An Investigation of Walleye Egg Hatching Success in the Lower Fox River, Wisconsin

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1. Walleye in the Fox River and Green Bay

The walleye (Stizostedion vitreum) is endemic to Green Bay and the Fox River (Becker, 1983) and has been a part of the commercial and sport-fishing catch for many years. In 1885, the annual combined catch of pike and pickerel (walleye and northern pike) from lower Green Bay was 365,000 pounds (Smith and Snell, 1891). The walleye, however, has never been an abundant or highly sought-after component of the fishery in either the Fox River or lower Green Bay. Past commercial fishing operations in Green Bay have focused on lake trout (Salvelinus namaycush), whitefish (Coregonus clupeaformis), lake herring (Coregonus artedii), smelt (Osmerus mordax), and alewife (Alosa pseudoharengus). The most abundant catches of walleye have been associated with sport-fishing activities in northern Green Bay and Big- and Little Bay-De-Noc in the 1940s (Bertrand et al., 1976). The lower Fox River and southern Green Bay have, however, received some commercial fishing pressure. As late as 1973-74, walleye comprised 2.8-3.7% (by number) of the commercial catch at a site just downstream of the DePere Dam (Kernen, 1974). Analysis of data from commercial catch reports and Wisconsin Department of Natural Resources (WDNR) surveys (Table 1), shows that walleye accounted for 3-15% of the catch in the lower Fox River (fyke nets) and $\leq$1% of the catch in southern Green Bay (drop nets). While direct comparison is difficult due to differences in time and season of sampling and gear selectivity (fyke vs. drop nets), these data show that walleye are a relatively small component of the overall catch. The complete species composition breakdown for fyke net surveys in the Fox River for 1973-79 is presented in Table 2.

Table 1. Commercial catch, 1973-1979

a. Lower Fox River - Commercial fyke net (% of total catch)

Species	1973	1974	1975	1976	1977	1978	1979
Walleye	3	3	8	15	11	6	4
Carp	30	22	19	12	15	26	47
Bullheads	34	34	37	35	51	49	26
Catfish	<1	<1	1	<1	<1	1	4
White Sucker	14	9	8	7	6	3	1
Others	18	31	27	30	16	15	18

b. Southern Green Bay - Commercial drop net (% of total catch)

Species	1973	1974	1975	1976	1977	1978	1979
Walleye	<1	<1	<1	<1	<1	<1	1
Carp	8	<1	<1	2	<1	3	23
Bullheads	51	5	18	13	14	32	6
Catfish	<1	<1	<1	<1	<1	<1	1
White Sucker	<1	2	1	<1	<1	2	<1
Others	38	89	78	82	82	61	68

Source: Kernen (1974) and Lepinski (1978, 1979, and 1980)

Table 2. Species composition of fyke net surveys (1973-1979)

Bullhead	Lake trout	Pumkinseed	Green sunfish
Carp	Northern pike	Coho salmon	American eel
White bass	Channel catfish	Largemouth bass	Brook trout
White sucker	Burbot	White crappie	Muskellunge
Black crappie	Sauger	Quillback	Bigmouth buffalo
Alewife	Longnose gar	Smallmouth bass	Longear sunfish
Walleye	Bluegill	Brown trout	Longnose gar
Gizzard shad	Rainbow trout	Lake sturgeon	Flathead catfish
Freshwater drum	Rock bass	Mooneye	Bowfin
Yellow perch	Shorthead redhorse	Silver redhorse	Chinook salmon
Shortnose gar			

Carp (Cyprinus carpio), bullheads (Ictalurus melas, I. natalis, and I. nebulosus), channel catfish (I. punctatus) and white sucker (Catostomus commersoni) accounted for nearly 70% of the total survey catch over the period 1973-1979 in southern Green Bay and the lower Fox River. Carp, bullheads and catfish increased in abundance, especially in the Fox River, over that same period. Numbers of white suckers, a species usually abundant in less perturbed systems, declined. In 1973 bullheads were the most abundant species, with carp placing second; the commercial catch of carp from southern Green Bay and the lower Fox River that year was 2,000,000 pounds (Kernen, 1975). In 1979, carp overtook bullheads as the most abundant fish in the system. These vigorous, benthic feeding species often disturb bottom sediments and vegetation and may impact reproduction by other species.

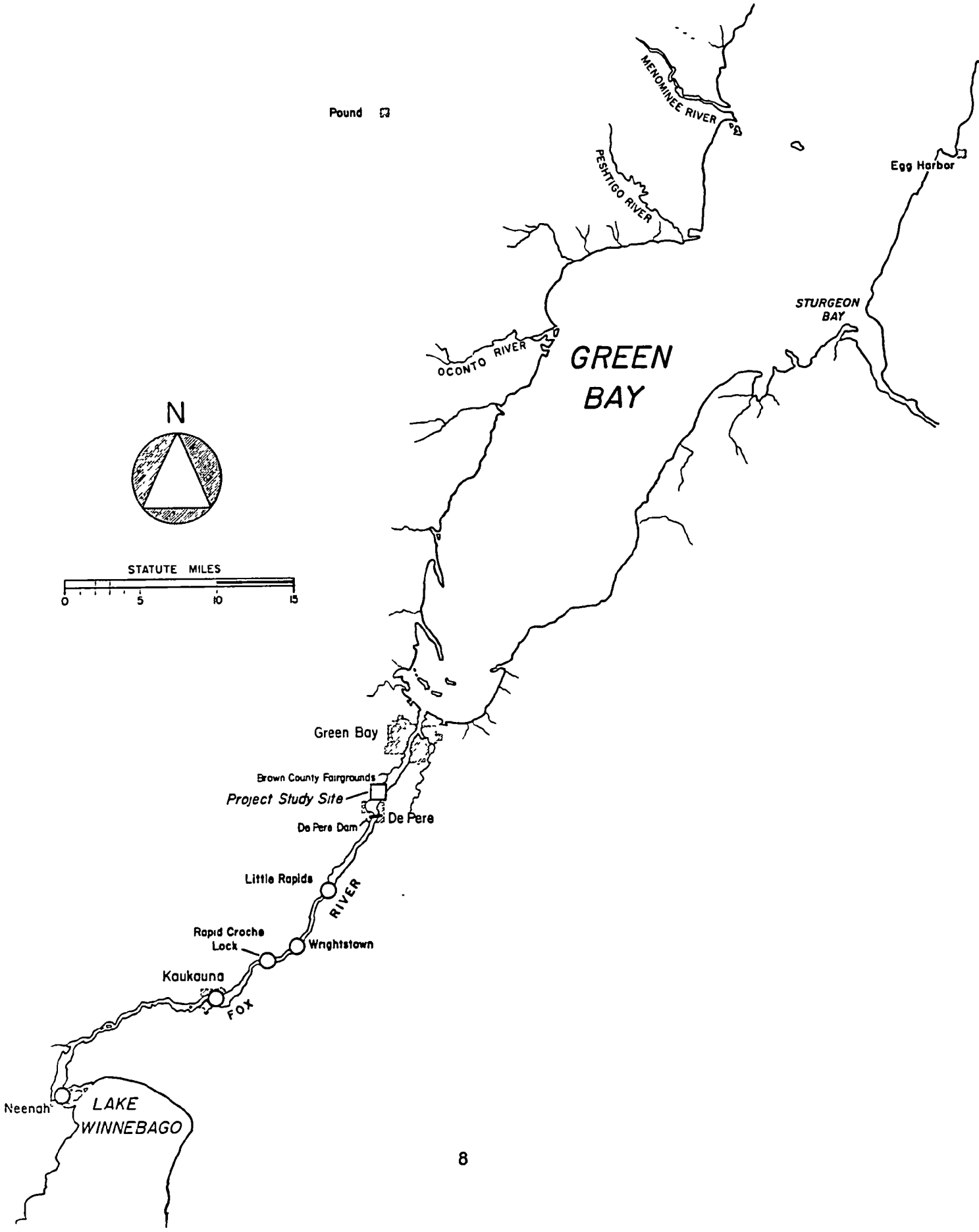
Several factors seem to have interacted in reducing the viability of the walleye fishery in the lower Fox River. As early as 1925, the effect of the DePere Dam in blocking walleye migration routes and forcing spawning near the dam rip-rap was noted (Bertrand et al., 1976). Clearly, water quality has been of potential importance, with municipal and industrial waste discharges meriting local concern for many years (see below). Finally, the dominance of benthic fish species seems in direct conflict with species such as the walleye

which broadcast spawn and provide no parental care.

Rehabilitation of the walleye fishery has been identified as a "[management] option with high potential" for the lower Fox River and southern Green Bay (Harris et al., 1982, p. 32). State-sponsored stocking programs designed to rehabilitate the Green Bay walleye fishery began in 1973. The Fox River received walleye fingerlings in 1977 and fry in 1978-1982 (Lychwick and Pellett, 1982). A tagging operation was initiated by WDNR in the fall of 1981 and spring of 1982 to assess the size of the walleye population. Results of the fall tagging operation indicated that 60,000 walleye were occupying the area immediately below the DePere Dam. Six year classes were present, primarily representing the five years of fingerling/fry stocking, 1977-1981. The spring, 1982 tagging and netting survey produced an estimate of 12,000 walleye in that same area. Recovery by sport fishermen, of fish tagged in 1981, revealed some interesting movements by walleye in the Fox River system. Walleye tagged in the lower Fox River were recovered above the DePere Dam near Little Kaukauna, Little Rapids, Wrightstown, Rapide Croche and Neenah, 6, 6.5, 10, 12, and 32 miles upstream of the DePere Dam, respectively (Figure 1). A few walleye moved out of the Fox River and were caught near Egg Harbor, Sturgeon Bay and the Menominee River (Figure 1) according to Lychwick and Pellett (1982).

Historically, the lower Fox River and southern Green Bay have supported substantial populations of walleye. A combination of factors, largely if not exclusively associated with cultural activities, has seriously reduced the abundance of walleye in these regions. Recent stocking efforts by WDNR have established a resident population of walleye in the lower Fox River and southern Green Bay. Very little movement of the resident population from this area has been reported, yet natural reproduction in the lower Fox River has

Figure 1. The lower Fox River and Green Bay



not been documented. This study examines several factors which may be impacting walleye egg hatching success in the lower Fox River.

II. Fox River Water Quality in Relation to the Walleye Fishery

The lower Fox River is defined here as the 37-mile segment between Lake Winnebago and Green Bay (Figure 1). This reach receives its primary hydrologic loading from Lake Winnebago and is subject to pollutant discharges from Lake Winnebago, industrial and municipal waste treatment plants and agricultural and urban runoff. Historically, water quality in the Fox River has been of major concern to state and local authorities. A 1938-39 investigation of the lower Fox River concluded that "...these waters could not support fish life at times of warm temperatures and low stream flows..." and that "...the Fox River will remain in its present highly polluted condition so long as the sulfite [pulp] mills continue to discharge their waste into the stream..." (WSCWP, 1939, p. 14). The passage of more than 40 years has seen a substantial improvement in Fox River water quality as a result of the joint efforts of government and industry (cf. Day et al., 1980). Yet, a recently published ecosystem rehabilitation plan for Green Bay (Harris et al., 1982) identified the Fox River as the primary source for three of the four critical stresses influencing the Green Bay ecosystem (nutrients, suspended solids, and toxic chemicals). The fourth critical stress, fishing and exotic fish species, remains closely tied to the Fox River.

Water quality features of direct concern to the walleye fishery include levels of toxic organic compounds, hydrogen sulfide, dissolved oxygen and oxygen-demanding substances, and suspended sediment. Chlorinated hydrocarbons have reached the Fox River as a result of agricultural pesticide applications (Bertrand et al., 1976) and through paper mill and sewage

treatment plant effluents (Harris et al., 1982). Chlorinated hydrocarbons have been found associated with bottom sediments in tributaries to Green Bay (Johnson et al. 1967) and have bioaccumulated in fish (Hickey et al., 1965) and herring gulls (Keith, 1966). Polychlorinated biphenyls have been "inadvertently discharged" to the Fox River by paper recycling mills and are found associated with bottom sediments and bioaccumulated in fish (Harris et al., 1982). The impact of toxic substances on the walleye fishery in the lower Fox River are not addressed in this study.

Dissolved oxygen, biochemical oxygen demand (BOD-5) and suspended solids have been measured in the lower Fox River at the DePere Dam and the river mouth as part of research on dissolved oxygen in Green Bay (U.S. EPA Grant No. R809521010). Fox River dissolved oxygen concentrations in late May, 1982 ranged from 8.9-9.7 mg/L. The minimum measured dissolved oxygen concentrations measured over the period May-October, 1982 were 5.0 mg/L at the mouth on 19 July and 5.1 mg/L at the DePere Dam on 5 August. BOD-5 ranged from a low of 2.7 mg/L on 25 May 1982 to a maximum of 16 mg/L on 13 July 1982. The Fox River discharges in nearly 60 metric tons of BOD-5 to Green Bay each day (annual average, 1978-82). Suspended solids levels in the river range from a minimum of 7 mg/L on 5 June 1982 to a maximum of 41 mg/L on 10 August 1982. The average daily discharge (1978-82) of suspended solids to Green Bay from the Fox River is in excess of 400 metric tons. The high BOD-5 and suspended solids levels are reflected in the organic, anaerobic nature of the bottom sediments of the river. Bottom sediments in the Fox River and their potential impact on oxygen levels are discussed elsewhere in this report.

Much of the information on hydrogen sulfide, dissolved oxygen and suspended solids in the lower Fox River is published in the form of reports which are not a part of the readily available primary literature. This

information will be summarized in the final report.

III. Importance of Selected Environmental Factors for Hatching Success

Five factors were initially identified as being of potential importance in determining walleye egg hatching success in the lower Fox River:

1) Dissolved oxygen concentration
2) Hydrogen sulfide concentration
3) Sedimentation and substrate character
4) Gamete production and viability
5) Impacts of synthetic organic chemicals

The current study has investigated the first three factors, dissolved oxygen, hydrogen sulfide, and sediment/substrate characteristics. Parallel activity at ERL-Duluth will address gamete viability and the potential impact of synthetic organic chemicals.

A. Dissolved Oxygen

Adequate levels of dissolved oxygen have long been recognized as critical to the maintenance of a healthy and balanced community of aquatic organisms. Federal and state authorities have established dissolved oxygen standards at levels designed to protect fish and other aquatic life in streams and rivers. Fishkills linked to dissolved oxygen depletion have been observed in the Fox River on several occasions (Wisconsin Conservation Commission, 1927 as cited by Bertrand et al., 1976). Despite contemporary improvements in Fox River water quality (cf. Day et al., 1980), it is reasonable to identify dissolved oxygen as a potential barrier to walleye egg hatching success in the lower Fox River.

Two questions need be addressed with respect to dissolved oxygen and walleye egg hatching success and survival in the Fox River: 1) what are

the dissolved oxygen levels during the spawning period and 2) what is the sensitivity of walleye eggs and larvae to variation in dissolved oxygen concentration. Walleye in Wisconsin spawn in the spring, shortly after ice-out (Becker, 1983). Favored spawning temperatures range from 2.2 to 15.5 ^{0}C, with most activity occurring in the range 5.6-7.8 ^{0}C. Eggs usually develop and hatch within 21 days (Preigel, 1970). Fox River walleye spawn during April and May (Preigel, 1970 and WDNR, personal communication). Conditions of high river flow, cold temperature and reduced biological activity during April and May should lead to near-saturation levels of dissolved oxygen in the Fox River at that time.

Several studies have demonstrated the sensitivity of walleye eggs and larvae to reduced levels of dissolved oxygen. Siefert and Spoor (1974) reported that walleye larvae survival at 17 ^{0}C was markedly reduced at dissolved oxygen saturations below 35% (3.4 mg/L). Over the temperature range 3-8 ^{0}C, greatest eyed-egg and sac-fry mortalities occur at dissolved oxygen concentrations below 3 mg/L (Colby and Smith, 1967). Little difference in the development of walleye larvae was observed at dissolved oxygen concentrations of 10, 3, and 2 mg/L for a temperature of 10^{0} C; however, larvae held at 1 mg/L did show poor development (Van Horn and Balch, 1957). Oseid and Smith (1971) incubated walleye eggs at 1 mg/L increments from 2-7 mg/L and a temperature of 12.1-13.2 ^{0}C. Egg survival was reduced from 58% to 31% over that range. It was concluded that low levels of dissolved oxygen substantially extended the time to hatch and reduced the mean length of larvae at hatch. The authors concluded that for optimum hatch success, oxygen levels must be maintained above 5-6 mg/L. The results of these studies indicates that walleye eggs exhibit a considerable resistance to reduced levels of dissolved oxygen.

In summary, river water dissolved oxygen levels at preferred spawning

sites in April and May may be anticipated to be sufficient for the relatively tolerant walleye eggs and young. Conditions of dissolved oxygen at the water/sediment interface, however, may be quite different. Sediment oxygen characteristics are discussed below.

B. Hydrogen Sulfide

Hydrogen sulfide is a natural product of the anaerobic decomposition of sulfur-containing organic material. The highly organic benthic sediments of the Fox River would be expected to provide a continuous input of hydrogen sulfide. Wood fiber sludges associated with the pulp and paper industry are particularly well known for their capacity to generate hydrogen sulfide. Hydrogen sulfide concentrations as high as 260 ug/L were measured in close proximity (2 mm) to fiber sludge deposits in the Rainy River of Minnesota (Colby and Smith, 1967).

Dissolved hydrogen sulfide exists in equilibrium with bisulfide ion and sulfde ion. The relative abundance of the species depends on pH and, to a lesser extent, temperature. Above pH 9, hydrogen sulfide concentrations are negligable; at pH 8, approximately 10% of the total sulfide is present as hydrogen sulfide, at pH 7.1, 50% and at pH 6.2, 90% (Broderius and Smith, 1976). Sulfide is highly reactive and may be oxidized to sulfate or may participate in precipitation reactions with metals such as iron, lead, and zinc (Snoeyink and Jenkins, 1980). Thus, under spring conditions in most rivers, the presence of substantial quantities of hydrogen sulfide may be expected to be highly transient and perhaps limited to the sediment-water interface.

Fish biologists recognize the toxicity of hydrogen sulfide, especially as a barrier to reproduction. Smith and Oseid (1974, p. 430) state that "many habitats with unexplained absence of satisfactory fish reproduction should be

examined for possible natural contamination with hydrogen sulfide in potential spawning and nursery areas." The authors further state (1974, p. 429) that, "fish populations which deposit eggs on bottoms where there is organic decomposition or where water containing low concentrations of hydrogen sulfide flows over eggs and fry resting on non-organic bottoms, may have their reproductive ability limited." Walleye broadcast their eggs on non-organic substrate, usually in areas of substantial flow.

Sensitivity to hydrogen sulfide varies with the life history stage of the fish (e.g. egg, fry, juvenile). Smith and Oseid (1974) reported that the "no effect" level for hydrogen sulfide impact on the survival and development of walleye eggs and fry was 9 ug/L as H_2S. The no effect level for juvenile walleye is reported as 3 ug/L as H_2S (Smith et al., 1976).

Smith and Oseid (1971) observed a 60-80% survival to hatch in walleye eggs exposed to 12-13ug/L H_2S; survival was reduced to 13-20% at 49 ug/L H_2S. Newly hatched fry were thought to be more sensitive to hydrogen sulfide than eggs of the same species. Shorter length at hatching and embryo deformities were reported where incubation occurred in water containing more than 20 ug/L H_2S. Low oxygen concentrations were reported to reduce egg and fry tolerance to hydrogen sulfide. It is clear that hydrogen sulfide is a potential barrier to walleye reproduction in the Fox River. The critical task is to obtain the necessary spatial resolution in sampling and analysis to detect the presence of H_2S at the sediment/water interface.

C. Sedimentation and Substrate Character

Walleye broadcast their eggs over large expanses of coarse gravel, rock or sand in moving water and clear shoreline areas (Auer, 1982). Although the Fox River contains large regions of highly organic sediment, there are areas of clean substrate with substantial flow. Walleye have been observed to

congregate near the rip-rap at the base of the DePere Dam during spawning season and are believed to spawn in that area (WDNR, personal communication).

Walleye eggs deposited in regions of high flow are not likely to be influenced by sediment or the products of sediment diagenesis. If Fox River walleye are forced to use less desirable substrate due to dam placement and/or water level regulation, sedimentation and chemical effects may influence egg survival.

IV. Materials and Methods

A. Fish and Egg Handling

Suitable spawning substrate in the lower Fox River is limited (WDNR, personal communication). Sexually ripe walleye are known to congregate each spring at a site approximately 1 km downstream of the DePere Dam. The bottom sediment in this area is primarily sand and water flows with sufficient velocity to keep the substrate free from debris. Each spring, Wisconsin DNR personnel collect ripe and spent adult walleye from the lower Fox River and record length, weight and sex information; these fish are then tagged and released. Adult walleye used in this study were provided by WDNR personnel during tagging operations on 21 April 1983, the peak of the spawning period. Water temperature at the time of capture was 7^{0} C (44^{0} F).

Several ripe male and female walleye were taken from WDNR nets and transported in portable metal mesh fish baskets to the study site staging area at the Brown County Fairground. Eggs from two large females were immediately stripped into a clean, dry plastic tub and milt from five males was squeezed directly onto the eggs. The mixture was slowly stirred with the fingers. After thorough mixing of the gametes, river water was slowly added to the tub. Eggs were repeatedly rinsed until the rinse water remained clear.

Eggs were not "mudded" to prevent adhesion, as the volume of eggs was small and would be placed immediately into egg-hatching traps. Very little clumping of eggs was observed.

All traps received fertilized eggs from the single batch harvested on 21 April 1983 (the start of ontogeny or Day 1). Following thorough mixing, three units of fertilized eggs were inoculated into each of eight test traps using a calibrated bulb/pipette. Four units of eggs were used for control traps. In each case, equivalent volumes were preserved in 10% formaldehyde for later enumeration.

Subsamples of the batch of fertilized eggs were examined immediately to determine the percentage of live eggs in each trap. It is difficult to differentiate fertilized live eggs from unfertilized live eggs at this stage of development. For the purposes of this study it is assumed that all live eggs were fertile. Eggs remaining after sampling and trap-filling were transported to Michigan Technological University for laboratory rearing experiments.

B. Trap Construction and Placement

Ten egg-hatching traps were constructed specifically for walleye eggs using a modification of the design by Swanson (1982). Traps were constructed of corrosion-resistant aluminum and measured 96.5 cm in length by 8.9 cm wide by 57.2 cm high. The narrow design was intended to minimize sediment and debris accumulation and to maximize floatation capabilities. A block of styrofoam, 91 cm long, 7.6 cm wide and 20.3 cm high was fitted to the top of the trap, out of contact with the egg chamber. The egg compartment section of the trap was 91.4 cm in length by 7.6 cm wide by 20.3 cm high. The open faces of the egg compartment were covered with 0.75 mm [1 mm diagonal opening] mesh net (Tetko Inc., PeCap ASTM 7-25-710). Walleye eggs range from 1.5-2.1 mm in

diameter; the depth at yolk sac of recently hatched larvae ranges from 1.18-1.42 mm (Auer, 1982). Photographs of the traps are provided as Figure 2.

Two types of egg traps were used: gravel traps and turf traps. A two-inch layer of washed pea gravel was placed in each of six "gravel" traps. Fertilized eggs were expressed into the trap through a delivery port. The egg compartment of the remaining four traps was outfitted with a six-layer turf "sandwich" composed of two layers of plastic grass with two layers of artificial turf on each side. The turf sandwich had a length of 91.4 cm and a height of 22.9 cm, leaving an open space, 7.6 cm high in the egg compartment. Eggs were expressed onto the grass surface, the layers of plastic grass and artificial turf sandwiched together, and the trap sealed.

Filled traps were placed at selected sites by divers and anchored in place, parallel to the current, with cast iron weights. Eight of the ten traps (four gravel, four turf) were placed on sandy substrate at a site on the east bank of the Fox River approximately 1 km downstream of the DePere Dam (Figure 1). The control traps (both gravel) were placed at a site 5 km upstream from the mouth of the Oconto River and in an outdoor raceway at the Evergreen trout hatchery in Pound, Wisconsin.

Paired traps (one gravel, one turf) were harvested from the Fox River site on Days 7, 13, and 19 (2 sets). Traps were moved submerged and intact from the incubation site to the dock at the Brown County Fairground. The traps were opened and the contents washed into a 363 micron, #2 mesh nylon plankton net. The gravel and turf were gently mixed with water several times to allow larvae and eggs to float free, uninjured. All eggs, larvae and debris washed from the traps were held at river water temperature and aerated until ready for laboratory examination (generally within two hours). Control traps were harvested using this method on Day 18.

Figure 2a. Egg traps - Front view, assembled

Figure 2b. Egg traps - Top view, dissasembled with turf

C. Rearing Experiments

Eggs remaining after filling traps were aerated and transported on ice to the laboratory at Michigan Technological University. The eggs were then placed in a mixed, aerated, continuous flow device (Figure 3) filled with Fox River water. A supply of refrigerated Fox River water was slowly dripped into the device via a poly-staltic pump; overflow water was discharged to waste. The device was maintained in the dark at 10^{0} C in a Percival Incubator (Boone, IA). Eggs were examined daily and all eggs with fungal contamination were removed. Developmental stages were identified using physical characteristics described by Olsen (1966). Photographs of eggs and larvae were made using a 35 mm Nikkormat camera and either a microscope or dissecting scope.

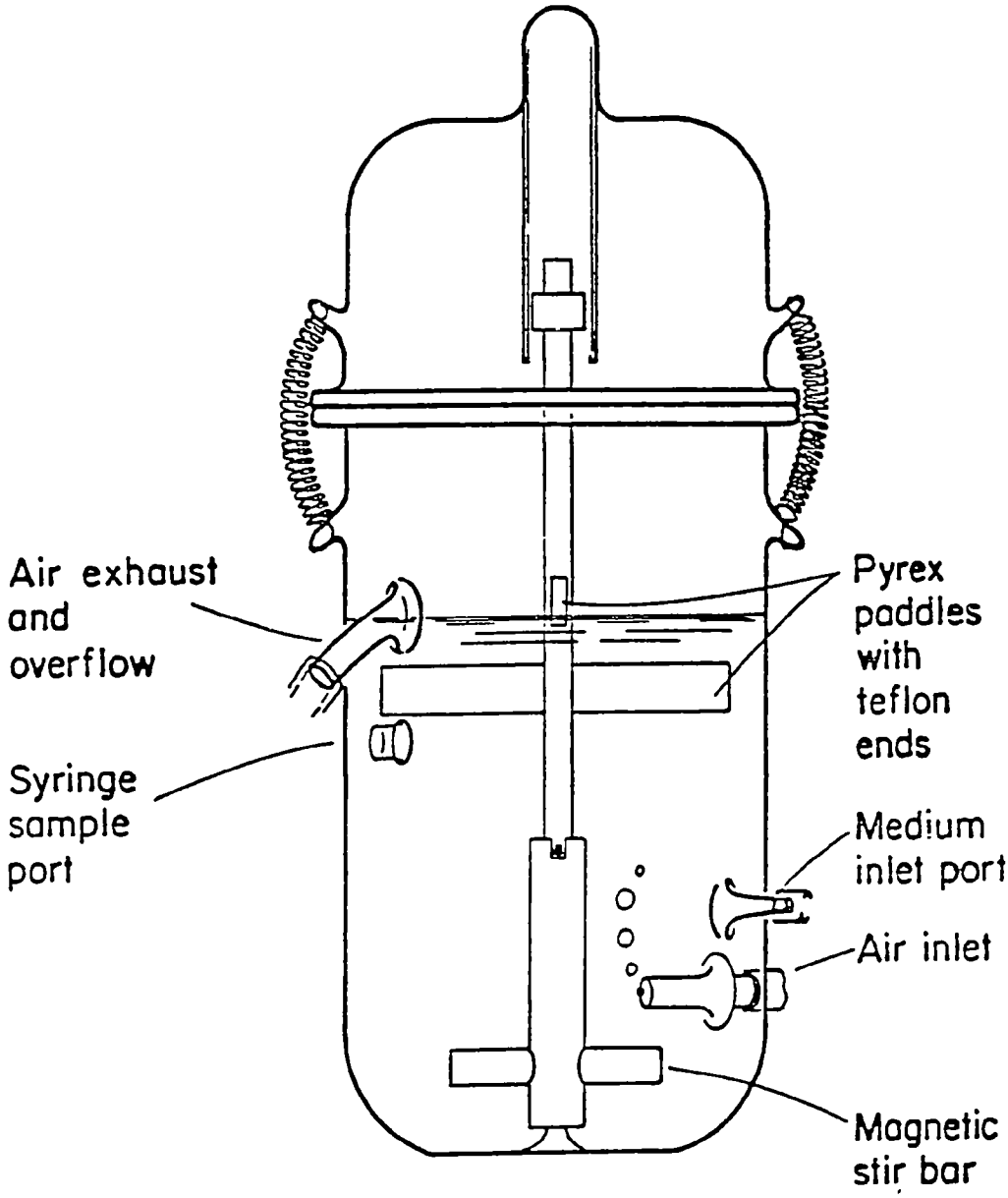
D. Fungi

Samples of Fox River water and walleye eggs were transported in sterile containers, on ice, to the laboratory at Michigan Technological University. Eggs (surface sterilized) and river water were plated on Rose Bengal agar and incubated at 20^{0} C for 7 days. A water sample from Portage Lake, Houghton County, Michigan was plated as a control. Fungi developing on the agar were quantified and identified.

E. Larval Fish Sampling

Sampling for naturally-spawned larval walleye was conducted at three-day intervals over the period 25 April to 6 June 1983. Sampling was conducted at night, in the Fox River near the egg trap study site. Fish larvae, arbitrarily defined as <1 inch in length, were collected by towing a 0.5 m diameter nylon plankton net (#2 mesh, 363 micron aperature) behind a boat for 5 minute periods. The volume of water filtered was quantified using a 5 inch diameter marine flowmeter (G.M. Mfg. & Inst. Co., Bronx, N.Y. 10451) with

Figure 3. Continuous flow device for rearing experiments.



dial counter attached to the center opening of the net. Fish larvae were also collected by seining the east and west shores at the study site. The seine has two 48 inch wings of #00 mesh and a center, 40 square inch #2 mesh cod end. Samples were preserved with formaldehyde for later identification and enumeration. This component of the project is not complete; the target date for a preliminary report is 16 December 1983.

F. Sediment Survey

During the spring and summer of 1983, sediment grab samples were collected on at five locations on each of 68 transects between the Fox River mouth and the dam at DePere. Sediment samples were analyzed for COD, volatile solids, moisture content, and gross texture. A relationship between sediment COD and sediment oxygen demand developed for the Green Bay oxygen project will be used to characterize the oxygen demand of Fox River sediments. The distribution of suitable spawning substrate can also be identified from this survey. This component of the project is not complete; the target date for a preliminary report is 16 December 1983.

G. Chemical Analyses

Water samples for determination of dissolved oxygen, hydrogen sulfide and pH were collected on 21 April 1983 (as traps were set) and 9 May 1983 (as final traps were harvested). Water samples for dissolved oxygen and pH were collected at the surface and at 14 intervals in the 100 cm above bottom using the siphon apparatus illustrated in Figure 4. Dissolved oxygen was measured using the azide modification of the Winklet technique (APHA, 1980). pH was measured using an Orion electrode and Corning Model 12 meter.

Water samples for hydrogen sulfide analysis using the multiple-syringe apparatus pictured in Figure 5. The syringes were filled by divers, capped,

Figure 4. Sampling device for dissolved oxygen and pH.

and the entire apparatus brought to the surface. The water was then forced from the syringe, through a 0.45 micron filter into 50 ml media bottles containing 2 mls of 0.1 molar zinc acetate. Preserved samples were stored at room temperature. Total dissolved sulfide was measured using the methods of APHA (1980) and Smith et al. (1976); hydrogen sulfide concentrations were determined using temperature/pH/ionization constant relationships.

Figure 5. Sampling device for hydrogen sulfide.

V. Results and Discussion

A. Egg Traps

The number of walleye eggs placed in each trap was estimated from the inoculation volume and the measured density of eggs in the fertilizing vessel. Traps placed in the Fox River contained approximately 4600 eggs, 2600 of which (56%) were alive and assumed fertilized. Control traps contained a total of 2760 eggs, 1550 of which were viable.

The first pair of traps (one gravel, one turf) was harvested from the Fox River after 7 days of incubation. Water temperature on that date was 13° C. Of 3407 eggs recovered from the gravel trap, 3177 (93%) were considered non-viable (opaque, white, and/or fungus-infested) and 230 (7%) were alive. The vertebral column and outlines of the eyes of the larvae were clearly visible through the corion of live eggs recovered on Day 7. Of 2387 eggs recovered from the turf trap, 2219 (93%) were dead and 168 (7%) were viable and showed normal signs of development.

The second pair of traps was harvested after 13 days of incubation. Water temperature on that date was 10.5° C. Of 2367 eggs recovered from the gravel trap, 24 (1%) were alive. One hatched larva was found swimming in the trap. Many of the dead eggs were clumped and heavily infested with fungi; over 200 chironomid larvae were found associated with the egg clumps. Only three (<1%) viable eggs were observed among 698 eggs recovered from the turf trap. Fewer chironomids (75) and less fungal contamination were observed for the turf trap.

The final two pair of traps were harvested from the Fox River after 19 days incubation. Water temperature at that time was 11.5° C. No live eggs were observed among 607 and 1793 eggs recovered from the two gravel traps; one live larva was found. The dead eggs were heavily infested with fungus;

chironomid larvae, too numerous to count, were observed among the egg clumps. The turf traps had collected large quantities of silt and organic debris. No live eggs or larvae were observed among the 753 and 900 eggs recovered from the turf traps.

The control traps were harvested after 18 days incubation. The (gravel) trap placed at the fish hatchery contained one live egg among 1966 eggs recovered. No funal growth was observed, but large amounts of organic material, resembling fish food pellet debris, was found in the trap and may have influenced egg development. The (gravel) trap from the Oconto River contained 597 dead eggs and 18 hatched, live larval walleye. The results of egg recovery are summarized in Table 3.

B. Rearing Experiments

Eggs incubated in the laboratory at Michigan Technological University were used to estimate development and time to hatch for field-incubated eggs. Laboratory egg development proceeded through the hatching stage, but no hatched larvae survived. Eggs were incubated in Fox River water which supported a prolific population of fungi. Many developmental stages of eggs and larvae were photographed.

C. Fungi

Plates of Fox River water and walleye eggs supported 110 fungal colonies per ml of river water, while the Portage Lake water control plates supported 20 fungal colonies per ml of lake water. Two varieties of fungi were observed on the Portage Lake control plates, while 3-4 varieties were observed on the Fox River water plates. One variety was much more abundant than all others and was thought to be Saprolegnia, the species found growing from the surface of sterilized eggs. Researchers from Wisconsin DNR have attempted to raise lake

herring (Coregonus artedii) by incubating eggs in Green Bay water. The eggs reportedly grew well until the eyed stage, at which point heavy fungal growth developed and all eggs were lost (B. Blonger, WDNR, *personal communication*).

Table 3. Egg and larvae recovery from egg traps.

a. Fox River - Gravel Traps

Day	Eggs	% Eggs Viable	Larvae
1	4600	56	na
7	3407	7	0
13	2367	1	1
19	1793	0	1
19	607	0	0

b. Fox River - Turf Traps

Day	Eggs	% Eggs Viable	Larvae
1	4600	56	na
7	2387	7	0
13	698	<1	0
19	753	0	0
19	900	0	0

c. Hatchery Control - Gravel Trap

Day	Eggs	% Eggs Viable	Larvae
1	2760	56	na
18	1966	<1	0

d. Oconto River Control - Gravel Trap

Day	Eggs	% Eggs Viable	Larvae
1	2760	56	na
18	597	0	18

D. Chemical Analyses

Water samples were collected on the first day of egg incubation (21 April 1983) and the final day of trap harvest (9 May 1983) at 5 or 10 cm intervals beginning at 5 cm above the bottom. Only slight variation in dissolved oxygen concentration was observed within that distance. Dissolved oxygen concentration ranged from 13.1-13.7 mg/L (124-129 % saturation) on 21 April and from 10.2-11.5 mg/L (96-105 % saturation) on 9 May.

Total dissolved sulfide levels ranged from negligable to 1.2 ugS/L on 21 April and from 0.6 to 4.1 ugS/L on 9 May. Actual values for each depth are presented in Table 5. Over the range of pH (8.05-9.15) and temperatures (11.5-13^{0} C) at the Fox River study site, 10% or less of the total sulfide is present as the toxic form, hydrogen sulfide. Thus, the hydrogen sulfide content of Fox River water samples at all depths on both dates was <1 ug/L.

VI. Summary and Conclusions

A. Trap Construction

Trap construction and incubation procedures were satisfactory for the retention and culture of eggs and larvae. Low recovery/survival numbers in turf traps compared with gravel may have been due to poor circulation of oxygen and fresh water in turf traps. Both approaches afforded some protection from sedimentation and predation, however, trap invasion by chironomid larvae and abundant fungal growth were not avoided.

B. Gamete Viability

The combined gametes from adult Fox River walleye proved viable in both field and laboratory studies; however, survival beyond hatch was not observed in either case. Gamete viability is only one of several factors fundamental

to the establishment of a naturally reproducing walleye population.

C. **Fungal Growth and Chironomid Larvae**

Fungal growth and predation by chironomid larvae must be acknowledged as potential barriers to egg development. As eggs died and developed profuse fungal growth, chironomid larvae may have been attracted to available sources of shelter and food. Saprolegnia usually grows from dead eggs, but will spread to live eggs. This fungal species was 5.5 times more abundant in Fox River water than in the Portage Lake (Houghton Co., MI) control water. It is suggested that Fox River water, rich in organic material, may support an unusually high standing crop of fungi.

D. **Sediment and Benthic Fish Species**

Sediment deposition and resuspension by benthic fish may play an important role in walleye egg hatching success. Walleye eggs may be smothered by solids settling from the water column in quiescent areas. Carp, bullheads, and catfish, all abundant in the lower Fox River, can resuspend sediment and consume eggs as part of their vigorous, benthic feeding activities. Bullheads and carp exhibit parental care or such great fecundity that their survival is assured, even under suboptimal conditons.

E. **Water Quality**

Water quality conditions, as evidenced by dissolved oxygen or hydrogen sulfide levels, do not appear to be significant barriers to walleye egg hatching success. Dissolved oxygen levels in the water column are near saturation during the spawning period. Hydrogen sulfide levels were <1 ug/L at all depths. The fact that no sampling was conducted at the sediment/water interface must not, however, be overlooked.

F. Future Directions

The following questions should be addressed to further clarify the potential for rehabilitation of the lower Fox River walleye fishery:

1. **What are the dissolved oxygen and hydrogen sulfide concentrations at the sediment/water interface?** This can be measured in cores or directly at the study site.

2. **Are eggs buried by sediment?** Smothering can be examined in the river in open-topped traps.

3. **Do adult walleye complete the spawning act and produce fertilized eggs?** Sampling for the presence of walleye eggs in the river could address this point.

4. **What is the survival rate for post-hatch young?** This would be addressed under controlled laboratory conditions.

5. **What role do heavy metals and synthetic organic chemicals play?** This may be an appropriate direction for activities at ERL-Duluth.

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