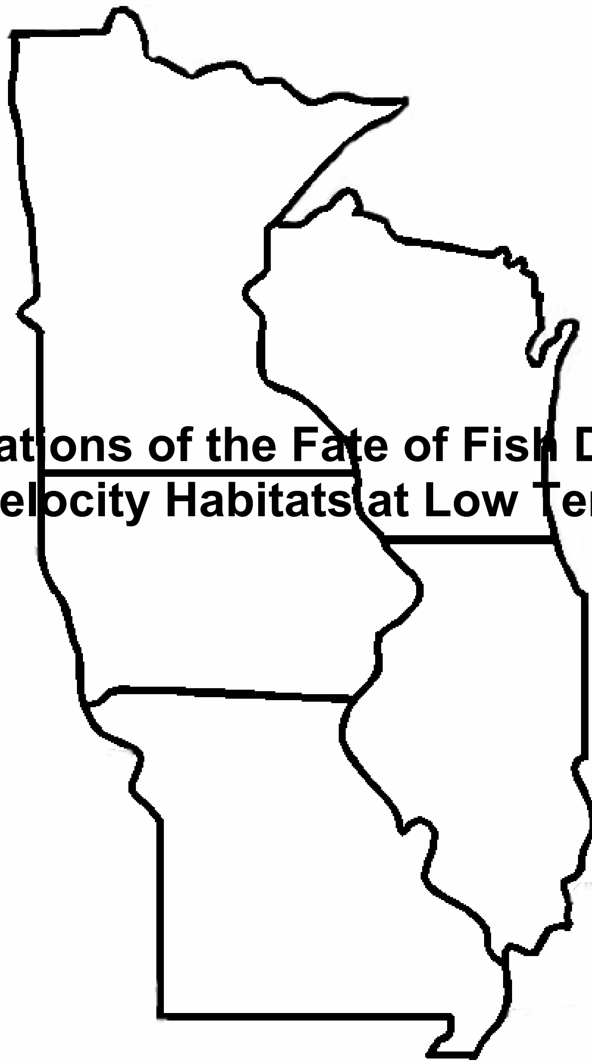
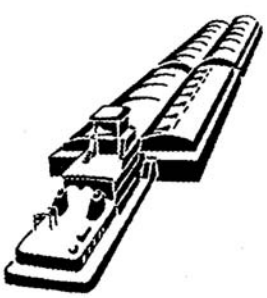
ENV Report 32

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



Determinations of the Fate of Fish Displaced from Low-Velocity Habitats at Low Temperatures





June 2004

Rock Island District
St. Louis District
St. Paul District

US Army Corps of Engineers

Upper Mississippi River - Illinois Waterway System Navigation Study

ENV Report 32
June 2004

Determinations of the Fate of Fish Displaced from Low-Velocity Habitats at Low Temperatures

Robert J. Sheehan, Paul S. Wills, Michael A. Schmidt, Joseph E. Hennessy

Cooperative Fisheries Research Laboratory
Southern Illinois University
Carbondale, IL 62951-6511

Interim report

Prepared for U.S. Army Engineer District, Rock Island
Rock Island, IL 61204-2004
U.S. Army Engineer District, St. Louis
St. Louis, MO 63103-2833
U.S. Army Engineer District, St. Paul
St. Paul, MN 55101-1638

ABSTRACT: The purpose of this study was to ascertain whether young-of-the-year bluegill, *Lepomis macrochirus*, channel catfish, *Ictalurus punctatus*, or walleye, *Stizostedion vitreum*, utilize low-velocity habitats at low water temperatures (0, 2, and 4 °C), and whether displacement from the habitats they select affects their behavior or survival. The results of this study are to be used to determine whether the effects of navigation traffic increases on wintering fish need to be explored more thoroughly.

Four circular tanks, 1.8 m in diameter and 1.2 m deep, were modified to serve as model rivers and simulate the river environment. Water jets were used to provide a circular water flow pattern. Each model river had three wing dams and three scour holes which provided low-velocity habitats. Intermediate-velocity back eddies occurred upstream of the wing dams. Velocities were highest between the tips of the wing dams and the perimeter of the model rivers, and relatively high velocities occurred around the remainder of the perimeter of the circular model rivers.

Four displacement frequencies were tested using temperature-acclimated fish: (1) no displacement (control), (2) a single displacement on day 0 (low frequency), (3) displacement every other day (medium frequency), and (4) daily displacement (high frequency) for 10 days. Displacement was accomplished by moving all test fish into high-velocity areas of the model raceways via a seine. Trials were conducted at 0, 2, and 4 °C. Each displacement frequency and temperature was evaluated in triplicate. All species tested were placed and evaluated together in model rivers during trials.

The walleye did not survive well during acclimation to test conditions in the model rivers, so tests were completed with bluegill and channel catfish only. Model rivers had 15 bluegill and 15 channel catfish per replicate when acclimation was initiated.

Bluegill and channel catfish used the two low-velocity habitats almost exclusively at all three test temperatures ($p < 0.0001$), even though low-velocity habitats comprised only about 20 percent of the available habitat. This preference for low-velocity habitats is essential to the basic premise of the study; namely, displacement from low-velocity habitats due to increases in navigation traffic may diminish survival in wintering fish.

Displacement frequency had a significant effect on cumulative mortality for bluegill and channel catfish ($p < 0.0001$). Cumulative mortality during the trials differed for channel catfish and bluegill ($p < 0.0001$), and total mortality was higher for channel catfish at all three test temperatures. Cumulative mortality was also affected by temperature ($p < 0.0001$). A significant interaction between displacement frequency and species ($p > 0.2$) was not detected. This indicates that mortality for the two species responded in the same manner to increased displacement frequency. However, mortality intensity was greater for channel catfish. Total mortality across all displacement frequencies was similar within species at 0 and 2 °C, but lower at 4 °C. There was a significant interaction between displacement frequency and temperature ($p < 0.0260$). Inspection of the cumulative mortality distributions for channel catfish and bluegill at 4 °C showed there was no clear trend in mortality in relation to displacement frequency. However, cumulative mortality for the control and low-frequency displacement regimes was less than cumulative mortality for the medium- and high-displacement frequency regimes for channel catfish and bluegill at 2 and 0 °C.

Although displacement frequency had a significant effect on mortality at temperatures at or below 4 °C, the data did not indicate any differences between the no-displacement and low-displacement frequency treatments, nor between the medium- and high-frequency displacement treatments. This can be interpreted in either of two ways. Mortality may increase as a function of displacement frequency in actuality, but mortality rate did not differ for all four of the displacement frequencies due to Type II statistical error (i.e., failing to reject the null hypothesis when it is false). Alternatively, a displacement frequency threshold exists, above which mortality is increased. If the latter is true, then it appears that displacement frequencies greater than once in 3 days can increase mortality in young-of-the-year bluegill and channel catfish.

Contents

List of Figures

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, 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 and to consider ecosystem restoration needs related to the navigation system. The study will determine the location and appropriate sequencing of potential navigation and improvements and ecosystem restoration measures in 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 report was written by Messrs. Robert J. Sheehan, Paul S. Wills, Michael A. Schmidt, and Joseph E. Hennessy, Cooperative Fisheries Research Laboratory, Southern Illinois University, Carbondale, IL.

1 Introduction

One concern regarding the effects of increased commercial navigation on fish is the hydraulic disturbance caused by vessel passage. Fish may react to hydraulic disturbance by changing location volitionally or they may be physically displaced by vessel-induced turbulence. There is strong evidence that such effects would have the greatest impact on fish during the winter.

Many Upper Mississippi River (UMR) fishes, especially young-of-the-year (YOY), require low-velocity habitats for overwintering due to their diminished swimming ability at temperatures less than 4 °C (Sheehan et al. 1990a; 1990b). Low-velocity habitats in river channels include the downstream side of wing dams and the scour holes at the distal ends of wing dams (Logsdon 1993), scour holes or sand ridges in channels (Stang and Millar 1985), and downstream of any other structures which obstruct water currents. There is considerable evidence that these are preferred winter habitats for many river fishes (Hawkinson and Grunwald 1979; Hesse and Newcomb 1982; Logsdon 1993; Lubinski 1985; Newcomb 1989; Stang and Nickum 1985; Talbot 1982).

Barge passage in the Illinois River caused displacement of adult channel catfish occupying main channel border habitats and forced YOY gizzard shad to the surface (Todd et al. 1989). If vessel passage displaces fish from low-velocity habitats, many species seemingly would not possess sufficient swimming ability at winter temperatures to cope with channel velocities (Sheehan et al. 1990a). Lubinski (1985) noted that even large channel catfish displaced from low-velocity habitats at winter temperatures lost volitional control over swimming and began to drift with the current. High numbers of Upper Mississippi River fishes are known to enter the “river drift” during the winter under certain circumstances, and their fate is unknown (Bodensteiner and Lewis 1994). They could continue to drift with the river current or actively or passively find and utilize another low-velocity habitat. If the former is the case, survival is doubtful; loss of volitional control over swimming is the standard endpoint used in acute temperature tolerance tests (Paladino et al. 1980), and risks to vessel propeller entrainment, predation, and other lethal factors would greatly increase. If fish find and utilize another low-velocity habitat after displacement, then increases in traffic levels may have little additional effect on overwintering fish.

On the other hand, the low temperatures, 0 to 4 °C, found in river channels during the winter can be lethal in and of themselves. Mortality in some YOY river fish species has been shown to be inversely related to water temperature at $\leq$4 °C and directly related to duration of exposure (Sheehan et al. 1990a).

Displacement from low-velocity habitats may further tax the ability of fish to cope with the physiological challenge of low water temperature, thereby causing mortality to increase.

Thus, there is a need to investigate whether YOY river fishes do indeed choose low-velocity habitats at winter water temperatures. If they do, then there is also a need to determine fate when displaced from low-velocity habitats and to determine whether fate is related to frequency of displacement, because increases in navigation traffic may be linked to increases in displacement from low-velocity habitats. Additionally, a need exists to determine if fate of fish displaced from low-velocity habitats is a function of water temperature.

It is reasonable to suggest that current commercial traffic levels may already influence the suitability of low-velocity habitats for overwintering fish in or adjacent to the navigation channel. However, there are several situations when increased traffic could further reduce the suitability of low-velocity habitats currently used by fish for overwintering. The first is the increase in probability that a particular low-velocity habitat will be subjected to vessel-passage turbulence; because every vessel travels a unique course through the channel, the probability that a vessel will pass over or near a particular location in the main channel increases as traffic increases. The magnitude of the exposure dose will also be influenced by traffic levels because the severity of hydraulic disturbance is a function of the distance from the vessel. More vessels mean an increased likelihood that some vessels will pass closer to a particular low-velocity habitat. Other quantitative factors directly related to traffic levels are frequency and duration of exposure; duration would increase due to increases in the frequency of overlapping vessel-passage events. Thus, the frequency and duration of exposure would be proportional to traffic levels.

Qualitative differences in traffic patterns resulting from increases in traffic could also affect wintering fish. Vessels would encounter oncoming vessels more frequently as traffic increases, resulting in more lateral use of the navigation channel, bringing more channel locations in the margins of the channel, such as wing dams, in proximity to vessel passage. Low-velocity areas near wing dams are known to be used by overwintering fish (Hesse and Newcomb 1982; Logsdon 1993).

Any loss of fish wintering habitat due to increases in navigation traffic cannot be extrapolated to the effects on fish populations at this time because too little is known about large river fish population abundances and dynamics. It is also not realistic to attempt to relate losses of YOY fish due to displacement from low-velocity wintering habitat to the equivalent adults framework. The technical difficulties in collecting sufficient biological data for this purpose during the winter, as well as the accompanying expense, preclude this approach. However, a framework based on habitat loss is feasible and desirable because (a) the amount of overwintering habitat lost or degraded can be estimated, and (b) mitigation of said loss is attainable through ongoing U.S. Army Corps of Engineers activities. Specifically, new or renovated wing dams can be designed to enhance and/or increase low-velocity, fish overwintering habitat. Side channels can be modified to enhance overwintering habitat by building hard structures that will promote the scouring out of holes during periods of high flow. These holes could then protect wintering fish from river currents, and they may stratify and provide the warmer water temperatures that many fish appear to seek during the winter. Also, increasing flows through side channels via bendway weir construction or other modifications should promote greater utilization. Fish in side channels would be much less susceptible to any of the direct impacts of vessel passage than their counterparts in navigation channels. Thus, the habitat lost framework is amenable to in-kind mitigation.

The purpose of this study was to ascertain whether YOY bluegill, *Lepomis macrochirus*, channel catfish, *Ictalurus punctatus*, and walleye, *Stizostedion vitreum*, utilize low-velocity habitats at low water temperatures (0, 2, and 4 °C), and whether displacement from the habitats they select affects their behavior or survival. The results of this study are to be used to determine whether the effects of navigation traffic increases on wintering fish need to be explored more thoroughly.

2 Materials and Methods

Test Fish

YOY channel catfish (total length (TL) 105 to 175 mm; 9.7 to 48.7 g), bluegill (TL 78 to 141 m; 3.4 to 59.9 g), and walleye (TL 127 to 180 mm; 12.5 to 42.7 g) were used in the tests. The walleye were obtained from Jake Wolf Memorial Fish Hatchery, Sandridge, IL. Bluegill were obtained from Fountain Bluff Fish Farm, Gorham, IL. Channel catfish were obtained from Logan Hollow Fish Farm, Gorham, IL.

The fish were initially held in a water-reuse raceway system at temperatures ranging from 10 to 15 °C and fed a maintenance ration of Silvercup™ Floating Trout Feed daily. The day-night cycle was held at 8:16 hr light:dark; this light/dark cycle was also used during the experimental trials. Prior to each experimental trial, 80 channel catfish, 80 bluegill, and 45 walleye were transferred to a 1.2-m-diam circular temperature tempering tank. Temperature was then reduced in the tempering tank at a rate of 2 °C /day until 7 °C was reached. Temperature was reduced at a rate of 1 °C /day thereafter. Once 4 °C was attained, 15 channel catfish, 15 bluegill, and 9 walleye were transferred to each of the four model rivers used in the trials. In the 0 and 2 °C experiments, the acclimation process continued at a rate of 1 °C/day in the model rivers until the test temperature was reached. Once the test temperature was attained, the fish were held for 2 days for acclimation to test conditions before the experiments began. Although several attempts were made, walleye did not survive acclimation to test temperatures; therefore, they were not evaluated.

Model Rivers

Model river systems (Figure 1) were used to determine whether test fish utilized low-velocity habitats at 0, 2, and 4 °C and whether displacement from low-velocity habitats would adversely affect them. Four 1.8-m-diam, 1.2-m-deep circular tanks were used as model rivers. Each model river had three equidistantly spaced water jet manifolds that established a circular water flow pattern in much of the model river. Three equidistantly spaced structures designed to simulate wing dams were built into the model rivers, each located immediately downstream of a water jet. A false bottom was placed in each model river that elevated most of the bottom by 15 cm. To simulate a scour hole, the false bottom was molded into a 15-cm depression at the distal tip of each wing dam. The scour

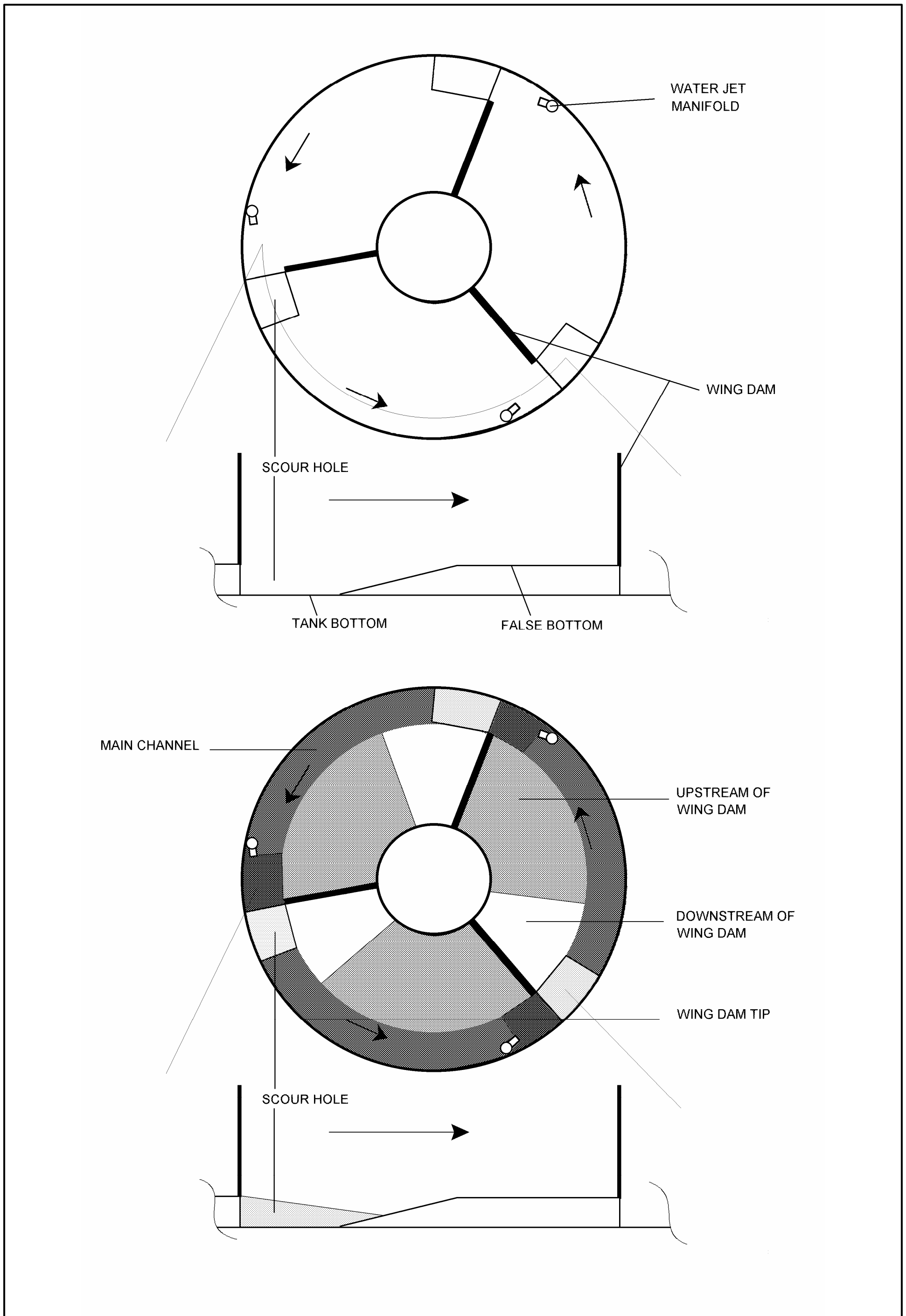


Figure 1. Top and longitudinal section views of model raceways showing placement of wing dams, scour holes, and water jets (upper), and habitat classifications based on water velocity (lower). Shading intensities are indicative of the velocity magnitudes. Wing dam tips and the main channel were considered high-velocity habitats; downstream of wing dams was considered intermediate velocity. The lightly shaded area in the top and longitudinal views in the lower diagram indicate the area considered to be the scour hole; fish in the water column above the shaded area were considered to be in the wing dam habitat

holes and wing dams (downstream) provided low-velocity habitats. Intermediate-velocity back eddies existed upstream of the wing dams. High-velocity areas occurred around the entire periphery of the model river, referred to as the “main channel,” with the highest velocities at the tank periphery adjacent to wing dam tips (Figure 1). River gravel was spread uniformly across the bottom of each model river. Each model river was coupled to its own water-reuse/biofiltration system. A 1.5-hp pump was used to pump water through the water jet manifolds. Water drained from the model rivers through a central standpipe via gravity flow to the biofiltration system.

The water jets provided water velocities as high as 1 m/s in high flow areas (near the wing dam tips); mean velocities at the wing dam tips ranged from approximately 0.6 to 0.8 m/s. Velocities were 0 m/s or slightly above in the lowest flow areas (behind the wing dams and in the scour holes). Velocities were about 0.05 m/s in the areas upstream of the wing dams (Figure 2).

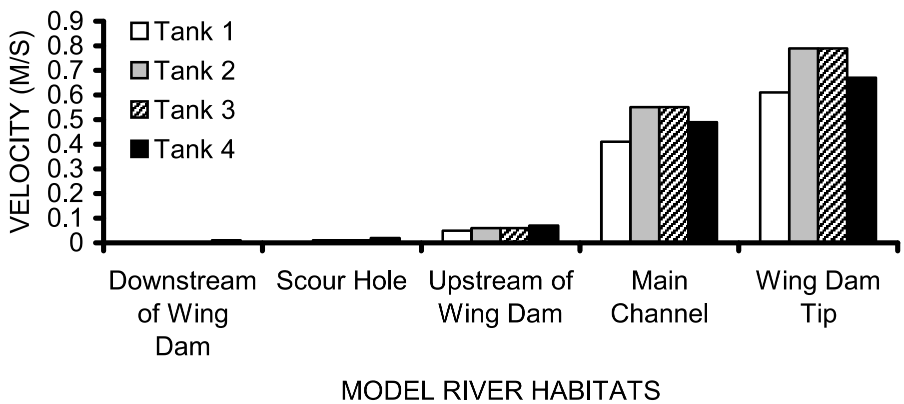


Figure 2. Mean water velocities in model river habitats

Temperature was manipulated during pre-trial acclimation periods and maintained during the trials in each model river by two 1-hp immersion-type chilling units and a microprocessor-controlled thermostat. Ammo-lock^{TM} ammonia detoxifying solution was added as needed to maintain total ammonia below 0.5 mg/L. Un-ionized ammonia did not exceed 0.0006 mg NH_3-N/L during the trials. Complete water changes were made after each series of three experimental trials.

Displacement from Low-Velocity Habitat Tolerance Tests

At the end of the acclimation period in the model rivers, each fish was observed and its condition and habitat choice recorded. The displacement regimes were then initiated. Water temperature was measured and recorded daily, and water quality was monitored every 5 days.

Tolerance to displacement from low-velocity habitat tests were conducted at 0, 2, and 4 °C, with three replicate trials per temperature and displacement frequency. Four displacement from low-velocity habitat frequencies were tested:

- No displacement (control).
- A single displacement on day 0 (low frequency).
- Displacement every other day (medium frequency).
- Daily displacement (high frequency).

All four displacement frequencies were evaluated, one displacement frequency per model river, in each trial. All three species were tested together in each model river in the 0 and 2 °C trials. Walleye were not evaluated at 4 °C, so only bluegill and channel catfish were tested (together) at 4 °C. The 4 °C trials were conducted first, the 0 °C trials second, and the 2 °C trials last. The displacement frequencies were rotated among model rivers after each trial to counterbalance tank (model river) effects. Each trial lasted 10 days.

Fish were displaced by pulling a small Vexar™ seine through low-velocity areas in the model rivers, such that all fish were moved into the high-velocity areas around the peripheries (Figure 1). Mortalities in all model rivers were recorded daily.

All fish were observed prior to each displacement, immediately after displacement, and every 5 min thereafter, for a total of 20 min post-displacement. Observation was facilitated by use of a cylindrical, clear plexiglass 7.5-cm-diam viewing tube. Locations of fish within the model rivers were classified as main channel (high velocity), wing dam tip (high velocity), scour hole (low velocity), downstream of wing dam (low velocity), and upstream of wing dam (intermediate velocity). The water flow pattern upstream of the wing dams can be best described as a back eddy, with the highest velocities occurring in an upstream direction (Figures 1 and 2).

Data Analyses

Fish position information from control groups is reported because this study was based on the premise that the test fish would choose the low-velocity habitats. Mortality data are reported for all treatments. Mortality yielded the most compelling information in regard to the treatment effects, both temperature and frequency of displacement from low-velocity habitats.

Using the SAS statistical software package General Linear Models (GLM), an analysis of variance (ANOVA) for cumulative mortality determined whether differences occurred among the main treatment effect, displacement frequency, temperature, and species. This analysis was also used to probe whether any interactions were occurring between the three treatment effects. A priori orthogonal contrast coding was used to determine where differences occurred within the levels of the treatment effects. Trend analysis was used to determine the nature of trends in the data. ANOVA was also used to determine whether the control fish selected the low-, intermediate-, or high-velocity habitats.

3 Results and Discussion

Results

Very few walleye survived the acclimation period in the model rivers. Several attempts were made to acclimate them to the test conditions, but survival was poor in all cases. Almost all of the bluegill survived the acclimation period at all three test temperatures. All channel catfish survived acclimation to 4 °C. However, only 55 percent of the channel catfish survived the acclimation period at 2 °C, and 43 percent survived acclimation at 0 °C (Table 1). Better survival for the bluegill, as compared to channel catfish, was not anticipated, but low-temperature mortality is inversely related to temperature and directly related to duration of exposure in YOY fish (Sheehan et al. 1990a). Due to the inability to acclimate a sufficient number of walleye to the test conditions, the effects of displacement from low-velocity habitats was analyzed for bluegill and channel catfish only.

Table 1
Mean Number of Channel Catfish (CC) and Bluegill (BG) That Survived the Acclimation Period in the Model Rivers Used in the Frequency of Displacement from Low-Velocity Habitats Tests (all model rivers were stocked with 15 CC and 15 BG at the beginning of the acclimation period)

Displacement Frequency	Species	0 °C		2 °C		4 °C	
		Mean	SD	Mean	SD	Mean	SD
Control	CC	8.7	7.0	9.7	3.8	15.0	0.0
	BG	14.3	0.5	15.0	0.0	15.0	0.0
Low	CC	6.0	2.9	10.0	2.9	15.0	0.0
	BG	14.3	0.9	14.3	0.9	15.0	0.0
Medium	CC	6.0	2.8	6.7	4.0	15.0	0.0
	BG	15.0	0.8	14.7	1.7	15.0	0.0
High	CC	5.0	4.3	7.0	3.6	15.0	0.0
	BG	14.7	0.5	13.7	1.2	15.0	0.0
All Treatments (%)	CC	6.4	4.8	8.3	3.9	15.0	0.0
		(42.7)		(55.3)		(100.0)	
	BG	14.6	0.8	14.4	1.3	15.0	0.0
		(97.3)		(96.0)		(100.0)	

YOY bluegill and channel catfish used the two low-velocity habitats, downstream of wing dams and the scour hole, almost exclusively (ANOVA; $p < 0.0001$) over the course of the study in the control (no displacement) trials (Figure 3). This agreed well with conclusions from previous studies; viz, the swimming ability of YOY channel catfish and bluegill diminishes at low water temperatures, requiring them to avoid high-velocity habitats and to seek out low-velocity habitats (Sheehan et al. 1990a; 1994). The preference for low-velocity habitats shown by YOY of these species was fundamental to the experimental design of the present study.

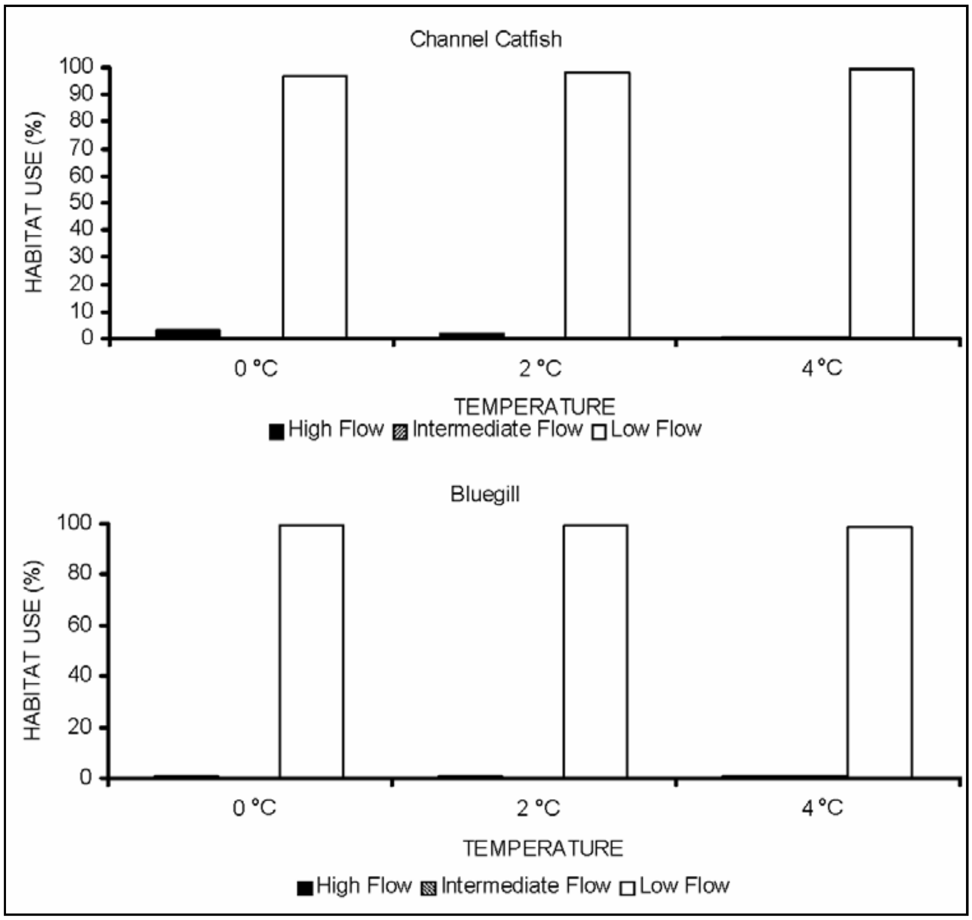


Figure 3. Use of river habitats by YOY bluegill and channel catfish in control trials at 0, 2, and 4 °C

Displacement frequency had a significant effect on cumulative mortality for bluegill and channel catfish (ANOVA; $p < 0.0001$) (Table 2). Cumulative mortality during the trials differed for channel catfish and bluegill (ANOVA; $p < 0.0001$), and total mortality was higher for channel catfish at all three test temperatures (Figure 4). Cumulative mortality was also affected by temperature (ANOVA; $p < 0.0001$) (Table 2), and total mortality was similar within species at 0 and 2 °C, but lower at 4 °C (Figure 4). There was a significant interaction between displacement frequency and temperature (ANOVA; $p < 0.0260$) (Table 2). Inspection of the cumulative mortality distributions for channel catfish

Table 2
GLM Summary Table and Power (1-β) Analysis of Multiple Regression Analysis of Cumulative Mortality of Bluegill and Channel Catfish

Source	df	Sum of Squares	Mean Squares	f	p	ϕ	Power (1-β)
Model	131	224.8	1.7	14.0	0.0001	--	--
DISP	3	5.0	1.7	13.5	0.0001	3.18	>0.99
TEMP	2	60.0	30.0	244.4	0.0001	12.77	>0.99
SP	1	60.9	60.9	496.0	0.0001	--	--
DISP*TEMP	6	1.8	0.3	2.4	0.0260	6.73	>0.99
DISP*SP	3	0.7	0.2	1.9	0.1217	8.23	>0.99
Error	588	72.2	0.1				
Total	719	297.0					

Note: The main effects displacement frequency (DISP), temperature (TEMP), species (SP), and pertinent interaction effects are included.

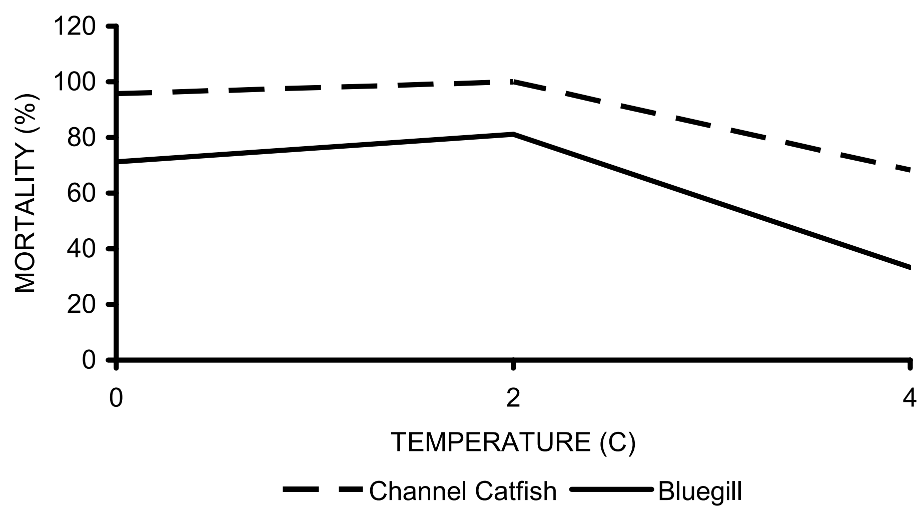


Figure 4. Total 10-day mortality at 0, 2, and 4 °C for YOY bluegill and channel catfish for all displacement frequencies from low-velocity habitats combined

and bluegill at 4 °C (Figures 5 and 6, respectively) showed there was no clear trend in mortality in relation to displacement frequency. However, cumulative mortality for the control and low-frequency displacement regimes was less than cumulative mortality for the medium- and high-displacement frequency regimes for channel catfish and bluegill at 2 °C (Figures 7 and 8, respectively) and 0 °C (Figures 9 and 10, respectively). Trend analysis of the relationship between mortality and temperature showed the relationship to be nonlinear (ANOVA; $p < 0.0001$).

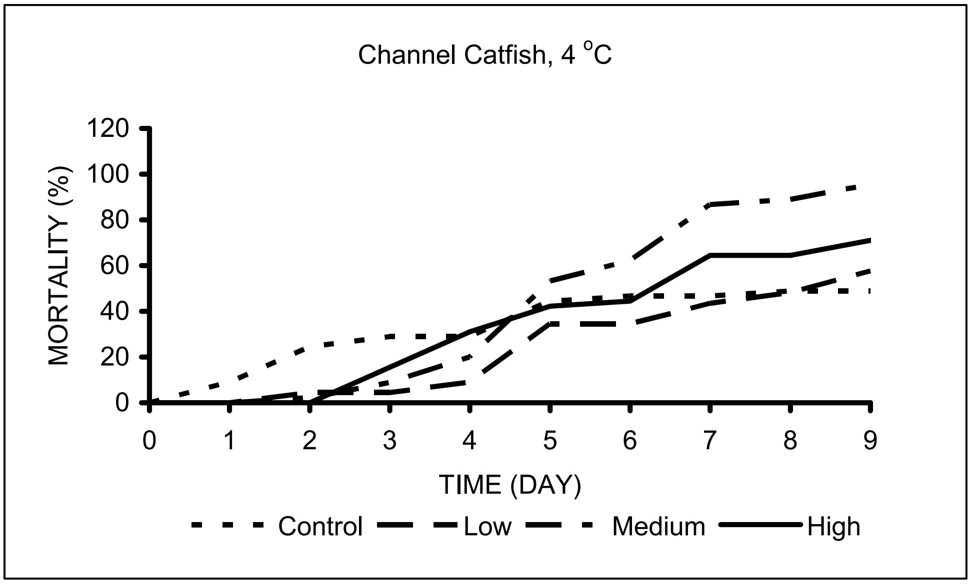


Figure 5. Cumulative mortality distributions for YOY channel catfish displaced from low-velocity habitats at 4 °C: control = no displacement; low = displacement on day 0 only; medium = displacement every other day beginning on day 0; and high = displacement every day

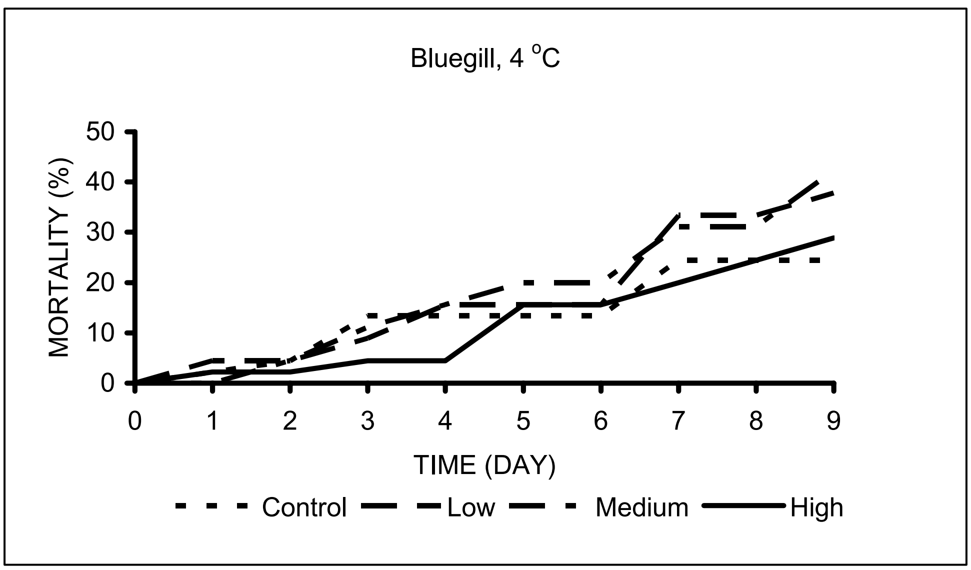


Figure 6. Cumulative mortality distributions for YOY bluegill displaced from low-velocity habitats at 4 °C: control = no displacement; low = displacement on day 0 only; medium = displacement every other day beginning on day 0; and high = displacement every day.

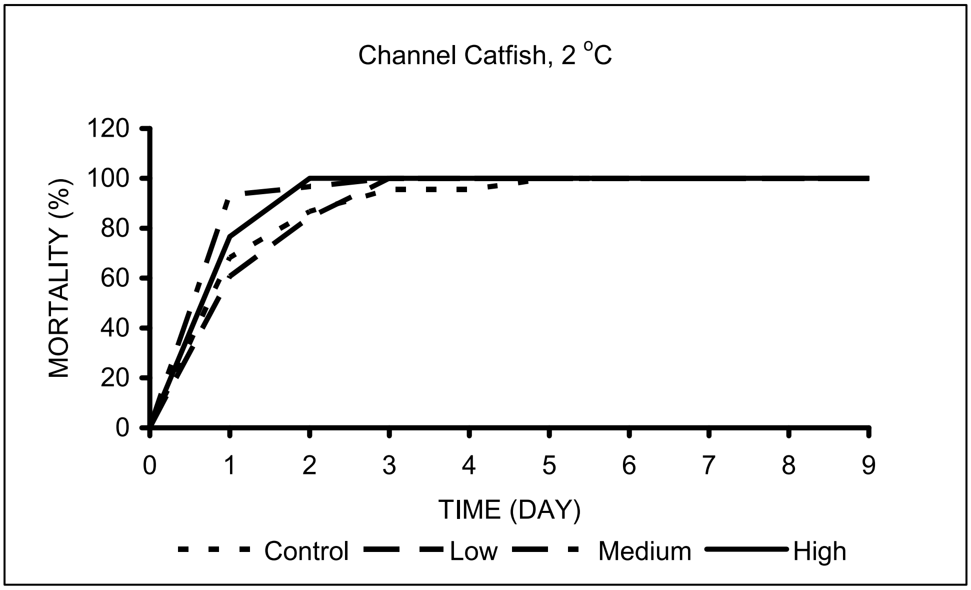


Figure 7. Cumulative mortality distributions for YOY channel catfish displaced from low-velocity habitats at 2 °C: control = no displacement; low = displacement on day 0 only; medium = displacement every other day beginning on day 0; and high = displacement every day

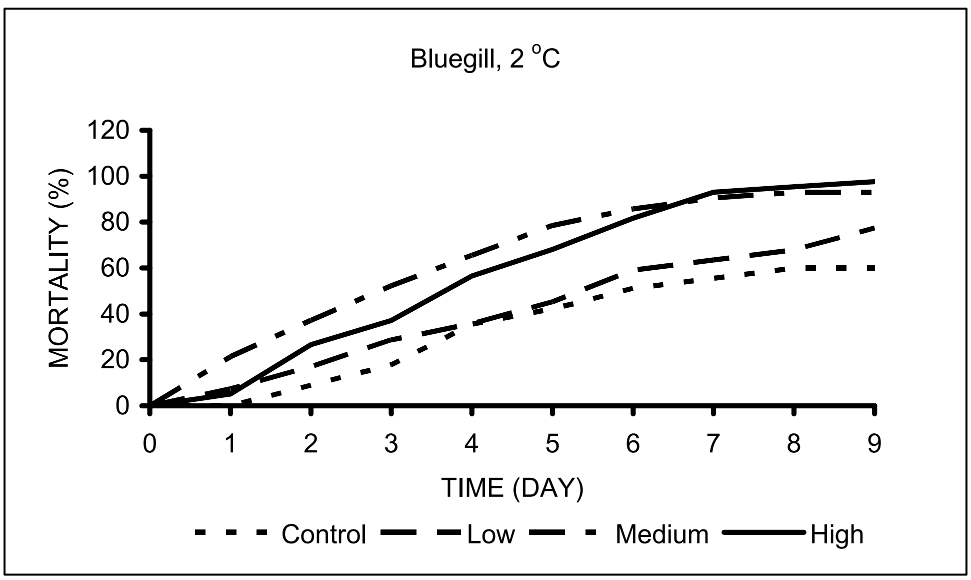


Figure 8. Cumulative mortality distributions for YOY bluegill displaced from low-velocity habitats at 2 °C: control = no displacement; low = displacement on day 0 only; medium = displacement every other day beginning on day 0; and high = displacement every day

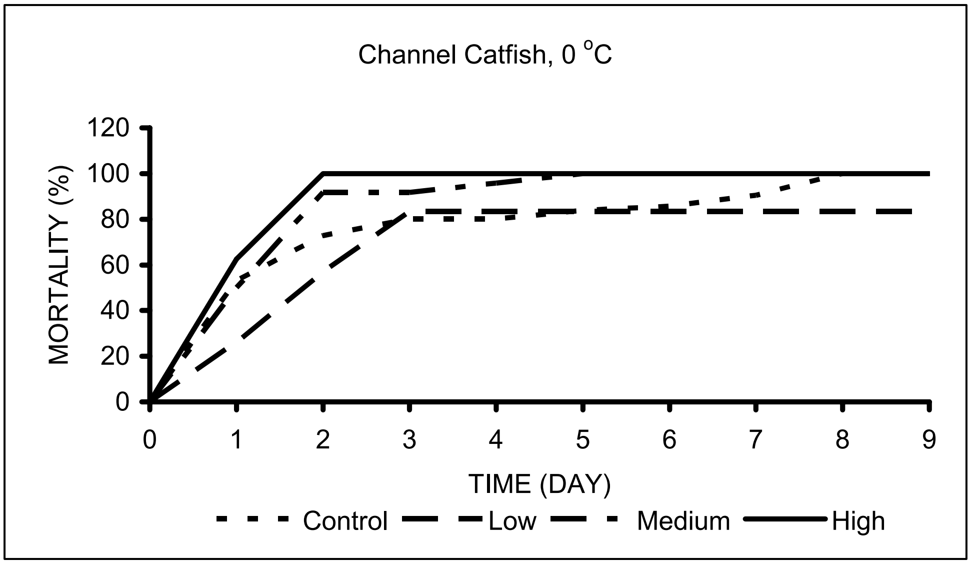


Figure 9. Cumulative mortality distributions for YOY channel catfish displaced from low-velocity habitats at 0 °C: control = no displacement; low = displacement on day 0 only; medium = displacement every other day beginning on day 0; and high = displacement every day

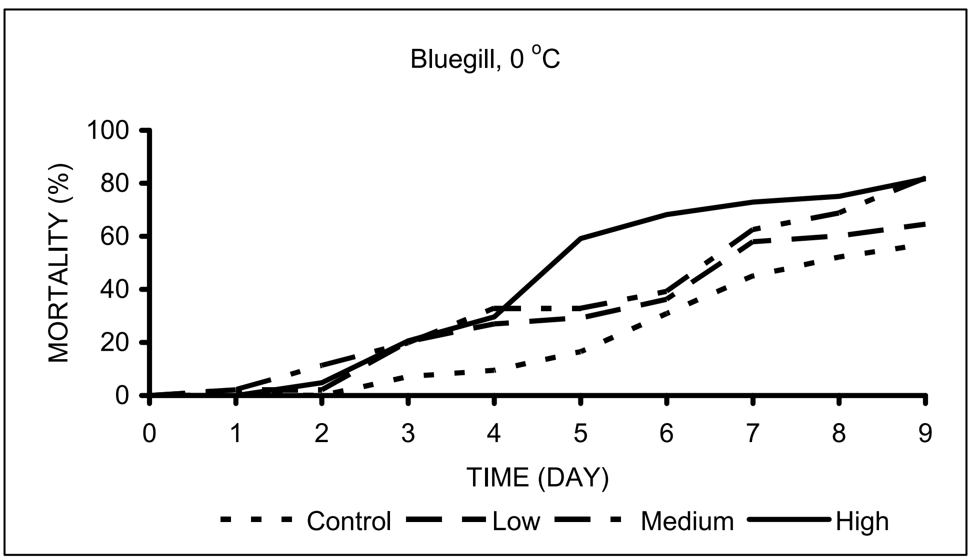


Figure 10. Cumulative mortality distributions for YOY bluegill displaced from low-velocity habitats at 0 °C: control = no displacement; low = displacement on day 0 only; medium = displacement every other day beginning on day 0; and high = displacement every day

A significant interaction between displacement frequency and species was not detected (ANOVA; $p < 0.1217$) (Table 2) indicating that mortality for the two species responded in the same manner to increased displacement frequency.

A priori orthogonal contrast analysis indicated that cumulative mortality did not differ between the control and low-frequency displacement groups (ANOVA; $p > 0.9$). Cumulative mortality in the medium- and high-frequency displacement groups also did not differ (ANOVA; $p > 0.5$). However, cumulative mortality in the control and low-frequency displacement groups was significantly lower than that of the medium- and high-frequency displacement groups (ANOVA; $p < 0.0001$).

Discussion

The basic premise of this study was that certain UMR fish species utilize low-velocity habitats during the winter. Habitat use by YOY bluegill and channel catfish substantiated this premise—they chose the two low-velocity habitats almost exclusively, even though the combined relative abundance of the low-velocity habitats was only a small fraction (about 20 percent) of the total habitat available in the model rivers. This strong indication of preference for low-velocity habitats validated the relevance of the research question addressed in this study; namely, what is the fate of fish displaced from low-velocity habitats?

The high mortality shown by YOY channel catfish in the model rivers prior to the trials (during the acclimation period) at 0 and 2 °C, and during the trials in the control groups at all three test temperatures, was not anticipated. Thirty-day mortality for YOY channel catfish held in aquaria was found to be only 9 percent at 0 °C, and no mortalities occurred at 2 and 4 °C (Sheehan et al. 1990a). However, the trends in mortality were anticipated based on findings from YOY of several fish species (Sheehan et al. 1990a); mortality at 0 to 4 °C varied inversely with test temperature.

Few studies are available that have garnered information on YOY channel catfish wintering strategies or habitats. YOY channel catfish were not encountered during winter sampling in Mississippi River backwaters (Sheehan et al. 1990b). Logsdon (1993) sampled Pool 26 using electrofishing and found seven age-0 and age-1 channel catfish behind wing dams, when water temperatures were less than 10 °C (November and March), whereas only one catfish was captured in side-channel borders, and fourteen larger channel catfish in scour holes at the tip of wing dams. Laboratory tests of low-temperature tolerance and swimming ability led Sheehan et al. (1990a) to the conclusion that YOY channel catfish may be capable of overwintering in low-velocity channel habitats.

As temperature decreases below 4 °C, bluegill swimming ability greatly diminishes, they become inactive, and they will roll over on their sides and lay on the bottom. This behavior was observed in the model rivers during the present study and in previous aquarium studies (Sheehan et al. 1990a). Bluegill chose the low-velocity areas behind the wing dams to exhibit this behavior in the model rivers. Although YOY channel catfish swimming ability at low temperatures is inversely related to temperature, they are more capable of swimming against a current than YOY bluegill. YOY channel catfish remain active, swimming about in aquaria at temperatures less than 4 °C (Sheehan et al. 1990a). Channel catfish ventured near or into the high-velocity areas more frequently than the bluegill in the model rivers, perhaps in an attempt to find a more suitable winter habitat.

The inability to acclimate YOY walleye to the test conditions was completely unexpected. YOY walleye showed the greatest capacity for swimming at low temperatures of all the species previously tested (Sheehan et al. 1990a), so it was not surprising to note in the present study that the walleye appeared to venture into the high-velocity habitats in the model rivers more than the other two species studied. Obviously, the model rivers used were artificial systems which do not duplicate winter conditions in the Mississippi River. Problems of scale may have influenced findings; the wing dams and scour holes were scaled-down versions, but the test fish could not be so scaled. The wing dams were spaced closely together in the model rivers. When test fish moved or were forced into the high-velocity habitats, they usually found another low-velocity habitat quickly, either volitionally or by being deposited there by the water currents. Thus, the fish were probably exposed to high velocities for a shorter period of time than they would have been in the Mississippi River under similar circumstances. On the other hand, the highest velocities areas (about 0.6 to 0.8 m/s) of the model rivers were only centimeters away from the relative safety of the low-velocity areas (scour holes) behind and next to the wing dams. The juxtaposition of the high velocities to the low-velocity habitats may have stimulated test fish capable of swimming at the test temperatures (walleye and channel catfish) to attempt to search for less precarious habitats. This behavior resulted in occasional forays into the high-velocity areas, and it may have led to additional physiological stress during attempts to return to low-velocity areas.

Another possible explanation for the high walleye and channel catfish mortality is that the model rivers employed may not have offered access to habitats or strategies typically used for overwintering. The authors are aware of no studies identifying winter habitat use by YOY walleye. Although larger walleye appear to be active in river channels during the winter, smaller fish, such as YOY, cool faster and maintain a lower excess body temperature than larger fish (Sheehan et al. 1990b). Thus, YOY walleye may use a different wintering strategy than older, larger walleye. Little is known of wintering strategies employed by catfishes (ictalurids) in general, but Rhone River black bullheads migrate to backwaters receiving inflows of warmer ground water in the winter. This species was reported to move into backwaters and burrow into the substrate during the winter, apparently in response to the availability of elevated thermal conditions; a number of marked individuals were found to leave the backwater in the spring, return again in fall, and remain there throughout the winter (Bouvet et al. 1985). This and possibly other wintering strategies would not have been possible for channel catfish or walleyes in this series of studies, but it should be kept in mind that at least some YOY channel catfish use low-velocity wing dam habitats in the Mississippi River during the winter (Logsdon 1993).

More is known about winter habitat use by bluegill. Laboratory studies of low-temperature tolerance and swimming ability indicate that YOY bluegill would be restricted to low-velocity habitats if they chose to or are left with no alternative but to winter in river channels at temperatures less than 4 °C; however, they would probably survive better in the warmer waters that are available in backwaters during the winter (Sheehan et al. 1990a). Field studies support these contentions. Bluegill are found in backwaters in high numbers during the winter in Mississippi River Pools 13, 25, and 26 (Sheehan et al. 1990b). Logsdon (1993) reported no difference between bluegill relative abundance in side channels and wing dams in August and April electrofishing samples in Mississippi River Pool 26, but bluegill almost exclusively used wing dams during November and March. Mean catch per unit effort for bluegill when water temperatures were less than 10 °C were 0.04 and 7.0 bluegill/min for samples in side-channel borders and from downstream of wing dams, respectively (Wilcoxin paired rank analysis, $p < 0.021$).

Despite the artificial nature of the model rivers and the stress-induced mortality the model river apparently imposed on the test fish, the experimental design produced some rather unequivocal findings. Increased frequency of displacement from low-velocity habitats increased mortality rate in YOY bluegill and channel catfish ($p < 0.0001$). The results indicated that a second main effect, temperature, had a strong influence on mortality ($p < 0.0001$), with mortality inversely related to temperature. However, the effect of displacement frequency on mortality was not the same at all three test temperatures ($p < 0.026$). Inspection of the data suggests that displacement frequency had its greatest effects on mortality at 0 and 2 °C.

Although displacement frequency had a significant effect on mortality, the data did not indicate any differences between the no-displacement and low-displacement frequency treatments, nor between the medium- and high-frequency displacement treatments. This can be interpreted in either of two ways. First, mortality may increase as a function of displacement frequency in actuality, but in this study mortality rate did not differ for all four of the displacement frequencies due to type II statistical error. This explanation is unlikely, however, because the experimental design provided very high statistical power (Table 2). An alternative explanation is that a displacement frequency threshold exists, above which mortality is increased. If the latter is true, then it appears that displacement frequencies greater than once in 3 days can increase mortality in YOY bluegill and channel catfish.

References

Bodensteiner, L. R., and Lewis, W. M. (1994). "Downstream drift of fishes in the Upper Mississippi River during winter," *Journal of Freshwater Ecology* 9(1), 45-56.

Bouvet, Y., Pattee, E., and Meggouth, F. (l985). "The contributions of back-waters to the ecology of fish populations in large rivers. Preliminary results on fish migrations within a side arm and from the side arm to the main channel of the Rhone," *International Journal of Theoretical and Applied Limnology* 22, 2576-2580.

Hawkinson, B., and Grunwald, G. (l979). "Observation of a wintertime concen-tration of catfish in the Mississippi River," Minnesota Department of Natural Resources Investigative Report 365, Minneapolis, MN.

Hesse, L. W., and Newcomb, B. A. (1982). "On estimating the abundance of fish in the upper channelized Missouri River," *North American Journal of Fisheries Management* 2, 80-83.

Logsdon, D. E. (1993). "Suitability of side channel border and wing dam habitats for fishes overwintering in Pool 26 of the Mississippi River," M.S. thesis, Southern Illinois University, Carbondale.

Lubinski, K. S. (1985). "Winter main channel habitat utilization of Mississippi River fishes," *Minutes of the Illinois chapter of the American Fisheries Society meeting, 12-14 March*, Edwardsville, IL.

Newcomb, B. A. (1989). "Winter abundance of channel catfish in the channel-ized Missouri River, Nebraska," *North American Journal of Fisheries Management* 9, 195-202.

Paladino, F. B., Spotila, J. R., Schaubauer, J. P., and Kowalski, K. T. (1980). "The critical thermal maximum: A technique used to elucidate physiological stress and adaptation in fish," *Review of Canadian Biology* 39, 115-122.

Sheehan, R. J., Bodensteiner, L. R., Lewis, W. M., Logsdon, D. E., and Scherck, S. D. (1990a). Long-term survival and swimming performance of young-of-the-year river fishes at low temperatures: Links between physiological capacity and winter habitat requirements." *The restoration of Midwestern Stream habitat.* 52nd Midwest Fish and Wildlife Conference Proceedings of Symposium, Rivers and Streams Technical Committee, North Central Division of the American Fisheries Society, 4-5 December 1990. Minneapolis, MN, R. Saur, ed., 98-108.

Sheehan, R. J., Lewis, W. M., and Bodensteiner, L. R. (1990b). "Winter habitat requirements and overwintering of riverine fishes," Final Report, Federal Aid in Sport Fish Restoration Program, F-29-R.

Sheehan, R. J., Lewis, W. M., and Bodensteiner, L. R. (1994b). "Winter habitat requirements and overwintering of riverine fishes," Project Completion Report to IDNR. Project F-79-R-6, Federal Aid in Sport Fish Restoration Program.

Stang, D. L., and Millar, J. G. (1985). "Evaluation of environmental impacts of thalweg disposal of dredged material," Report to the U.S. Army Engineer District, Rock Island, IL.

Stang, D. L., and Nickum, J. G. (1985). "Radiotracking of catfish and buffalo in Pool 13, Upper Mississippi River," Report to U.S. Army Engineer District, Rock Island, IL.

Talbot, M. J. (1982). "Catfish wintering habitat evaluation," Report to Wisconsin Department of Natural Resources, Madison, WI.

Todd, B. L., Dillon, F. S., and Sparks, R. E. (1989). "Barge effects on channel catfish," Aquatic Ecology Technical Report 89/5, Illinois Natural History Survey, Champaign, IL.