Largemouth Bass Response to Habitat and Water Quality Rehabilitation in a Backwater of the Upper Mississippi River

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Preface

This reprint originally appeared in the *North American Journal of Fisheries Management* 15:784–793 and is being provided in this format as a service to Long Term Resource Monitoring Program (LTRMP) partners.

LTRMP interests in the subject matter of this report are embodied in the LTRMP Operating Plan[1] in Strategy 3.3.2, *Test and Assess Effectiveness of Prototype Management.* This report was developed with partial funding provided by the Long Term Resource Monitoring Program.

The LTRMP is being implemented by the Environmental Management Technical Center, a U.S. Geological Survey science center, in cooperation with the five Upper Mississippi River System (UMRS) States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin. The U.S. Army Corps of Engineers provides guidance and has overall Program responsibility. The mode of operation and respective roles of the agencies are outlined in a 1988 Memorandum of Agreement.

The UMRS encompasses the commercially navigable reaches of the Upper Mississippi River, as well as the Illinois River and navigable portions of the Kaskaskia, Black, St. Croix, and Minnesota Rivers. Congress has declared the UMRS to be both a nationally significant ecosystem and a nationally significant commercial navigation system. The mission of the LTRMP is to provide decision makers with information for maintaining the UMRS as a sustainable large river ecosystem given its multiple-use character. The long-term goals of the Program are to understand the system, determine resource trends and effects, develop management alternatives, manage information, and develop useful products.

[1]U.S. Fish and Wildlife Service. 1993. Operating Plan for the Upper Mississippi River System Long Term Resource Monitoring Program. Environmental Management Technical Center, Onalaska, Wisconsin, Revised September 1993. EMTC 91-P002R. 179 pp. (NTIS #PB94-160199)

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Abstract.—Severe sedimentation since lock and dam construction in the 1930s has reduced water depth in Upper and Lower Brown's lakes, a backwater complex in Pool 13 of the upper Mississippi River, and resulted in periods of chronic anoxia. This backwater complex was rehabilitated by construction of a deflection levee, installation of a water control structure, and excavation of canals through the area. Water quality variables inside and outside the project area, movement of radio-tagged largemouth bass in response to changing oxygen concentrations, and creel statistics were used to evaluate the success of the improvements. Turbidity was significantly less in the Brown's Lake complex than in the main channel. Oxygen concentrations were allowed to deteriorate to 3 ppm before the water control structures were opened during the winter; within 7 d, oxygen concentrations as high as 10 ppm were found in the top strata in most of the Brown's Lake complex. Chemical and thermal stratification observed in the dredge canal water column were caused by colder (32°F), highly oxygenated water from the main channel moving over denser, warmer (36–38°F) water in the dredge canals. Water in the dredge canals remained stratified until ice-out, with colder, oxygenated water in the surface stratum; warmer, but anoxic, water in the bottom stratum; and a mixture (3–7 ppm oxygen and 35–36°F) in the middle stratum. Fourteen radio-tagged largemouth bass *Micropterus salmoides* were located in the Brown's Lake complex in December before oxygen concentrations began to decline. Concurrent with oxygen declines, most radio-tagged fish exited the complex through a slough connected to the main channel and returned when the water control structure was opened and oxygen concentrations increased. Some radio-tagged largemouth bass moved 4 mi under ice to return to the complex. Estimated angler effort and catch increased 58 and 117%, respectively, in the Lower Brown's Lake–Lainesville Slough complex following rehabilitation. A 10-fold increase in angler effort and catch was estimated for Upper Brown's Lake after the project was completed.

The Mississippi River has become less dynamic since construction of the lock and dam system during the 1930s. Although the tailwaters and upstream ends of navigation pools retain many of the characteristics of the preimpounded river, the lower ends of the navigation pools efficiently trapped sediment following dam construction. Backwater and off-channel areas that were originally flushed and scoured are now subject to continuous sedimentation. Sedimentation has been identified as one of the major causes of backwater habitat degradation on the upper Mississippi River (Brietenbach and Peterson 1980). Ackerman (1977) reported that 132 acre-ft of sediment were deposited annually in selected backwaters in Pool 11. The estimated life expectancy of some upper Mississippi River backwaters may be limited to 50 years (McHenry et al. 1976), and it has been predicted that they will slowly be eliminated (Eckblad et al. 1977). Bade (1980) noted the significance of side channels and backwaters as prime habitat for fish and wildlife of the upper Mississippi River. Pitlo (1992) concurred, recognizing that backwater areas provide critical winter habitat for a variety of fish species and noting that this habitat could be limiting. Declines in populations of yellow perch *Perca flavescens* and largemouth bass *Micropterus salmoides* in a backwater lake of the Illinois River was linked to sedimentation (Jackson and Starret 1959). The decline of an immense fishery resource in the lower Missouri River was also the result of habitat changes, particularly a reduction in the number of chutes and backwaters (Funk and Robinson 1974).

Brown's Lake is a 453-acre backwater complex located in upper Mississippi River Pool 13 at river mile 544.2–546.0 (Figure 1). Following construction of Lock and Dam 13 in 1939, Brown's Lake was 5–6 ft deep, according to U.S. Army Corps of Engineers preimpoundment surveys (Brown

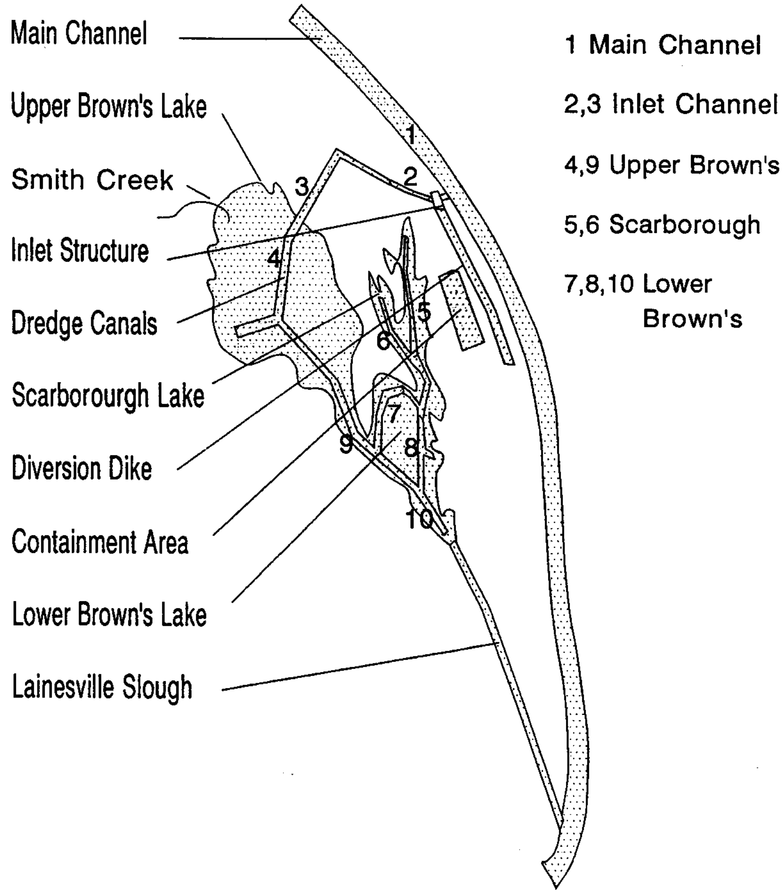

FIGURE 1.—Project features and water quality sampling locations (1–10) in Brown's Lake complex, upper Mississippi River, Pool 13.

1931) and normal pool elevations after dam construction. Although no historical data exist for the Brown's Lake complex, similar backwater areas have provided spawning, rearing, and wintering habitat for a variety of fish species (Christenson and Smith 1965; Schramm and Lewis 1974; Bade 1980; Sheehan et al. 1988; Pitlo 1992). By the 1980s, mean water depth within this complex had been drastically reduced by sedimentation, resulting in a shallow, densely vegetated lake with periods of chronic anoxia, particularly during winter ice cover. Sediment core borings (U.S. Army Corps of Engineers 1987) identified the Mississippi River as the major sediment source, with secondary inputs from the Smith Creek watershed, which drains into Brown's Lake.

Restoration of fisheries habitat in Brown's Lake began in 1988 and included (1) a 1,500-ft earthen levee to divert main channel flows containing high suspended sediment loads away from Brown's Lake, (2) a high-capacity water control structure with four 60 × 60-in gated tubes to regulate flow into Brown's Lake from the main channel, and (3) the dredging 400,000 yd^3 of sediment, which created 4.5 mi of canals, 8 ft deep by 60 ft wide (Figure 1). The canals were excavated to provide deepwater habitat and reliable access for fish to major features in the Brown's Lake complex. Three 20-ft holes were excavated in the canal system to increase habitat diversity. Construction was completed in late 1989, at a project cost of approximately US$1.6 million.

This study was initiated to (1) evaluate the response of wintering largemouth bass to water quality manipulation in Brown's Lake, (2) determine the success of the diversion levee and the water control structure in minimizing suspended solids within the Brown's Lake complex, and (3) develop recommendations for operation of the water control structure to maximize benefits for wintering fish.

Methods

Water quality assessment techniques were consistent with procedures outlined in the Long Term

Resource Monitoring Program Procedures Manual (U.S. Fish and Wildlife Service 1990). Water temperature, turbidity, current velocity, and dissolved oxygen concentrations were measured daily, weekly, or biweekly, as needed, to determine water quality. Nine sites were sampled within the Brown's Lake complex (subsamples were made 20 cm below the surface, at middepth, and 20 cm above the bottom of the water column) and in the main channel at river mile 546.5 (Figure 1).

Water temperature and dissolved oxygen concentration were measured with a Yellow Springs Instruments (YSI) model 57 meter. The YSI unit was air calibrated daily with a YSI model 5075A calibration chamber. Monthly precision and accuracy checks were performed with a certified thermometer and the Winkler method to verify accuracy of temperature and dissolved oxygen readings. Nephelometric turbidity units (NTU) were determined with a Hach model 16800 turbidimeter. The Hach unit was field calibrated daily with a set of Gelex field standards. Monthly precision and accuracy checks were performed with a separate set of Gelex laboratory standards. Current velocity was measured with a Marsh McBirney model 201D flowmeter. The sensor unit was mounted on a pole, lowered to the sample depth, and rotated in all directions to determine current velocity and direction.

We determined the water control gate settings necessary to allow inflow of adequate water to reoxygenate the Brown's Lake complex and maintain oxygen concentrations above 5 ppm to sustain wintering fish. Water control structure gates were kept closed until dissolved oxygen concentrations decreased to 3 ppm on January 17, 1991. Then, one gate was opened 12 in to introduce oxygenated water into Upper Brown's Lake. On January 23, when dissolved oxygen concentrations reached 10 ppm in the upper stratum of the water column throughout most of the dredge canal system, the gate opening was reduced to 6 in to determine a minimum gate opening that could maintain oxygen concentrations above 5 ppm. A minimum gate opening and correspondingly low current velocity were desirable because Pitlo (1992) reported that the absence of current velocity was an important characteristic of largemouth bass wintering habitat.

Radio transmitters were implanted into 20 largemouth bass weighing 2.2 lbs or more, which were collected by electrofishing during September 1990 in Lainsville Slough and in Upper and Lower Brown's lakes. Radio transmitters were surgically implanted into the abdominal cavity of each fish according to procedures described by Pitlo (1978, 1989). A numbered Floy tag was inserted below the dorsal fin of each fish for external identification, and all fish were released at the capture location. Radio transmitters, receivers, and antennas were obtained from Advanced Telemetry Systems, Inc. Transmitters operated in the 48–49 MHz band; individual frequencies were spaced 10–15 kHz apart. Transmitters weighed 0.92 oz and had an expected life of 275–310 d. A Yagi antenna and a hand-held loop antenna were used to determine fish location.

Angler creel surveys were used to estimate sport fishery statistics, including total anglers, angler effort, total fish caught, and total fish harvest in the Brown's Lake complex and Lainsville Slough. Surveys were conducted during open water (May–October) and ice cover (December–February) periods from May 1, 1988, to February 28, 1991. Survey days were divided into two 5-h periods during the winter and two 6-h periods during the summer. The sampling design was further stratified by weekend and weekdays, and sampling periods and days were randomly selected. Survey clerks were stationed at points of primary access to Upper and Lower Brown's lakes during the winter and at the mouth of Lainesville Slough during the summer to collect trip information as anglers left the area. Angler survey data was extrapolated to seasonal totals as outlined by Pitlo (1992).

Results

Water Quality

Analysis of turbidity observations in the main channel and at eight sites within the Brown's Lake complex revealed significantly lower suspended solids in Brown's Lake during high water (Wilcoxon rank sum test, $P < 0.01$; Figure 2). Turbidity measurements in the main channel reached 140 and 199 NTU during spring runoff in 1990 and 1991, whereas mean values within the Brown's Lake complex remained significantly lower, at 29 and 75 NTU, during the same periods. A dramatic reduction in turbidity levels in Brown's Lake relative to the main channel was evident following a thunderstorm in August 1990, when main channel turbidity measurements reached 214 NTU but mean Browns's Lake turbidity was 12 NTU. Higher turbidity levels in Brown's Lake during mid-1989 were due to disturbances caused by project construction and were limited to the vicinity of dredging activity (Figure 2).

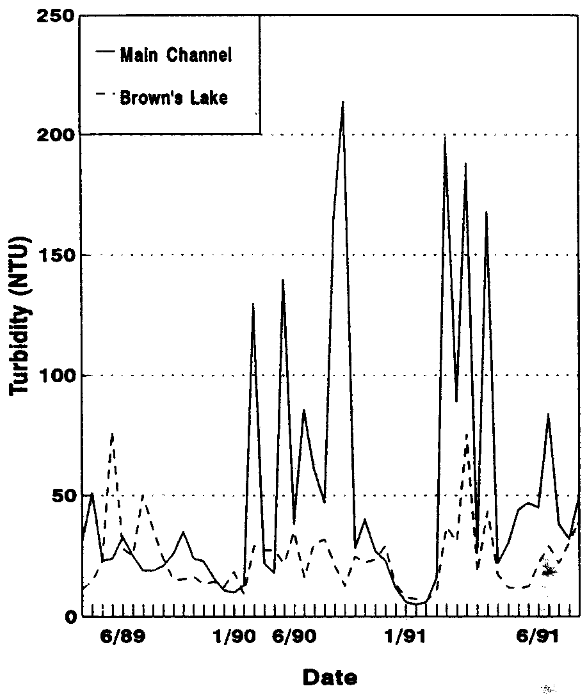

FIGURE 2.—Mean Turbidity (nephelometric turbidity units, NTU) within the Brown's Lake complex and the upper Mississippi River main channel between mid-1989 and mid-1991. The time scale is not linear. The greatest main-channel turbidity (214 NTU) occurred in August 1990.

By late December 1990, the entire water column adjacent to the dredge canals was frozen, leaving the dredge canals as the only available aquatic habitat for overwintering fish. After the water control gate was opened on January 17, 1991, increased dissolved oxygen concentrations (up to 10 ppm) were immediately observed in the dredge canal near the inlet structure. Minimal flow through the inlet structure resulted in delayed reoxygenation of remote sites, especially those in Scarborough Lake (Figure 3). An increase in dissolved oxygen concentrations at all sampling sites in the Brown's Lake complex was measured within 7 d after opening the inlet structure. Although dissolved oxygen concentrations increased to 10 ppm in the top stratum of the dredge canal water column, oxygen concentrations in the bottom stratum were minimally affected by the gate openings (Figures 3, 4); complete oxygenation of the water column occurred only at the inlet site. During the first 3 months of 1991, vertical distributions of oxygen and temperature were inversely related in the dredge canal: oxygen concentrations ranged from 13 ppm in the upper stratum to 0.1 ppm in the bottom stratum, whereas temperature dropped to 32°F near the surface but reached 38°F near the bottom (Figure 5). Current velocity was detected only in the upper stratum and ranged from 0 to 0.13 ft/s. All deep holes were stratified; dissolved oxygen concentrations were less than 1.0 ppm below the 10-ft depth.

A decrease in the gate opening to 6 in on January 23 resulted in declines in surface dissolved oxygen concentrations at all sampling locations except the inlet channel (Figure 3). Declines up to 6 ppm were observed in Lower Brown's Lake after inputs from the main channel were reduced (Figure 3). Depressed dissolved oxygen concentrations persisted in the Brown's Lake complex until ice-out on March 20 (Figure 4).

Fish Response

Fourteen radio-tagged largemouth bass used the Brown's Lake complex as overwintering habitat during 1990–1991. Six radio-tagged largemouth bass ultimately were harvested by anglers or relocated during fishing tournaments. Radio-tagged fish remained in the Brown's Lake complex throughout December and began to leave the area in early January as dissolved oxygen concentrations declined to 6 ppm (Figure 6). By January 16, dissolved oxygen concentrations decreased to 2.0–3.1 ppm in some of the dredge canals. Concurrent with declining oxygen concentrations, nine radio-tagged largemouth bass moved out of the Brown's Lake complex and by mid-January, only five radio-tagged largemouth bass remained near the mouth of Lower Brown's Lake (Figure 6).

The inlet gate was opened on January 17, and 5 d later, six radio-tagged largemouth bass were located in Lower Brown's Lake, and several fish moved into sections of the dredge canal system that were previously anoxic (Figure 6). During this period, dissolved oxygen concentrations improved in all dredge canals with the exception of Scarborough Lake. By January 28, dissolved oxygen concentration was above 6 ppm in the upper stratum of all dredge canal habitat, and 10 radio-tagged largemouth bass returned to the Brown's Lake complex. By February 28, all 14 radio-tagged largemouth bass had returned to the dredge canals, where they remained until ice-out.

Angler Survey

Approximately 26,000 anglers fished the Brown's Lake–Lainesville Slough area during 1988 through 1991. Angler use was concentrated during the open-water season: 93% (54,288 h) of the estimated effort was expended during May–

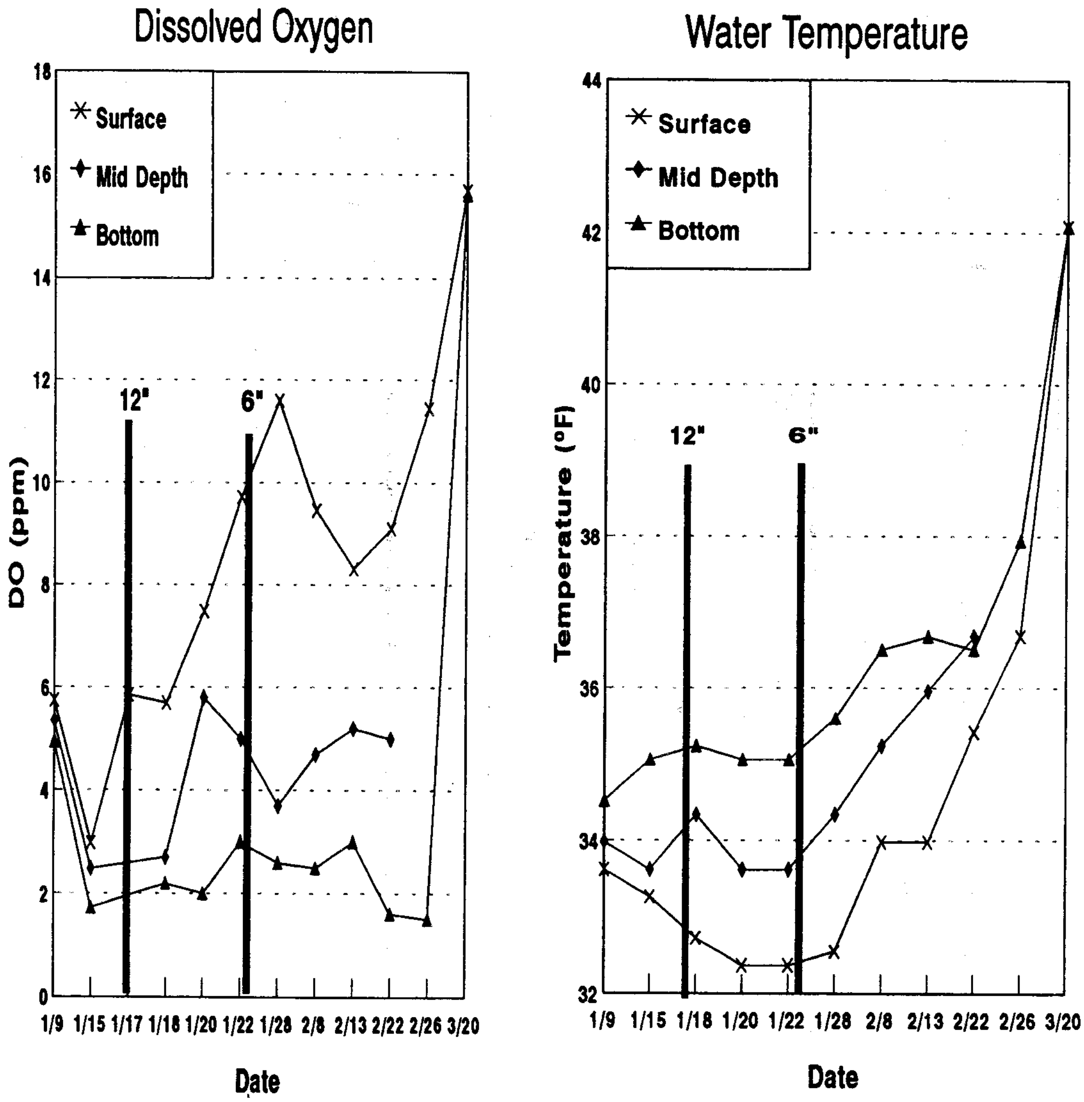

FIGURE 4.—Mean dissolved oxygen (DO) concentrations and mean water temperatures at dredge canal sites in the Brown's Lake complex, upper Mississippi River, Pool 13, January 9–March 20, 1991. Vertical bars show the dates on which the gate opening was 12 and 6 in, respectively. The time scale is not linear.

Closure of the water control structure during high water also effectively protected the Brown's Lake complex from high suspended-solid loads in the main channel.

Water control structures delivering discharges of 15–50 ft^3/s were adequate to maintain oxygen–temperature requirements for overwintering largemouth bass in Brown's Lake, and these would be applicable to similar upper Mississippi River backwaters. Large, high-capacity structures constructed as part of the Brown's Lake project are not necessary, considering low flow requirements for wintering fish. Pitlo (1992) reported that largemouth bass in the upper Mississippi River selected sites with no current velocity for wintering habitat. Reoxygenation of the Brown's Lake canal system was accomplished during the winter of 1991 with inflows of only 15 ft^3/s through the control structure. Flows rates above 15 ft^3/s may be necessary to oxygenate the Brown's Lake complex when water levels are higher and water volume increases lateral to the dredge canals, but during this study, all water adjacent to the dredge canals was frozen down to the substrate.

Vertical density differentials between cold (32–33°F) water from the main channel and warmer (37–39°F) water in the dredge canals facilitated the transport of oxygenated water throughout the canal system. Cold, lighter water from the main channel flowed over warm, heavier water in the

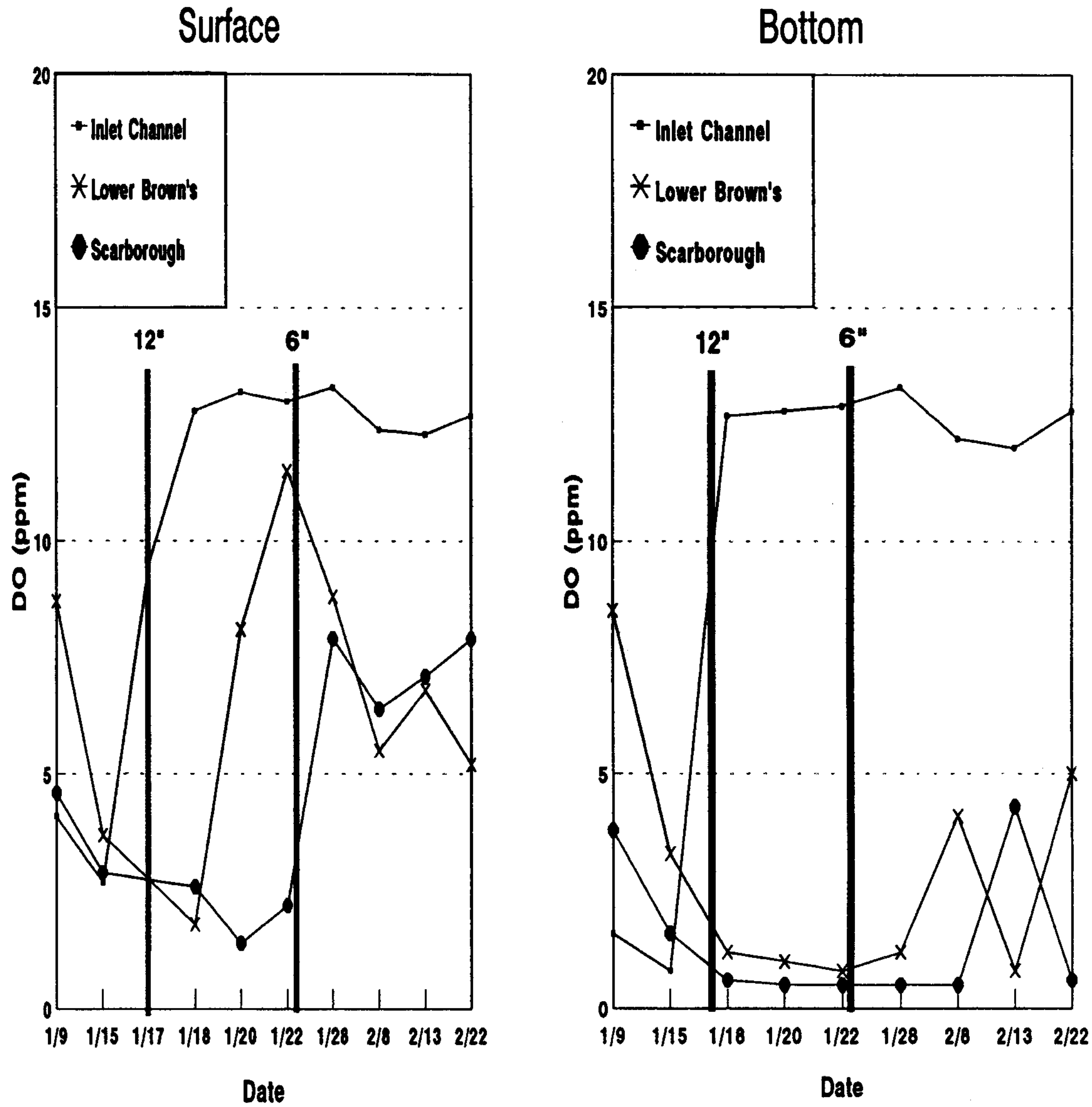

FIGURE 3.—Surface and bottom dissolved oxygen (DO) concentrations at selected sites during the period inlet gates were open, Brown's Lake complex, upper Mississippi River, Pool 13, January 9–February 22, 1991. Vertical bars show the dates on which the gate opening was set at 12 and 6 in, respectively. The time scale is not linear.

October (Table 1). Estimated angler effort and total catch were both higher after restoration of the backwater (1990–1991) than before (1988–1989). Angler effort increased 58% (by 13,214 h) and catch increased 117% (by 29,546 fish). Open-water fishing in Upper Brown's Lake exhibited the greatest change with a 10-fold increase in angler and catch estimates (Figure 7). Although total catch showed substantial improvement after restoration, harvest remained stable, except for open-water fishing in Upper Brown's Lake, which increased (Table 1). Extremely shallow water during both 1988 and 1989 reduced access into Upper Brown's Lake, which resulted in lower angler activity.

Discussion

Habitat rehabilitation in Brown's Lake, which consisted of a network of deepwater canals in combination with a gated structure to control inflows, was successful in creating wintering habitat for largemouth bass. Oxygenation of the top stratum of the water column in the dredge canal system was accomplished in 11 d with a minimal increase in current velocity. This improvement resulted in the return of radio-tagged largemouth bass to the dredge canal system. Inlet gate openings were reduced from 12 to 6 in to ensure that current velocities would not be detrimental to wintering largemouth bass and other centrarchid species.

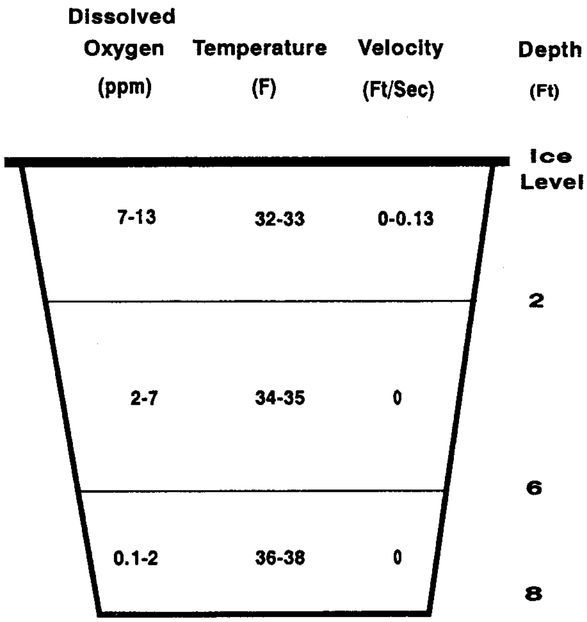

FIGURE 5.—Dissolved oxygen, water temperature, and current velocity profiles in the dredge canals during the winter period, Brown's Lake complex, upper Mississippi River, Pool 13, January–March 1991.

dredge canals, creating density currents that transported oxygenated water to all dredge canal segments. This density differential also resulted in pronounced oxygen and thermal stratification in the dredge canals. Stratification of the water column may be a beneficial management tool because various oxygen–temperature–current gradients created a variety of microhabitats in the canals. High dissolved oxygen concentrations were found in the surface stratum, but were mitigated by colder water temperatures and the presence of current. Water temperatures at or near 32°F and current were found to be undesirable to overwintering largemouth bass (Pitlo 1989) and other species (Sheehan et al. 1988). Conversely, water temperatures in the bottom stratum were warmer and current was absent; however, dissolved oxygen concentrations were prohibitively low. A gradient of oxygen and temperature values and an absence of current velocity in the midstratum allowed individual fish to select optimal zones by moving vertically in the dredge canals. Although vertical position of the radio-tagged largemouth bass could not be determined, reports and observations by anglers during the winter creel survey indicated that bluegill *Lepomis macrochirus,* black crappie *Pomoxis nigromaculatus,* white crappie *Pomoxis annularis,* and largemouth bass were suspended in the middepth transition zone of the dredge canals. Opening the inlet structure prematurely (before ice cover) may eliminate the temperature and density differentials that caused the stratification and thus negate the observed benefits of microhabitat zones in the dredge canals.

Deepwater habitat, created by deep dredging of holes, was anoxic and unsuitable for wintering fish during most of the ice cover period. None of the radio-tagged largemouth bass were found in association with this habitat, and the benefits of deepwater habitat to wintering fish are questionable in lentic, backwater systems.

Largemouth bass movements balanced use of the dredge canals with dissolved oxygen concentration. Radio-tagged largemouth bass showed an affinity for the dredge canal habitat in the Brown's Lake complex when winter dissolved oxygen concentrations remained above 3 ppm, but they moved to the main channel through Lainesville Slough when critically low oxygen concentrations persisted. Reoxygenation of the dredge canal system triggered an immediate return of radio-tagged largemouth bass to the dredge canal. Radio-tagged largemouth bass also showed individual tolerances to low dissolved oxygen concentrations. Most radio-tagged fish avoided dissolved oxygen concentrations below 6 ppm, preferring to move into Lainesville Slough, where oxygen levels ranged from 6 to 10 ppm. However, five radio-tagged largemouth bass remained in Lower Brown's Lake as dissolved oxygen concentrations fell to 3 ppm,

TABLE 1.—Estimated annual angler activity in the Brown's Lake–Lainsville Slough complex, 1988–1991.

	Open-water fishing								Ice fishing			
	Lower Brown's Lake–Lainsville Slough				Upper Brown's Lake				Lower Brown's Lake–Lainsville Slough			
Statistic	1988	1989	1990	1991	1988	1989	1990	1991	1988	1989	1990	1991
Number of anglers	4,771	4,562	6,877	4,468	0	306	1,557	2,225	145	255	68	767
Effort (h)	10,260	9,987	12,489	11,028	0	763	3,231	6,530	516	1,019	160	2,321
Number of fish caught	9,771	10,321	24,028	12,986	0	945	4,598	7,002	706	3,421	307	5,789
Number of fish harvested	7,911	7,236	9,570	7,714	0	568	2,543	3,765	706	3,313	307	4,844

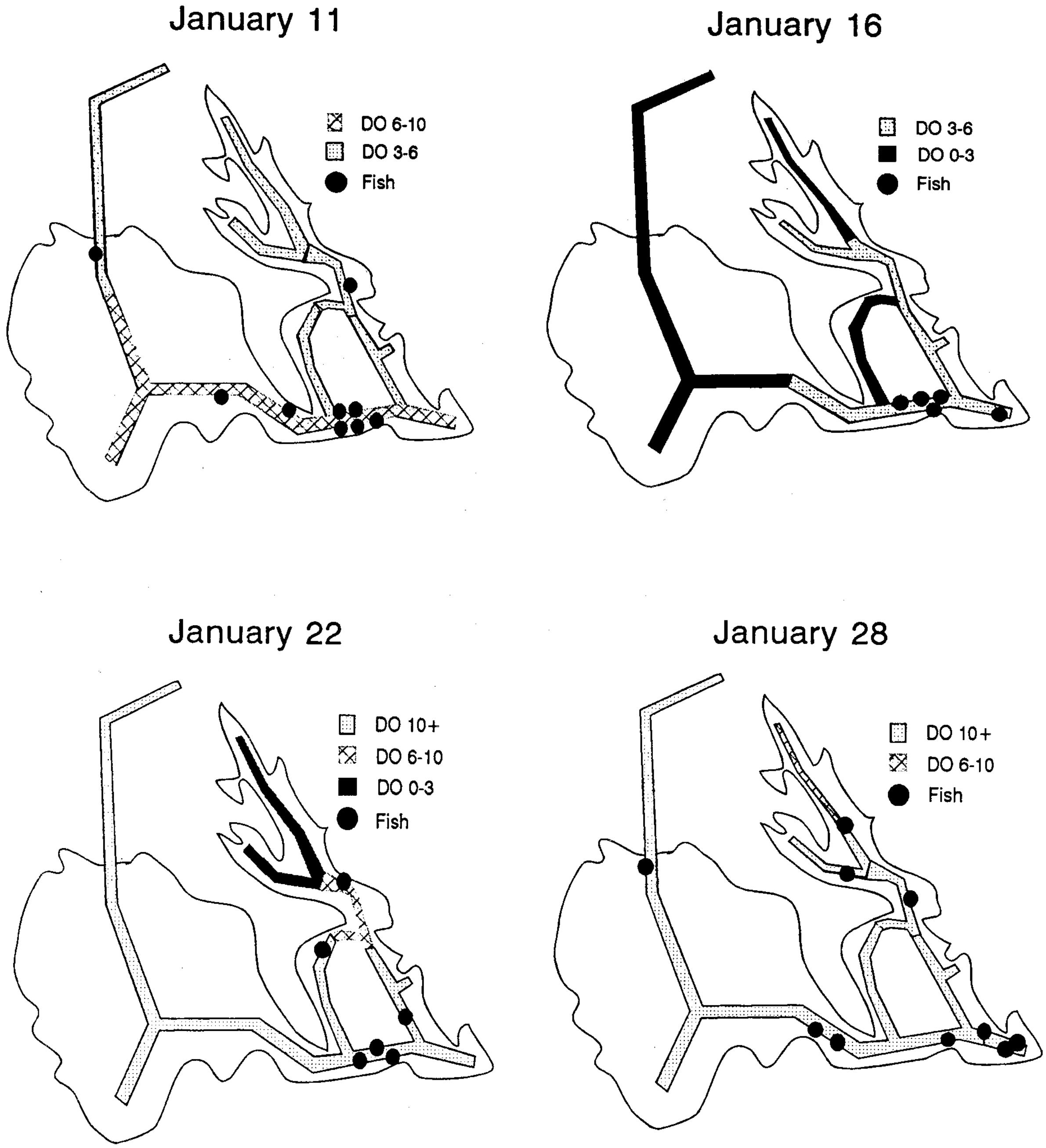

FIGURE 6.—Radio-tagged largemouth bass locations and dissolved oxygen (DO) concentrations (ppm) on four January dates in Brown's Lake dredge canals, upper Mississippi River, Pool 13, 1991.

although they stayed near the exit into Lainesville Slough.

Increased angler effort and catch reported in the creel estimates also support the conclusion of increased fish utilization of Brown's Lake following remedial work. Although unusually low water levels in 1988 and marginal ice cover during the winter of 1990 curtailed angling activity and induced high variation in angler and catch estimates, substantial increases were documented in postproject comparisons. Better angler accessibility following project construction influenced creel statistics during both open-water and ice fishing seasons, but comparisons of creel survey estimates before and after rehabilitation consistently illustrated increases in fish catch and angler effort following rehabilitation.

Angler activity and the movement of radio-

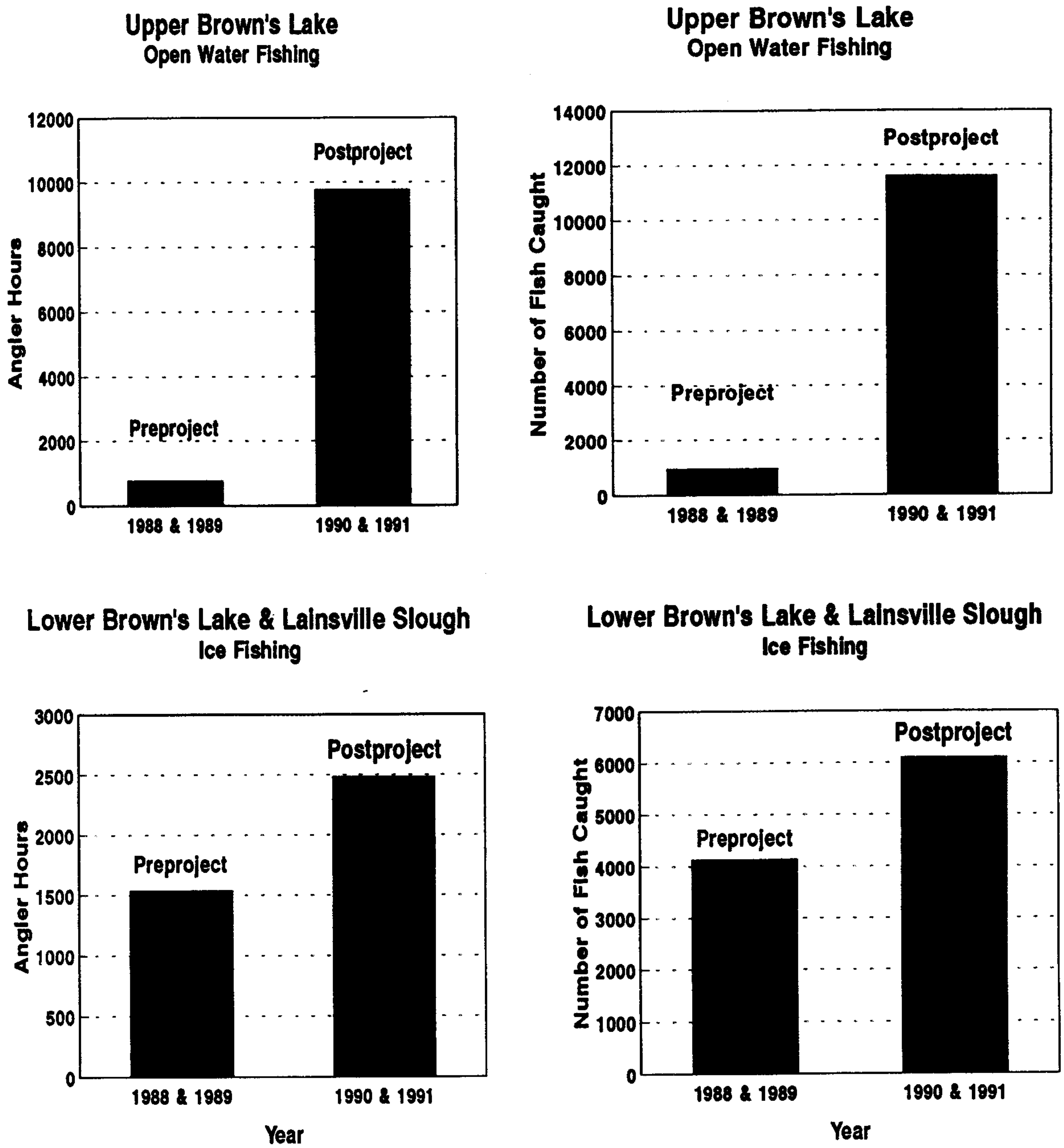

FIGURE 7.—Comparison of angler effort and total catch before and after completion of the rehabilitation project, Upper and Lower Brown's lakes, upper Mississippi River, Pool 13.

tagged largemouth bass during manipulation of oxygen levels in the dredge canals showed a strong association. Angler effort and catch rapidly declined in January, coinciding with radio-tagged largemouth bass movement out of Brown's Lake as oxygen levels declined. Movements of radio-tagged largemouth bass and a severe decline in fish catch and angler effort support the assumption that most centrarchids moved out of Brown's Lake or ceased feeding in response to anoxic conditions. Return of radio-tagged largemouth bass to the Brown's Lake dredge canals in late January coincided with a resurgence of ice fishing activity and catch. Although angling statistics cannot be an absolute index of fish response, the creel surveys were useful in assessing fish responses to changes in habitat and environmental factors.

Based on our findings, we make several recommendations. First, the rehabilitation techniques used in the Brown's Lake project were successful in achieving habitat enhancement and should be considered in the design of future projects. However, dredging projects alone cannot maintain adequate wintering habitat with the existing accelerated sedimentation rates in many upper Mississippi River backwaters. New techniques are necessary that use river hydraulics or other means to restore and maintain these valuable habitats on a larger scale. Second, water control structures intended to benefit overwintering fish should be designed for minimal flows. A small-capacity control structure with two gates (36 × 36 in) would be adequate for freshwater inputs to backwater complexes similar to Brown's Lake. Third, the cost-benefit ratio of deep-hole dredging should be considered in future backwater habitat projects. Although deep-hole dredging will provide increased storage for sedimentation, fish use of this habitat was restricted to spring and fall when the water was not stratified. With respect to Brown's Lake specifically, one gate of the water control structure should be opened 12 in 2 weeks after ice cover forms. The gate should remain open until spring ice-out unless turbidities exceed 40 NTU in the main channel or 100 NTU in the Maquokota River. All gates in the control structure should be closed before the spring run-off.

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13. ABSTRACT (Maximum 200 words)

Severe sedimentation since lock and dam construction in the 1930s has reduced water depth in Upper and Lower Brown's lakes, a backwater complex in Pool 13 of the upper Mississippi River, and resulted in periods of chronic anoxia. This backwater complex was rehabilitated by construction of a deflection levee, installation of a water control structure, and excavation of canals through the area. Water quality variables inside and outside the project area, movement of radio-tagged largemouth bass in response to changing oxygen concentrations, and creel statistics were used to evaluate the success of the improvements. Turbidity was significantly less in the Brown's Lake complex than in the main channel. Oxygen concentrations were allowed to deteriorate to 3 ppm before the water control structures were opened during the winter; within 7 d, oxygen concentrations as high as 10 ppm were found in the top strata in most of the Brown's Lake complex. Chemical and thermal stratification observed in the dredge canal water column were caused by colder (32°F), highly oxygenated water from the main channel moving over denser, warmer (36–38°F) water in the dredge canals. Water in the dredge canals remained stratified until ice-out, with colder, oxygenated water in the surface stratum; warmer, but anoxic, water in the bottom stratum; and a mixture (3–7 ppm oxygen and 35–36°F) in the middle stratum. Fourteen radio-tagged largemouth bass *Micropterus salmoides* were located in the Brown's Lake complex in December before oxygen concentrations began to decline. Concurrent with oxygen declines, most radio-tagged fish exited the complex through a slough connected to the main channel and returned when the water control structure was opened and oxygen concentrations increased. Some radio-tagged largemouth bass moved 4 mi under ice to return to the complex. Estimated angler effort and catch increased 58 and 117%, respectively, in the Lower Brown's Lake—Lainesville Slough complex following rehabilitation. A 10-fold increase in angler effort and catch was estimated for Upper Brown's Lake after the project was completed.

14. SUBJECT TERMS

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