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No. 481

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January 2000

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Division of Fish and Wildlife

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Minnesota Department of Natural Resources
Investigational Report 481, 1999

Seasonal Distribution, Habitat Use, And Spawning Locations of Walleye *Stizostedion Vitreum* And Sauger *S. Canadense* in Pool 4 of The Upper Mississippi River, With Special Emphasis on Winter Distribution Related to a Thermally Altered Environment

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Abstract— We used biotelemetry to determine the seasonal distribution, habitat use, and spawning locations of walleye *Stizostedion vitreum* and sauger *S. canadense* in navigational Pool 4 of the Upper Mississippi River. Our study area contained Lake Pepin, one of Minnesota's 10 largest walleye lakes. Special attention was provided to winter distributions relative to a thermal discharge from a nuclear power generating utility to investigate the hypothesis that walleye and sauger have altered their winter distribution in favor of a thermally enhanced environment in the upper reaches of the pool, thereby explaining Lake Pepin's perceived ice fishery decline. Twenty-seven walleye and 33 sauger collected from random locations throughout Lake Pepin were implanted with either radio or sonic transmitters and tracked by boat, plane, or snowmobile for 18 consecutive months beginning in November 1997. Temperatures in the upper reaches of the pool were monitored during the winter of 1998-99 for thermal effects attributable to the nuclear power station. Both scheduled and unscheduled plant shutdowns resulted in a wide range of thermal discharges throughout the winter. Operating capacities below 50% resulted in no net change in water temperature between test and control sites, suggesting that residual waste heat from the power plant dissipated before reaching Lake Pepin. When the power plant operated at 100% capacity, mean water temperature at the head of Lake Pepin averaged 0.84°C warmer than at a control site above the point of residual heat discharge. During full operating capacity, however, no relationship between the thermal effect and walleye and sauger winter distribution could be found. Near exclusive use of lake habitat by walleye and sauger throughout two winters provided additional evidence against the hypothesis. We found walleye and sauger to partition their habitat throughout the year. With the exception of spring, both walleye and sauger relied heavily on lake habitat, partitioned by depth between the species. During spawning, both species exclusively used riverine habitat above Lake Pepin for spawning, sauger using side channel border habitat and wing dams, and walleye principally using flooded backwater habitat. The lowest 18 km of the pool were never used by tagged walleye and only briefly used by tagged sauger.

Introduction

We initiated this study in response to a perceived decline in the winter ice fishery for walleye *Stizostedion vitreum* and sauger *S. canadense* in Lake Pepin, MN, one of Minnesota's 10 largest walleye lakes (Anonymous 1997) (Figure 1). Throughout the 1960s and 1970s, trends in angling success (CPUE) for Lake Pepin walleye and sauger differed little between open water and ice seasons. However, since the early 1980s, ice angling success has been generally poor relative to open water angling (Figure 2). Because the decline in the ice fishery cannot be attributed to changes in population dynamics, anglers have assigned most of the blame to changes in the operation plan of Northern States Power Prairie Island Nuclear Generating Plant (PINGP), located 1 km upstream of Mississippi River Navigational Pool 4 (Pool 4) in which Lake Pepin resides (Figure 3). Beginning in the winter of 1982-83, PINGP was permitted to change to a once-through cooling water cycle during winter months, resulting in an increased thermal load to Pool 4. Sport anglers speculate that the decline in the walleye and sauger ice fishery on Lake Pepin is due to behavioral changes in distribution attributable to PINGP's alteration of the thermal habitat in the upper reaches of Pool 4. The justification for this perception lies in an ice fishery decline that coincides with the permitted change in PINGP winter operations.

The extent and magnitude of PINGP thermal effect on the upper reaches of Pool 4 are largely unknown. As part of its operating permit, PINGP is required to monitor thermal conditions of the water between the receiving canal and Lock and Dam 3. Thermal effects on waters below Lock and Dam 3 are not a mandated component in this permit, and have never been directly monitored (Kenneth N. Mueller, PINGP, personal communication). Stefan (1987) investigated the potential effects of increased winter thermal load on Lake Pepin ice cover using a one-dimensional heat exchange model based on climatological variables and known heat exchange processes. He concluded that the process of heat rejection to the atmosphere depends on weather, river flow and the amount of waste heat discharged, and is not necessarily complete when the Mississippi River enters Lake Pepin. No empirical observations of the thermal habitat in the upper reaches of Pool 4 have been made, nor has any study of potential impacts on important fish species been conducted.

Temperature can potentially alter the distribution of walleye and sauger. In both laboratory and field situations, fish have been demonstrated to preferentially select temperatures that optimize their physiological functions (Coutant 1987). Moreover, thermal discharges from electrical power plants have been demonstrated to cause abnormal aggregation or repulsion of fish depending on season, fish age, and fish species (Neill and Magnuson 1974; Coutant 1975; Spigarelli and Thommes 1979; Shuter et al. 1985).

The primary questions in this study are whether a thermal impact of sufficient magnitude to initiate a behavioral response exists during the winter period in Lake Pepin, and secondly, whether walleye and sauger preferentially select and alter their distribution in response to this thermal impact, thereby linking PINGP actions to the decline in the winter fishery.

Our use of biotelemetry methods to determine walleye and sauger response to the PINGP thermal discharge permitted us to address several secondary objectives. These secondary objectives included descriptions of walleye and sauger seasonal distribution, spawning behavior, habitat use, and habitat partitioning in Pool 4. Advancements in biotelemetry techniques have greatly enhanced the quality and quantity of behavioral information collected in field studies (Younk et al. 1996; Winter 1996), and have been used extensively to infer walleye and sauger seasonal distribution, spawning behavior and habitat preference throughout the Upper Mississippi River (Bahr 1977; Freiermuth 1986 and 1987; Gangl et al. In press; Holzer and Von Ruden 1983; McConville and Fossum 1981; Pitlo 1983, 1989, 1998).

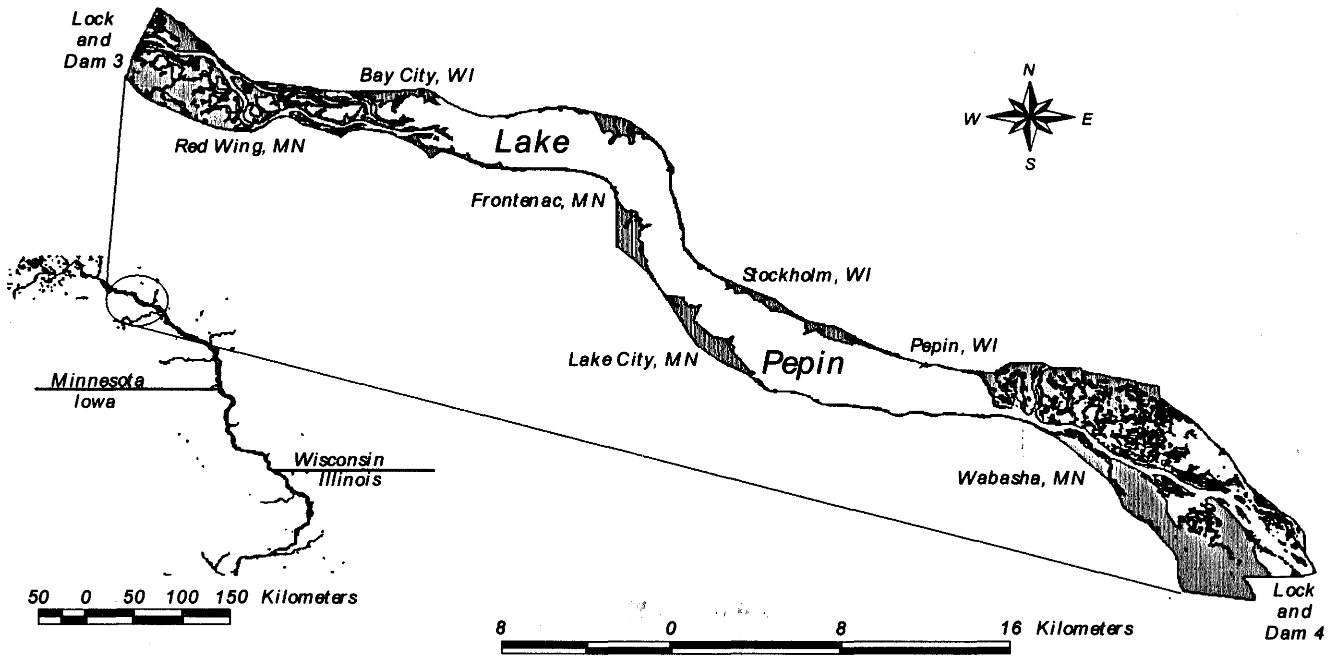


Figure 1. Pool 4 walleye and sauger biotelemetry project study area and its placement in the upper Mississippi River system. Pool 4 is bounded by Lock and Dam 3 at River Kilometer 1284.2, and Lock and Dam 4 at River Kilometer 1210.0.

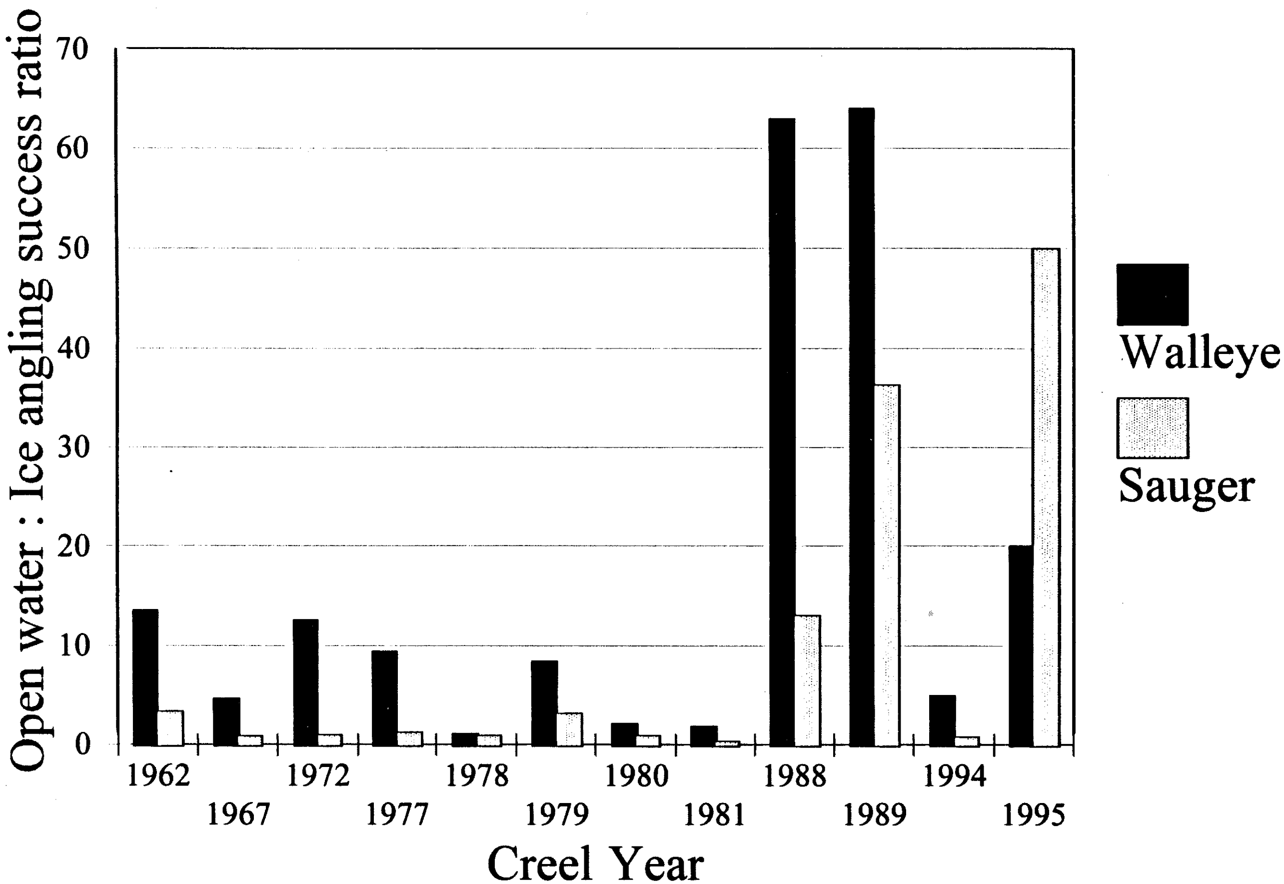


Figure 2. Trends in the proportional success rate, measured as harvest per unit angling effort from intermittent creel surveys, between open water and ice fisheries in Lake Pepin, MN. Smaller bars are indicative of relatively equal success between open water and ice angling seasons, while larger bars are indicative of greater open-water success relative to ice angling success. Creels were conducted by MDNR Lake City Management Unit either as part of their routine stock assessment program on Lake Pepin, or as part of special projects directed at walleye and sauger.

Several studies of walleye and sauger spawning habitat in Upper Mississippi River navigation pools suggest that walleye and sauger utilize a broad diversity of substrates for reproduction, and that the relative use of any substrate type differs widely among the pools (Gangl et al. In press; Holzer and Von Ruden 1984; Pitlo 1983, 1989; Siegwarth 1993; Gebken and Wright 1972; Brooks 1993; Brooks and Weaver 1995; Freiermuth 1986, 1987). Because of interpool variability in spawning habitat preference and availability, it becomes necessary to identify spawning habitat on a pool-by-pool basis. Three issues are apparent regarding Pool 4.

First, increasing effort and exploitation in the Pool 4 system require a better understanding of the processes that drive stock dynamics. A key component in fishery stock dynamics is the relationship between stock and recruitment, and the role that interacting habitat availability and environmental stochasticity play in producing new recruits on an annual basis (Hilborn and Walters 1992). As a first step in managing walleye and sauger stocks in Lake Pepin, it is necessary to identify critical spawning habitats, develop management plans to protect or enhance them, and to use this information to investigate the implications of any given habitat use on stock dynamics.

Second, the identification of spawning habitats is required to assess the long-term effects of reservoir aging attributable to creation and operation of the lock and dam system in the Upper Mississippi River watershed. While the lock and dam system provide the mechanism by which reservoir aging occurs, agricultural practices and urbanization provide the material. Engstrom and Almendinger (in press) estimate that 17% of Lake Pepin's volume in 1830 has been replaced by sediment, largely from agricultural practices in the Minnesota River basin, and at current accumulation rates the remainder will be filled in another 340 years. Pitlo (1998) estimated that 43% of the original 595 wing and closing dam structures associated with the Iowa border of the Mississippi River have been either, eroded, covered by sediment, or removed. The long term effects of such sedimentation and habitat loss on walleye and sauger spawning ecology is of concern.

Lastly, information on spawning habitat is required to ensure its protection. The U.S. Army Corps of Engineers (USCOE) is in the process of planning the needs of the lock and dam system for the next 50 years (Stevens 1994). Currently, a major renovation of Lock and Dam 3 is being considered that may close off significant amounts of off-channel habitat in the upper reaches of Pool 4. The continuous threats of marina development, recreational and commercial boat traffic, water appropriation, and exotic species introductions also have the potential to adversely affect spawning habitats.

Seasonal distribution and habitat selection also have management implications. Distributional ecology has been widely studied for numerous fish species, and has been used as the basis for regulating seasonal recreational and commercial effort when stocks are particularly aggregated and susceptible to harvest (Noble and Jones 1993). The Pool 4 walleye and sauger recreational fisheries have been open to angling continuously since 1969. This is in contrast to inland Minnesota lakes that have a closed season from mid-February to mid-May. Because of this difference, and Pool 4's close proximity to a major metropolitan area (Minneapolis and St Paul, MN), Pool 4 supports a very popular spring tailwater fishery. Thorn (1984) investigated the effects of continuous fishing on the Pool 4 walleye and sauger stocks and concluded that no significant impacts existed. However, if loss of habitat by channel alteration, backwater exclusion, or long-term sedimentation become important, the effect of continuous fishing on stock dynamics could become increasingly critical.

The majority of seasonal distribution, habitat selection, and spawning behavior studies on Mississippi River walleye or sauger have been autecological, focusing on one or the other species. In Pool 4, sauger are considerably more abundant than walleye and support nearly twice the median annual yield, yet little is known about the interactions between walleye and sauger in Pool 4. A better understanding of the distributional ecology and habitat selection between walleye and sauger will allow managers to evaluate and fine tune their stock assessment programs, and to understand interactions between these species that may effect their abundance and potential yield.

The purpose of this study was to measure the extent and magnitude of PINGP's thermal discharge on the upper reaches of Pool 4 in the winter months, and to observe Lake Pepin walleye and sauger distributional responses to the discharge. We also addressed secondary objectives, including seasonal distributions, habitat use, habitat partitioning between species, and the identification of spawning areas.

Study Area

Pool 4 of the Upper Mississippi River extends from Lock and Dam 3 near Red Wing, MN (River Kilometer 1282.4) to Lock and Dam 4 at Alma, WI (River Kilometer 1210.0), and is part of the USCOE's navigational system for commercial shipping (Figure 1). The largest pool in the Upper Mississippi River navigation system, Pool 4 is 71 km in length with a full pool surface area of 17,820 ha. A broad diversity of habitat occurs throughout the pool including both riverine and lake habitats. Consequently, a cosmopolitan fish community of nearly 85 species resides in this system (Rasmussen 1979). Walleye and sauger are the most popular sport species in this system and together comprise greater than 50% of the annual sport yield, producing median annual yields of 13,200 kg and 24,000 kg, respectively (Anonymous 1997).

We identify three distinct zones of walleye and sauger habitat in Pool 4. The first, represented by the first 18 km of the pool, is lotic with both a main channel used for navigation and a shallower back channel. A system of backwater lakes and sloughs connect the channels resulting in a braided network. This reach is unique in the sense that there are only 4 wing and closing dams in the entire reach, and is atypical of impounded Upper Mississippi River pools.

The second zone is lentic and is known as Lake Pepin, a natural impoundment of the Mississippi River contained within the man-made impoundment of Pool 4 (Figure 1). Lake Pepin is 35 km in length, averages 2.8 km in width, and covers 10,125 ha. While all of the flow of the Mississippi River goes through Lake Pepin, it has many characteristics of an inland lake. It is subject to wave action, demonstrates little current, possesses a lentic fish community, and has a mean and maximum depth of 6.4 m and 18.3 m, respectively (Figure 4).

The third zone, represented by the lowest 18 km of the pool, is also lotic with a series of backwater lakes and sloughs. This reach is more typical of impounded Upper Mississippi River pools. It differs from the first zone in that 1) nearly 130 wing and closing dams are present, and 2) there is no tailwater habitat.

Methods

We studied seasonal distribution, habitat use, and spawning behavior of Lake Pepin walleye and sauger from October 1997 through May 1999 using both radio and sonic telemetry. Special consideration was given to winter distribution relative to the available thermal habitat in the upper reaches of Pool 4. Over 18 months, 27 walleye and 33 sauger were captured throughout Lake Pepin using DC electroshocking, short-term gill net sets and trap nets, and tracked using either radio or sonic telemetry (Table 1).

Biotelemetry We surgically implanted transmitters into abdominal cavities following methods similar to those described by Hart and Summerfelt (1975). Thirty-eight radio tags were implanted into 20 walleye and 18 sauger during September and October 1997. Seven radio tags, recovered from dead test fish and anglers, were re-implanted into seven walleye in October 1998. Additionally, 15 sonic tags were implanted into sauger during October 1998. Surgeries and releases occurred at the site of capture, resulting in a random allocation of tags

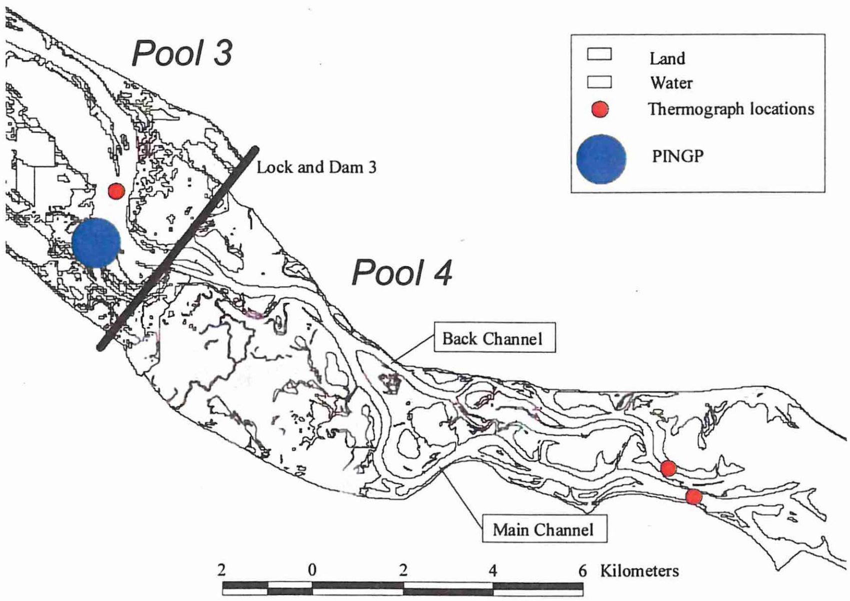


Figure 3. Location of Northern States Power Prairie Island Nuclear Generating Plant (PINGP), and the thermograph sites used to calculate a heat budget for determining thermal effects on Lake Pepin attributable to PINGP during the winter of 1998-99.

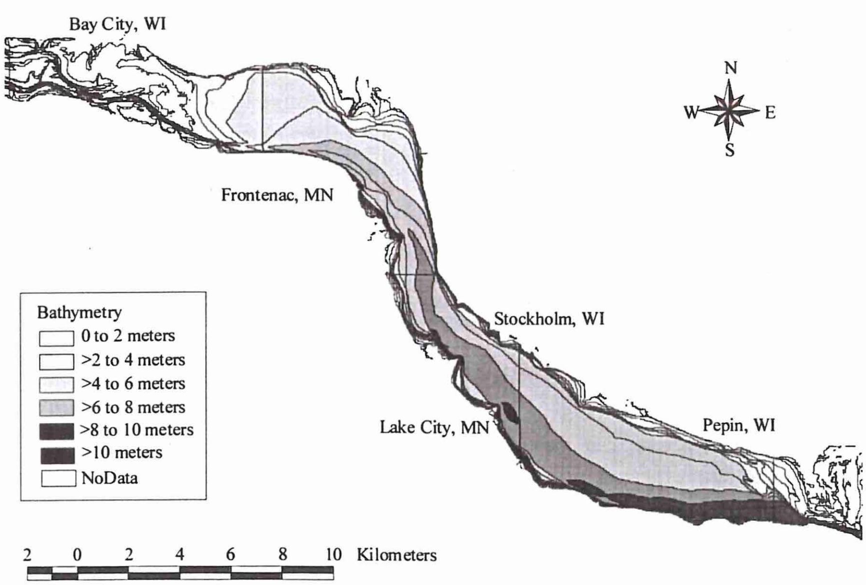


Figure 4. Bathymetry of Lake Pepin.

Table 1. Summary of tagging and tracking histories for radio and sonic tagged walleye and sauger in Pool 4 of the Upper Mississippi River, 1997-1999.

Transmitter frequency (MHZ)	Sex	Total length (mm)	Age	Date tagged	Date last located	Number of times located	Number of days at large
				Radio Tagged Sauger			
48.120	M	424	6	14 Oct 97	05 Mar 98	3	143
48.141	M	465	8	15 Oct 97	16 Oct 97	0	1
48.171	F	541	9	21 Oct 97	20 Apr 98	6	182
48.181	F	569	9	22 Oct 97	11 Apr 98	1	172
48.191	F	579	10	23 Oct 97	04 Apr 98	4	164
48.201	F	511	7	23 Sep 97	03 Sep 98	7	346
48.211	F	460	5	20 Oct 97	19 Feb 98	2	123
48.221	F	439	5	21 Oct 97	11 May 98	9	203
48.261	M	460	6	21 Oct 97	18 Jul 98	9	271
48.290	M	465	6	07 Oct 97	14 May 98	4	220
48.321	F	528	9	22 Oct 97	11 Apr 98	3	172
48.341	F	480	6	22 Oct 97	11 May 98	7	202
48.351	F	498	7	20 Oct 97	19 Jul 98	2	273
48.360	F	495	9	16 Sep 97	07 Oct 97	3	22
48.400	M	457	6	14 Oct 97	18 Mar 99	19	521
48.440	F	508	6	16 Sep 97	07 Oct 97	2	22
48.450	F	523	8	15 Oct 97	--------	0	0
48.551	M	495	5	21 Oct 97	04 Apr 98	3	166
				Sonic Tagged Sauger *			
5763	F	472	7	10 Oct 98	15 Apr 99	9	188
5762	M	479	8	10 Oct 98	14 Apr 99	7	187
5765	F	511	7	11 Oct 98	21 Apr 99	9	194
5766	F	493	5	12 Oct 98	12 Apr 99	11	184
5764	M	478	6	18 Oct 98	21 Apr 99	10	186
5767	M	498	6	18 Oct 98	21 Apr 99	27	186
5769	F	521	5	18 Oct 98	21 Apr 99	23	186
5774	F	465	4	18 Oct 98	30 Apr 99	24	195
5768	F	549	6	18 Oct 98	08 Apr 99	14	173
5773	F	564	7	18 Oct 98	21 Apr 99	26	186
5772	F	513	5	18 Oct 98	30 Apr 99	24	195
5770	F	432	4	23 Oct 98	21 Apr 99	25	183
5775	M	445	6	23 Oct 98	21 Apr 99	25	183
5771	F	544	7	23 Oct 98	21 Apr 99	28	183
5776	M	467	6	23 Oct 98	21 Apr 99	18	183
				Radio Tagged Walleye			
48.161	M	488	4	15 Sep 97	25 Mar 98	4	192
48.231	F	460	4	17 Sep 97	10 Feb 98	9	147
48.241	F	480	4	22 Sep 97	17 Nov 97	5	57
48.251	M	500	6	11 Sep 97	30 Apr 99	45	597
48.271	F	467	5	22 Sep 97	18 Nov 97	1	58
48.301	F	460	4	17 Sep 97	09 Jan 98	6	115
48.371	M	495	5	11 Sep97	03 Dec 97	2	84
48.381	M	457	5	17 Sep 97	08 Dec 97	4	83
48.421	F	488	4	16 Sep 97	11 Nov 97	3	57
48.431	F	513	5	11 Sep 97	08 Apr 99	31	575
48.460	M	500	6	11 Sep 97	08 Dec 97	8	89
48.472	M	521	7	15 Sep 97	30 Apr 99	29	593
48.501	F	592	9	11 Sep 97	22 Aug 98	8	346
48.512	M	513	4	16 Sep 97	18 Sep 97	2	2
48.521	F	627	9	22 Sep 97	24 Oct 97	2	33

Table 1. Continued

Transmitter frequency (MHZ)	Sex	Total length (mm)	Age	Date tagged	Date last located	Number of times located	Number of days at large
48.531	F	673	7	15 Sep 97	30 Apr 99	25	593
48.559	F	526	5	20 Oct 97	26 Mar 98	7	158
48.568	F	582	5	15 Sep 97	02 Feb 98	3	141
48.598	F	599	6	11 Sep 97	19 Jul 98	22	312
48.911	F	597	6	07 Oct 97	05 May 98	9	211
48.320	M	500	8	06 Oct 98	30 Apr 99	6	207
48.140	M	475	7	06 Oct 98	27 Mar 99	5	173
48.370	M	530	9	06 Oct 98	30 Apr 99	13	207
48.280	M	547	9	06 Oct 98	30 Apr 99	16	207
48.380	F	555	6	06 Oct 98	30 Apr 99	15	207
48.180	F	579	7	06 Oct 98	30 Apr 99	18	207
48.910	F	705	12	06 Oct 98	25 Jan 99	1	112

* Sauger sonic frequencies are reported as serial numbers. Sonic tags operated on 50, 54, and 57 kHz frequency bands. Within each frequency band, 5 transmitters were "stacked" by varying the pulse period between successive "pings", allowing individual identification of each tag.

throughout Lake Pepin (Figure 5). Although attempts were made to ensure equal representation from both sexes, only 41% of the walleye and 33 % of the sauger were male. All tagged fish were sexually mature, and were a minimum of 430 mm in total length to avoid exceeding the suggested 2% transmitter weight to fish weight ratio (Winter 1996).

We used radio telemetry for walleye throughout the 18 month study (November 1997 - April 1999) and for sauger during the first year of the study (November 1997- October 1998). Forty radio transmitters of two types were used. Ten of the tags measured 66 mm in length, 18 mm in width, weighed 30 g, and operated continuously. The remaining 30 radio tags measured 46 mm in length, 17 mm in width, weighed 20 g, and operated on a 12 hour on/12 hour off duty cycle. On time was set at 0800 CST. Each radio transmitter operated at a unique output frequency within the 48 MHz band with adjacent transmitters separated by a minimum of 9 Khz. All radio transmitters had a minimum life expectancy of 18 months.

Radio tracking equipment consisted of a programmable scanning receiver, a four-element boat-mounted Yagi antenna, a handheld loop antenna, two airplane wing strut mounted loop antennas, and a coaxial whip antenna. During open water periods, tracking was accomplished using a boat. During winter, tracking was accomplished with either an airboat or a snowmobile. Aerial tracking was used year-round to locate lost fish. We used methods described by Niemala et al. (1993) to obtain positions on fish accurate to 3 m.

We used sonic telemetry for sauger during the second year of the study (November 1998 - April 1999). Fifteen sonic tags were stacked on 3 frequencies (50, 53, and 57 Khz) by providing a 45 msec minimum spacing between pulse intervals for signals on the same frequency. Sonic tags operated on a 12 hour on/12 hour off duty cycle with an on time of 0800 hours CST. Minimum sonic tag life expectancy was six months.

Sonic equipment consisted of a programmable scanning sonic receiver and a linear array hydrophone. Fish locations were ascertained by tracking until a strong signal could be heard in all directions (360°) at the lowest gain setting. When multiple fish on the same frequency were in close proximity, we used a computer algorithm embedded in the receiver to identify the fish. Tracking was accomplished by boat during open water, and by snowmobile or airboat in the winter.

Monitoring began a minimum of one week after the last surgery for either year of the study to allow the fish to behaviorally acclimate to the implants (Winter 1996). Summer, autumn, and winter tracking was conducted twice per month, while spring tracking effort was increased to three to four times per month, each time being defined as a tracking event. We attempted to apply uniform and equal effort to all trackable water in the pool per tracking event by beginning each event at Lock and Dam 3 and proceeding downstream to Lock and Dam 4. For radio tracking, each tracking event required four to five days of effort to achieve full pool coverage, while for sonic tracking, uniform coverage could be accomplished in one to two days. Each event proceeded until either all study fish were found or the full pool was covered. All tracking was conducted during daylight hours.

For each fish location, we recorded date, contact time, water depth, water temperature, tag frequency and notes. Initially, we collected information on substrate type, cover, habitat type, dissolved oxygen, and Secchi transparency, but discontinued collecting these data for all seasons except spring due to the nearly exclusive use of lake habitat that was homogeneous for these variables. We acquired fish position using a differential global positioning system (DGPS) (Jeffrey and Edds 1997) and recorded position in UTM coordinates, NAD83 projection. We measured depth with a boat mounted depth sounder or estimated it for winter observations from Geographic Information System (GIS) coverages of Pool 4. All data were integrated into a GIS using Arcview software[a].

Habitat use Associations to available habitat types were made using positional data and existing GIS habitat coverages for Pool 4. Lake habitat was classified as nearshore (< 50 m from shore), contour break (> 25% contour slope), point (< 50 m from a natural shoreline projection), shallow flat (< 25 % contour slope and < 3 meters in depth) and deepwater flat (< 25% slope and > 3 m in depth), while river habitat was classified as flooded backwater (seasonally inundated off-channel areas), backwater lake (year-round inundated off-channel areas), main channel (USCOE maintained shipping channel), side channel border (side margins of the main channel with contour and secondary channels), and wing/closing dam (man-made flow control structure). We made no attempt to inventory available habitat in the nearly 18,000 ha study site.

Spawning We identified spawning areas by tracking tagged individuals onto their spawning areas. We made attempts to verify spawning during the first year of the study (Spring 1998) using a one square meter dipnet lined with 0.5 mm mesh screen in flooded backwater sites, and a boat-towed epibenthic sled, described by Brooks and Weaver (1995), in main channel, side channel, and suspected lake spawning sites. Collected eggs were keyed as *Stizostedion spp.* or Other, and then incubated to hatching to verify initial egg identification and to make species identifications (Auer 1982).

Temperature monitoring We empirically measured the extent and magnitude of PINGP thermal effects on the upper reaches of Pool 4 using datalogging thermographs and information from PINGP's temperature monitoring program. We placed two temperature recording dataloggers in the lowest reaches of the upper river (Figure 3), one in each of the back and main channels, respectively. The thermographs were initialized for simultaneous recording. Thermographs were placed one meter off the bottom, in the deepest water available at each site. Prior to deployment, and following final retrieval, the thermographs were subjected to an in-lab calibration check against a certified reference thermometer for temperatures ranging from 0 to 30°C Data were recorded at one hour intervals for one full year. Information from these units was coupled with temperature data collected by PINGP at a control site to calculate

[a]*Use of any referenced product does not imply endorsement by the authors.*

a heat budget, and to determine whether Lake Pepin was receiving a thermal load attributable to PINGP. River discharge was obtained from a USCOE gauge station operating at Lock and Dam 3 (www.mvp-wc.usace.army.mil/projects/ Lock3.html). Additional data on waste heat discharge and reactor down times were provided by PINGP.

Temperature recording made the assumption that river water was thoroughly mixed by entrainment through the dam and that no vertical or cross channel gradients existed. To check this assumption, monthly vertical temperature profiles were taken at three cross channel sites in proximity to each thermograph site using a weighted YSI model 51B dissolved oxygen and temperature meter[a].

Analysis To facilitate analyses, we partitioned the data by season and species. Seasons were defined as spring (March-May), summer (June-August), autumn (September-November), and winter (December-February). Ranges were defined as the total linear distance (km) between extreme upstream and downstream locations of each fish. We used total population range as a measure of distribution density, defined as the maximum linear distance between the most spatially extreme positions during any given season or month for each species. Student's t-tests were used to investigate differences in depth, and temperature between species and seasons. Temperature effects on winter distribution were determined using Pearson correlation and ordinary least squares regression. All statistical tests were conducted at the 5% level of significance.

Results

We documented seasonal distribution, habitat use and partitioning, and spawning behavior for Pool 4 walleye and sauger. The magnitude and extent of PINGP thermal impact in the upper reaches of Pool 4 were determined for the winter of 1998-99, and walleye and sauger winter distribution relative to the thermal impact was observed. Over 18 months, we obtained 662 locations, of which 58% were from radio transmitters, and 42% were from sonic transmitters. Sauger and walleye accounted for 53% and 47% of the locations, respectively. Monitoring periods for each fish varied widely for radio-tagged fish, ranging from 0 to 593 days, but were remarkably consistent for sonic tagged sauger, ranging from 173 to 195 days (Table 1). Differences in length of individual monitoring periods were primarily due to fish mortality, or radio signal attenuation in the case of sauger. Only one fish was harvested and reported by an angler. Unconfirmed reports of angler caught and released fish were received for two of the study walleye in the autumn of 1998.

Seasonal distribution

Both walleye and sauger exhibited seasonal changes in their longitudinal distribution throughout Pool 4. With the exception of spring, both walleye and sauger utilized lake habitat in Lake Pepin almost to the exclusion of all other available habitat types in Pool 4. All study fish of both species used riverine habitat above Lake Pepin to spawn. Interpool movement was only observed for two walleye that bypassed Lock and Dam 3 in 1998 by migrating up the Vermillion River, returning to Lake Pepin following spawning. Otherwise, all spawning for both species was limited to the upper 18 km of Pool 4. Walleye were never observed to use the lower riverine reaches of the pool, while sauger used this reach only briefly during the winter of 1997-98. Ranges were smallest during the summer for walleye and during winter for sauger. The greatest ranges were observed during the spring for each species.

Spring accounted for 54% of the total observations. Spring movements associated with spawning coincided with the greatest activity for both species. Walleye staged exclusively in the upper one-third of Lake Pepin on shallow, silt substrate flats during March, with 84% of the observations coming from the Wisconsin one-half of the lake (Figure 6). During spawning, walleye were widely distributed throughout the backwater complexes of the

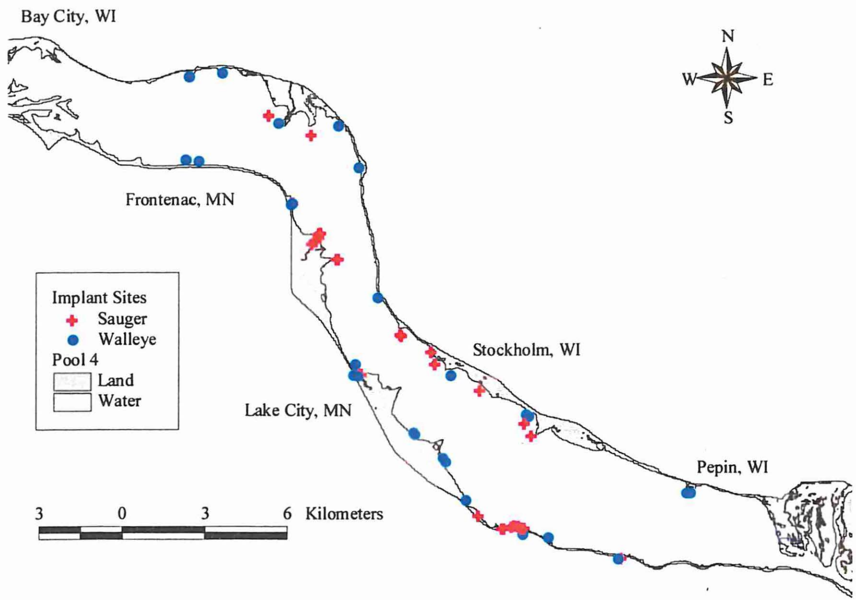


Figure 5. Locations of transmitter implant and release sites of biotelemtry tags throughout Lake Pepin. Study fish were captured using DC electroshocking, trap nets, and short-term gill net sets in nearshore areas.

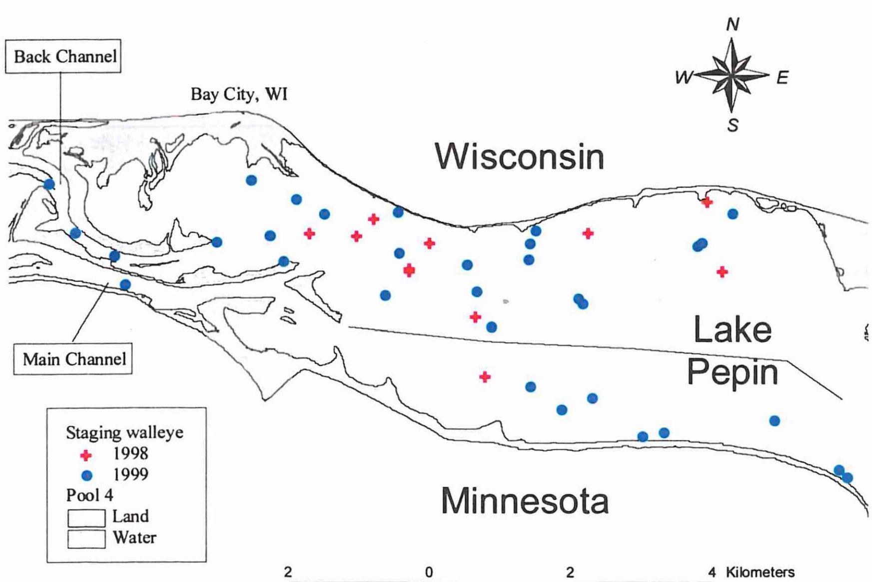


Figure 6. Pre-spawn distribution of walleye during the 1998 and 1999 spawning seasons, Pool 4 of the upper Mississippi River. Observations from 1998 represent the distribution of 7 study fish, while 1999 observations represent the distribution of 10 study fish. Inclusive of dates 07 March - 26 March 1998 and 14 March - 31 March 1999. Some study fish represented in this figure contributed several observations, however, the observations were considered independent.

upper riverine reaches of the pool (Figure 7). Walleye returned to Lake Pepin quickly following spawning. Ranges during spring varied for individual fish, but range for the whole tagged walleye population measured 61 km in 1998 and 37 km in 1999.

Sauger staged almost exclusively in main and side channel border areas at the confluence of the upper river navigational channel with Lake Pepin (Figure 8). In 1998, sauger arrived in this area of the pool from both upstream points near Lock and Dam 3, and downstream points near Wabasha, MN. During spawning, sauger aggregated in four primary main and side channel sites in the upper 5 km of Pool 4 (Figure 9). Ascent to the spawning grounds was rapid during March. No sauger were observed to leave Pool 4, and all sauger returned to Lake Pepin by early May following spawning .

Summer accounted for only 5 % of the total observations due to high over-winter and post-spawn mortality. Following their wide-ranging spring distribution, walleye established small nearshore summer ranges in Lake Pepin. Twenty-five observations were made, primarily on four walleye. Summer home range size was small, ranging from 0.005 km^2 to 0.35 km^2, and averaging 0.154 km^2 for these four fish. Three of these home ranges were established in embayments, near contour breaks. Summer walleye depths averaged 3.1 m, and ranged from 1.2 to 6.7 m. In 1998, three of the four walleye established summer home ranges near where they were tagged the previous autumn, demonstrating homing behavior.

Only six observations were made on radio tagged sauger during summer, due to use of deep habitats leading to signal attenuation. Three of these observations were made in the upper riverine portions of Pool 4, while the remaining observations were made in Lake Pepin. Depth averaged 4.0 m.

Autumn accounted for 14% of the total observations. Walleye were widely distributed throughout Lake Pepin in 1997 and 1998, likely resulting from a broad and random implantation effort in both years (Figure 10). Walleye primarily used nearshore contour breaks and points throughout autumn. Nearshore contour breaks accounted for 60% of the autumn observations, while points accounted for 35 %. Open water areas were infrequently used and accounted for only 4% of the observations. One walleye was found in the upper riverine portion of the pool in November 1997. Average depth during autumn was 4.2 m, indicative of walleye locations near the tops of contour breaks.

Sauger distribution during the autumns of 1997 and 1998 were limited to the Lake Pepin basin proper (Figure 11). Similar to walleye, sauger were widely distributed. Sauger were predominantly associated with deepwater flats and nearshore contour breaks. Consequently, mean depth was greater than for walleye (mean 7.1 m, $P < 0.0001$, $t=6.18$).

Winter accounted for 27% of the total observations. In December, walleye were still widely distributed throughout Lake Pepin. Beginning in January, walleye made upstream movements. Notable aggregation occurred in the upper one-third of Lake Pepin throughout the winter, accounting for 75% of the observations (Figure 12). Walleye were observed to alter their distribution relative to shifting ice margins during the winter of 1997-98. Tagged population range for walleye during winter was 27.1 km in 1997-98 and 11.9 km in 1998-99. With the exception of 2 walleye that entered the upper river in the winter of 1997-98, walleye distribution was limited to Lake Pepin. Of the walleye that moved into the upper river, one overwintered 5 km below Lock and Dam 3, while the other entered a backwater lake and perished.

Information on sauger was limited for the winter of 1997-98 due to deep water distribution and associated radio signal attenuation. However, 18 observations were made (Figure 13). One sauger overwintered in the tailwaters of Lock and Dam 3. Three more were located briefly in December in the lower riverine reach near Wabasha, MN. Four other sauger were found to be distributed through the mid-reaches of Lake Pepin.

Sonic observations during the second winter confirmed that sauger were found within the mid-lake reach of Lake Pepin (Figure 13).

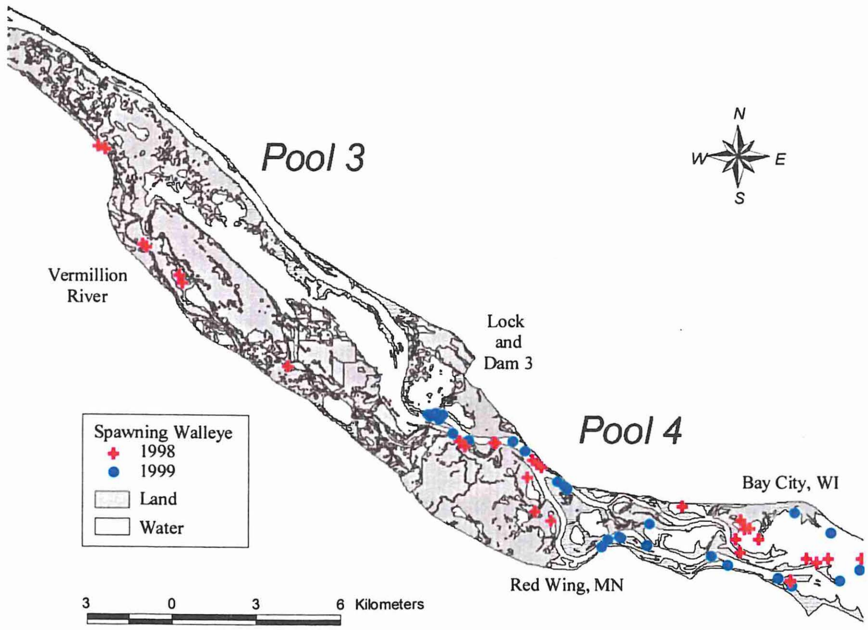


Figure 7. Distribution of spawning walleye during the 1998 and 1999 spawning seasons, Pool 4 of the upper Mississippi River. Observations from 1998 represent the distribution of 9 study fish, while 1999 observations represent the distribution of 11 study fish. Inclusive of dates 05 April - 28 April 1998 and 12 April - 09 May 1999. Some study fish represented in this figure contributed several observations, however, the observations were considered independent.

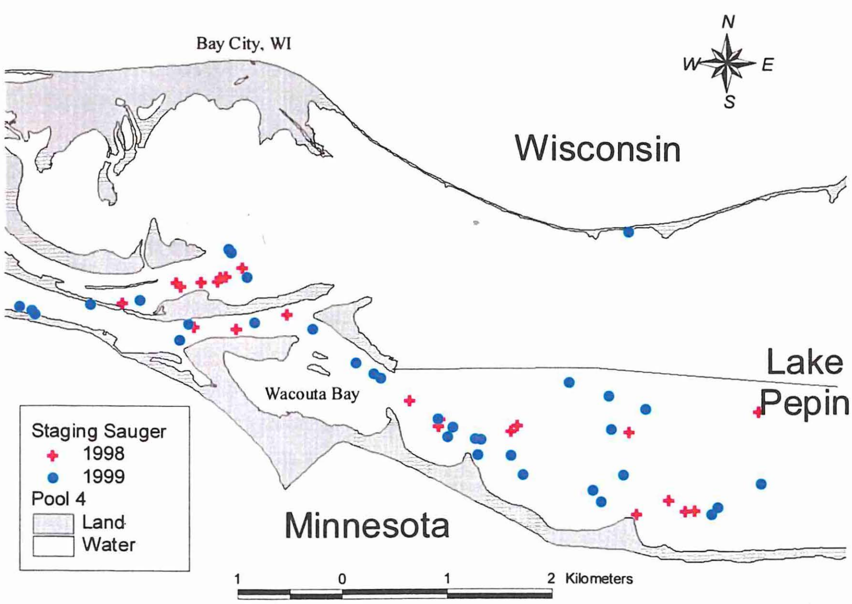


Figure 8. Pre-spawn distribution of sauger during the 1998 and 1999 spawning seasons, Pool 4 of the upper Mississippi River. Observations from 1998 represent the distribution of 9 study fish, while 1999 observations represent the distribution of 13 study fish. Inclusive of dates 05 March - 05 April 1998 and 12 March - 14 April 1999. Some study fish represented in this figure contributed several observations, however, the observations were considered independent.

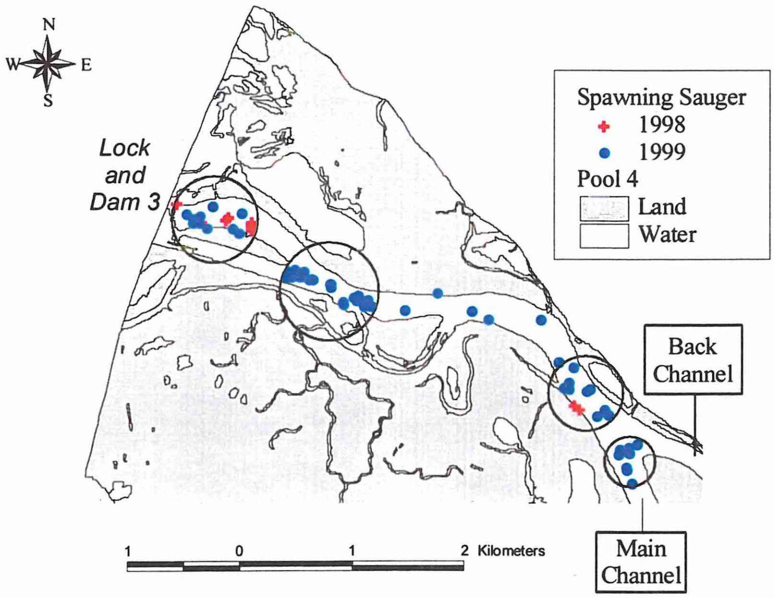


Figure 9. Notable spawning aggregations of sauger during the 1998 and 1998 spawning seasons, Pool 4 of the upper Mississippi River. Primary habitats were wing dams, and side channel borders. Observations from 1998 represent the distribution of 4 study fish, while 1999 observations represent the distribution of 12 study fish. Inclusive of dates 11 April - 11 May 1998 and 18 March - 15 April 1999. Some study fish represented in this figure contributed several observations, however, the observations were considered independent. Observations from 1998 were obtained using radio tags, while 1999 observations were obtained using sonic tags.

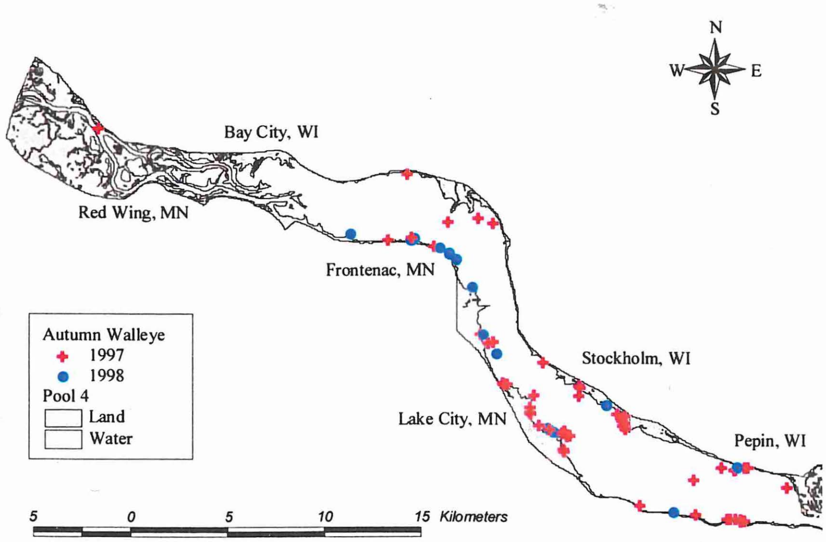


Figure 10. Autumn distribution of walleye in Pool 4 of the upper Mississippi River 1997 and 1998. Observations from 1997 represent 19 study fish while 1998 observations represent 10 study fish. Some study fish represented in this figure contributed several observations, however, the observations were considered independent.

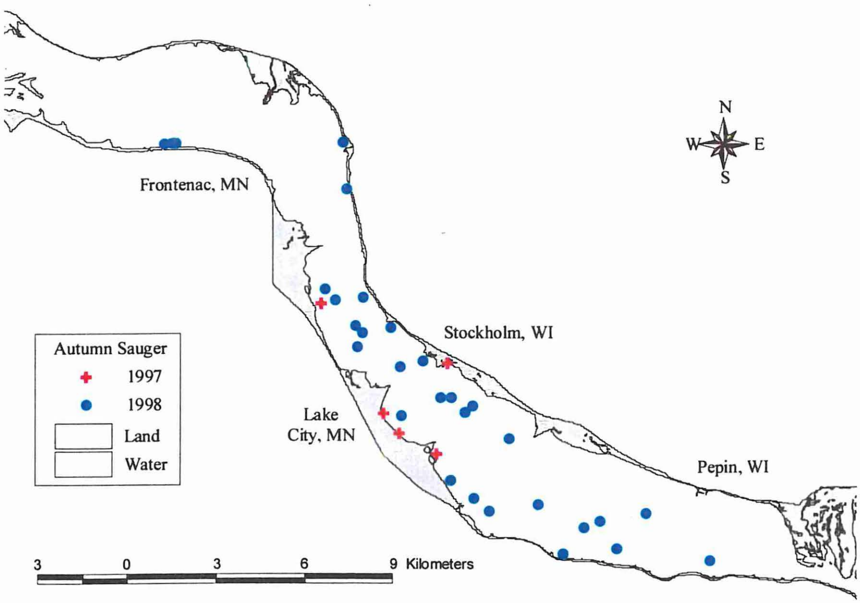


Figure 11. Autumn distribution of sauger in Pool 4 of the upper Mississippi River 1997 and 1998. Observations from 1997 represent 9 study fish while 1998 observations represent 14 study fish. Some study fish represented in this figure contributed several observations, however, the observations were considered independent.

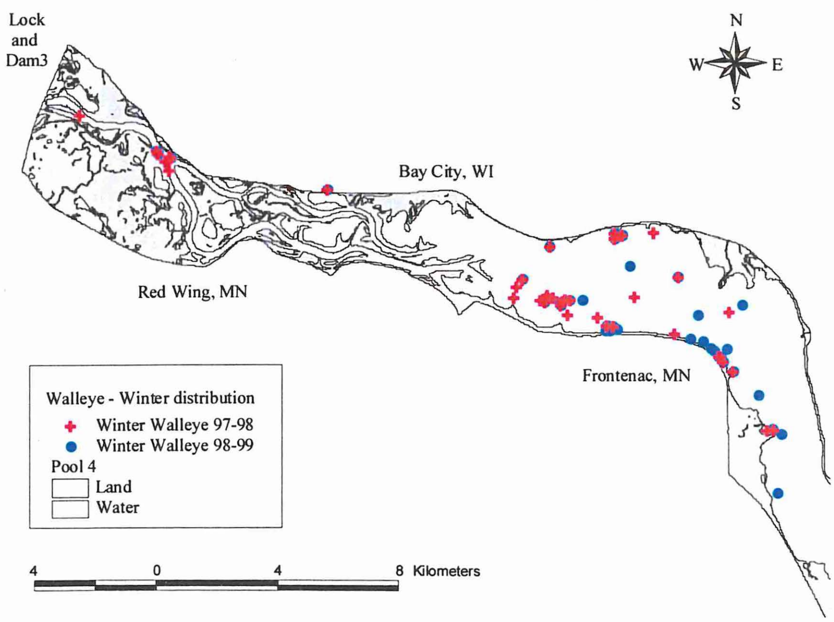


Figure 12. Winter distribution of walleye in Pool 4 of the upper Mississippi River 1997-98 and 1998-99. Observations from 1997-98 represent 10 study fish while 1998-99 observations represent 9 study fish. Some study fish represented in this figure contributed several observations, however, the observations were considered independent.

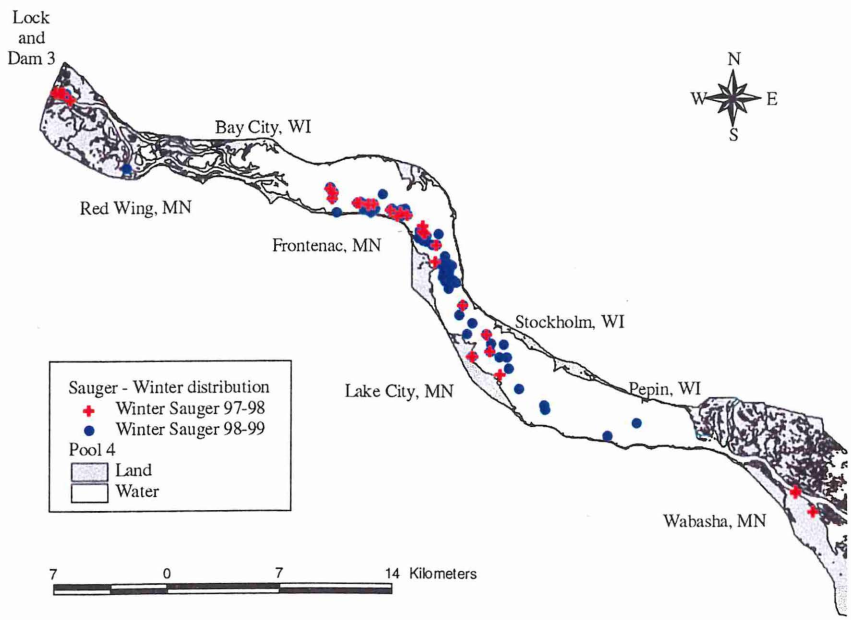


Figure 13. Winter distribution of sauger in Pool 4 of the upper Mississippi River 1997-98 and 1998-99. Observations from 1997-98 represent 8 study fish while 1998-99 observations represent 15 study fish. Some study fish represented in this figure contributed several observations, however, the observations were considered independent.

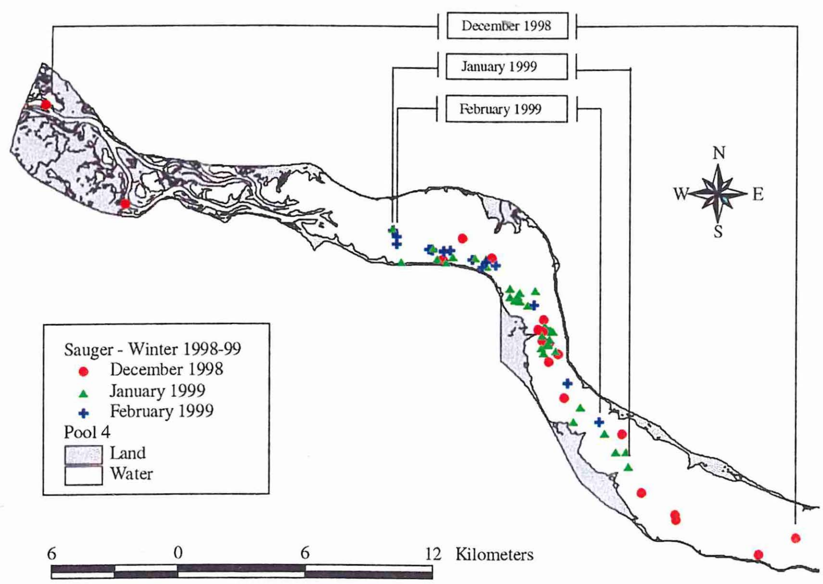


Figure 14. Distribution of sonic tagged sauger during the winter of 1998-99 in Pool 4 of the upper Mississippi River. Observations represent 15 study fish. Some study fish represented in this figure contributed several observations, however, the observations were considered independent.

Observations from the winter of 1998-99 showed that sauger in December were widely distributed throughout the lower two-thirds of Lake Pepin. Two sauger did enter the upper river in December, one going within 1 km of Lock and Dam 3, but both returned to Lake Pepin within a week. Slow, but persistent upstream movements were made by all sauger, largely in unison, during January resulting in offshore aggregations at Long Point and Methodist Camp points, in the deepest water available (mean = 7.3 m). Sauger distribution became more dense throughout the winter (Figure 14). By February, 89 % of the observations were made in the upper one-third of Lake Pepin, exclusively within the deep shipping thalweg. No sauger were observed to use the lower riverine section of the pool during the second year.

Habitat use and partitioning

Walleye and sauger demonstrated seasonal and interspecific differences in habitat use in Pool 4, reflecting changes in their seasonal distribution. Summer, autumn, and winter habitat use was primarily limited to lake habitat throughout Lake Pepin for both walleye and sauger. In spring, lake habitat was used during pre-spawn staging while river habitat was used exclusively during spawning for both species (Table 2).

Walleye Walleye were most frequently observed in association with nearshore contour breaks and shallow flats throughout Lake Pepin during autumn, winter, and summer seasons. Habitat use was very similar during autumn of both study years, with nearshore contour breaks and points accounting for 88% of the observations in both 1997 and 1998. Walleye tended to be most closely associated with the top edges of the nearshore breaks, which typically begin at 3 m and drop precipitously to greater than 10 m around the majority of the lake. Deep water flats and shallow water flats were the only other lake habitats used, and were relatively unimportant. Only one walleye observation was made in riverine habitat during the autumn.

Summer habitat observations were dominated by nearshore contour breaks (87 %). Shallow and deep water flats were the only other habitat types observed to be used by walleye during summer.

Lake habitat comprised 73 % and 100 % of the walleye observations during the winters of 1997-98 and 1998-99, respectively. During 1997-98, the most used winter habitat was shallow flats located in the upper one-third of Lake Pepin. Side channel border was the second most observed habitat type, however, all observations of this habitat type came from a single fish that overwintered in the upper riverine reaches of the pool, approximately 5 km from Lock and Dam 3. Walleye also used points, deep water flats and nearshore contour breaks during the winter of 1997-98. The principal habitat used during the second winter of the study was nearshore contour breaks, accounting for 56 % of the observations. All other types of lake habitat were used during the winter of 1998-99, however, no use of river habitat was observed.

Walleye habitat use in the spring differed between years and was apparently related to water levels. During 1998, flooded backwater habitat accounted for 78% of the riverine habitat observations associated with spawning. Main channel, side channel border, and wing/closing dam habitats were unimportant. Lake habitat observations for spring consisted of both pre-spawn and post-spawn habitat use. Pre-spawn staging principally occurred on shallow, silt substrate flats at the head of Lake Pepin in 1998. Various points, located throughout Lake Pepin, represented the primary post-spawn habitat. Contrary to 1998, side channel border was the most frequented spawning habitat in 1999, due to backwater habitat largely being unavailable. Also differing from 1998, pre-spawn staging primarily occurred along nearshore contour breaks on the Minnesota side of Lake Pepin in the upper one-third of the lake.

Sauger During autumn, sauger were observed to use lake habitat exclusively, with nearshore contour breaks accounting for the majority of observations in 1997 and deepwater flats ac-

Table 2. Seasonal occurrence of radio and sonic tagged study fish in various habitat types in Pool 4 of the upper Mississippi River, 1997-1999. Percentages for a season are in parentheses.

Habitat type **	Autumn 1997	Autumn 1998	Winter 1997-98	Winter 1998-99	Spring 1998	Spring 1999	Summer 1998
			Walleye				
River Habitat							
Flooded backwater	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	25 (43.0)	11 (7.9)	0 (0.0)
Backwater lake	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Main channel	0 (0.0)	0 (0.0)	1 (3.0)	0 (0.0)	1 (1.7)	1 (1.3)	0 (0.0)
Side channel border	1 (1.8)	0 (0.0)	7 (21.2) *	0 (0.0)	5 (8.6)	20 (21.3)	0 (0.0)
Wing/closing dam	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.7)	2 (2.6)	0 (0.0)
Tailrace	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	3 (3.9)	0 (0.0)
Lake Habitat							
Nearshore contour break	33 (57.9)	12 (70.6)	1 (3.0)	14 (56.0)	2 (3.4)	13 (17.1)	20 (87.0)
Point	17 (29.8)	3 (17.6)	6 (18.2)	3 (12.0)	10 (17.2)	3 (3.9)	0 (0.0)
Shallow flat	1 (1.8)	0 (0.0)	14 (42.4)	3 (12.0)	13 (22.4)	25 (32.9)	2 (8.7)
Deepwater flat	5 (8.8)	2 (11.8)	4 (12.1)	5 (20.0)	0 (0.0)	0 (0.0)	1 (4.3)
			Sauger				
River Habitat							
Flooded backwater	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Backwater lake	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Main channel	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	3 (7.7)	35 (22.6)	0 (0.0)
Side channel border	0 (0.0)	0 (0.0)	4 (22.2) *	2 (2.2)	18 (46.2)	54 (34.2)	3 (50.0)
Wing/closing dam	0 (0.0)	0 (0.0)	1 (5.6)	0 (0.0)	7 (17.9)	8 (5.2)	0 (0.0)
Tailrace	0 (0.0)	0 (0.0)	2 (11.1)	0 (0.0)	0 (0.0)	3 (1.9)	0 (0.0)
Lake Habitat							
Nearshore contour break	3 (60.0)	6 (66.7)	4 (22.2)	2 (2.2)	0 (0.0)	10 (6.5)	1 (16.7)
Point	0 (0.0)	0 (0.0)	1 (5.6)	0 (0.0)	1 (3.6)	4 (2.6)	0 (0.0)
Shallow flat	0 (0.0)	2 (22.2)	0 (0.0)	4 (4.5)	9 (23.1)	10 (6.5)	2 (33.3)
Deepwater flat	2 (40.0)	1 (11.1)	5 (27.8)	81 (91.0)	1 (3.6)	31 (20.0)	0 (0.0)

* All observations from a single fish

counting for the majority in 1998. We suspect that radio signal attenuation with depth biased observations in 1997 and that the predominant use of deepwater flats observed in 1998 with sonic methods is a truer representation of autumn sauger habitat use in Pool 4.

Summer habitat use included both river and lake habitat, though observations were limited. Side channel border and shallow flats accounted for 50% and 33% of the observations, respectively.

The most frequently used habitat during the winter in both years was deep water flats, accounting for 28 % and 81 % of the observations during the winters of 1997-98 and 1998-99, respectively. Sauger were observed to use side channel border habitat, located in the upper reach of the pool. However, all of the side channel border observations collected for the winter of 1997-98 came from one fish that overwintered below Lock and Dam 3, while the two observations collected in 1998-99 came from two fish that entered the river and returned to the lake within a one week period.

Spawning habitat was similar between years. Side channel border was the most frequently observed habitat during spring spawning, however, main channel habitat was also important in 1999. Principal pre-spawn staging occurred in deep and shallow water flats associated with the shipping channel at the confluence of the upper river with Lake Pepin. Post-spawn habitat was mainly comprised of nearshore contour break habitat.

Habitat partitioning between species Walleye and sauger showed strong habitat partitioning throughout the study. Walleye and sauger were found to partition their habitat primarily by depth, though spatial partitioning was also evident. With the exception of summer, mean depth by season differed significantly between walleye and sauger ($P \ll 0.001$, $t = 6.18$). Mean sauger depth was twice that of walleye during every season, averaging 7.0 m for the entire study (Table 2).

In autumn, though both species shared nearshore contour breaks as an important habitat, walleye and sauger partitioned this habitat by depth. Walleye were found at the top of the breaks, while sauger were found near the base of the breaks. In winter, walleye and sauger again partitioned by depth, with walleye relying on shallow flats near the head of Lake Pepin, and sauger relying on deep water flats adjacent to the Minnesota shoreline. In spring, partitioning occurred spatially as well as by depth. Sauger were found significantly deeper than walleye ($P \ll 0.001$, $t = 11.7$), and were found to primarily rely on main and side channel border habitat. Conversely, walleye relied on shallow, flooded, off-channel habitat for spawning, when available.

Spawning behavior

Walleye Walleye, overwintering in the upper one-third of Lake Pepin, staged for spawning in the most upper, and shallow reaches of Lake Pepin during the last two weeks of March. Dark silt substrates and full sun conditions resulted in temperatures from 1.4 to 3.8° C warmer than surrounding lake water in the pre-spawn staging area. Peak migrations occurred from 1-10 April 1998 and from 27 March - 7 April 1999 at temperatures between 6.0 and 9.9° C. Peak spawning appeared to occur from 13-23 April 1998 and from 7-15 April 1999 at temperatures ranging from 7.2 to 10.3° C (Figure 15). Of seven walleye tracked during spawning in 1998, six used flooded off-channel habitats for spawning, consisting of flooded timber, bulrush, and reed-canary grass. Off-channel sites included two sites in the Vermillion River. One walleye, a male, used classic cobble substrates on a side channel margin area. In 1999, four of nine walleye used side channel or wing dam habitat in the upper 2 km of the pool, while five other walleye used flooded habitat near the channel margins. Peak pool elevations occurred on 10 April 1998 at 206.9 m above sea level and on 20 April 1999 at 206.2 m above sea level.

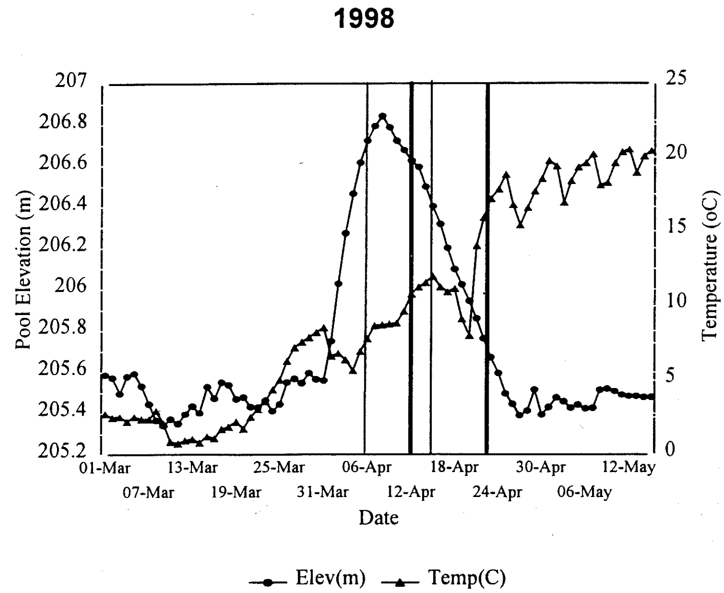
Walleye were diffuse and dispersed in their spawning habits. No aggregations of tagged fish were observed. Sixteen likely spawning areas were identified. With the exception of three sites, all spawning areas were in off-channel, flooded habitat.

Sauger Sauger staged for spawning in the navigation channel at its confluence with Lake Pepin (Figure 8). In 1998, sauger were observed to arrive at this site from both upstream and downstream sites, ranging over 58 km. Peak migrations occurred from 24 March - 3 April 1998 and from 18 - 31 March 1999 at temperatures between 4.3 and 9.1° C. Peak spawning occurred from 13 April - 3 May 1998 and from 5 - 15 April 1999 at temperatures ranging from 5.2 to 10.3° C (Figure 15). Four primary spawning sites were identified (Figure 9). All these sites were located in the upper five km of Pool 4 in side and main channel habitats. No interpool movement by sauger was observed during the study period.

Temperature monitoring

Monthly vertical cross channel temperature profiles failed to measure any significant vertical or cross channel temperature gradients, supporting our assumption of homogenized thermal conditions in the upper river due to entrainment of thermally enhanced water through Lock and Dam 3. The greatest vertical difference in temperature was 0.17°C and the greatest cross channel difference was 0.11°C.

During the winter of 1998-99, PINGP experienced both planned and unplanned shutdowns of their two reactors, resulting in a wide range of thermal discharges and operating capacities (Figure 16). From 1 November 1998 to 13 January 1999, PINGP operating capacity



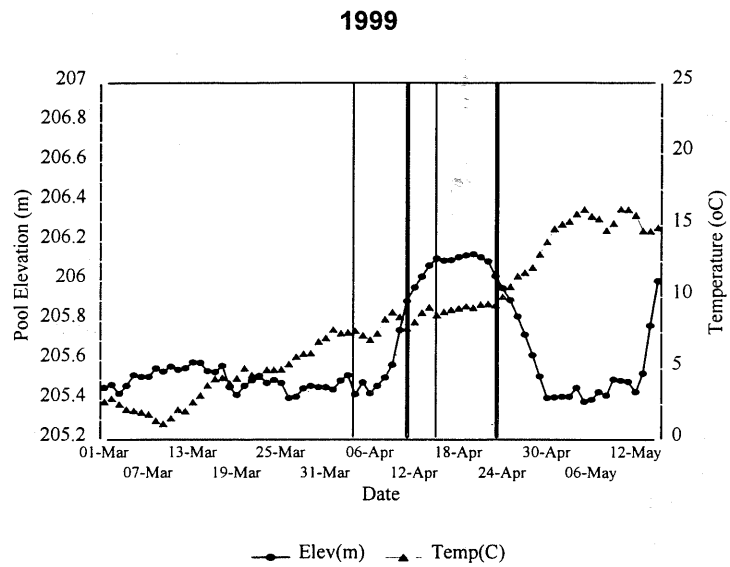


Figure 15. Pool elevation (m) and water temperature (°C) during the 1998 and 1999 walleye and sauger spawning seasons, Pool 4 of the upper Mississippi River. Peak spawning for both years and species are represented by vertical lines through the plots with dark lines corresponding to walleye and light lines corresponding to sauger. Pool elevation data was obtained from the USCOE Lock and Dam 3 gauge station, while temperature data. was provided by PINGP.

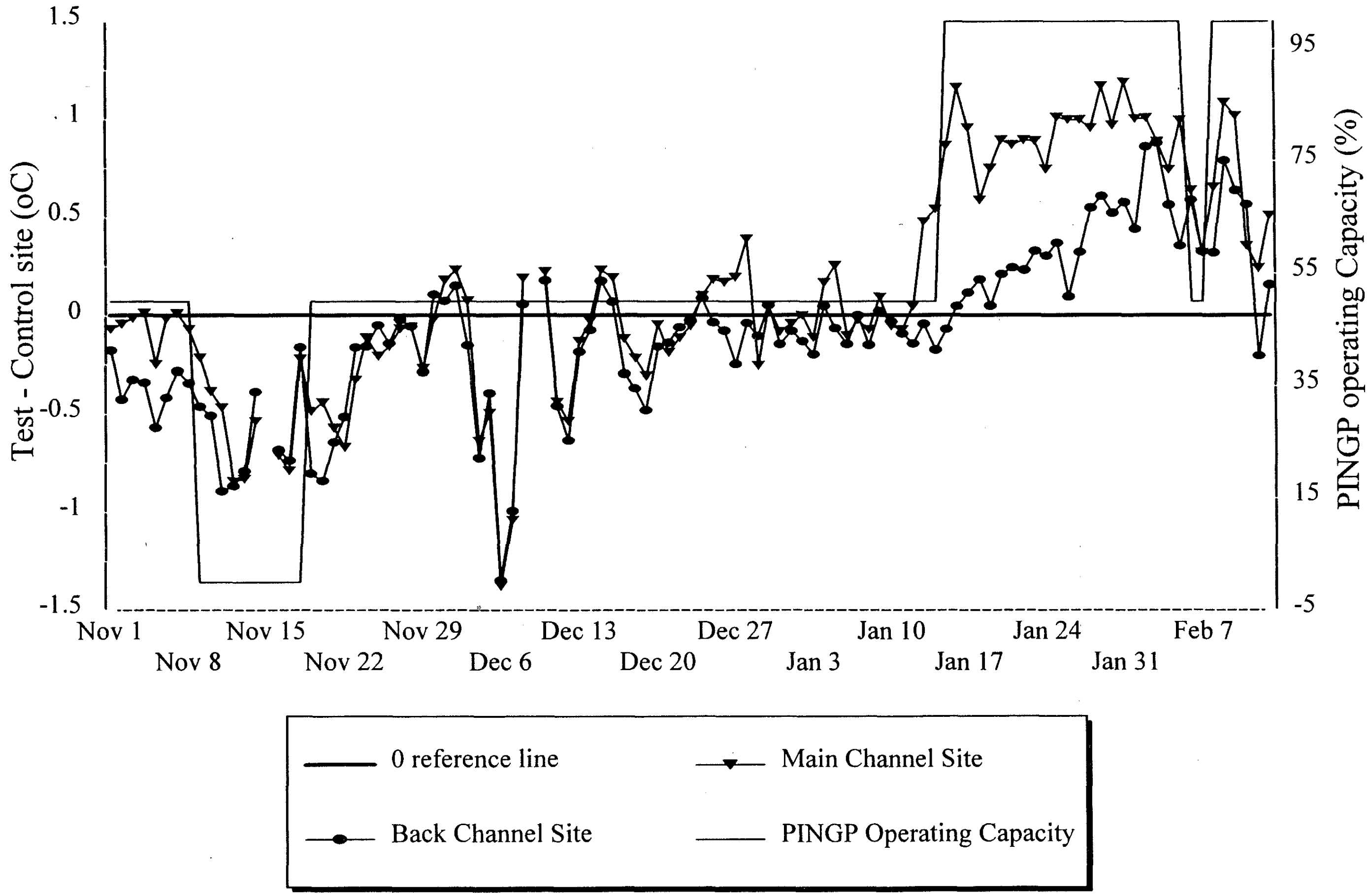


Figure 16. Temperature (°C) difference between each of 2 test thermograph sites located in the main and back channels of Pool 4, respectively, and a control site located above PINGP in Pool 3 of the upper Mississippi River.

never exceeded 50%. During this period, no temperature differences between the test sites and control sites were observed; temperature at the test sites were generally equal to or less than the control site (Figure 16). Average differences in temperature between the test thermographs and the control site were -0.16 and -0.27°C, for the main and back channels respectively. This suggests that all residual heat from PINGP dissipated before reaching the downstream thermographs during this time period. From January 14, 1999 to February 13, 1999, PINGP operated at full capacity, resulting in positive differences in temperature between the test and control thermographs. Mean temperature differences during this time period were 0.84 and 0.37 °C for the main and back channels, respectively. During full operational capacity, the main channel carried a significantly greater thermal load than the back channel ($t=7.23$, $P<<0.001$).

To test whether walleye and sauger responded directly to temperature during the period of positive temperature differences between test and control thermograph sites (14 January - 13 February 1999), we calculated correlations between mean daily temperature difference (°C) between the main channel test site and the control site, and the mean position of the tagged population in the system (River Kilometers). No significant correlation was found for walleye ($R^2 = 0.046$, $P = 0.88$) or sauger ($R^2 = 0.085$, $P = 0.79$). We also performed t-tests to determine whether mean position in the system changed significantly during the winter by month. Mean position in the system did not differ significantly across months for either walleye or sauger (Table 3). Walleye and sauger mean position also did not differ significantly between the no-difference period (1 November 1998 - 14 January 1999) and the period of positive temperature differences (14 January - 13 February 1999) ($t = 0.72$, $P = 0.48$ and $t = 0.61$, $P = 0.55$ for walleye and sauger, respectively).

Discussion

Winter distribution relative to PINGP thermal effects

The hypothesis of altered thermal habitat accounting directly for the decline in the winter ice fishery on Lake Pepin hinges on there being a thermal impact of sufficient magnitude and extent so that lake resident walleye and sauger can experience and respond to it. Thus, two issues are apparent: was there a thermal impact on Lake Pepin, and, if so, did lake resident walleye and sauger directly alter their distribution in response to any impact?

We first discuss the issue of observed temperature differences, describing the factors involved in creating them. Next we discuss how walleye and sauger responded to observed temperature differences and offer alternative perspectives on their winter distribution. We close this section by discussing other aspects of the winter ice fishery on Lake Pepin, and how temperature differences attributable to PINGP may effect them.

Both scheduled and unscheduled reactor shutdowns during the winter of 1998-99 allowed us to observe PINGP thermal effects on Lake

Table 3. Results of t-tests for determining whether walleye or sauger mean distribution (River Kilometers) differed among winter months during the winter of 1998-99, Pool 4 of the Upper Mississippi River.

	Walleye		Sauger	
Month combination	t-stat	p-value	t-stat	p-value
Dec x Jan	-0.18	0.86	-0.68	0.50
Jan x Feb	-0.96	0.34	0.59	0.56
Dec x Feb	-0.95	0.35	-1.63	0.11

Pepin across a wide range of discharge conditions. Under the conditions we observed, PINGP appears to produce a thermal effect on Lake Pepin only during full-capacity operation (Figure 16). At 50% operating capacity or less, no thermal effect on Lake Pepin could be observed.

Because PINGP's thermal effluent appears to be homogenized by entrainment through Lock and Dam 3, heat transport in the upper reaches of Pool 4 can be thought of as a longitudinal downstream gradient. As the thermal effluent travels downstream, heat loss will be a function of the initial heat content (PINGP thermal effluent load), the prevailing meteorological conditions, and river flow (Stefan 1987). Because the rate at which the heat dissipates depends on these three principal factors, whether or not Lake Pepin receives a thermal load will also depend on them.

During a period of impact, Mississippi River water temperature will be warmer than the ambient conditions in Lake Pepin (at or very near 0° C). Thus, how the thermal effect manifests itself in Lake Pepin will depend on water density differences between the upper riverine reach of Pool 4 and the water of Lake Pepin. Density differences will cause the impacted water to plunge until either hitting the bottom of the lake or arriving at mid-strata equilibrium with prevailing lake density gradients. Because the thermal effect will vary with thermal discharge, river flow, and prevailing meteorological conditions, how the effect manifests itself in Lake Pepin will vary vertically and longitudinally, resulting in an ephemeral, ever shifting and changing impact.

While no attempt was made to model the process of heat exchange as a function of thermal discharge, river flow, and climatological conditions, whether Lake Pepin receives a thermal load appears to depend somewhat on PINGP discharge. During the period of no effect on Lake Pepin (1 November 1998 - 14 January 1999), PINGP was only operating at one-half capacity due to reactor shutdowns. As soon as both reactors were brought back on line on 14 January 1999, a thermal effect on Lake Pepin was observed and continued until 13 February 1999 when monitoring ceased. The thermal effect manifested itself primarily in the main navigation channel, averaging 0.84 °C warmer than the control site above PINGP's discharge point.

Even though we demonstrated that PINGP effects the temperature of the water entering Lake Pepin, we could find no evidence that Lake Pepin resident walleye and sauger directly responded to it. We found no significant correlation between water temperature at the downstream thermograph sites, and walleye and sauger position in the lake. Moreover, walleye and sauger position in the lake did not significantly differ among months during winter, or between no-effect and effect periods. If a strong and significant behavioral response to an altered thermal environment occurred, we would expect a far greater proportion of winter telemetry observations to come from the warmest reaches of the pool, namely the upper river and specifically, the tailrace below Lock and Dam 3. No such behavior was observed. Thus, we were unable to demonstrate that walleye and sauger directly responded to temperature during the winter in our study.

The determination of habitat and thermal preference *in situ* has proven difficult in other studies. Part of the problem has been the lack of control over competing preference variables (i.e. depth, forage, current, cover, water clarity), and in the inability to determine how test fish acclimate to a thermally enhanced environment. Ross and Siniff (1982) found yellow perch *Perca flavescens* tagged from a thermal discharge bay to select winter temperatures 1°C greater than those observed outside the discharge bay, however, all of the study fish in this study were tagged from the discharge bay and had acclimation histories closely tied to power plant discharges. Test fish were also found to select significantly lower temperatures than found in laboratory experiments. Thus, uncontrolled, competing factors, such as forage availability and physical habitat needs as well as acclimation history, serve to reduce the strength of temperature selection in a field situation.

Shuter et al. (1985) used over 50 years of basic research data to model the effects of a thermal discharge on a small and localized smallmouth bass *Micropterus dolomieu* population in Baie du Dore, Lake Huron. Their ecological approach was able to account for competing preference variables and to attribute changes in distribution and subsequent increased angling mortality to thermal impacts from the power plant. Unlike Shuter et al. (1985), we cannot account for other factors responsible for walleye and sauger winter distribution in Lake Pepin. However, as an initial determination of PINGP effects, we found no evidence of direct behavioral response to a thermally altered environment.

Given the apparent ephemeral nature of the thermal effect on Lake Pepin, factors other than temperature likely regulate the winter distribution of walleye and sauger in Pool 4. Due to the role that acclimation plays in temperature selection, it is more likely that river resident walleye and sauger, rather than Lake Pepin residents, would demonstrate behavioral responses to any PINGP effect on water temperature, since river resident fish would have acclimation histories associated to changes in their thermal habitat.

While no direct response to temperature could be demonstrated for Lake Pepin walleye and sauger, anecdotal information suggests that our study fish were located in areas that were not historically significant components of the ice fishery. The ice fishery primarily focused on nearshore contour breaks and points throughout the lower two-thirds of Lake Pepin. Walleye were found to inhabit the upper one-third of Lake Pepin throughout the winter period while sauger were found to almost exclusively use deepwater flats throughout the mid- and upper-reaches of Lake Pepin during winter.

Myriad alternative hypotheses about factors regulating walleye and sauger winter distribution in Lake Pepin are possible. We discuss a few that we feel could be likely, but which will require further work to determine.

First, we relied on relatively older and larger fish than typically compose the ice fishery. This was required to meet transmitter weight to fish weight limitations imposed by the long term design of this study. Size differences in behavior and habitat requirements have been well documented in many species (Coutant 1987), and could be responsible for the observed winter distribution of study fish.

Second, these observations could be due to secondary thermal effects acting on preferred forage. Gizzard shad *Dorosoma cepedianum* are an important component of the walleye and sauger diet in Pool 4 and are near the northern limit of their range in this system. Thermal impacts attributable to PINGP may provide the gizzard shad with thermal refugia during the winter in Pool 4, resulting in large aggregations of shad in the upper reaches of Pool 4. It is possible that the use of the upper one-third of the lake by walleye and sauger during winter is due to a shift in gizzard shad distribution owing to PINGP thermal effects. While we expected winter distributions of Lake Pepin resident walleye and sauger to reflect direct thermal preference, it may be more beneficial for Lake Pepin walleye and sauger to reside in the low current velocity of the upper one-third of Lake Pepin and to exploit aggregations of gizzard shad than to reside in the riverine portions of Pool 4 during the winter. This behavior could explain the use of the upper reaches of Lake Pepin by lake resident walleye and sauger, and why no significant relationship between temperature and fish position could be found.

Our study focused only on aspects of this fishery related to fish ecology. Unpublished data and anecdotal reports suggest that ice anglers have expended less effort since PINGP was permitted to change its operating plan in 1983. Much of this change can be attributed to perceived safety issues. Anglers report that the frequency of poor ice conditions has increased since 1983, especially along the Minnesota shoreline. Our study did demonstrate that a thermal effect on Lake Pepin attributable to PINGP occurs during full-operating capacity. However, we did not investigate the effect any such impact would have on ice cover conditions in Lake Pepin.

Spawning habitat and behavior

The type and amount of spawning habitat available to walleye and sauger varies annually with river conditions. The type and amount of spawning habitat also varies longitudinally down the Mississippi River due to channel separation from backwaters, and interpool differences in navigation aid constructs and shoreline improvements. Pitlo (1989) identified walleye spawning habitat in Pool 13 of the Upper Mississippi River. He found that walleye principally spawn over hard substrates at water depth ranging from 0.6 to 6.1 m. Substrates largely consisted of sand, cobble, gravel, and mussel beds. Gebken and Wright (1972) found walleye to utilize flooded riprap in the tailwaters of Pool 7 while Holzer and VonRuden (1984) found walleye to spawn over reed canary grass *Phalaris arundinacea* in flooded timber in Pool 8. Gangl et al. (In press), studying both walleye and sauger in Pool 2, observed spawning migrations into the Minnesota River, the tailrace below Lock and Dam 1, and a small tributary at the head of Pool 2. Sauger spawning habitat is less well documented in the Upper Mississippi River, but has been described to be generally similar to walleye in many areas. Freiermuth (1986, 1987) studied sauger spawning in Pool 4, and found sauger utilize wing dams in the tailrace below Lock and Dam 3 and side channel margins, composed primarily of sand substrates.

Lastly, in this study, walleye and sauger were found to partition their spawning habitat spatially, though not temporally. Temporal overlap in spawning was observed, and is consistent with spawning temperatures and dates reported for other Mississippi River populations (Gebken and Wright 1972; Freiermuth 1986,1987; Pitlo 1989) and the species in general (Scott and Crossman 1985). Spatially, walleye demonstrated preference for flooded backwater habitats similar to those described by Holzer and VonRuden (1984) for the Pool 8 population, whereas sauger were found to use main and side channel areas identical to those described by Freiermuth (1986, 1987).

Walleye affinity for flooded backwaters during spawning appeared muted in 1999. Walleye were observed to migrate to spawning areas more slowly than in 1998, and to reside close to shore for several days. This behavior appears to be related to pool elevation and river discharge (Figure 15). Peak discharge was 29% lower in 1999 and did not occur until 20 April, in contrast to 8 April in 1998. This level of peak discharge in 1999 corresponded with only a bank-full flood. While some walleye used spawning habitat more typical of sauger in Pool 4 in 1999, many of the tagged fish appeared to delay their spawning until river stage exceeded flood stage, moving just off the channel margin into near channel flooded habitat to spawn. In comparison, in 1998, walleye ran far into flooded backwaters when river stage was nearly two meters above flood stage. Walleye made almost exclusive use of this habitat for spawning in 1998.

Sauger used similar areas each year for spawning, and some of the sites we identified further confirmed Freiermuth's (1986, 1987) findings. Sauger spawning habitat does not appear to be limited in quantity or annual availability, occurring on and near wing dams in the Pool 4 tailrace and at several side channel margin sites within the upper five km of the pool.

Preferential use of flooded backwater habitats for spawning by Pool 4 walleye may have important management implications. As evidenced during this study, the availability of backwater habitat can vary considerably on an annual basis. Moreover, discharge regimes dictate how long this habitat is available, having important implications for early life survival of walleye in Pool 4. Physical processes associated with spring river dynamics should be expected to be related to walleye recruitment in the Pool 4 system. Thorn (1984) identified a significant correlation between walleye recruitment and spring discharge. It is likely that other, more precise analyses could be used to investigate the relationships between walleye recruitment, their preferential use of flooded backwater habitat for spawning, and physical processes associated with spring river dynamics, thereby leading to a better understanding of recruitment mechanisms of Pool 4 walleye and sauger populations.

Seasonal habitat and distribution

Seasonal distribution appeared closely related to habitat use. While walleye and sauger exhibited similar longitudinal movements, they partitioned their habitat by depth during all seasons. In Lake Pepin, depth was partitioned by walleye preferring the tops, or shallow portions of near shore contour breaks, while sauger preferred the base, or deep portions of these breaks. Winter and spring were transitional periods for both species with slow, gradual, and continual uplake movements occurring during winter and rapid movements to and from spawning areas in the upper river occurring during spring. Return to Lake Pepin following spawning resulted in walleye establishing small summer home ranges and a largely sedentary existence. Homing, defined as the return to a place formerly inhabited rather than going to other equally likely places, was demonstrated by walleye following spawning. Homing behavior in walleye has been reported by Crowe (1962), Olson et al. (1978), and Olson and Scidmore (1962). Jennings et al. (1996) presented evidence that homing in walleye has a heritable component.

Management Implications and Future Work

Our research demonstrated that a thermal effect on Lake Pepin is possible during full-capacity operation of PINGP. While no direct thermal preference, and hence impact could be demonstrated for walleye and sauger, secondary effects related to changes in forage distribution attributable to thermal effects are potentially possible. We feel, however, that such hypotheses are largely untestable *in situ*. While inference on such linkages could be gained by studying gizzard shad winter distributions and walleye and sauger winter diets, thermal causation would require experimental manipulation of PINGP thermal discharge regimes. We view this prospect as unlikely.

While PINGP's thermal effects on the winter ecology of Lake Pepin walleye and sauger appear benign, we do not discount that the thermal effects observed under full operating capacity could have detrimental effects on ice cover. It is widely held that during ice cover, the Minnesota shoreline of Lake Pepin is considerably more treacherous than the Wisconsin shoreline. This is consistent with our empirical observation that the Minnesota shoreline receives the majority of the thermal load, emanating from the main navigation channel. If managers wish to manage for a winter ice fishery on Lake Pepin, they must first decide if ice safety issues are currently limiting ice angling participation. If so, they must then decide if the thermal loading to the head of Lake Pepin observed during this study is sufficient to warrant consideration of ice safety issues. Because ice dynamics on Lake Pepin depend upon climate, river flow, and PINGP discharge components (Stefan 1987), managers would need to design a study that accounts for all of these factors.

The principal use of flooded backwater habitats for spawning by walleye has important management implications. The dynamic and variable physical processes that dictate the amount of backwater habitat available, and the duration of its availability should be quantified in an effort to better understand and perhaps sustain walleye recruitment processes in Pool 4. This is especially critical in light of proposed USCOE modifications of Lock and Dam 3 that may close off some backwater areas, and may indirectly affect the annual availability and functional utility of others. In the longer term, there is a need to understand recruitment processes in backwater spawning walleye populations so that the long term effects of impoundment can be assessed.

Managers should consider how habitat partitioning between walleye and sauger in Pool 4 (specifically Lake Pepin) may affect their stock assessment estimates. Information on seasonal movements can be utilized to improve stock assessment methods. Historical data should be analyzed with a focus on nearshore fish community changes that could have resulted in winter distributional shifts for sauger. Examples include changes in forage abundance, type, and preference; changes in size distribution of sauger over time; and abundance of potential competitors.

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Acknowledgements

We would like to thank Mark Stopyro, Tim Schlagenhaft, Dale Sogla, Todd Marwitz, Randy Binder, Dan Deiterman, and Al Schmidt of MDNR's Lake City Management Unit for logistical support and field assistance during this project. We are grateful to Ken Mueller (Northern States Power) and numerous other staff members who provided data and assistance during temperature monitoring study design and implementation. The Frontenac Sportsmen's Club graciously provided funding for the ultrasonic transmitters used in sauger during the second year of the study. Rick Walsh (MDNR, East Metro Region) coordinated the initiation of the project. Brent Knights (USGS/BRD, LaCrosse, WI) provided sonic tracking equipment during the second year of the project and shared information on surgical techniques, while Jerry Younk (MDNR) provided a demonstration of surgical methods. Chris Kochanney (Advanced Telemetry Systems) provided guidance on tracking techniques and transmitter design. Craig Schaeffer (Schaeffer Aviation) piloted the aircraft. Bart Richardson (MDNR, East Metro Region) assisted in design of the GIS applications. Sheri K. Ickes provided field assistance and assisted with report graphics. Scott Gangl (University of Minnesota) provided assistance during implantation surgeries and aided with tracking early in the project. Eric Dierks (Frontenac Sportsmen's Club) assisted in SCUBA operations to recover lost radio transmitters. Tim Schlagenhaft and Mark Stopyro reviewed earlier drafts of the manuscript.

Edited by:

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