Population biology and management of the walleye in western Lake Superior. No. 177 1992

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ABSTRACT

The walleye stock in western Lake Superior is one of the few Great Lakes walleye stocks to perpetuate itself over the past century. The stock had been lightly exploited because of water quality problems, which affected fish taste, and because there was no commercial fishery. With the opening of a new waste treatment facility in 1978, and improved water quality, walleye in western Lake Superior became more palatable and sport and commercial interests were revived.

Surveys were conducted from 1978-85 to determine spawning areas, age and growth, movement patterns, population density, survival, disease, and harvest of this stock. Results indicated that the majority of walleyes which inhabit western Lake Superior migrate to the St. Louis River estuary during spring spawning season. Spawning occurs almost entirely at Fond du Lac, Minnesota, in a 2-mile stretch of river below a power dam, approximately 25 miles upriver from Lake Superior. Nearly 50,000 mature walleyes spawned at Fond du Lac in 1981, and over 67,000 mature fish inhabited the river and Lake Superior combined. Growth rates were slow and numerous age classes were present, with walleyes up to age 20. Tag returns indicated adult walleyes move downstream from the rapids after spawning and remain in the estuary several weeks to several months before entering Lake Superior. Once in Lake Superior, the walleye moved eastward during the summer but generally not past the Apostle Islands. A westward movement back to the Superior Entry occurred during late fall or early winter.

Lymphocystis was observed on walleyes handled during the 1980-85 spawning period. Annual survival was estimated at 58-60% for mature walleye.

Sport angling increased considerably once the fish became edible. In addition, an assessment commercial fishery began in 1980 by the Red Cliff Band of Chippewa. The two user groups target separate segments of the population. Sport anglers harvest primarily immature fish and males, and the commercial fishery harvests primarily mature fish, which average 60% females. Management recommendations stress protecting the size structure of the fishery and continued data collection to monitor stock characteristics. After the study was completed, more restrictive regulations went into effect both on the St. Louis River and in Lake Superior.

Key Words: Walleye, sea lamprey, St. Louis River, Lake Superior, Great Lakes, fisheries management, age structure, exploitation, movements, population estimates, lymphocystis, harvest.

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INTRODUCTION

Great Lakes walleye[1] stocks have fluctuated dramatically during the past century as a result of commercial and sport exploitation, interspecific competition, habitat alteration, and water quality degradation (Schneider and Leach 1977). Most Lake Superior populations have declined due to overfishing and water pollution (Ryder 1968, Schneider and Leach 1977, Colby and Nepszy 1981). In contrast, the population in the western Lake Superior waters of Wisconsin is one of the few Great Lakes walleye stocks that have persisted. As early as 1900, water pollution from upstream paper mills had caused oxygen deficiencies. Fish taste and odor were affected by a variety of chlorophenolic products produced during the pulping process. There was a sport fishery in the St. Louis River but harvest was limited because water quality problems gave fish a poor flavor. Concern over increased harvest levels in Lake Superior, where flavor was not a problem, resulted in closing the commercial fishery in 1956. Reduced exploitation rates then allowed the western Lake Superior stock to thrive. After 1979, however, the western Lake Superior stock was subjected to greater harvest pressure.

In 1978 the Western Lake Superior Sanitary District (WLSSD) began treating domestic and industrial wastes from a 500-mile^2 area within the St. Louis River watershed. Many of these wastes were previously discharged into the river, including chloro-organics from upstream paper mills. Diversion of chloro-organics to WLSSD markedly improved the palatability of fish from the St. Louis River. As a result, angling pressure increased dramatically. In addition, a limited Native American commercial fishery began in 1980.

In response to this increase in fishing pressure and to concern over possible adverse impacts from exploitation, the Wisconsin Department of Natural Resources (WDNR) began a comprehensive study of the western Lake Superior walleye stock in 1978. The study objectives were to determine spawning areas, stock discreteness, population size, age and growth characteristics, movement patterns, and mortality rates, and to document fishing pressure and harvest.

HISTORICAL PRODUCTION AND FISHERY SURVEYS

Some of the earliest historical accounts of fishing in western Lake Superior were reported by Nute (1944) and Kaups (1978, 1984). All make references to walleye being harvested at Fond du Lac (St. Louis River) during the spawning run. According to Kaups (1984) apparently only 3 kinds of gear were used in the seasonal spawning run fisheries in the St. Louis River. At the rapids, walleye and whitefish were taken in scoop nets; sturgeon were taken with spears. Lower down the river, sturgeon were taken in seines. Kaups (1978) states:

> The spring walleye fishery on the St. Louis River continued to yield good returns and some notion about its annual catch is provided by the number of barrels packed in 1860. On May 5, the *Superior Chronicle* reported:
>
> *Pickerel — the run of these fish on the St. Louis River is now over; within the past three weeks there has been caught about three hundred barrels, that is, some 60,000 pounds of dressed fish. Two hundred and sixty barrels were the product of two commercial fisheries and the rest, about forty or fifty (barrels), in small lots of from five to ten for family use, represented individual effort.*

According to Nute (1944), 90 fish make a barrel. Three hundred barrels, therefore, would require an estimated harvest of approximately 27,000 walleyes with an average dressed weight of 2.2 lb. Historical accounts are somewhat vague when referring to "pickerel" and/or "northern pike." Northern pike are abundant in the St. Louis estuary today and we assume they were then. However, Fond du Lac has never been a northern pike spawning area. Consequently, it is reasonable to assume that the majority of the spring run of "pickerel" at Fond du Lac were probably walleyes.

A commercial fishery on the walleye stock occurred between Superior and Cornucopia, Wisconsin and averaged slightly over 18,500 lb annually from 1936-55 (Table 1). Pound nets were the main gear, with some gill nets used in the 1940s and 1950s. Fearing overexploitation, anglers convinced the Wisconsin Conservation Commission to close the season from 1940-42 and after 1955. Beginning in 1980, the Red Cliff Band of Lake Superior Chippewa reported an average annual commercial harvest of 3,334 lb for the period 1980-85 (Bronte et al. 1985).

There have been summer and winter fish kills in the St. Louis River. However, since few were recorded, how frequently or why they occurred is unknown. Oxygen depletion caused one incident on 22 May 1958, when 30 walleyes and 17 longnose suckers were found dead along the shoreline at Oliver, Wisconsin (G. King, WDNR, to C. A. Wistrom, in letter 27 May 1958). A dissolved oxygen reading of 1.5 ppm was taken at this location. Further

[1] Scientific names of fish are listed in Appendix Table 1.

The lower falls of the St. Louis River, which stopped upstream walleye migration. We assume that the photograph was taken immediately upstream from the present Fond du Lac dam. St. John (1846) reported a perpendicular fall of some 15 ft near the American Fur Company Station, which was at present-day Fond du Lac, Minnesota. Photograph from Turner (1888).

upstream 34 longnose suckers were found dead along the Wisconsin shoreline at Fond du Lac. A test revealed no oxygen present in the water.

A WDNR tagging study conducted from 1967 to 1969 determined the distribution, movements, harvest rate, and age and growth of the western Lake Superior walleye population (King and Belonger 1970). Recoveries from 2,201 walleyes tagged or marked at 7 locations during May-August indicated that the population inhabited the waters from the St. Louis River to Port Wing, Wisconsin. One fish, however, was tagged in Allouez Bay and recaptured in the Ontonagon River, Michigan. Scale aging revealed a young population of mainly 2-, 3-, and 4-year-old fish. However, the scales probably underestimated actual age. No spawning areas were identified.

WDNR surveys in the St. Louis River during the early 1970s were site specific. They evaluated fisheries impacts from proposed dredging projects and waterfront development. These surveys identified and protected important walleye nursery areas.

DeVore (1978) summarized fishery investigations conducted by various agencies between 1973 and 1978. He concluded that no reclamation efforts were needed to improve or protect estuarine fishery resources, and that degraded water quality was the stream's primary problem. Recommendations emphasized decreasing pollutants and preserving remaining habitat.

Table 1. *Commercial walleye production between Superior and Cornucopia, Wisconsin, 1936-55.*

	Harvest (lb)		
Year	**Superior to Brule**	**Port Wing to Cornucopia**	**Total**
1936	6,415	3,374	9,789
1937	14,338	3,735	18,073
1938	26,390	8,693	35,083
1939	16,760	10,467	27,227
1940*	–	–	–
1941*	–	–	–
1942*	–	–	–
1943	15,197	4,982	20,179
1944	22,044	4,527	26,571
1945	7,768	5,686	13,454
1946	18,411	6,397	24,808
1947	16,354	2,354	18,708
1948	26,676	1,392	28,068
1949	16,019	2,282	18,301
1950	25,628	932	26,560
1951	7,851	1,718	9,569
1952	6,653	528	7,181
1953	10,525	139	10,664
1954	12,079	25	12,104
1955	8,912	632	9,544
1936–55 **Mean harvest**	15,177	3,404	18,581

*Closed season.

STUDY AREA

Lake Superior

The portion of Lake Superior sampled extended from the mouth of the St. Louis River (Superior Entry) eastward to the western Apostle Islands (Fig. 1). On the Minnesota side, western Lake Superior has a rocky shoreline and a bottom that drops sharply to depths of 700 ft. Wisconsin's side has relatively shallow and frequently turbid water with a bottom that slopes gradually out to 300 ft. Water warms faster on the Wisconsin shore but surface temperatures can fluctuate quickly with wind shifts. Most of the nearshore sampling areas were easily accessible from a small boat.

St. Louis River

The St. Louis River is the largest United States tributary entering Lake Superior. The lower 25 miles (11,500 acres) form an estuary. This is the state boundary between Wisconsin and Minnesota (Fig. 2). The majority of the estuary is less than 10 ft deep, except for a 21-27 ft dredged navigational channel. A power dam upstream from the village of Fond du Lac, Minnesota, prevents further upstream migration of fish. The dam was constructed by Minnesota Power and Light Company and completed in 1924. From the dam downstream to Fond du Lac (2 miles) a series of rapids limits small boat navigation. From Fond du Lac to the Richard Bong Bridge the river takes on the character of an estuary with numerous bays, small islands, emergent vegetation, and shallow water. Downstream from the Richard Bong Bridge the river is characterized by shipping channels and waterfront development in the form of docks, piers, and bridges. The only areas left undisturbed in this part of the estuary are portions of Minnesota Point and Allouez Bay.

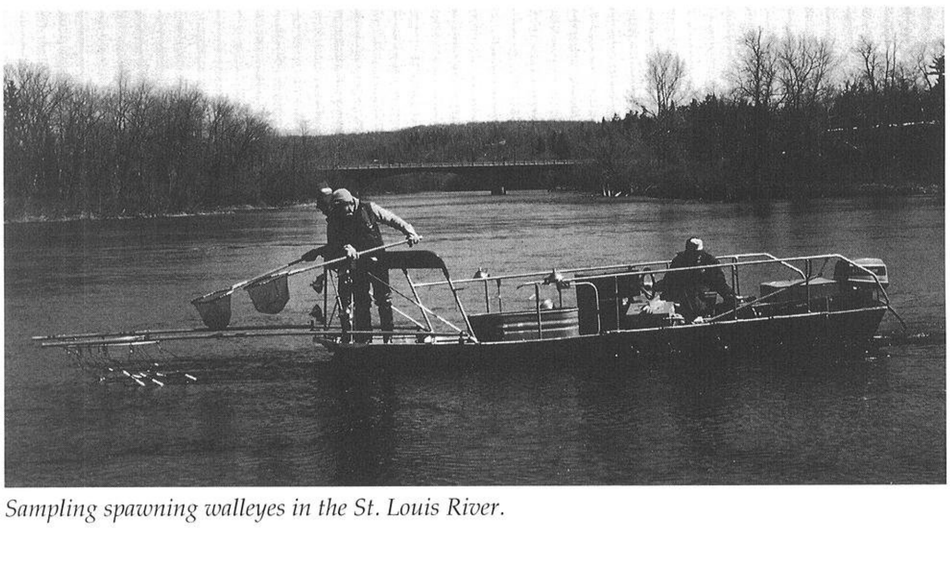
Commercial vessels enter the estuary through the Duluth Entry or through the mouth of the river (Superior Entry). The estuary supports a large and diversified fish population. The study found 51 different species (Append. Table 1). Many of these species are seasonally abundant, using the estuary to spawn but spending most of the year in Lake Superior.

METHODS

Sampling Gear

From 1978 through 1985, 18,050 walleyes (Table 2) were sampled at 79 stations (Figs. 1, 2) in western Lake Superior and its adjacent tributaries between the Apostle Islands and the Duluth-Superior area. There was a major sampling effort in 1981 in historical and suspected spawning areas to establish population estimates and continue movement observations. Sampling in other years was less intensive and was focused on monitoring movement patterns. Electrofishing units, fyke nets, trap nets, and gill nets were used to mark and recapture mature and juvenile walleye. Commercial pound and gill nets were used to recapture tags from marked walleye. The limnetic fry sampler and seine were used to monitor the movement of young-of-the-year walleye.

Walleye were sampled at the Fond du Lac spawning area during April and May of 1978-82 and 1984-85 and at the river mouths during April-May 1980-81 using a 20-ft AC-DC electrofishing boat. DC current was most effective. The boat was equipped with a 230-volt 3-phase generator operated at 80% duty cycle at 2-4 amperes. Smaller tributaries were sampled with a 230-volt AC stream electrofishing unit.



Sampling spawning walleyes in the St. Louis River.

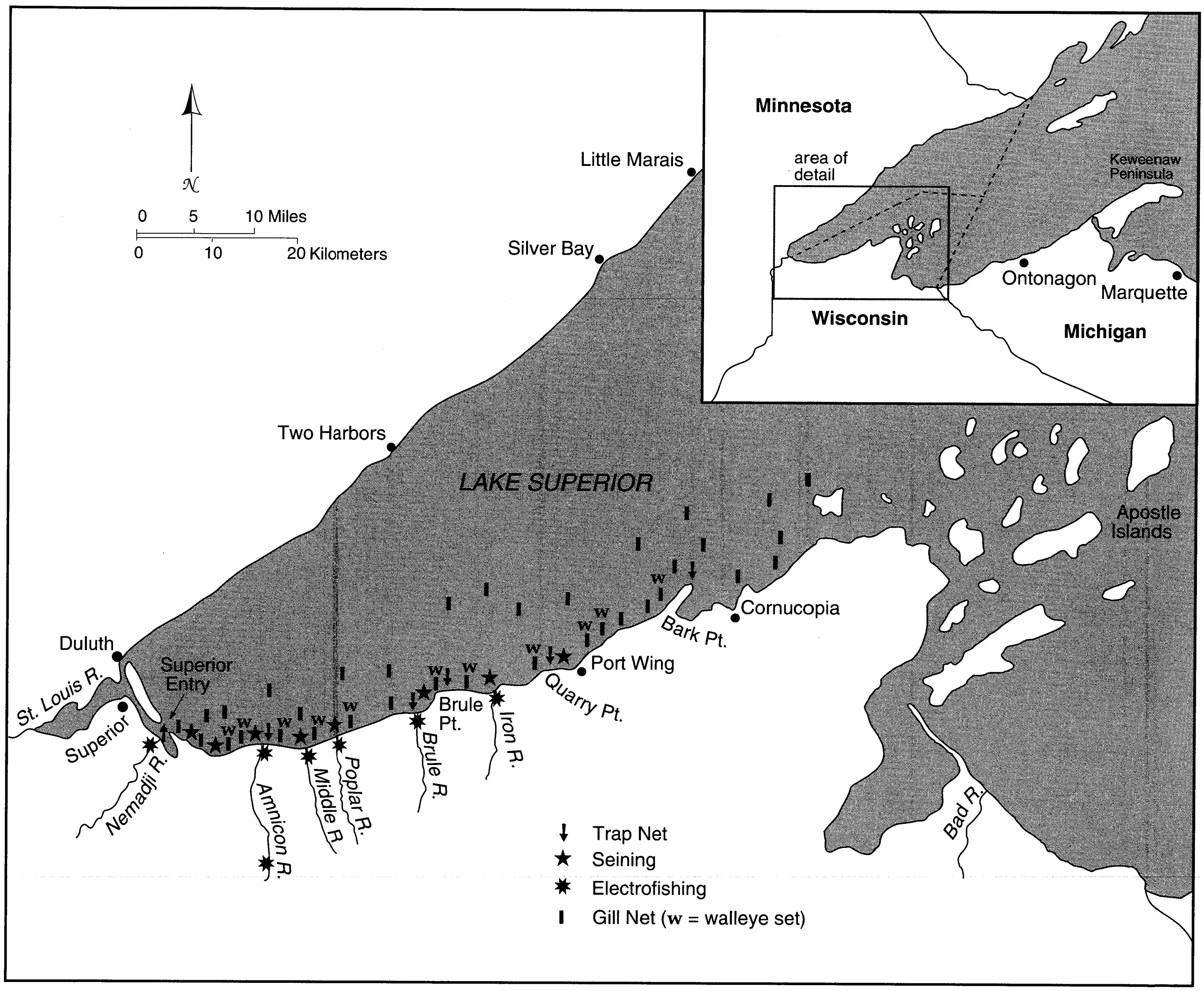


Figure 1. *Lake Superior sampling locations.*

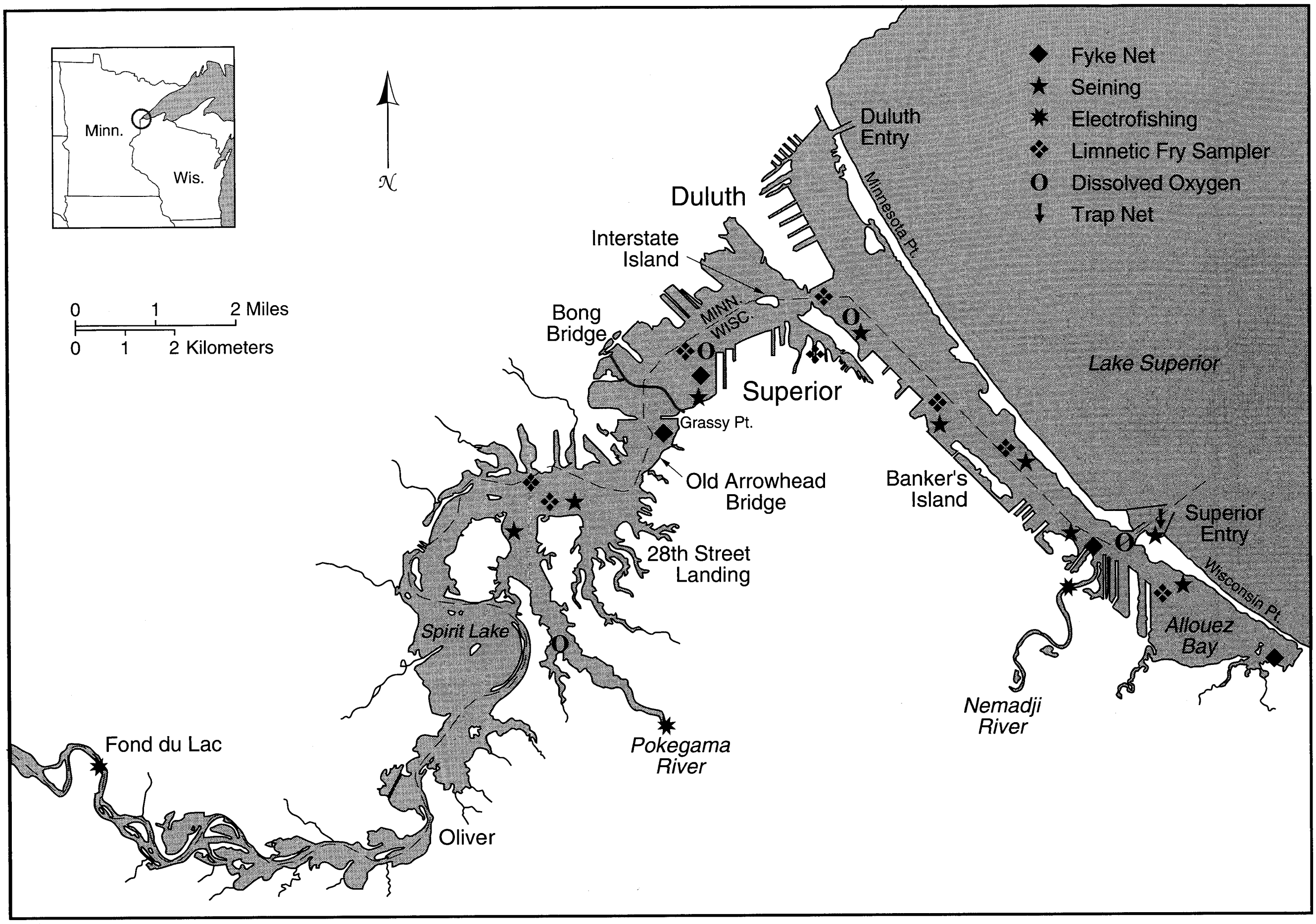


Figure 2. *St. Louis River Estuary sampling locations.*

Table 2. *Total number of walleyes sampled in western Lake Superior by year and gear type.*

	Year								
Gear	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**Total**
Electrofishing	118	173	3,205	6,044	1,167	NS	1,130	1,364	13,201
Fyke net	NS*	NS	56	328	127	163	131	108	913
Trap net	NS	179	49	699	20	933	297	NS	2,177
Limnetic fry sampler	2	NS	2	0	NS	NS	NS	NS	4
Seine	2	0	213	39	213	53	64	72	656
Gill net	245	283	NS	149	NS	148	NS	255	1,080
Commercial pound net**	NS	13	NS	NS	6	NS	NS	NS	19
TOTAL	367	648	3,525	7,259	1,533	1,297	1,622	1,799	18,050

* NS = no sampling.
** Limited DNR onboard monitoring.

Fish were sampled in the estuary during 1980-85 using 4-ft fyke nets with 1-inch and 3/8-inch stretch mesh, and 75-ft leads. Nets were generally set once or twice a month for 2 nights from April through November and lifted every 24 hours.

A single-pot trap net consisting of 2-inch stretch mesh in the wings and heart and 1-inch stretch mesh in the pot was fished at 6 different locations in Lake Superior during May-September 1979-84. A 100-ft lead of 2-inch stretch mesh was used in 1979, a 300-ft lead of 5-inch stretch mesh was used in 1980-81, and a 300-ft lead of 2-inch stretch mesh was used in 1982-84. The net was fished at depths ranging from 8 to 30 ft and lifted every 24-36 hours, depending primarily on weather conditions.

Nylon gill nets were fished at 35 locations along the Lake Superior shoreline in July and August of 1978-79, 1981, 1983, and 1985. Eleven stations immediately adjacent to shore were fished specifically for walleyes. These nets totaled 1,800 ft (six 100-ft nets each of 4-inch, 4-1/2-inch, and 5-inch stretch mesh) set in water depths from 12 to 50 ft. The other 17 stations were intended to sample all species and were fished in water depths ranging from 12 to 378 ft. These nets totaled 3,600 ft and contained twelve 300-ft nets of different stretch meshes from 1-1/2 to 7 inches in half-inch increments. All nets were lifted after 24 hours. Water temperatures were taken at every 10 ft of depth at each sampling location.

Additional fish were collected from commercial pound nets set for smelt in the St. Louis estuary during the springs of 1979 and 1982. Fish were also collected from commercial gill nets set in Lake Superior by the Red Cliff commercial fishers during August-September 1980-85.

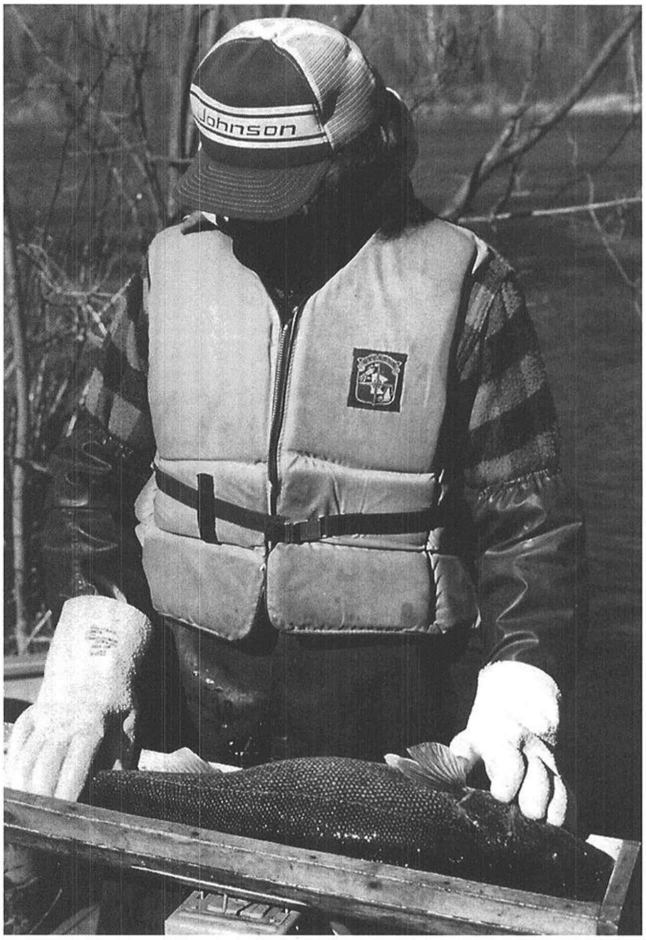
During 1978 and 1980-81, larval walleyes were sampled at 7 stations in the estuary during May and June with a limnetic fry sampler. The net had a 3-ft mouth diameter, a tapered 6-ft main filtration net with 1/8-inch and 1/32-inch mesh, and a straining bucket with a 3-inch mouth diameter. The net was towed on the surface about 40 ft behind a 16-ft boat. Each tow was approximately 100 ft. All stations were sampled between 10:00 a.m. and 2:00 p.m. Twenty-eight tows were made in 1978, and 16 each in 1980-81.

A 50-ft bag seine with 3/16-inch mesh was used during July-August 1978-85 to sample for young-of-the-year walleyes at 9 locations within the estuary and 8 locations along the Lake Superior shoreline. A single 100-ft pull was made at each site either along the shoreline or in about 2-1/2 ft of water away from shore where shoreline seining was not practical.

Estimation of Fishery Characteristics

All walleyes were measured to the nearest 0.1 inch (total length) and inspected for sea lamprey marks and disease. During the spawning season, walleyes were weighed to the nearest ounce and sexed, when possible, by extrusion of gametes.

Age was determined from scale samples and dorsal spine cross-sections (Margenau 1982). Scales were used in 1978-80, but their reliability as estimators of age was suspect due to crowding of annuli on the outer margins of older fish. Scales were used on younger fish to back-calculate length-at-age. Beginning in 1981 ages of fish 3 years and older were determined and validated from cross-sections of the second and third dorsal spines (Schram 1989). Aged subsamples for each sex were expanded proportionally to the entire sample. Although spine sections sometimes showed false annuli and occasional cloudiness near the center, which made some age estimates difficult, only 7.8% of the spines were not readable.



Determining vital statistics from spawning walleye in the St. Louis River.

Maturity was determined from age data, assuming 100% maturity was the most frequent age found during the spawning season, and from gonadal development from creeled walleyes during an ice fishery in Lake Superior.

All live walleye greater than 10.0 inches were marked with anchor tags (Floy[2] FD68B in 1978-79, FD68BC, in 1980, 1981, and 1985, and FD67C in 1981, 1982, and 1984) inserted near the posterior portion of the first dorsal fin and locked between the interneural spines. Other commitments prevented us from tagging fish in 1983. Tags were numbered serially on one side and printed with "Mail to DNR, Brule, WI", or "DNR Brule, WI" on the other. Anglers returned tags voluntarily. We wrote back to anglers who returned tags reporting the date, location, and size of the walleye when it was tagged. Fish sampled during the 1980 spawning season were also finclipped to determine tag loss. Walleyes less than 10.0 inches were measured and released.

Movement patterns were determined by recovering tagged walleyes. Sources of recapture included sport anglers, commercial fishers, and Minnesota and Wisconsin DNR assessment sampling. Distribution of age 0, 1, and 2 walleye was determined from netting stations in the St. Louis River and in Lake Superior. During 1981 and 1983 the trap net was set at the Superior Entry for several weeks in May, immediately after the spawning period. The purpose was to document the adult post-spawning movement downstream and into Lake Superior. Spawning areas were determined by sampling in habitats thought to be used by walleye for spawning, and by results from previous surveys.

In 1981 a population estimate was made in the St. Louis River for adult walleye greater than or equal to 21.0 inches using Bailey's modification of the Peterson mark and recapture method (Ricker 1975). Twenty-one inches was the size at which 100% maturity was assumed based on the age and length-frequency distributions during the 1981 spawning run. This precaution assured that only mature fish were inspected for marks during the recapture period, and eliminated bias caused by juvenile walleyes mixing with adults after the spawning period.

Fish were marked during the spring spawning run (April-May 1981) and recaptured from May through August by fyke nets, gill nets, a trap net, and commercial gill nets. Sampling gear was fished in both the estuary and Lake Superior.

Estimates were corrected for tag loss by multiplying the number of tagged fish (M) by the April-August tag retention rate (T). A tag retention rate of 90.8% was estimated from fish examined during a creel survey by the Minnesota DNR (Tracy Close, Minn. DNR, pers. comm. 1981). Variance of the tag retention rate was based on the total number of fish examined for tag loss (n): $\mathrm{Var}(T) = T(1-T)/n$.

The variance of the corrected population estimate was calculated assuming the tag retention rate estimate was independent from the uncorrected population estimate. The following formula can be derived by factoring the tag retention rate out of the standard Bailey formula. It is the standard variance approximation for the product of 2 independent variables (Goodman 1960):

$$\hat{\mathrm{Var}}(\hat{N}) = \mathrm{Var}(N^*T)$$

$$= T^2\,\mathrm{Var}(N^*) + (N^*)^2\,\mathrm{Var}(T) - \mathrm{Var}(T)\,\mathrm{Var}(N^*)$$

where:

$\hat{N}$ = Bailey estimate corrected for tag retention
N^* = uncorrected Bailey estimate
T = tag retention rate

The variance of N^* was calculated using the standard Bailey estimate variance formula (Ricker 1975).

The total number of mature walleyes (all sizes) and its associated variance was then calculated by proportionally correcting for the percentage of walleyes less than 21.0 inches which were handled during the spring spawning run, using the formulas:

$$\tilde{N} = \hat{N} / r$$

$$\mathrm{Var}(\tilde{N}) = (\hat{N} / r)^2\ [\mathrm{Var}\,\hat{N} / \hat{N}^2 + \mathrm{Var}(r) / r^2]$$

where:

$\tilde{N}$ = estimated number of mature walleyes (all sizes)
$\hat{N}$ = estimated number of mature walleyes (≥ 21.0 inches)
r = percentage of walleyes handled during the spawning run ≥ 21.0 inches.

The variance of r was based on the total number of walleyes captured in the spawning run (M): = $\mathrm{Var}(r) = r(1-r)/M$. It was assumed that the covariance between r and N was zero.

Estimates were generated for the number of walleyes which spawned at Fond du Lac in 1981, and for the total number of mature walleyes in the estuary and in Lake Superior. The number of walleyes that had spawned at Fond du Lac in 1981 was estimated using recapture information from sampling locations in the estuary and from the Superior Entry and Amnicon River mouth trap net sets. Total number of mature walleyes in the estuary and Lake Superior was estimated by combining recapture information from all gear (fyke nets, trap net, WDNR gill nets, and Red Cliff commercial gill nets).

Recruitment by growth of walleyes less than 21.0 inches during the July-August recapture period was adjusted using the length-at-age relationship from the spring spawning run. Recruitment during late May and June was considered negligible.

Survival of adult walleyes was estimated using two independent methods: catch curves and a computer program (**ESTIMATE**), which is an extension of models developed for analysis of banding data by Seber (1970) and Robson and Youngs (1971) (cited in Brownie et al.

[2] Use of product names does not constitute endorsement by the Wisconsin Department of Natural Resources.

1978). Estimates from both methods are reported, and the effectiveness of the computer program is evaluated compared to catch curves.

Catch curves were generated from spring sampling by electrofishing in 1980-82. These 3 successive years of data were combined to reduce irregularities from unstable recruitment (Ricker 1975). Calculations of instantaneous mortality for males, females, and both sexes combined were based on age groups 11-17. Instantaneous mortality rates were then converted to annual survival rates for comparison.

Survival estimates generated using the program **ESTIMATE** (Brownie et al. 1978) use 4 general stochastic models to analyze banding experiments. The model is a triangular array of voluntary angler tag returns for each year of tagging over a period of time (in this situation, 1979-82). Each model in **ESTIMATE** makes different assumptions about year-to-year differences in survival and recovery rates. The most general model (0) assumes year-to-year differences, while the simplest model (3) assumes few year-to-year differences. The simplest model to adequately fit the data is then selected based on Chi-square goodness-of-fit tests. The models and their basic assumptions are:

- model 0 - time-specific survival and recovery rates where the first-year recovery rates are different from recovery rates of previously banded cohorts
- model 1 - time-specific survival and recovery rates
- model 2 - constant survival but time-specific recovery rates
- model 3 - constant survival recovery rates

Model 2 was selected as the best model for all data sets analyzed. This model assumes that survival is constant from year to year, but recovery rates (voluntary tag returns) will vary by year. The recovery rate is the product of the catch rate and the tag reporting rate.

ESTIMATE requires a large tagging effort and assumes that there is no tag loss. We estimated annual tag loss by removing the left pectoral fin on all fish tagged in 1980 and inspecting recaptured fish in 1981 for fin clips. Annual tag loss for walleye in this study was estimated at 44.2%. To **ESTIMATE**, tag loss appears to be mortality, making it necessary to correct survival estimates for tag loss.

Annual uncorrected rates of survival (S) generated from **ESTIMATE** and annual tag retention (Q) (or tag "survival") were converted to instantaneous rates (Z and t) using $Z = -ln\ S$ and $t = -ln\ Q$, respectively, making these forces of mortality additive. By subtracting the instantaneous tag survival rate from the instantaneous survival rate, the actual mortality from death was estimated using the formula:

$$(F + M) = Z - t$$

where:

Z = uncorrected instantaneous total mortality
F = instantaneous fishing mortality
M = instantaneous natural mortality
t = instantaneous tag loss mortality

Subtracting 2 logarithm-transformed variables is equivalent to dividing the variables on the original scale. Thus, the corrected survival rate is the ratio of 2 independent random variables and the variance is calculated using the formula (Mood et al. 1974):

$$\mathrm{Var}(S') = (S\ /\ Q)^2\ [\mathrm{Var}(S)\ /\ S^2 + \mathrm{Var}(Q)\ /\ Q^2]$$

where:

S' = corrected survival estimate
S = uncorrected survival estimate
Q = tag "survival" estimate
Var(S) = variance of S from ESTIMATE

The variance of t was calculated from the number of fish examined for tag loss (n) as $t(1\text{-}t)/n$.

Estimation of Fishing Pressure

A creel survey was conducted on the Wisconsin waters of the St. Louis River May through September 1980 and 1981. Anglers were interviewed at 6 locations on the St. Louis River: the old Arrowhead bridge, 28th Street, Barker's Island, Nemadji River, Allouez Bay, and Wisconsin Point. These access points were the primary locations used by anglers. Walleye harvested in the upper stretches of the river were generally landed in Minnesota. A creel survey was also conducted during February and March 1982, in Lake Superior just offshore from Wisconsin Point. The survey was designed to collect maturity data and estimate the harvest.

The creel clerk worked a 5-day, 40-hour week. Every weekend day and all holidays, plus 3 randomly selected week days were sampled. Each creel day was sampled from 6:00 a.m. to 2:00 p.m., or 2:00 p.m. to 10:00 p.m. The time period for each shift was randomly selected.

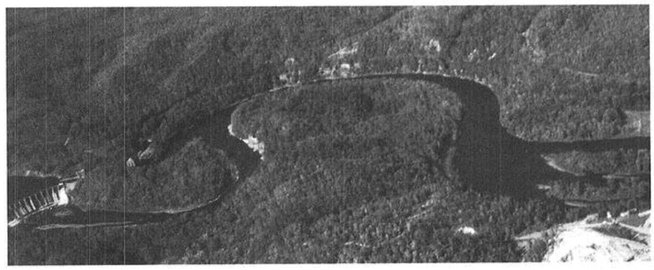
Instantaneous counts of anglers were made at each sampling location twice a day. Angler interviews for both incomplete and completed trips were conducted whenever anglers were encountered. Data collected during the interview included length of fishing trip, state of residence, number of anglers in party, location fished within the river, and the identity, number and lengths of any fish harvested. Average instantaneous counts were expanded by the assumed fishing day length and the total number of days in the sampling period to derive estimates of fishing effort. Effort estimates were multiplied by catch rates to estimate total harvest. Estimates were made separately by month and day type (weekday vs. weekend).

RESULTS AND DISCUSSION

Spawning Areas

Walleyes were found spawning at the rapids in the St. Louis River at Fond du Lac. The rapids extend downstream from a power dam for approximately 2 miles (Fig. 3). The bottom is primarily rock-rubble intermixed with gravel. Water depth in the area ranges from 1 to 11 ft, and the average flow is near 2,585 cfs (Sather and Johannes 1972). However, the flow can change quickly depending on the power dam discharge. We observed walleye eggs in water up to 36 inches deep.

Walleyes were also found spawning in the Pokegama and Amnicon rivers, although very few fish were found there compared to Fond du Lac (Figs. 1, 2). The Pokegama River, a tributary to the St. Louis River, has an unstable sand, gravel, and clay bottom. It averages 4 ft wide, and has an average flow of only 0.1 cfs (Sather and Johannes 1972). The Amnicon River is a tributary to Lake Superior, but only the lower 6 miles are accessible to Lake Superior walleye. A falls at Amnicon Falls State Park prevents further migration upstream. The river has an average flow of 2.0 cfs, except during periods of high precipitation or spring runoff. The bottom is a mixture of gravel, boulders, sand, and clay, and the average width is 30 ft (Sather and Johannes 1972). Despite efforts to find other spawning areas none were found in tributary streams or in Lake Superior.



The area downstream from the Fond du Lac dam (far left) was the main spawning area for western Lake Superior walleyes.

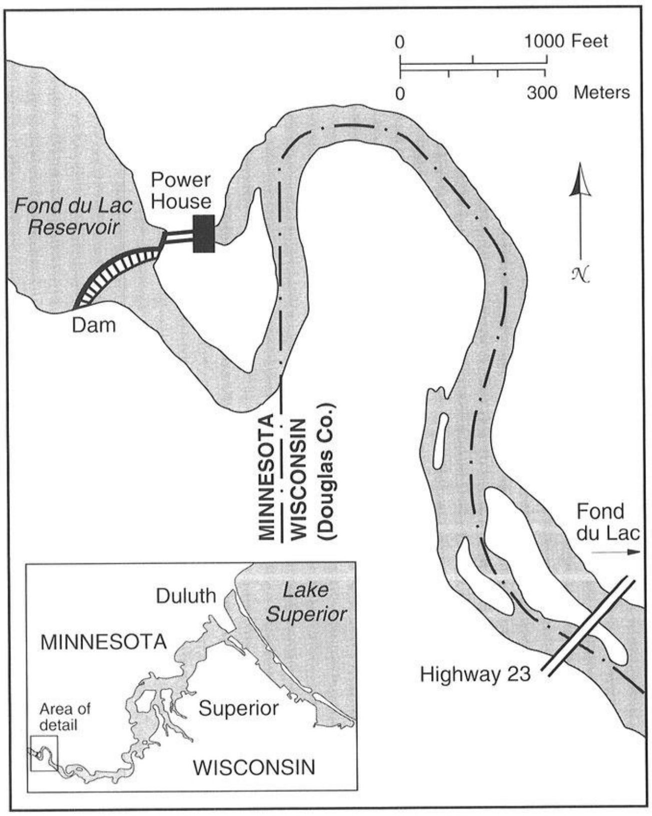


Figure 3. *Primary spawning area for western Lake Superior walleye stock in relation to the St. Louis River estuary and Lake Superior.*

Spawning Population Characteristics

Active spawning in 1981 began in western Lake Superior when water temperatures reached 42-44 F in the spawning areas (Append. Table 2). Males arrived first on the Fond du Lac spawning grounds. Male to female sex ratio was 1.5:1 during the entire 1981 spawning period (N = 5,691; Table 3). A length frequency distribution for 1981 showed that females were larger than males (Fig. 4; Tables 4, 5). Throughout the study period, male and female mean length and weight in samples remained constant. Although mean age decreased for males, mean age remained similar for females (Table 3).

Population Estimate

The population of walleyes of spawning age and size found in both the estuary and Lake Superior was estimated to be 67,036. The spawning population found just at Fond du Lac was estimated at 49,690 (Table 6). Although this difference may have been a real result, the higher estimate in the estuary and lake was influenced

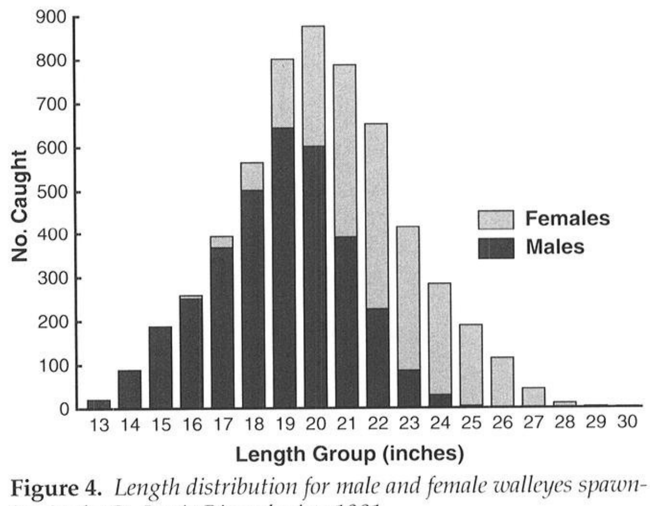


Figure 4. *Length distribution for male and female walleyes spawning in the St. Louis River during 1981.*

by a greater ratio of untagged to tagged walleyes from gear (gill nets and trap net) fished farther from the estuary. The untagged to tagged ratio for gill nets (WDNR and Red Cliff) and trap nets (excluding Superior Entry and Amnicon River sets) was 27:1 compared to a ratio of 10:1 for recapture efforts in the estuary and the Superior Entry and Amnicon River trap nets. More untagged fish may have been caught because of:

- dilution from other walleye stocks
- adult walleyes from the St. Louis River stock which did not spawn in 1981 and remained in Lake Superior
- immature walleyes over 21.0 inches
- progressive increase in tag loss during the recapture period
- non-reporting of tags from commercial nets, or
- a combination of all of the above.

Dilution of the number of tagged fish by other walleye stocks seems unlikely based on previous sampling. The Amnicon River and Pokegama River spawning populations were small compared to the St. Louis River population. We sampled 112 walleyes from 1978 through 1982 at those sites. Recapture information from the trap net at the mouth of the Amnicon River also did not show an inflated ratio (8.6:1) of untagged to tagged walleye as would be expected if a substantial spawning population was using the Amnicon River (Append. Table 3). It is reasonable to assume that walleye spawning in the Amnicon and Pokegama rivers are of the same stock as the St. Louis River. A walleye captured while spawning in the Amnicon River in 1982 had been originally tagged spawning at Fond du Lac in 1981. Another fish captured while spawning at Fond du Lac in 1982 had been originally tagged spawning in the Amnicon River in 1978.

Dilution of tagged walleye by walleye of the same stock which remain in Lake Superior and spawn in alternate years seems feasible but is speculative. No information justifies this possibility. A more logical assumption is that tag loss increases progressively with time and therefore walleyes sampled later in the recapture period would have a greater chance of shedding a tag. This possibility seems to have merit since the estuary and river mouth areas were sampled in May and June, while gill netting and trap netting away from the river mouth occurred in July and August.

We assume that progressive tag loss and/or non-reporting of tags from commercial nets are the primary causes of these differing estimates. This means that the abundance estimate based on recapture information from gill nets and trap net sets (other than Superior Entry and Amnicon River mouth) may be biased upward. We report this estimate, however, in case future monitoring shows alternate year spawning by this walleye stock or by substantial numbers of walleye from a different stock.

Age and Growth

Growth of walleye was relatively slow, and many age classes were present. Young of the year (YOY) reached an average length of 2.5 inches by July, and 5.7 inches by the end of the first year. Growth after the first year of life was highly variable and appears to depend on the distribution of the fish (Lake Superior vs. St. Louis estuary). Juveniles (unknown sex) averaged 17.4 inches at age 6. Annual individual growth rates for mature females were greater than growth rates for mature males. A single year class often showed a wide range of lengths. For example, in 1981, fish sampled from the 1974 year class (age 7) ranged in size from 14.9 to 22.5 inches, and fish sampled from the 1970 year class (age 11) ranged in size from 16.8 to 27.5 inches. Annual individual growth rates determined from the recapture of 136 tagged fish averaged 0.3 inches for males and 0.6 inches for females.

A considerable portion of the 1981 spawning population consisted of older fish. Male walleyes ranged from 3 to 18 years (Table 4) and females ranged from 5 to 20

Table 3. *Mean length, weight, and age by sex of tagged spawning walleye, Fond du Lac, 1980-85.**

	Length and Weight						Age			
	Males			Females			Males		Females	
Year	Sample Size	Length (inches)	Weight (lb)	Sample Size	Length (inches)	Weight (lb)	Sample Size	Mean Age (years)	Sample Size	Mean Age (years)
1980	2,074	18.8 (2.1)	2.4 (0.9)	1,071	21.5 (2.2)	4.3 (1.5)	–	–	–	–
1981	3,396	19.2 (2.2)	2.9 (0.9)	2,295	22.6 (2.2)	5.1 (1.6)	629	10.2 (2.2)	572	11.2 (2.2)
1982	590	19.0 (2.4)	2.8 (1.0)	412	22.7 (2.2)	5.2 (1.5)	47	9.5 (2.4)	59	11.1 (2.2)
1984	499	18.4 (2.7)	2.6 (1.2)	534	23.5 (2.3)	5.8 (1.6)	96	8.8 (2.7)	115	11.2 (2.3)
1985	883	18.5 (2.5)	–	399	23.6 (2.4)	–	187	8.8 (2.6)	173	12.3 (2.4)

*Standard deviation in parenthesis. No sampling occurred in 1983.

Table 4. *Mean length-at-age (inches) for male spawning walleyes, Fond du Lac, 1981.*

Inch Group	Total	No. Aged	Length by Age Group 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
13.0	21	17	–	6	9	5	1	–	–	–	–	–	–	–	–	–	–	–
14.0	89	44	2	6	10	49	20	2	–	–	–	–	–	–	–	–	–	–
15.0	188	49	4	11	23	73	65	4	4	4	–	–	–	–	–	–	–	–
16.0	251	49	–	–	–	87	113	41	5	–	5	–	–	–	–	–	–	–
17.0	367	51	–	–	–	50	65	94	58	43	50	–	7	–	–	–	–	–
18.0	501	57	–	–	–	–	35	88	79	123	167	9	–	–	–	–	–	–
19.0	643	98	–	–	–	–	13	66	125	144	223	59	13	–	–	–	–	–
20.0	601	82	–	–	–	–	–	14	14	110	198	140	81	30	14	–	–	–
21.0	390	61	–	–	–	–	–	–	–	13	83	96	70	58	58	6	6	–
22.0	226	52	–	–	–	–	–	–	–	–	48	13	48	74	35	4	–	4
23.0	86	44	–	–	–	–	–	–	–	–	2	6	17	33	14	12	2	–
24.0	29	21	–	–	–	–	–	–	–	–	–	1	7	7	7	1	.6	–
25.0	4	3	–	–	–	–	–	–	–	–	–	–	–	3	1	–	–	–
26.0	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Sample size	3,396	629	6	23	42	264	312	309	285	437	776	324	243	205	129	23	14	5
Percent of total			0.2	0.7	1.2	7.8	9.2	9.1	8.4	12.9	22.8	9.5	7.2	6.0	3.8	0.7	0.4	0.1
Mean length			15.2	14.7	14.8	16.0	16.7	18.2	18.8	19.3	19.8	20.7	21.4	22.2	22.1	22.8	23.1	23.3
Standard deviation			0.5	0.9	0.8	1.1	1.2	1.2	1.0	1.1	1.3	1.0	1.3	1.1	1.1	0.9	1.5	1.8
Minimum length			14.6	13.4	13.2	13.7	13.8	14.9	15.7	15.8	16.8	18.7	17.2	20.4	20.5	21.0	21.4	22.2
Maximum length			15.7	15.9	15.9	17.9	19.7	20.1	20.5	21.9	23.4	24.7	24.5	25.6	25.4	24.6	24.6	26.9

Table 5. *Mean length-at-age (inches) for female spawning walleyes, Fond du Lac, 1981.*

Inch Group	Total	No. Aged	Length by Age Group 5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
16.0	8	7	–	7	–	–	–	–	1	–	–	–	–	–	–	–	–	–
17.0	26	21	4	11	4	5	2	–	–	–	–	–	–	–	–	–	–	–
18.0	63	47	–	14	23	16	4	5	1	–	–	–	–	–	–	–	–	–
19.0	158	58	–	14	44	38	19	19	19	5	–	–	–	–	–	–	–	–
20.0	275	58	–	5	24	57	52	57	47	28	–	–	5	–	–	–	–	–
21.0	396	57	–	7	7	28	90	104	125	14	14	–	7	–	–	–	–	–
22.0	426	72	–	–	6	6	6	71	213	71	29	24	–	–	–	–	–	–
23.0	331	52	–	–	–	–	6	32	134	64	32	51	6	–	6	–	–	–
24.0	255	46	–	–	–	–	11	–	55	22	44	50	61	6	6	–	–	–
25.0	185	52	–	–	–	–	–	–	18	25	39	21	60	18	4	–	–	–
26.0	113	49	–	–	–	–	–	–	2	9	9	21	49	14	9	–	–	–
27.0	43	38	–	–	–	–	–	–	1	–	1	7	18	9	5	1	1	–
28.0	11	10	–	–	–	–	–	–	–	–	–	1	6	2	1	–	1	–
29.0	3	3	–	–	–	–	–	–	–	–	–	–	–	1	1	1	–	–
30.0	2	2	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1
Sample size	2,295	572	4	58	108	150	190	288	616	238	168	175	212	50	32	3	2	1
Percent of total			0.2	2.5	4.7	6.5	8.3	12.5	26.8	10.4	7.3	7.6	9.2	2.2	1.4	0.1	0.1	0.0
Mean length			17.5	18.8	19.7	20.2	21.2	21.6	22.5	23.1	24.1	24.4	25.4	26.2	25.8	29.2	28.0	30.5
Standard deviation			0.0	1.5	1.1	1.1	1.3	1.1	1.3	1.6	1.4	1.4	1.5	1.1	1.6	1.5	0.7	0.0
Minimum length			17.3	16.0	17.0	17.2	17.4	18.5	16.8	19.1	21.7	22.1	20.4	24.7	23.8	27.9	27.6	30.5
Maximum length			17.8	21.5	22.5	22.1	24.3	23.7	27.5	26.8	27.4	28.5	28.6	29.5	29.0	30.4	28.2	30.5

years (Table 5). The mean age for males was 10.2 and for females 11.2. Sixty-three percent of the mature males were age 10 or older, and 5.0% were age 15 or older. Of the female spawners sampled, 77.6% were age 10 or older, and 13.0% age 15 or older. The 1970 year class was exceptionally strong and accounted for 22.8% of all males and 26.8% of all females sampled.

Female spawner length-at-age was greater than corresponding male length-at-age in all sampled years (Table 7). No trends in length-at-age between 1981 and 1985 were noted.

Male walleyes began spawning at age 3 and females at age 5, but only a small portion (less than 1%) of the walleyes sampled in 1981 were from these age groups. Limited maturity data collected from a 1982 ice fishing creel survey in Lake Superior (Wisconsin Point) during February-March (when juvenile and mature walleye mix), indicated that most males were not mature until age 5 or 6, while most females did not reach maturity until past age 6 (Append. Table 4).

Compared to other Great Lakes stocks the western Lake Superior walleye stock had slow growth and the oldest reported age (Table 8). This is likely attributable to the cooler water temperatures found in Lake Superior. Most of the other stocks were associated with bays where warmer and more fertile waters exist. Colby et al. (1979) suggest water temperature and forage abundance are the primary influences on walleyes growth. Optimum growth temperatures for walleye ranged from 48.0 F to 73.4 F (Ferguson 1958, Hokanson 1977), but Kelso (1972) found that at approximately 53.0 F, food consumption was reduced to maintenance levels. The mean surface temperature in the St. Louis River estuary was 69.8 F in August (Append. Table 5); however, the mean water temperature (surface to 30 ft) in Lake Superior during August was 60.5 F, and ranged from 55.2 F to 66.4 F during 1970-85 (Append. Table 6). Water temperatures in near shore waters change abruptly as a result of wind action on warmer surface waters. Water temperature fluctuations of up to 10 F within several hours were not uncommon. Since water temperatures normally reach their maximum during August in Lake Superior, walleye from this stock are subject to lower than optimal temperatures and may spend a considerable portion of the year feeding at maintenance levels. Rainbow smelt was found to be the major forage species for walleye in western Lake Superior (Swenson 1977).

No trends were noted between 1981 and 1985 in length-at-age. However, improved environmental conditions within the estuary have increased walleye residency time (see movements section following) and may increase growth rates. This could potentially mask the effects of exploitation.

Weight

Weight-length equations were obtained using fish captured during 1980-82 (Table 9).

During the 1981 spawning season, pre-spawn and post-spawn weights of 58 individual females were sampled to estimate percent weight loss from spawning. Females lost 12.8-17.2% of their body weight during spawning (Table 10). No definite patterns were observed, but sample sizes were considered small.

Table 6. *Population estimates for mature walleyes that spawned at Fond du Lac in 1981, and total number of mature walleyes in the St. Louis River estuary and Lake Superior.*

Location	Estimated No. of Fish	95% Confidence Interval
Fond du Lac		
All mature walleye	49,690	29,573-69,807
Walleye ≥ 21 inches	21,848	13,026-30,670
Lake Superior/Estuary		
All mature walleye	67,036	44,612-89,460
Walleye ≥ 21 inches	29,476	19,654-39,298

Table 7. *Mean walleye length-at-age (inches) for male and female spawners, Fond du Lac.*

	Length by Age Group																			
Year	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
1981																				
Males	15.2	14.7	14.8	16.0	16.7	18.2	18.8	19.3	19.8	20.7	21.4	22.2	22.1	22.8	23.1	23.3	–	–	–	–
Females	–	–	17.5	18.8	19.7	20.2	21.2	21.6	22.5	23.1	24.1	24.4	25.4	26.2	25.8	29.2	28.0	30.5	–	–
1982																				
Males	13.5	–	15.0	15.9	17.5	16.5	19.0	19.6	19.9	21.1	20.9	22.7	–	23.7	24.1	–	–	–	–	–
Females	–	16.2	17.5	18.2	20.1	20.7	21.3	21.2	22.4	23.6	25.5	24.9	26.3	26.3	27.1	–	26.5	–	–	–
1984																				
Males	14.1	15.1	16.7	16.8	17.1	17.5	18.5	20.1	21.1	21.3	21.2	21.5	23.8	22.5	21.5	–	–	–	–	–
Females	–	–	16.5	19.5	19.3	20.1	21.5	23.0	23.7	24.7	24.4	24.9	26.1	26.4	27.0	27.1	–	–	–	–
1985																				
Males	–	14.2	15.9	17.0	17.7	18.5	18.7	19.2	20.6	21.4	21.5	21.8	21.5	22.2	22.4	23.8	23.6	24.5	–	–
Females	–	–	18.3	19.9	20.8	21.1	23.0	23.0	24.0	23.8	24.2	24.9	25.5	25.2	25.1	25.8	26.8	26.4	–	27.5

Table 8. *Mean total length (inches) of walleye from Great Lakes studies.*

Location	Length by Age Group																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
LAKE ERIE																				
West Basin (Wolfert 1977)																				
Males	9.2	14.5	17.0	19.0	20.1	21.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Females	8.4	14.6	17.9	20.2	22.2	23.9	25.5	26.9	28.4	29.9	–	–	–	–	–	–	–	–	–	–
East Basin (Wolfert 1977)																				
Males	7.9	13.3	16.8	18.7	20.0	21.2	23.2	23.4	23.8	–	–	–	–	–	–	–	–	–	–	–
Females	7.0	13.0	17.7	20.5	22.7	24.6	26.1	27.0	27.9	28.0	28.7	–	–	–	–	–	–	–	–	–
LAKE HURON																				
North Channel (Payne 1965)																				
Unknown sex	–	10.9	14.4	16.8	18.5	20.7	22.2	23.6	24.7	25.5	24.4	–	–	–	–	–	–	–	–	–
Saginaw Bay (Hile 1954)																				
Males	6.7	10.7	13.4	15.3	16.6	17.6	18.3	18.9	19.5	20.3	20.4	20.7	21.0	21.3	–	–	–	–	–	–
Females	6.9	10.9	13.8	16.0	17.8	19.3	20.3	21.0	21.7	22.3	22.9	23.5	24.0	24.5	25.0	–	–	–	–	–
LAKE MICHIGAN																				
N. Green Bay (Niemuth, Churchill, Wirth 1959)																				
Males	6.6	10.1	12.8	15.1	17.2	18.6	19.7	24.8	25.8	26.8	–	–	–	–	–	–	–	–	–	–
Females	6.7	10.2	12.9	15.7	18.1	19.8	21.1	26.8	27.9	–	–	–	–	–	–	–	–	–	–	–
S. Green Bay (Niemuth, Churchill, Wirth, 1959)																				
Males	8.9	13.1	15.7	18.5	19.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Females	8.5	13.2	16.6	19.7	22.0	24.3	27.2	28.0	–	–	–	–	–	–	–	–	–	–	–	–
LAKE SUPERIOR																				
Chequamegon Bay (Swedberg, Selgeby 1979)																				
Unknown sex	6.1	10.2	13.8	16.3	17.8	19.0	20.1	21.0	21.8	23.0	24.2	27.2	25.7	26.1	26.8	–	–	–	–	–
St. Louis River (Present Study)																				
Males	–	–	15.2	14.7	14.8	16.0	16.7	18.2	18.8	19.3	19.8	20.7	21.4	22.2	22.1	22.8	23.1	23.3	–	–
Females	–	–	–	–	17.5	18.8	19.7	20.2	21.2	21.6	22.5	23.1	24.1	24.4	25.4	26.2	25.8	29.2	28.0	30.5
Unknown sex	5.7	8.9	11.7	14.1	16.0	17.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 9. *Weight-length equations for western Lake Superior walleyes, 1980-82.*

Sex	Equation	No. Sampled	r
Males	$ln W = -8.0604 + 3.0569\ lnL$*	5,990	0.92
Females	$ln W = -7.8591 + 3.0298\ lnL$	3,774	0.93
Sexes combined	$ln W = -8.7111 + 3.2888\ lnL$	9,769	0.95

* W = weight in pounds; L = total length in inches.

Movements

Adult spawning walleyes exhibited a seasonal movement pattern in which they spent a portion of the year in the estuary and a portion in Lake Superior between the St. Louis River and the Apostle Islands. After spawning during April and May at Fond du Lac, walleye gradually moved downstream in the estuary remaining there for several weeks to several months before entering Lake Superior.

Tag returns from trap net catches at the Superior Entry in May indicated females generally moved downstream faster than males. One female entered Lake Superior 17 days after it had spawned at Fond du Lac, travelling a distance of approximately 25 miles in that time. In 1981, 8 of 10 tagged recaptures were female and all had entered the lake within 36 days from the date they were tagged at Fond du Lac. Assuming their movement was constant from tagging to recapture, the 2 males would have averaged 0.64 miles/day and the females 0.81 miles/day. For comparison, a study by Spangler et. al. (1977) showed that dispersal after spawning in Lake Huron tributaries sometimes exceeded 0.62 miles/day.

Angler tag returns also show this differential movement by sex. Returns from fish tagged at Fond du Lac and caught by anglers during May suggested an initial gradual movement downstream into the Oliver and Spirit Lake area (Fig. 5, Table 11). Seventy-seven percent of all tagged fish caught during May were males. Nearly all were caught in the upper estuary above Grassy Point. No tags were returned in May from Lake Superior.

Table 10. *Mean weights of pre-spawn and post-spawn female walleyes and percent mean weight loss during 1981 spawning season.*

Inch Group	Sample Size	Pre-spawn Weight (lb)	Post-spawn Weight (lb)	Weight Difference (lb)	% Mean Body Weight Loss	Range (%)
20	8	3.9	3.2	0.7	17.9	14.3-20.5
21	8	4.4	3.6	0.8	18.2	11.4-22.9
22	10	4.9	4.0	0.9	18.4	9.6-25.4
23	8	5.7	4.7	1.0	17.5	12.5-19.6
24	11	6.4	5.4	1.0	15.6	9.6-21.5
25	8	7.5	6.4	1.1	14.7	2.9-19.8
26	4	8.0	6.6	1.4	17.5	15.0-18.3
27	1	9.1	7.6	1.5	16.5	16.5

Table 11. *Location by month of angler-caught fish tagged during spawning at Fond du Lac, 1981.*

	No. of Tagged Fish Caught by Location (See Fig. 5)								Total	
	A*	B	C	D	E	F	G	H	No.	%
May										
Males	90	94	102	1	2	0	2	0	291	(76.6%)
Females	9	18	57	2	1	0	2	0	89	(23.4%)
June										
Males	23	47	129	1	1	5	0	4	210	(71.9%)
Females	3	19	48	0	2	3	3	4	82	(28.1%)
July										
Males	0	11	24	2	1	13	2	7	60	(58.3%)
Females	0	3	16	0	0	9	1	14	43	(41.7%)
August										
Males	0	0	0	0	0	1	0	5	6	(33.3%)
Females	0	0	0	0	0	0	0	12	12	(66.7%)
TOTAL										
Males	113 (90.4%)	152 (79.2%)	255 (67.8%)	4 (66.7%)	4 (57.1%)	19 (61.3%)	4 (40.0%)	16 (34.8%)	567 (71.5%)	(71.5%)
Females	12 (9.6%)	40 (20.8%)	121 (32.2%)	2 (33.3%)	3 (42.9%)	12 (38.7%)	6 (60.0%)	30 (65.2%)	226 (28.5%)	(28.5%)

*A = Fond du Lac dam to Hwy. 23 bridge.
B = Hwy. 23 bridge to Oliver bridge.
C = Oliver bridge to Grassy Point (includes Spirit Lake).
D = Grassy Point to Interstate Island.
E = Interstate Island to east end of Banker's Island.
F = East end of Banker's Island to Superior Entry.
G = Allouez Bay.
H = Lake Superior.

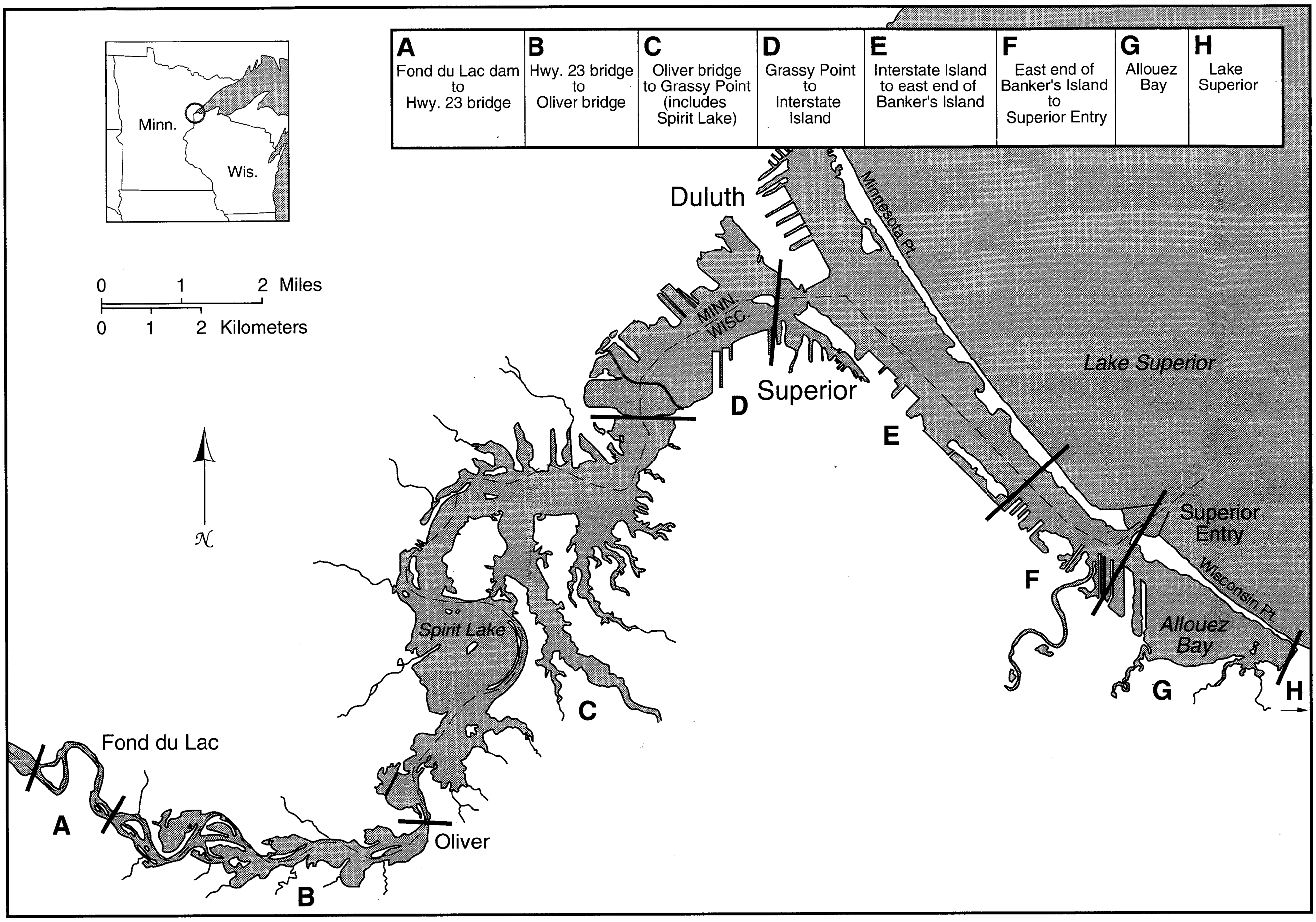


Figure 5. *St. Louis River estuary showing locations of tagged walleyes caught by anglers May through August 1981.*

During June, the majority of tagged fish were caught in Spirit Lake and 72% were males. Only 8 tag returns came from Lake Superior and half were males. The number of tag returns fell off in July, but the majority still came from Spirit Lake. Fifty-eight percent of the total returns were males and 33% of the 21 Lake Superior returns were males. In August only one male was caught in the estuary, while 5 (29%) were caught in Lake Superior. Twelve tagged females were caught in the lake in August.

Walleye residency in the estuary appears to have increased as a result of improved water quality. Prior to the start of the Western Lake Superior Sanitary District (WLSSD), walleye would generally leave the estuary by mid-July (DeVore 1978). Netting during this study documented walleye remaining in the estuary into October.

Once they are in Lake Superior, walleyes generally move eastward along the shore (Fig. 6). Some walleyes were recaptured on the surface where water is 100 ft deep although most were found near shore. Some moved into stream mouths and up the stream as far as 6 miles. These upstream movements are thought to be associated with feeding activities and that the distance moved is limited only by rapids. The eastward movement in Lake Superior generally does not extend past the western Apostle Islands, although tagged walleyes have been recaptured in Michigan waters: one in the Ontonagon River, and another in Marquette Harbor. The fish caught in the Ontonagon River was a female tagged at Fond du Lac on 18 April 1981 and recaptured on 6 June 1982. Assuming the fish moved near shore, it would have traveled approximately 191 miles, or 0.46 miles per day. The fish caught at Marquette Harbor was a male tagged at Fond du Lac on 7 April 1981 and recaptured on 28 May 1982. If this fish went around the Keweenaw Peninsula, it would have traveled approximately 370 miles, or 0.91 miles per day. This is the longest known movement of a fish from this stock.

Distribution and movement in the lake were probably determined by a combination of limnological and biological factors such as water temperature, morphometry, currents, turbidity, and food availability. Holt et al. (1977) found that walleye movements occurred parallel to shore in Lake Bemidji, and that the movements coincided with heavy cloud cover, precipitation, wind speed, and direction. Spangler et. al. (1977) found that during May and in late summer and fall, walleyes in the North Channel of Lake Huron were mainly confined to within 6.2 miles of river mouths and inshore of the 30-ft depth contour.

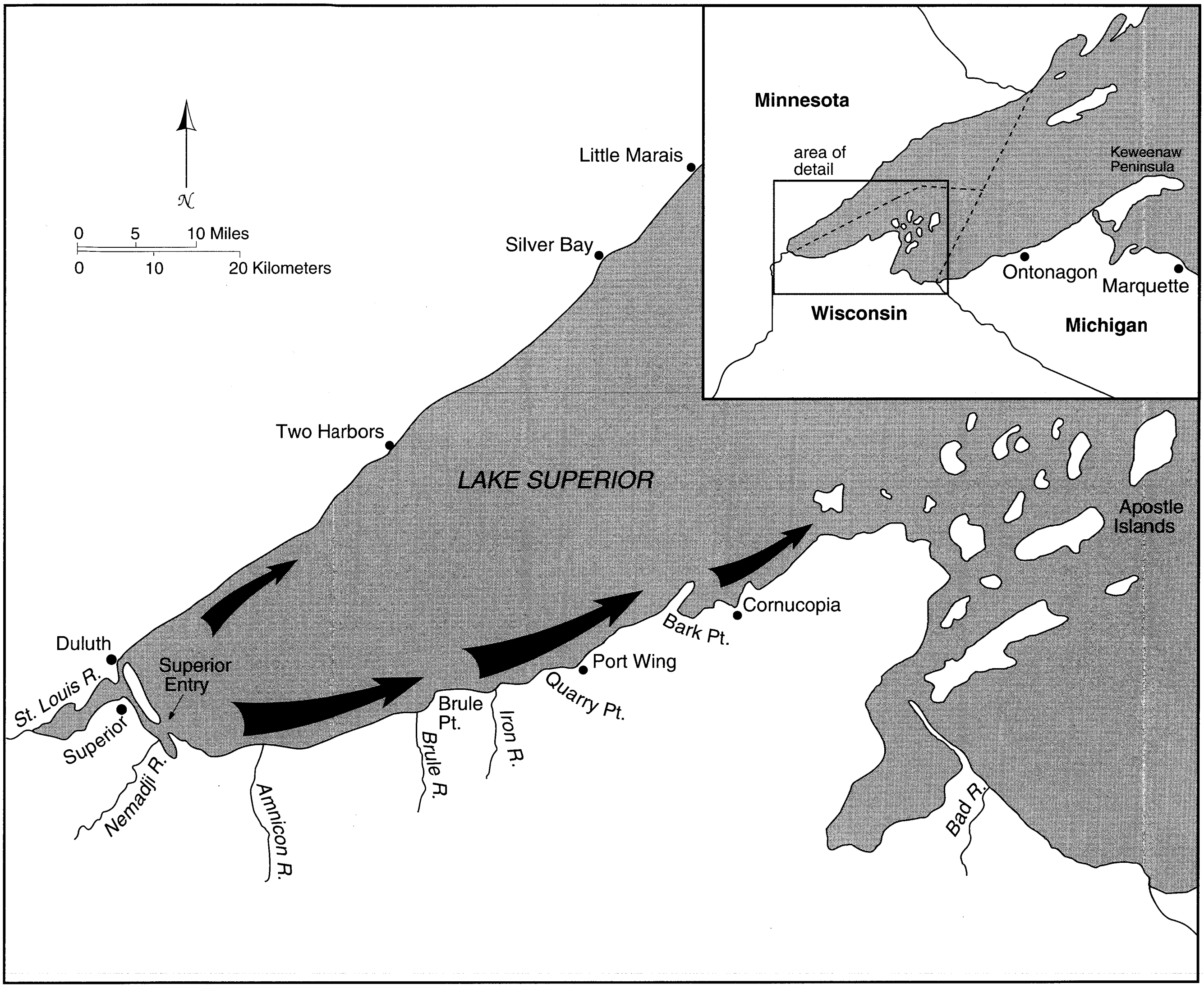


Figure 6. *Walleye movement patterns in western Lake Superior during the summer and fall of 1981. Reverse movement is assumed to occur during late fall and winter. Larger arrow widths correspond to greater numbers of fish.*

Tag returns for this study showed that the eastward movement continued into September. Limited data were available on lake distribution during late fall and early winter, but a westward movement must occur during this period. By January, walleyes began concentrating outside the Superior Entry and were abundant there during February and March. A few began filtering upstream in February, but the majority probably moved into the river in late March. Such homing of Great Lakes walleye has been documented in several locations (Crowe 1962, Ryder 1968, Ferguson and Derksen 1971, Colby et al. 1979).

Walleye movements along the Minnesota shore of Lake Superior appear to be quite limited based on tag returns. The farthest reported tag return was from Little Marais, about 85 miles from Fond du Lac. We assume that walleye avoid this shoreline because they prefer the shallow, warmer, productive waters in Wisconsin to the deeper, colder waters in Minnesota.

Tag returns from fish sampled and tagged in a trap net set at the Superior Entry during May 1981 and 1983 indicated juveniles moving into the estuary at the same time adults were beginning to move out (Fig. 7). Juveniles moved upstream as far as Fond du Lac and contributed substantially to the creel. This type of differing movement patterns for adults and juveniles was also found in Lake St. Clair (Ferguson and Derksen 1971).

Some juveniles remain in the lake during the summer, moving in and out of tributary streams. More detailed movement and distribution patterns for these fish were not determined. Wolfert (1963) marked yearling walleyes in Lake Erie over a 3-year period and found the average distance traveled was 25 miles.

In our study, YOY walleyes were found throughout the estuary during the summer. Larval fish were first sampled in June, although the sampling effort for larval fish was limited and few were caught. Those sampled were pelagic.

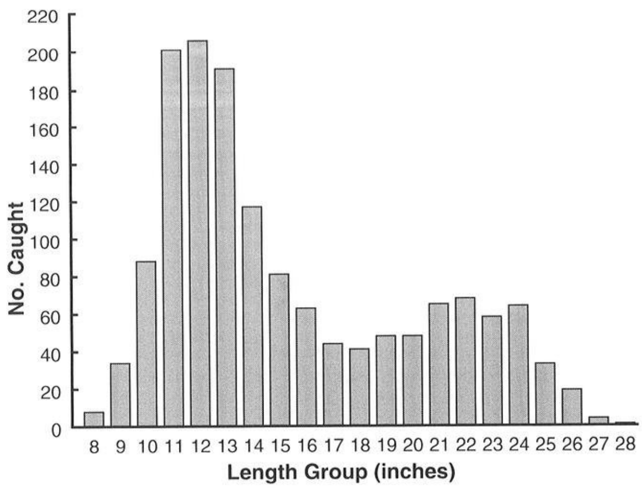


Figure 7. *Length-frequency of walleyes sampled from the trap nets set at the Superior Entry in May 1981 and May 1983. Full maturity is assumed at 21 inches.*

By July, YOY walleyes were readily captured in the estuary by shoreline seining. Distribution within the estuary after September was not determined. YOY were sampled along the Lake Superior shoreline as far east as the Brule River during July and August. Based on distribution of YOY and known spawning areas for this stock, some YOY walleye may move as far as 45 miles during the first summer.

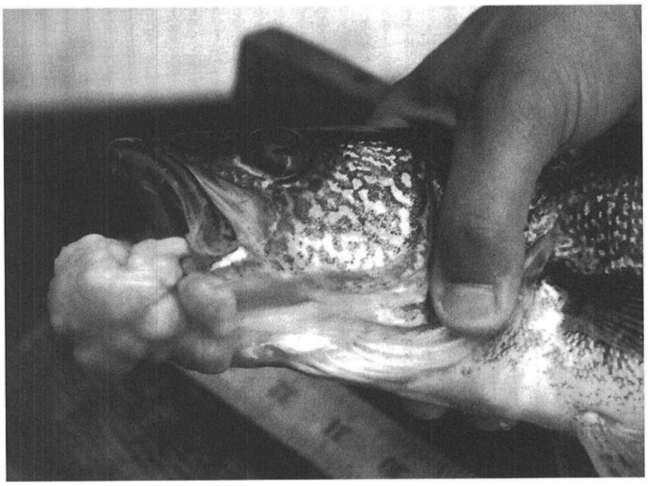
Diseases and Parasites

Margenau et al. (1988) reported that the lymphocystis virus infected 18% of spring spawning walleye in the St. Louis River. Mortality of walleye from infections was inferred because tag return rates at spawning one year later were higher for fish uninfected at time of tagging vs. those that were infected. Yamamoto et al. (1976, 1985) noted that viral infections such as dermal sarcoma and epidermal hyperplasia can co-exist with lymphocystis within the same walleye population. No field observations were made of these infections in the St. Louis River population, but it is possible that they were present.

Sea lamprey attack marks were observed on 0.1% to 0.3% of adult walleye sampled from 1980 to 1985 (Table 12, Append. Table 7). Ryder (1968) also found a low incidence (less than 1%, 1955-57) of sea lamprey marking in the Nipigon Bay walleye population of Lake Superior. These low marking percentages may be the result of the sea lamprey's host preference and seasonal distribution. During the early stages of their parasitic life (Morman et al. 1980) when feeding is at its highest level (Johnson and Anderson 1980), sea lamprey inhabit greater depths (60-120m) than is common for walleye. Feeding rates are low when sea lampreys move to inshore areas prior to their spawning run (Johnson and Anderson 1980, Morman et al. 1980). Walleye would be available as host items at this time, particularly as they congregate near the river mouth before their spawning migration up the St. Louis River.

Sea lamprey ammocetes were found in the St. Louis River in 1979, one year after WLSSD began operation. Since then, several other sea lamprey year classes have been found (Paul Rugen, U. S. Fish and Wildlife Service, pers. comm. 1983). Ryder (1968) suggested sea lamprey did not adversely effect other Lake Superior walleye populations (Nipigon Bay and Black Bay) where tributary streams supported substantial sea lamprey spawning runs.

Gill lice (*Ergasilus* spp.) were commonly observed on gills of walleye during spring spawning runs of 1980-81 although no effort was made to quantify their occurrence. Heavy infestations of *Ergasilus* can cause mortalities in a fish population from impaired respiration and secondary infections (Hoffman 1977). There were no obvious signs of distress from gill lice infestations; it was not considered as a mortality factor.



Lymphocystis virus on spawning walleye.

Sea lamprey mark on spawning walleye.

Survival and Mortality Estimates

Annual survival estimates for all mature walleye were similar using both catch curves and the program **ESTIMATE.** Survival for both sexes combined was 58.5% using a catch curve, and 59.2% using **ESTIMATE** (Table 13). These estimates are slightly higher than the 50% estimated by Busiahn (1981) from Red Cliff commercial gill net catches.

Survival of male walleye using a catch curve and **ESTIMATE** was 52.5% and 55.1%, respectively. Survival of female walleye was greater: 65.1% and 71.9% respectively. Female spawners may survive better because they leave the estuary before males, making them less vulnerable to angler exploitation.

Large walleye of both sexes had higher survival estimates than all sizes combined. Large male walleye (≥19.0 inches) had survival estimates of 66.1% compared to 55.1% for all males, while large females (≥21.0 inches) had survival estimates of 84.2%, compared to 71.9% for all females.

Table 12. *Number and percent of lamprey marks and mean length of attacked walleyes sampled during spring spawning run in western Lake Superior, 1980-85.*

Year	Total Walleyes Sampled	Lamprey Marks: No.	Lamprey Marks: Percent of Total	Mean Length (inches) of Attacked Walleye
1980	3,205	6	0.2	20.1
1981	6,044	16	0.3	22.4
1982	1,156	4	0.3	19.6
1983*	–	–	–	–
1984	1,130	4	0.4	25.0
1985	1,364	1	0.1	23.5

*No sampling.

Table 13. *Survival estimates of St. Louis River adult walleye based on catch curves (ages 11-17) and program* **ESTIMATE.**

Category Sampled	Annual Survival (%): Catch Curve	Annual Survival (%): Program ESTIMATE	Annual Survival (%): 95% Confidence Interval	Years Tagging	Years Recovery
All walleye	58.5	59.2	46.4- 72.0	1979-82	1979-84
Males					
Total	52.5	55.1	42.1- 68.0	1979-82	1979-84
≥19.0 inches	–	66.1	46.5- 85.8	1980-82	1980-84
Females					
Total	65.1	71.9	49.8- 93.9	1980-82	1980-85
≥21.0 inches	–	84.2	53.7 -114.6	1980-82	1980-84

Table 14. *Number harvested, size, and catch rates of St. Louis River creeled walleyes, 1980-82.*

Year	Wisconsin Waters: Harvest (no. fish)	Wisconsin Waters: Average Length (inches)	Wisconsin Waters: Harvest/hour	Minnesota Waters*: Harvest (no. fish)	Minnesota Waters*: Average Length (inches)	Minnesota Waters*: Catch/hour
1980	2,459	16.2	0.165	45,718	17.8	0.221
1981	781	17.8	0.053	24,141	17.5	0.171
1982	–	–	–	23,816	16.7	0.170

*Minnesota data from D. L. Pereira, Minn. DNR, pers. comm. 1984.

Sport Harvest

Anglers harvested an estimated 2,459 walleyes in 1980 and 781 walleyes in 1981 in the St. Louis River using Wisconsin access sites (Table 14). Mean length of creeled walleyes increased from 16.2 inches in 1980 to 17.8 inches in 1981, but the modal size group remained at 14 inches for both years.

A creel survey conducted during May through July of the same period by the Minnesota DNR for Minnesota waters, estimated the harvest at 45,718 in 1980, 24,141 in 1981, and 23,816 in 1982 (D.L. Pereira, Minn. DNR, pers. comm. 1984). The Wisconsin and Minnesota estimates were combined to determine a total harvest from the estuary. Pereira felt the 1980 figure of 45,718 was an overestimate due to sampling problems. The availability and heavy use of access sites along the Minnesota shore accounted for their higher harvest estimates. Based on angler tag returns of walleyes tagged during the 1980-81 spawning runs, 86.7% were harvested between Fond du Lac and the Bong Bridge. At the time of the creel survey, only 2 usable access sites (Arrowhead Bridge and 28th Street) were available in Wisconsin on this upper portion of the river.The length frequency of creeled walleyes compared with that of the spawning population suggests that angler exploitation targeted mostly juveniles and male spawners (Fig. 8). Larger female spawners leave the river sooner than males, and are apparently less susceptible to exploitation by anglers. Boundary water regulations on the St. Louis River during the study allowed anglers to harvest 6 walleyes/day, with no size limit, from the Saturday nearest May 1 through March 1 of the following year.

There is an ice fishery in Lake Superior off Wisconsin Point during February and March. Angler success is highly variable depending on ice conditions. Conditions during the 1982 creel survey were unfavorable for ice fishing. Harvest reflected these poor conditions as an estimated 3,516 angler hours resulted in a harvest of only 243 fish, and a harvest rate of 0.069 walleye/hour. The mean size was 15.3 inches. Observations of this ice fishery in previous years indicated that there is a significant harvest of pre-spawning walleye when ice conditions are favorable. Wisconsin Lake Superior regulations in effect during the study allowed anglers to harvest 5 walleyes/day with no size limit and a year-round season.

Commercial Harvest

Commercial fishing was not allowed on this walleye stock from 1955-80. Under agreement with the WDNR, the Red Cliff Band of Lake Superior Chippewa began conducting a gill net assessment fishery in 1980 to determine the feasibility of a sustained commercial harvest of walleye from this stock. Contracts with 2 commercial fishers selected by lottery each year allowed them to fish a 5,000 pound quota during a designated time and in a specified area. Under a later agreement signed in 1986, the quota was set at 5,000 pounds on the west side of

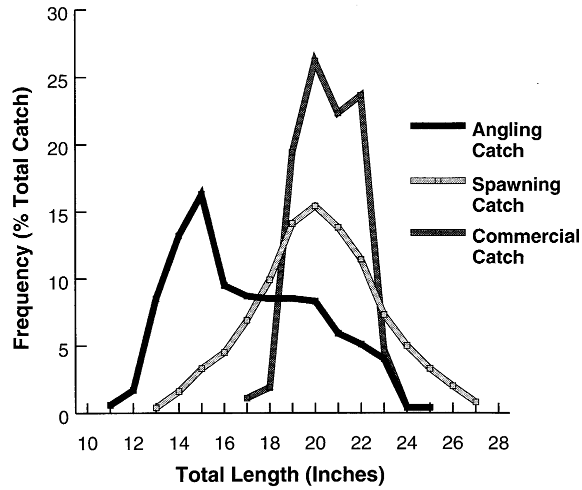


Figure 8. *Length-frequency distribution of walleyes tagged during the 1981 spring spawning assessment compared with the distribution of angling catch (from D. L. Pereira, Minn. DNR, pers. comm. 1984) and commercial catch (from Busiahn 1981).*

Bark Point and unlimited on the east side. This quota remains in effect until the end of the agreement in 1995.

The commercial catch primarily targets the spawning portion of the population (Fig. 8). Fishing effort has increased while yield per effort has decreased (Table 15). Mean length and weight varied slightly until 1985, when larger and older walleyes were harvested. The female portion of the catch averaged 60.1% for the 1981-85 period, allowing this fishery the potential harvest of a large number of female spawners. Variations in catch have been attributed to weather conditions, to changes in net mesh size, and to individual variations in fishing experience (Bronte and Gurnoe 1983).

Total fishing mortality on mature fish (≥21.0 inches) was estimated at 14.7% (Table 16). This rate was determined by combining the harvest of mature sport-caught walleye with the portion (50%) of the commercial harvest over 21.0 inches and dividing by the population estimate for mature walleye. It was divided into sex based on tag return rates for fish over 21.0 inches and commercial catch statistics. The fishing rate on immature fish was not included since the population estimate was based on spawners and not juveniles.

Natural and instantaneous mortality were calculated according to Ricker (1975) based on a Type 2 fishery (Table 17). Natural mortality resulted from a combination of mortality from sea lamprey, lymphocystis, and unknown causes.

A Ricker-type (Ricker 1975) equilibrium yield model was used to determine the effects of various fishing mortality rates on the stock. Different user groups exploited different segments of the population. In consequence, separate models were developed for male and female walleye. Fishing and natural mortality were assumed to be constant for all age groups since age specific mortality by sex was not available from the creel survey. Since the potential harvestable portion of the population included 17 separate female age groups and 15 separate male age groups, we felt that the assumption of constant fishing mortality over the entire age span was not indicative of actual fishing mortality, especially since a high harvest of immature fish occurred during the sport fishery and both immature and mature fish were harvested by the commercial fishery. The modeling approach was then rejected until more specific creel data are available from future studies.

Table 15. *Catch statistics from Red Cliff commercial harvest of western Lake Superior walleye, 1980-85*.*

Year	Yield (lb)	No. Fish	Effort (ft)	Yield/ Effort (lb/1,000 ft)	Mean Length (inches)	Mean Weight (lb)	Mean Age (years)	% Female
1980	5,014	1,462	90,000	55.7	–	–	–	–
1981	3,735	1,132	98,700	37.8	20.7	3.3	11.7	66.0
1982	2,451	791	139,800	17.5	20.3	3.1	9.5	53.4
1983	2,588	835	112,800	22.9	20.1	3.1	8.4	55.5
1984	3,209	944	247,200	13.0	20.5	3.4	9.8	44.2
1985	3,009	568	161,200	18.7	23.4	5.3	11.9	81.4

* From Bronte et al. 1985.

Table 16. *Fishing mortality of western Lake Superior walleye, 1981.*

Harvest Characteristics	Sport Harvest (No. Fish)			Commercial Harvest (no. fish)	Total Harvest (no. fish)	% Total Fishing Mortality Lake Superior and Estuary*
	Wis.	Minn.	Total			
Fish harvested	781	24,141	24,922	1,132	26,054	–
No. ≥ 21 inches	–	–	3,763	566	4,329	14.7
% ≥ 21 inches	–	–	15.1**	50.0	–	–
% Female	–	–	74.7	59.7	–	–
No. females ≥ 21 inches harvested	–	–	2,811	338	3,149	10.7
No. males ≥ 21 inches harvested	–	–	952	228	1,180	4.0

* No. mature walleye (≥ 21 inches) population estimate for mature walleye (29,476 from Table 6).
** T. Close, Minnesota Department of Natural Resources, pers. comm.

Table 17. *Mortality rates for female and male walleye. Fishing mortality rates are for walleye ≥ 21.0 inches.*

Statistic	Females	Males	Sexes Combined
Survival rate (*S*)	.651	.525	.585
Annual expectation of death			
Total (*A*)	.349	.475	.415
Fishing (*u*)	.107	.040	.147
Natural causes (*v*)	.241	.438	.268
Instantaneous mortality rates			
Total (*Z*)	.429	.645	.536
Fishing (*F*)	.132	.054	.190
Natural causes (*M*)	.297	.051	.346
Annual mortality rates			
Total (*A*)	.349	.475	.415
Fishing (*m*)	.124	.053	.173
Natural causes (*n*)	.257	.446	.292

CONCLUSIONS

1. The rapids in the St. Louis River at Fond du Lac are the primary spawning area for western Lake Superior walleye. Additional sites were found in the Pokegama and Amnicon rivers.
2. The number of walleyes spawning at known spawning sites and the known movements and distribution of adults within the St. Louis River estuary and Lake Superior strongly suggest the presence of a single walleye stock inhabiting Lake Superior from the Apostle Islands westward.
3. Nearly 50,000 adult walleyes spawned at Fond du Lac in 1981, and over 67,000 adults inhabited the St. Louis River estuary and Lake Superior combined. Because this estimate was made only 2 fishing seasons after the water quality of the river was improved, it is considered somewhat representative of the population structure before any significant fishing mortality.
4. Western Lake Superior walleye are slow-growing, late-maturing, and old compared to other Great Lakes populations. This makes them vulnerable to overexploitation.
5. Since the St. Louis River's water quality has improved, post-spawning walleyes are staying in the river longer.
6. Tag returns indicate female walleyes generally moved downstream faster than males after spawning at Fond du Lac. However, mature fish of both sexes remained in the estuary up to several months before entering Lake Superior. Once in Lake Superior, walleyes moved eastward during the summer but generally not past the Apostle Islands. A westward movement back to the Superior Entry was assumed to occur during late fall or early winter because walleyes were found there during the February-March creel survey.
7. Catch curves can be used to determine total mortality since results were similar to program **ESTIMATE.** Furthermore, the large tagging effort needed for **ESTIMATE** will not be duplicated in the future, and tag loss requires a large correction factor to the program's estimates.
8. Sea lamprey predation was a minor component of natural mortality. However, the improved water quality in the St. Louis River has increased the river's potential as a sea lamprey spawning location. This may result in higher lamprey marking rates on walleye in the future.
9. Creel surveys and commercial catch statistics showed that sport anglers harvested primarily males and immature fish while commercial fishing harvested primarily females and mature fish.

MANAGEMENT IMPLICATIONS

The western Lake Superior walleye stock has a life history pattern that makes it extremely vulnerable to overexploitation. Until 1978 this western Lake Superior walleye stock had been lightly exploited because poor water quality caused the fish to be unpalatable. However, once the new waste treatment facility opened in 1978 water quality improved in the St. Louis River, the fish tasted better, and fishing pressure increased.

Exploitation has played a major role in the decline of certain other Great Lakes walleye stocks in the last several decades, particularly when it was combined with other perturbations, such as pollution and exotic fishes (Schneider and Leach 1977).

Considering this population's characteristics, we strongly recommend a biologically conservative management strategy to protect this western Lake Superior stock and maintain its uniquely broad size structure. We feel this walleye stock deserves special protection due to its size and age structure, its late maturity, and the history of overexploitation in other Lake Superior stocks.

Regulation changes were not recommended for either Lake Superior or the boundary waters of the St. Louis River at the conclusion of this study in 1985. However, after this study was completed, river fishing regulations were changed in 1989 to counter an exotic species there, and new Lake Superior regulations went into effect in 1991. In Lake Superior a 15-inch minimum size limit was created, and the bag limit is 5 walleyes, of which only one can be over 20 inches.

Data necessary for managing the western Lake Superior walleye include:

1. Annually collecting length, sex and age information from a minimum of 1,000 spawners at Fond du Lac. Lake harvest estimates should also be obtained annually. In addition, population estimates and survival rates should be determined at least every 6 years. Current budgeting and manpower problems preclude making population estimates any more frequently. However, annual data collection has continued since the end of the study. A population estimate was made in 1987 and another is scheduled for 1993.
2. Continue obtaining annual commercial catch statistics.
3. Obtain other data whenever possible (e.g. movements, distribution, sea lamprey wounding), as supporting evidence for determining trends.
4. Study the interaction with sea lamprey and other exotic fish in western Lake Superior and the St. Louis River estuary. If sea lamprey reproduction in the St. Louis River continues to increase, walleye may be

affected. The species composition of predators in western Lake Superior may change with increased stocking of exotic fish. Their impact on this walleye stock, if any, should be monitored. After this study was completed, the European ruffe (*Gymnocephalus cernuus*) was discovered in the St. Louis River estuary. New restrictive regulations on walleye, designed to suppress the ruffe population, went into effect for the St. Louis River in 1989. The daily bag limit on the river was reduced from 6 to 2, and a minimum size limit of 15 inches was created.

5. Carefully evaluate any habitat alterations for adverse impacts on walleye. Preservation of spawning and nursery areas is essential for continuation of a healthy fish stock.

APPENDIX

Appendix Table 1. *Fishes sampled in the St. Louis River during 1978-85.*

Family	Common Name	Scientific Name
Petromyzontidae	Silver lamprey	*Ichthyomyzon unicuspis*
	Sea lamprey	*Petromyzon marinus*
Anguillidae	American eel	*Anguilla rostrata*
Clupeidae	Alewife	*Alosa pseudoharengus*
Salmonidae	Lake herring	*Coregonus artedi*
	Pink Salmon	*Oncorhynchus gorbuscha*
	Chinook salmon	*Oncorhynchus tshawytscha*
	Rainbow trout	*Oncorhynchus mykiss*
	Splake	*Salvelinus fontinalis* x *S. namaycush*
	Brown trout	*Salmo trutta*
	Lake trout	*Salvelinus namaycush*
Osmeridae	Rainbow smelt	*Osmerus mordax*
Umbridae	Central mudminnow	*Umbra limi*
Esocidae	Northern pike	*Esox lucius*
	Muskellunge	*Esox masquinongy*
Cyprinidae	Lake chub	*Couesius plumbeus*
	Common carp	*Cyprinus carpio*
	Common shiner	*Luxilus cornutus*
	Golden shiner	*Notemigonus crysoleucas*
	Emerald shiner	*Notropis atherinoides*
	Spottail shiner	*Notropis hudsonius*
	Mimic shiner	*Notropis volucellus*
	Fathead minnow	*Pimephales promelas*
	Blacknose dace	*Rhinichthys atratulus*
	Longnose dace	*Rhinichthys cataractae*
Castostomidae	Longnose sucker	*Catostomus catostomus*
	White sucker	*Catostomus commersoni*
	Silver redhorse	*Moxostoma anisurum*
	Shorthead redhorse	*Moxostoma macrolepidotum*
Ictaluridae	Black bullhead	*Ameiurus melas*
	Yellow bullhead	*Ameiurus natalis*
	Brown bullhead	*Ameiurus nebulosus*
	Channel catfish	*Ictalurus punctatus*
	Stonecat	*Noturus flavus*
	Tadpole madtom	*Noturus gyrinus*
Percopsidae	Trout-perch	*Percopsis omiscomaycus*
Gadidae	Burbot	*Lota lota*
Gasterosteidae	Ninespine stickleback	*Pungitius pungitius*

(Continued on next page)

Appendix Table 1. *Continued.*

Family	Common Name	Scientific Name
Percihthyidae	White bass	*Morone chrysops*
Centrarchidae	Rock bass	*Ambloplites rupestris*
	Pumpkinseed	*Lepomis gibbosus*
	Bluegill	*Lepomis macrochirus*
	Smallmouth bass	*Micropterus dolomieu*
	Largemouth bass	*Micropterus salmoides*
	Black crappie	*Pomoxis nigromaculatus*
Cottidae	Spoonhead sculpin	*Cottus ricei*
Percidae	Johnny darter	*Etheostoma nigrum*
	Yellow perch	*Perca flavescens*
	Logperch	*Percina caprodes*
	Walleye	*Stizostedion vitreum*
Sciaenidae	Freshwater drum	*Aplodinotus grunniens*

Appendix Table 2. *Daily catch of male and female walleyes and water temperatures during the 1981 spawning season, western Lake Superior.*

	No. Fish			
Date	Total	Males	Females	Water Temperature (F)
2 Apr	1	1	0	36
7 Apr	21	15	6	37
9 Apr	80	54	26	37
10 Apr	122	85	37	43
11 Apr	254	162	92	42
12 Apr	332	232	100	44
13 Apr	401	268	133	41
14 Apr	421	314	107	41
15 Apr	449	264	185	43
16 Apr	672	435	237	44
17 Apr	721	417	304	46
18 Apr	630	308	322	46
19 Apr	456	215	241	47
20 Apr	531	275	256	47
21 Apr	428	226	202	47
22 Apr	465	304	161	46
23 Apr*	53	41	12	43
27 Apr	7	5	2	44
Total	6,044	3,621	2,423	

* A heavy rainfall occurred on the evening of 22 April. Water levels rose substantially, making the river unshockable on 23 April.

Appendix Table 3. *Recaptured walleyes (≥ 21.0 inches) by gear and location, 1981.*

Gear/Location	All Recaptures	Tagged Recaptures	Untagged:Tagged Ratio
Fyke nets			
Nemadji River mouth	29	2	13.5:1
Allouez Bay	67	6	10.2:1
Reiss Coal Dock	4	1	3.0:1
Grassy Point	0	0	–
Trap nets			
Superior Entry	71	6	10.8:1
Amnicon River mouth	48	5	8.6:1
Brule Point	1	0	1.0:0
Quarry Point	9	1	8.0:1
Bark Point	6	0	6.0:0
Gill nets			
WDNR	64	1	63.0:1
Red Cliff	256	10	24.6:1

Appendix Table 4. *Sample size, percent mature, and mean length of male and female walleyes sampled during a Lake Superior winter creel survey, 1982.*

Age Group	Sample Size	% Mature	Mean Length (inches)
Males			
Age 3	2	0.0	12.9
Age 4	11	27.0	13.3
Age 5	6	66.0	14.8
Age 6	5	100.0	15.6
Females			
Age 4	5	0.0	12.8
Age 5	5	0.0	15.4
Age 6	1	0.0	15.7

Appendix Table 5. *Mean surface water temperature (F) (rounded to the nearest degree) during August at dissolved oxygen monitoring stations in the St. Louis River estuary, 1981-85.*

Year	Wisconsin Point	Connors Point	Reiss Coal Dock	Mean
1981	70	70	72	70.7
1982	73	70	73	72.0
1983	71	73	75	73.0
1984	71	70	73	71.3
1985	61	61	64	62.0
Station mean	69.2	68.8	71.4	69.8

Appendix Table 6. *Mean water temperatures (F) during August for Wisconsin waters of Lake Superior (Bark Point to Superior Entry), 1970-85.*

Year	Depth (ft)				Mean for Year
	Surface	10	20	30	
1970	70.7	68.7	65.7	60.7	66.4
1971	63.0	61.7	59.0	50.0	58.4
1972	57.0	55.3	55.0	53.7	55.2
1973	65.2	64.0	61.6	56.7	61.9
1974	60.0	59.0	58.0	58.0	58.7
1975	63.7	63.5	59.7	50.2	59.3
1976	65.7	65.3	63.2	61.2	63.8
1977	58.2	58.0	56.8	54.2	56.8
1978	63.1	62.3	61.0	59.5	61.5
1979	59.8	59.2	56.7	53.2	57.2
1981	65.3	64.7	63.1	61.2	63.6
1983	68.7	68.1	62.7	56.1	63.9
1985	62.6	61.4	58.7	54.7	59.4
Mean temperature all depths	63.3	62.4	60.1	56.1	60.5

Appendix Table 7. *Classification of lamprey marks (King 1980) on attacked walleyes during spring spawning at Fond du Lac, 1980-85.*

Year	Total Lamprey Marks	Mark Types							
		A1	A2	A3	A4	B1	B2	B3	B4
1980	6	Marks not classified							
1981	16	2	9	1	–	–	4	–	–
1982	4	–	1	–	–	–	3	–	–
1983	–	No sampling.							
1984	4	1	1	–	–	1	–	–	1
1985	1	–	–	1	–	–	–	–	–

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