J. Great Lakes Res. 26(4):482–488
Internat. Assoc. Great Lakes Res., 2000

NOTE

Assessment of the Dunnville Fishway for Passage of Walleyes from Lake Erie to the Grand River, Ontario

Christopher M. Bunt[1,*], Steven J. Cooke[2], and R. Scott McKinley

Waterloo Biotelemetry Institute, Department of Biology
University of Waterloo
Waterloo, Ontario N2L 3G1

ABSTRACT. *A Denil fishway in Dunnville, Ontario was built to provide upstream passage for walleyes* (Stizostedion vitreum) *from Lake Erie to the Grand River. Few walleyes have been observed to use this fishway. Coded radiotelemetry was used to track 24 adult walleyes (12 male, 12 female) downstream from the fishway to explore reasons for limited use. Activity was monitored by a fixed array of three antennas within the fishway that continuously scanned for signals from all radio-tagged fish, and by mobile tracking. In April and May 1997, 17 attempts to use the fishway by 3 male and 2 female radio-tagged walleyes were recorded. During this period, the attraction efficiency of the Dunnville Fishway was approximately 21%. All attempts took place between 1600 and 0600 hours, with most activity near midnight. Walleyes occupied the first resting pool of the fishway for up to 17 h. Subsurface water velocity during the study was approximately 2 m/s. No radio-tagged walleyes passed through the Dunnville Fishway. Behavior modifying hydraulic conditions including turbulence, entrained air, backcurrents and whirlpools in fishway resting areas may delay or prevent successful upstream passage of walleyes. There was also evidence of large-scale movements by walleyes that may have spawned in the Grand River downstream from Dunnville.*

INDEX WORDS: *Walleye,* Stizostedion vitreum, *Denil fishways, radiotelemetry, attraction, upstream passage, Lake Erie.*

INTRODUCTION

The walleye (*Stizostedion vitreum*) is one of the most popular and exploited freshwater fishes in North America (Rawson 1957, Ney 1978, McConville and Fossum 1981). Lake Erie is the largest walleye producer and supports many populations (Todd and Haas 1993). As springtime water temperatures increase to 3 to 4°C, walleyes return to previously used spawning areas in search of suitable habitat (Crowe 1962, Olson and Scidmore 1962). There is evidence that these migrations are guided by homing (Olson and Scidmore 1962, Bahr 1977, Olson *et al.* 1978, Todd and Haas 1993) that often consist of movements from lakes into tributaries (Ferguson and Derksen 1971, Todd and Haas 1993). In river systems, barriers such as dams and weirs, disrupt spawning by altering physical conditions, water chemistry, flow and bed-load transport (Bunt *et al.* 1998), impeding upstream migration (Crowe 1962, Behmer 1964), resulting in harvest vulnerability, and by restricting access to spawning areas downstream (Pitlo 1984, Paragamian 1989). Ultimately, year-class strength may be reduced if the quality or quantity of spawning habitat downstream from the barrier is limited. Unfortunately, barriers that restrict spawning migrations and delay spawning activities can cause fish to resorb gametes and refrain from reproducing (Shikhshabekov 1971). However, barriers can also create spawning habitat for some species (Bunt *et al.* 1998).

Fishways are mitigative devices that allow fish to swim past otherwise impassable river barriers

[1]Current address: Biotactic Inc. 640 Hidden Valley Rd., Kitchener, Ontario N2G 3W5.
[2]Current address: Center for Squatic Ecology, Illinois Natural History Survey, Champaign, Illinois 61829.
[*]Corresponding author. E-mail: biotactic@hotmail.com

(Beach 1984, Clay 1995). Although percids worldwide have been shown to use fishways to varying degrees (Schwalme *et al.* 1985, Katopodis *et al.* 1991, Harris and Mallen-Cooper 1994, Dexter and Ledet 1997, Bunt *et al.* 1998), walleyes appear to not use most fishways effectively (Schwalme *et al.* 1985, Fernet 1984, Dexter and Ledet 1997). Reasons for this are unclear but may be related to poor entrance attraction efficiency, supercritical water velocities that exceed walleye swimming abilities at cold temperatures, turbulence that interferes with rheotactic behavior, or a reluctance to enter or remain in artificial channels. The objectives of this study were to: 1) examine walleye movement patterns downstream from the Dunnville Weir on the Grand River, Ontario, and 2) to assess the performance of a Denil fishway for passing walleyes upstream.

METHODS

Study Area

This study was conducted in Dunnville, Ontario (42° 85′ N, 79° 65′ W), where four weirs between a series of islands have blocked upstream migrants from Lake Erie into the Grand River for well over a century (Fig. 1). The river is turbid with high levels of suspended solids, large amounts of shallow habitat and several deep pools. To facilitate spawning and the establishment of walleye populations upstream from the Dunnville Weir, a Denil fishway was installed in November 1994 near weir III (Fig. 1). The fishway consists of a 47 × 1.35 m concrete channel on a 10.5% slope, with two resting pools. The fishway is not linear and two major direction changes (i.e., bends) exist between the fishway entrance and exit (Fig. 2).

Fishway Use and Conditions

Fish activity was continuously monitored by a radio tracking system that was installed within the fishway and at the fishway entrance (see below). Midday water temperatures within the fishway were continuously recorded with data loggers throughout the study period. Water velocities were measured using a portable ultrasonic velocity meter.

Radio-tagging

In early April 1997, 24 walleyes were captured 110 m downstream from weir III using Trammel nets and were held in 8 m^3 pens until the fish were

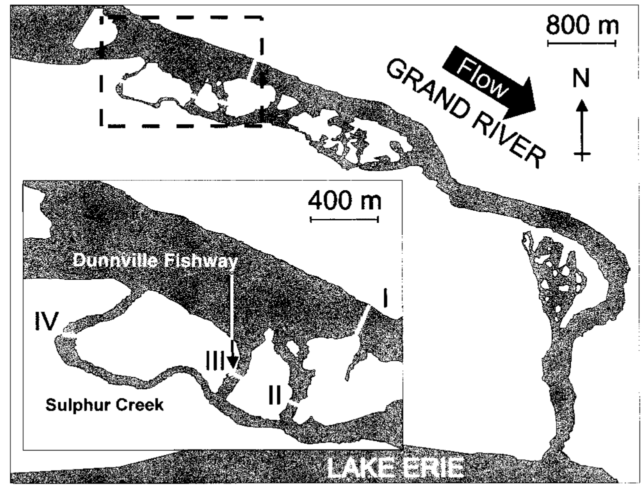

FIG. 1. The lower Grand River and the four weirs (I,II,III,IV) that compose the Dunnville Weir and island complex (enlargement). The fishway is located at weir III. Sulphur creek flows between weir III and weir IV.

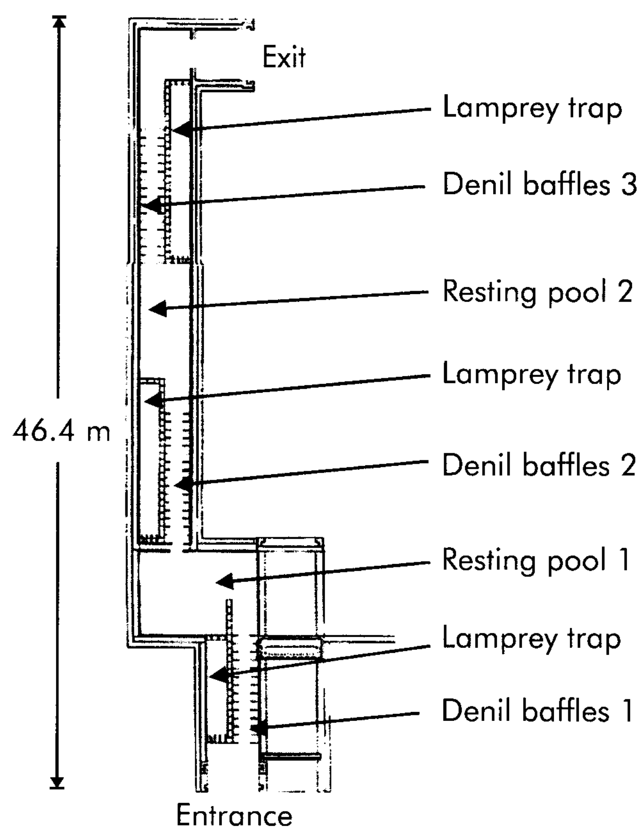

FIG. 2. Schematic of the Dunnville Fishway.

examined and radio-tagged. Twelve female walleyes and 6 male walleyes were externally radio-tagged on 12 April according to the method described in Bunt *et al.* (1999). Six additional male walleyes were radio-tagged on 19 April. Coded radio transmitters (1.9 g in water, 10.6 × 28 mm with 2.5 s pulse rates, battery life about 30 d) were attached through the dorsal musculature and held in place with surgical wire twisted over a neoprene-coated plastic back-plate. After a 1 h recovery period, all fish were released near the capture site. This tagging procedure has been shown to have negligible effects on behavior, movement patterns, and social interactions among walleyes in Lake Bemidji, Minnesota (Holt *et al.* 1977). External tagging was chosen because fish were gravid and therefore considered unfit for surgical implantation without the risk of affecting normal spawning behavior.

Tracking

To allow behavioral acclimatization to the transmitters, data were not collected until at least 24 h after fish were released. A fixed system that consisted of three sequentially-scanned antennas continuously monitored the fishway entrance, first resting area and exit of the fishway, for 34 d. Pulse-code discrimination software within the receiver (SRX_400, Lotek Engineering Ltd.) was used to decode radio signals. Prior to the study, reference radio-tags were positioned at various locations within the fishway to calibrate the receiver. Measurements of relative signal strength permitted determinations of transmitter location and fish positions in the fishway to within 1 m. Manual tracking using a scanning receiver and hand-held H-antenna was also conducted daily from 0900 to 1800 hours by watercraft. Fish locations were determined to within 5 m and were plotted on enlarged aerial photographs (scale 1:8,000) to describe movements between the weirs and Lake Erie.

Statistical Analysis

Fishway performance was divided into two primary components that included estimates of attraction efficiency and passage efficiency. Attraction efficiency was calculated as the proportion of walleyes that located the fishway entrance relative to the number released downstream. Passage efficiency was calculated as the number of walleyes that reached the fishway exit, relative to the number of walleyes that entered the fishway. All means are reported ± 1 S.D. Confidence intervals (95% CI) for efficiencies were calculated according to probability theory, and statistical comparisons of movement were evaluated for differences between male and female walleyes as follows. First, a Shapiro-Wilks test was used to test for normality among the data. Then, Levene's test was used to test for homogeneity of variances. A one-factor ANOVA was used to test the null hypothesis of no difference between distances moved by male and female walleyes. All statistical tests were performed using SAS 9.0 with an alpha level of 0.05 (SAS 1999).

RESULTS

Fishway use by walleyes increased as water temperatures rose from 4 to 8°C. The maximum temperature during fishway use was 12°C. Fishway discharge ranged only from 1.062 to 1.070 m^3/s, and the water velocity 10 cm below the surface of the flow, at a position midway along the length of the fishway, was approximately 2 m/s.

The Dunnville Fishway was monitored continuously for 816 h, during which time 17 attempts to use the fishway by radio-tagged walleyes were recorded. Five different fish (3 males, 2 females) entered the fishway. Attraction efficiency was 21% (95% CI = 5–37%). Since no radio-tagged walleyes successfully passed through the fishway, passage efficiency was estimated to be 0%. All but one walleye used the fishway at night (between 1800 and 0600 hours), with peak activity between 2100 and 0100 hours. Walleyes occupied the lower reaches of the fishway for between 1.2 and 1,020 min, with a median occupancy time of 1.2 min (Table 1). One female fish (walleye #3, Table 1) entered the fishway at 0611 hours on 16 April and remained within the first resting pool (Fig. 2) for 17 h, until 2313 hours on 17 April. This fish swam just over one third of the distance (35%) between the fishway entrance and the fishway exit (Table 1).

From 12 April to 8 May 1997, walleye positions were determined 108 times (mean 6 locations/fish). For analysis of movements, movement data from one male was eliminated due to signal loss soon after release. For the remaining 23 fish, no differences in distances between locations of male and female walleyes were detected ($F = 0.13$, $F_{0.05,1,22}$, $= 3.44$, $P = 0.72$, Table 2). Extensive lateral movement near the weirs, as well as upstream and downstream movements (3 km in < 7.5 h), from weir I to weir IV were common. Walleyes spent long periods

TABLE 1. Patterns of activity and repeated entry into the Dunnville Fishway by five radio-tagged walleyes, during 816 h of continuous monitoring. Proportion of full ascent indicates how far each walleye swam into the fishway.

Walleye #	Date	Time	Time to first locate fishway (h)	Time in fishway (min)	Proportion of full ascent (%)
1	13 Apr	23:47	37	42	< 15
2	14 Apr	21:53	59	< 1.2	< 15
2	15 Apr	2:29	—	< 1.2	< 15
3	15 Apr	18:10	79	4	15
3	15 Apr	18:24	—	5	15
3	15 Apr	19:49	—	< 1.2	< 15
3	15 Apr	19:57	—	< 1.2	< 15
3	15 Apr	20:00	—	1.2	15
3	15 Apr	20:36	—	2.5	15
3	15 Apr	20:40	—	3.7	15
3	16 Apr	4:55	—	< 1.2	< 15
3	16 Apr	6:07	—	< 1.2	< 15
3	16 Apr	6:11	—	1,020	35
4	20 Apr	0:51	10	< 1.2	< 15
5	23 Apr	0:23	152	< 1.2	< 15
5	25 Apr	22:27	—	< 1.2	< 15
5	25 Apr	22:42	—	4.5	15

TABLE 2. Mean total lengths (mm) and distances moved (m) ± 1 S.D. by male (n = 11) and female (n = 12) walleyes downstream from the Dunnville Fishway.

Sex	TL (range)	Number of locations	Mean distance between locations (range)
Male	511 ± 34 (467–570)	56	679 ± 1,154 (0–6,840)
Female	604 ± 83 (488–741)	52	667 ± 988 (0–4,320)

of time between weir III and weir IV in Sulphur Creek (Fig. 1). Fish were located in Sulphur Creek for up to 11 d and were positioned over areas with previously known deposits of gravel substrate (submerged gravel roads and areas where gravel had eroded from the river bank). Downstream movements from weir IV to about 1.5 km upstream from Lake Erie (approx. 8 km) occurred over the course of 6 d. Downstream movements were more common than upstream movements after the last week in April. All fish returned to Lake Erie by mid May.

DISCUSSION

There are many variables and assumptions that must be considered before generalizations can be made about the interactions between migratory walleyes, river barriers, and fishways. In the Grand River, walleyes moved extensively throughout the river downstream from the Dunnville weir and attempts to use the fishway were rare. Lack of upstream passage, delay, and extensive exploratory movements by walleyes downstream from dams has also been observed in Michigan (Eschmeyer 1950), Iowa (Behmer 1964, Pitlo 1984, Paragamian 1989), and Minnesota (Holt *et al*. 1977). In agreement with this study, limited or nonexistent use of Denil fishways by walleyes has been documented from trap studies in Alberta (Fernet 1984, Schwalme *et al*. 1985), and videographic observations of several fishways of the St. Joseph River in Michigan and Indiana (Dexter and Ledet 1997). Dexter and Ledet noted that the modest numbers of walleyes that used the fish ladders was unusual, because they were well represented in the St. Joseph River below the dams.

Attraction efficiency of walleyes at the Dunnville Fishway was less than half of the attraction efficiencies calculated for other species at similar fishways (Table 3). Attraction efficiencies of walleyes

TABLE 3. Attraction efficiencies and passage efficiencies of smallmouth bass, white suckers, and walleyes at various Denil fishways on the Grand River, Ontario.

Species	Fishway slope (%)	Attraction Efficiency (%)	Passage Efficiency (%)	Source
Smallmouth bass	10	82	36	Bunt *et al.* 1999
Smallmouth bass	20	55	33	Bunt *et al.* 1999
White sucker	10	50	55	Bunt *et al.* 1999
White sucker	20	59	38	Bunt *et al.* 1999
Walleye	10.5	21	0	This paper

at the Dunnville Fishway may have been negatively affected by distracting flows that originated upstream from the fishway in Sulphur Creek, and near weir IV (Fig. 1). In similar studies of Denil fishways, passage efficiencies of other species have been estimated to vary between 33% and 55% (Table 3). If more walleyes were radio-tagged, a better estimate of passage efficiency would likely have been achieved. Low passage efficiencies of walleyes likely result from excessive water velocities, turbulence that reduces critical swimming speeds (Pavlov *et al.* 1994), air entrainment, back-currents and disorienting flows which have been observed to inhibit and delay passage of percids (Schwalme *et al.* 1985, Bunt *et al.* 1998) and non-percid species (Haro *et al.* 1999) through Denil fishways. In the Dunnville Fishway, major vortices occur in the resting pools. This is important because walleyes have shown tendencies to avoid turbulent water, especially when the water temperature was low (Ryder 1977). Furthermore, behavioral studies in an artificial flume, showed that less than 50% of walleyes swam past each sharp corner (Peake 1997). For walleyes to be successful at using the Dunnville Fishway, a minimum of four corners, or abrupt changes in direction must be negotiated. This would therefore result in the net passage of only 6% of the total number of walleyes that enter the fishway, if the corner variable was valid and considered independently. It has not yet been determined if corners are either physical or motivational obstacles for walleyes. Spiral fishways, or fishways with rounded corners, as well as linear fishways with resting pools that do not create back-currents or whirlpools, should be considered as possible alternatives to double-backed, or convoluted fishways.

Behavior and movement patterns of walleyes downstream from barriers appears to be consistent. For example, Pitlo (1984) implanted walleyes with radio transmitters and observed them to move upstream to the tailwater of a dam on the Mississippi River. These walleyes then dispersed downstream and spawned at several sites (Pitlo 1984). Similarly, Paragamian (1989) radio-tagged walleyes and observed them to migrate to the Waverley Dam and the Cedar Falls Dam on the Cedar River, Iowa. These fish proceeded to spawn exclusively in the dam tailwaters. Recruitment of native walleyes in the Cedar River was poor (Paragamian 1989) and the author speculated that substrate downstream from the dams (sand and fine gravel) may be a factor, since walleye embryo survival is greatest in areas with clean gravel-cobble substrates (Corbett and Powles 1986). Dams often produce hydraulic conditions and ice scour that help unembed substrate thereby producing clean gravel-cobble areas that may function as suitable spawning sites for walleyes (Paragamian 1989) and other percids (Bunt *et al.* 1998). In this study, walleyes occupied areas with known gravel deposits as well as tailwater areas of the weirs, that may indicate spawning occurred downstream from the weirs.

This paper describes a situation that is site specific—as all fishways are. Lessons learned from assessments of walleye behavior at the Dunnville Fishway may be applicable to other fishways that are to be built to pass walleyes. Since most fishways do not appear to pass walleyes effectively, different designs should be developed and tested. Modifications of existing fishways, and/or areas immediately downstream from fishway entrances should also be evaluated to increase attraction and passage efficiencies.

ACKNOWLEDGMENTS

We thank the Grand River Conservation Authority for providing fishway discharges, water velocities, and temperature data. T. Nash, K. Chandler, L. Richardson, W. Dolan, and the Dunnville Hunters and Anglers Club assisted with field operations. MIE Consulting Engineers produced diagrams of the Dunnville Fishway that were modified for this publication. E. Holm, G. Power, K. Ostrand, and M. Hoff provided useful comments on an earlier version of this manuscript. Funding for this study was provided by the Department of Fisheries and Oceans (Burlington, Ontario), and the Natural Sciences and Engineering Research Council of Canada (NSERC) in the form of post-graduate scholarships to C.M.B and S.J.C. and a research grant to R.S.M.

REFERENCES

Bahr, D.M. 1977. Homing, swimming behaviour, range, activity patterns and reaction to increasing water levels of walleye (*Stizostedion vitreum vitreum*) as determined by radio-telemetry in navigational pools 7 and 8 of the upper Mississippi River during spring, 1976. M.S. thesis, Wisconsin State Univ., LaCrosse. WI.

Beach, M.A. 1984. *Fish Pass Design*. Fisheries Research Technical Report No. 78, Ministry of Agriculture, Fisheries and Food, Lowestoft, UK.

Behmer, D.J. 1964. Movement and angler harvest of fishes in the Des Moines River, Boone County, Iowa. *J. Iowa Acad. Sci.* 71:259–263.

Bunt, C.M., Cooke, S.J., and McKinley, R.S. 1998. Creation and maintenance of habitat downstream from a weir for the greenside darter (*Etheostoma blennioides*)—a rare fish in Canada. *Env. Biol. Fish.* 51:297–308.

———, Katopodis, C., and McKinley, R.S. 1999. Attraction and passage efficiency of white suckers and smallmouth bass by two Denil fishways. *N. Am. J. Fish. Man.* 19:793–803.

Clay, C.H. 1995. *Design of Fishways and Other Fish Facilities*, second edition. Boca Raton, Florida: Lewis Publishers.

Corbett, B.W., and Powles, P.M. 1986. Spawning and larva drift of sympatric walleyes and white suckers in an Ontario stream. *Trans. Am. Fish. Soc.* 115:41–46.

Crowe, W.R. 1962. Homing behaviour in walleyes. *Trans. Am. Fish. Soc.* 91:350–354.

Dexter, J.L., and Ledet, N.D. 1997. *Estimates of fish passage on the St. Joseph River in 1993 using time-lapse video recording*. Michigan Department of Natural Resources Fisheries Division. Fisheries Technical Report No. 95-4.

Eschmeyer, P.H. 1950. *The life history of the walleye,* Stizostedion vitreum vitreum *(Mitchill) in Michigan*. Bull. Inst. Fish. Res., Michigan Department of Conservation. No. 3.

Ferguson, R.G., and Derksen, A.J. 1971. Migration of adult and juvenile walleyes (*Stizostedion vitreum vitreum*) in Southern Lake Huron, Lake St. Clair, Lake Erie and connecting waters. *J. Fish. Res. Board Can.* 28:1133–1142.

Fernet, D.A. 1984. *An evaluation of the performance of the Denil 2 fishway at Fawcett Lake during the spring of 1983.* Environmental Management Associates, Calgary, Alberta.

Haro, A., Odeh, M., Castro-Santos, T., and Noreika, J. 1999. Effect of slope and headpond on passage of American shad and blueback herring through simple Denil and deepened Alaska steeppass fishways. *N. Am. J. Fish. Man.* 19:51–58.

Harris, J.H., and Mallen-Cooper, M. 1994. Fish-passage development in the rehabilitation of fisheries in mainland south-eastern Australia. In *Rehabilitation of Freshwater Fisheries*, ed. I.G. Cowx, pp. 185–193. Oxford, UK: Blackwell Scientific Publications.

Holt, C.S., Grant, G.D.S., Oberstar, G.P., Oakes, C.C., and Brandt, D.W. 1977. Movement of walleye, *Stizostedion vitreum*, in Lake Bemidji, Minnesota as determined by radiotelemetry. *Trans. Am. Fish. Soc.* 106:163–169.

Katopodis, C., Derksen, A.J., and Christensen, B.L. 1991. Assessment of two Denil fishways for passage of freshwater species. *Am. Fish. Soc. Sym.* 10: 306–324.

McConville, D.R., and Fossum, J.D. 1981. Movement patterns of walleye (*Stizostedion v. vitreum*) in pool 3 of the Upper Mississippi River as determined by ultrasonic telemetry. *J. Fresh. Ecol.* 1:279–285.

Ney, J.J. 1978. *A synoptic review of yellow perch and walleye biology.* American Fisheries Society Special Publication 11:1–12.

Olson, D.E., and Scidmore, W.J. 1962. Homing behaviour of spawning walleyes. *Trans. Am. Fish. Soc.* 91: 355–361.

Olson, D.E., Schupp, D.H., and Macins, V. 1978. An hypothesis of homing behaviour of walleyes as related to observed patterns of passive and active movement. *Amer. Fish. Soc. Spec. Pub.* 11:52–57.

Paragamian, V.L. 1989. Seasonal Habitat use by walleye in a warmwater river system, as determined by radiotelemetry. *N. Am. J. Fish. Man.* 9:392–401.

Pavlov, D.S., Lupandin, A.I., and Skorobogatov, M.A. 1994. Influence of flow turbulence on critical flow velocity for gudgeon (*Gobio gobio*). *Doklady Biological Sciences* 336:215–217.

Peake, S.J. 1997. Swimming performance of Atlantic salmon, brook trout, brown trout, walleye and lake sturgeon relative to migratory behaviour, habitat selection and fishway design. M.S. thesis. University of Waterloo. Waterloo, ON.

Pitlo, J., Jr. 1984. *Wing and closing dam investigations*. Iowa Conservation Commission. Federal Aid in Fish Restoration, Completion Report F-96-R, Des Moines.

Rawson, D.S. 1957. The life history and ecology of the yellow walleye, *Stizostedion vitreum*, in Lac La

Ronge, Saskatchewan. *Trans. Am. Fish. Soc.* 86: 15–37.

Ryder, R.A. 1977. Effects of ambient light variations on behaviour of yearling, subadult, and adult walleye (*Stizostedion v. vitreum*). *J. Fish. Res. Board Can.* 34:1481–1491.

SAS Institute, Inc. 1999. *SAS users guide: statistics version 9.* SAS Institute, Inc., Cary, North Carolina.

Schwalme, K., Mackay, W.C., and Lindner, D. 1985. Suitability of vertical slot and Denil fishways for passing north-temperate, nonsalmonid fish. *Can. J. Fish. Aquat. Sci.* 42:1815–1822.

Shikhshabekov, M.M. 1971. Resorbtion of the gonads in some semi-diadromous fishes of the Arakum Lakes (Dagestan USSR) as a result of regulation of discharge. *J. Ichth.* 11(3):427–431.

Todd, T.N., and Haas, R.C. 1993. Genetic and tagging evidence for movement of walleyes between Lake Erie and Lake St. Clair. *J. Great Lakes Res.* 19: 445–452.

Submitted: 24 September 1999
Accepted: 2 July 2000
Editorial handling: John Janssen