STATUS OF WALLEYE IN THE GREAT LAKES: CASE STUDIES PREPARED FOR THE 1989 WORKSHOP

Great Lakes Fishery Commission

SPECIAL PUBLICATION 91-1

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STATUS OF WALLEYE IN THE GREAT LAKES: CASE STUDIES PREPARED FOR THE 1989 WORKSHOP

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FOREWORD

The case studies in this publication were produced as preparatory material for the Walleye Rehabilitation Workshop held June 5-9, 1990 at the Franz-Theodore Stone Laboratory at Put-in-Ray, Ohio. This workshop was sponsored by the Great Lakes Fishery Commission's Board of Technical Experts. For a number of years, Henry H. Regier had urged the Board to initiate such a study to document recent changes in walleye populations that were particularly evident inwestern Lake Erie. A broad examination of walleye population changes in the Great Lakes was last undertaken at the Percid International Symposium held in 1976, and an update was very desirable. Peter Colby graciously agreed to chair the workshop for the Board and gratefully acknowledges the support of the steering committee: Carl Raker, Robert Haas, Joseph Koonce, Cheryl Lewis, Kenneth Mimms, and Terry Lychwick. Also very noteworthy were the contributions of Special Editor Wilbur Hartman and Associate Editor Gail Etter.

R. L. Eshenroder
December 6, 1990

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LAKE SUPERIOR WALLEYE STOCKS: STATUS AND MANAGEMENT

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ABSTRACT. This paper describes the current status of walleye (Stizostedion vitreum vitreum) stocks in Lake Superior. Although Lake Superior is oligotrophic with a fisheries comprised primarily of cold-water species, walleye have played an important role in shallow-water areas and embayments. The western Lake Superior stock was lightly exploited until dramatic water quality improvements occurred in 1979. The stock now supports a popular sport fishery in both Wisconsin and Minnesota. The slow growth of this stock may make it extremely vulnerable to overexploitation. Other Wisconsin stocks are found in Kakagon Slough and the Bad River. Both stocks support sport and tribal fisheries and the use of supplemental stocking is being investigated. The three large stocks historically in Ontario waters include Nipigon Bay, Black Bay, and Whitefish Bay. All stocks are depressed and stocking is being used for rehabilitation.

Overfishingwas identified as the primary reason for declining Lake Superior walleye abundance. Several potential, but undocumented, adverse impacts from exotic species are noted. Contaminant levels on largerwalleye have exceeded recommended consumption guidelines in several areas. Managers attempting to rehabilitate walleye stocks will have to determine basic population characteristics and identify sources of stress before developing a management plan.

INTRODUCTION

This paper reports on the current status of major walleye (_Stizostedion vitreum vitreum_) stocks in Lake Superior (Fig. 1). Lake Superior is classified as oligotrophic due to its low productivity and the glacial characteristics of its drainage basin (Lawrie and Rahrer 1972; Matheson and Munawar 1978). Among the Great Lakes, Lake Superior has the lowest summer surface temperature and mean annual lake temperature (Bennett 1978). Native fish are comprised primarily of cold-water species:

1) lake trout (_Salvelinus namaycush_),

2) lake herring, (_Coregonus artedii_), and

3) lake whitefish, (_Coregonus clupeaformis_).

This community was severely depleted by the stresses of exploitation, exotic species, and habitat degradation (Lawrie 1978). Walleye and other cool-water species better adapted to shallow, mesotrophic systems have played an important but secondary role, both ecologically and in sport and commercial fisheries (Ryder 1968; Lawrie and Rahrer 1972). Walleye were historically harvested in shallow-water areas and discrete embayments (Nutte 1944; Ryder 1968; Pereira et al., Minnesota DNR, unpubl. data; Schram et al., Wisconsin DNR, unpubl. data). Maximum commercial harvests from U.S. waters were 56,000 kg obtained in Minnesota in 1885, and 170,000 kg from Ontario waters in 1966 (Fig. 2) (Baldwin et al. 1979).

Lack of data on most Lake Superior walleye stocks limit analysis of stock problems. Some problems have been documented with biological data, while others are the opinion of local managers. The decline of stocks in Black Bay (Ontario) and in Michigan's waters were believed to be due primarily to overharvest (Schneider and Leach 1977; Colby and Nepszy 1981). Pollution and/or overexploitation played a major role in the decimation of the walleye in Nipigon Bay (Ryder 1968; MacCallum and Selgeby 1987). Exotic species such as rainbow smelt (_Osmerus mordax_) and sea lamprey (_Petromyzon marinus_) are present, but any adverse impact is unknown (Schneider and Leach 1977).

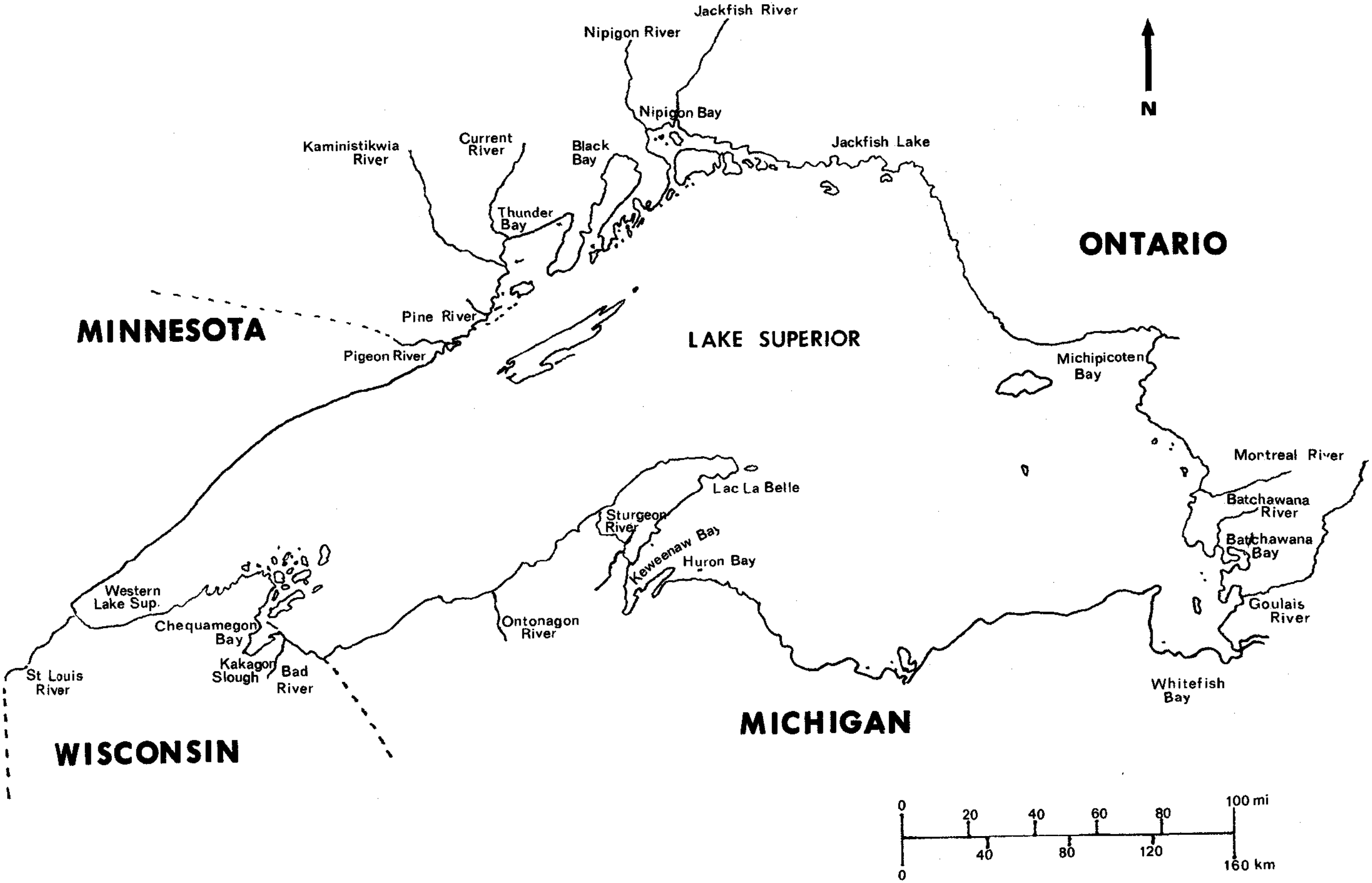

Fig. 1. Lake Superior showing walleye stocks and locations mentioned in the text.

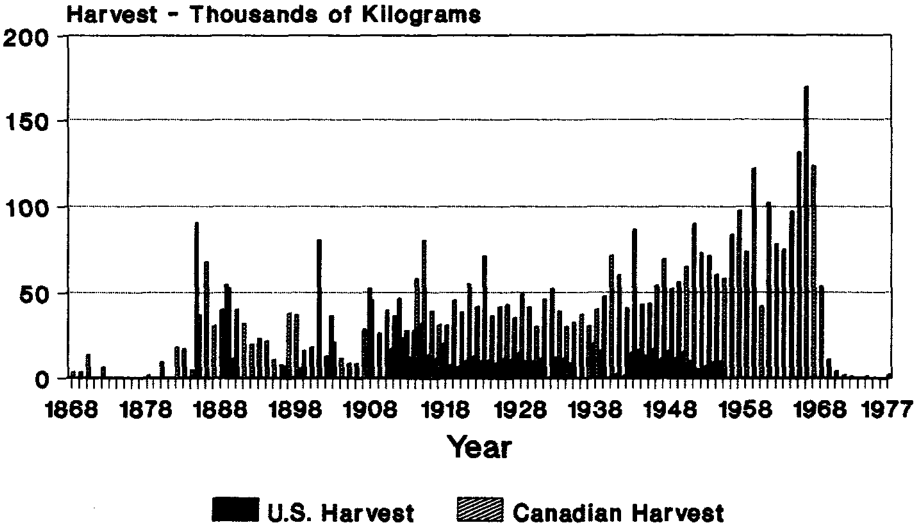

Fig. 2. Lake Superior commercial walleye production, 1868-1977 (Baldwin et al. 1979).

STOCK INFORMATION

Minnesota

Minnesota shares a small walleye population in the Pigeon River with Ontario and shares the western lake Superior stock with Wisconsin. The Pigeon River population spawns in the Pigeon River but little else is known about its biology. In 1980, samples of fish over 394 mm exceeded the current action level for mercury as established by the U.S. Food and Drug Administration. There is a small tribal subsistence fishery on this stock (Steven Hirsch, Minnesota DNR, pers. commun.). Additional stock data were summarized by Ball (1988a). The western Lake Superior stock provides a high-quality sport fishery for anglers in the St. Louis River. This stock is discussed in detail in the Wisconsin section. Minnesota's walleye season extends from the second Saturday in May to February 15, with no size limit and a possession limit of six.

Wisconsin

Three walleye stocks inhabit Wisconsin waters:

1) western Lake Superior,
2) Kakagon Slough, and
3) Bad River.

Each stock has experienced different levels of exploitation from sport and commercial fisheries. All stocks live primarily in Lake Superior or Chequamegon Bay and spawn in tributary streams. Commercial production during 1944-55 averaged 10,600 kg annually. Fearing overexploitation, anglers convinced the Wisconsin Conservation Commission to close the commercial fishery after 1955. In 1971, the Wisconsin Supreme Court removed control of tribal fisheries from the state to the Lake Superior Band of Chippewas. Beginning in 1972, the Bad River Band began gillnetting the spawning runs in the Kakagon Slough and Bad River. In 1980, an assessment fishery by the Red Cliff Band began on the western Lake Superior stock. Both Bands still continue their commercial and subsistence fisheries on these stocks.

Contaminant monitoring has been conducted since 1970. Elevated mercury levels from walleye collected in 1984-85 prompted the issuance of a fish consumption advisory for Lake Superior and the St. Louis River. Currently, sport anglers have an open season with a daily bag limit of five, and no size limit.

Western Lake Superior

The western Lake Superior stock is one of the few Great Lakes walleye stocks to perpetuate over the past century. Survival is due to low exploitation rates prior to 1979. As early as 1900, water pollution in the St. Louis River from upstream paper mills had caused oxygen deficiencies and fish taste and odor problems associated with a variety of chlorophenolic products produced during the pulping process. A sport fishery occurred in the St. Louis River but harvest was limited by the water quality problems which gave fish a poor flavor. In 1978, the Western Lake Superior Sanitary District (WISSD) began treating domestic and industrial wastes from a 1,300 sq km area within the St. Louis River watershed. Much 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 and increased angling pressure dramatically.

Since 1979, the western Lake Superior stock has been subjected to increasing angler pressure. In response to a concern over possible adverse impacts from exploitation, the Wisconsin DNR initiated a comprehensive study of the western Lake Superior walleye stock in 1978 (Schram et al. Wisconsin DNR, unpubl. data) and the Minnesota DNR conducted spawning assessments and creel surveys during 1980-82 (Pereira et al. Minnesota DNR, unpubl. data.).

Throughout the study period, mean length and weight of both sexes remained constant, although mean age decreased for males, and remained similar for females (Table 1). Walleye growth was relatively slow and many age classes were present. Much of the 1981 spawning population consisted of older-age fish (Schram et al. Wisconsin DNR, unpubl. data). Of the mature males, 63% were age x or older and 77.6% of the females were age X or older. The mean age of male spawners in 1981, based on examination of dorsal spines, was 10.2. The mean age for females was 11.2.

Table 1. Mean length, weight, and age of spawning walleye, St. Louis River, 1980-85 (Schram et al., unpubl. data) and sport fishery mean age, 1980-82 (Pereira et al. Minnesota DNR, unpubl. data).

	Males				
Year	Sample size	Length (mm)	Weight (kg)	Mean age	Sport fishery mean age
1980	2,074	478	1.1	--	8.2
1981	3,402	488	1.3	10.2	8.1
1982	590	483	1.3	9.5	7.8
1983	No Sampling				
1984	499	467	2.2	8.8	--
1985	883	470	--	8.8	--

	Females				
Year	Sample size	Length (mm)	Weight (kg)	Mean age	Sport fishery mean age
1980	1,071	546	1.9	--	8.2
1981	2,296	574	2.3	11.2	8.1
1982	412	577	2.3	11.1	7.8
1983	No Sampling				
1984	534	597	2.6	11.2	--
1985	399	599	--	12.3	--

The majority of walleye which inhabit western Lake Superior migrate to the St. Louis River during the spawning season. In 1981, the spawning population in the St. Louis

River estuary was estimated near 50,000, of which 44% were greater than or equal to 533 mm. This estimate was made from a mark-recapture experiment that assumed 100% maturity at 533 mm. A greater number (67,000, of which 44% were greater than or equal to 533 mm) were estimated to inhabit the estuary and Lake Superior. Possible explanations for differing estimates include:

1) interference from other Lake Superior walleye stocks,

2) adult walleye from the St. Louis River which did not spawn in 1981 and remained in Lake Superior,

3) immature walleye over 533 mm,

4) a progressive increase in tag loss during the recapture period,

5) nonreporting of tags from commercial nets,

or a combination of all of the above (Schram et al. Wisconsin DNR, unpubl. data). Population estimates of the entire spawning stock in the St. Louis River (based on tagged fish observed by creel clerks for 1980-82) were approximately 78,000, 78,000, and 79,000 respectively. Similar estimates of walleye greater than or equal to 508 mm for 1980-82 were approximately 16,000, 36,000, and 28,000 respectively (Pereira et al. Minnesota DNR, unpubl. data).

Adult walleye moved downstream after spawning and spent several weeks to several months in the St. Louis River estuary before entering Lake Superior. Females generally moved downstream faster than males. Based on 1981 angler tag returns of fish caught within the estuary from walleye tagged during the 1981 spawning season, 71.5% were males. Once the walleye were in Lake Superior, there was generally an eastward movement along the shore to the western Apostle Islands. Movement along the Minnesota shore was limited. The longest-known movement of a fish from this stock was a fish captured at Marquette, Michigan, a distance of 592 km (Schram et al. Wisconsin DNR, unpubl. data). Tag returns from juvenile walleye indicated a movement into the estuary when many adults were moving out. Some juveniles remained in the lake during the summer and moved in and out of tributary streams (Schram et al. Wisconsin DNR, unpubl. data).

Two potential components of natural mortality were examined. Margenau et al. (1988) reported on the lymphocystis virus infecting 18% of spring spawning walleye in the St. Louis River. Mortality of walleye resulting from infection was suggested based on higher return rates of spawning one year later for fish not infected at the time of tagging compared to fish infected. Sea lamprey attack marks were observed on 0.1 to 0.3% of adult walleye sampled from 1980 to 1985. Low marking percentages were assumed to be the result of the sea lamprey's host preference and their seasonal distribution (Schram et al. Wisconsin DNR, unpubl. data).

Survival estimates for mature walleye by sex was estimated to be 65.1% and 52.5% for females and males respectively (Table 2). Higher survival of female spawners was thought to be occurring because they leave the estuary before males, making them less vulnerable to angler exploitation (Schram et al. Wisconsin DNR, unpubl. data).

Table 2. Estimates of exploitation, annual survival, and instantaneous natural mortality for walleye in the St. Louis River estuary.

Parameter[1]	Year	Method of calculation	Sex	Size[2]	Age	Estimate	Reference[3]
u, St. Louis River; sport fishery; May-July	1980	Harvest-stock size[4]	Both	≥ 508 mm	-	0.333	-
	1981				-	0.143	-
	1982				-	0.146	-
u, Red Cliff; commercial fishery	1981				-	0.004	-
	1982				-	0.013	-
S	1979-82	Catch curve	Both	All spawners	-	0.585	Schram et al., unpubl. data
		Brownie et al. 1978			-	0.592	ibid.
		Catch curve	Male	All spawners	-	0.525	ibid.
		Brownie et al. 1978		All spawners	-	0.551	ibid.
				≥ 483 mm	-	0.661	ibid.
		Catch curve	Female	All spawners	-	0.651	ibid.
		Brownie et al. 1978			-	0.719	ibid.
				≥ 533 mm	-	0.842	ibid.
	1980-82	Catch curve	Both	All spawners	≥ 10	0.520	Pereira et al., unpubl. data
	1981	Hoenig, 1983	Both	All spawners	-	0.80[5]	ibid.
M	1981	Pauly, 1979[6]	Both[7]	All spawners	5-17	0.142	-
			Female[8]	All spawners	5-17	0.110	-
			Male[9]	All spawners	4-18	0.157	ibid.

[1]As defined in Ricker (1975)

[2]Ages and size refer to those present in the spawning stock

[3]If no reference is listed, then estimate was derived after cited reports

[4]von Bertalanffy growth parameters used: L-infinity = 732 mm; K = 0.0732

[5]Maximum age used in this estimate was 20 years

[6]Used a mean environmental temperature of 10^{o} C for all three estimates of M

[7]von Bertalanffy growth parameters used: L-infinity = 846 mm; K = 0.663

[8]von Bertalanffy growth parameters used: L-infinity = 950 mm: K = 0.0475

[9]von Bertalanffy growth parameters used: L-infinity = 732 mm; K = 0.0732

Length frequency of creeled walleye compared with the spawning population suggests angler exploitation targeting mostly on juveniles, while the commercial catch targets primarily on the spawning portion of the population (Fig. 3). Ryder (1968) found an almost identical situation in Nipigon Ray.

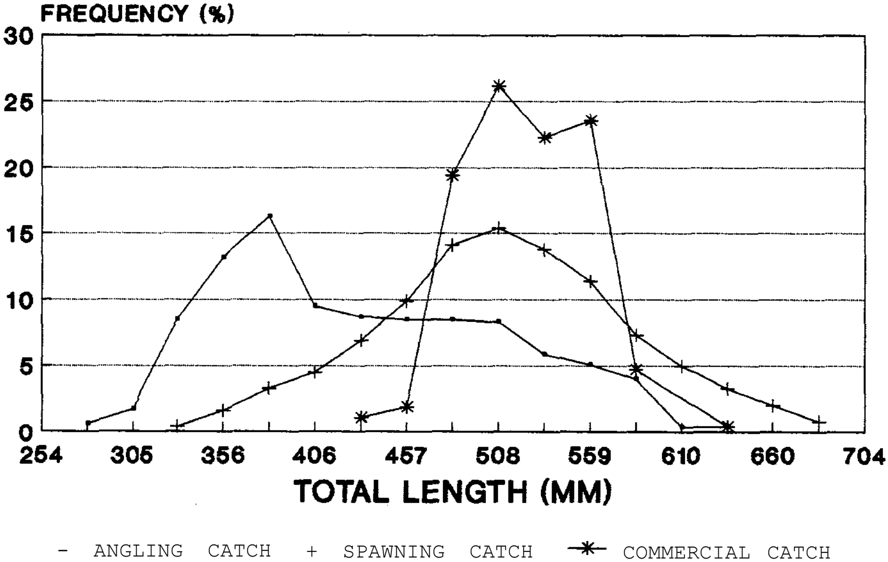

Fig. 3. Length-frequency distribution of western Lake Superior walleye tagged during the 1981 spring spawning assessment compared with the distribution of angling catch and commercial catch (from Schram et al. Wisconsin DNR, unpubl. data).

The Wisconsin DNR is protecting critical habitat by purchasing river frontage adjacent to the major spawning area. Wisconsin is attempting to develop a biologically conservative management strategy aimed at providing adequate stock protection. Impacts from exploitation are monitored by following population parameter trends. It will be difficult to determine if parameter changes are the result of exploitation, responses to improved environmental conditions within the estuary, or some combination of the two.

Kakagon Slough

Biological data have been collected on four different surveys:

1) 1947-53 (Daly 1953),
2) 1954 and 1962 (Belonger 1972),
3) 1973-78 (Swedberg and Selgeby 1979), and
4) 1988 (Schram 1988).

Daly (1953) found walleye migrating out of Chequamegon Bay and into Kakagon Slough during the spawning run in late March and April. Some migration out of the slough occurred in late May. Tag returns from anglers indicated 90.8% of the spawners were captured within three miles of the tagging site. The farthest-known movement of a fish from this stock was 35 km. Tagging indicated walleye were old and slow growing. Although no aging data were available during the early studies, adults tagged on their spawning run had been recaptured as long as 16 years later and grew an average of 25 mm per year (Belonger 1972). Length distributions for the 1947-88 surveys showed spawning females larger than males. Sex ratios varied from 1.3:1 male to female in 1988 to 7.7:1 in 1962.

The Bad River Band of Lake Superior Chippewa began commercially harvesting walleye during the spawning run in 1972. In 1973, the U.S. Fish and Wildlife Service began monitoring the fish community in Chequamegon Bay. Swedberg and Selgeby (1979) found the age structure changing from 1973-78. Older walleye (V-XI) were relatively common in 1973, but by 1975 they had declined considerably and remained low through 1978 (Table 3). It was concluded that walleye stocking, in combination with a reduction in exploitation, was needed to rebuild the population. The Wisconsin DNR began stocking walleye fingerlings (50-75 mm) at a rate of 9.1 fingerlings/ha annually in the western areas of 14,000 ha Chequamegon Bay in 1980. The goal was to stock 200,000 fish annually. However, problems with fish availability resulted in an average of just over 128,000 fish stocked annually between 1980 and 1985. Preliminary assessments indicate the fish have survived and may be contributing to increased adult abundance. Two blank year-classes (1986 and 1988, no stocking) will be used to evaluate the success of the program. Aging data collected by the Wisconsin DNR in 1988 indicated the spawning population was much younger than the western Lake Superior stock. The mean dorsal-spine age for males was 6.6 years, and 7.9 years for females. A multiagency technical working group is continuing to collect population data and will be developing a management plan.

Table 3. The percentage that each age group of walleye contributed to the total catch made during the Chequamegon Bay trawling surveys conducted each August, 1973-78. Actual numbers of fish sampled are in parentheses (Swedberg and Selgeby 1979).

Age Group	1973	1974	1975	1976	1977	1978
0	2 (3)	7 (20)	15 (7)	13 (10)	2 (2)	11 (7)
I	41 (52)	2 (6)	5 (2)	74 (55)	14 (10)	8 (5)
II	9 (12)	55 (154)	20 (9)	1 (1)	64 (47)	27 (18)
III	9 (12)	14 (40)	54 (25)		2 (2)	44 (30)
Iv	12 (15)	10 (27)	2 (1)	8 (6)	3 (3)	8 (5)
V	2 (3)	2 (6)	-		13 (10)	2 (1)
VI	3 (4)	2 (6)	4 (2)	1 (1)		
VII	2 (3)	1 (3)	-			
VIII	6 (7)	2 (6)	-			
Ix	6 (7)	2 (6)	-	3 (3)		
X	7 (9)	1 (3)	-		1 (1)	
XI	-	1 (3)	-			
XII	1 (1)	-	-		1 (1)	
XIII	-	1 (3)	-			
Walleye in sample	(128)	(283)	(46)	(76)	(76)	(66)

Bad River

Walleye enter the Bad River in the spring and move approximately 23 km upstream before spawning below a falls. Prior to 1972, the only known fishery in the Bad River was sport, and that occurred primarily in the summer. In the spring of 1972, a tribal gillnet fishery began on spawners entering the river. The abundance of spawners has gradually declined over the years. Sport fishing (except by Indians) has nearly ceased over the past 16 years because of closed boat-launch ramps to non-Indians. Other biological data on this stock are lacking (Joe Dan Rose, Bad River biologist, pers. commun.).

Michigan

Four walleye stocks are thought to inhabit Michigan waters:

1) Ontonagon River,

2) Lac La Belle,

3) Keweenaw Bay, and

4) Whitefish Bay.

Occasional walleye are also found along the shore in association with river mouths: however, limited data preclude any further analysis of these areas (Richard Schorfhaar, Michigan DNR, pers. commun.). Commercial walleye harvest from Michigan has contributed little to the total production from Lake Superior (Baldwin et al. 1979). The species was commercially harvested until 1969 when it gained sport status. Presently, a small tribal and sport harvest is localized near each stock. Michigan's walleye season extends from May 15 to March 15, with a daily bag limit of five and a 381 mm minimum size limit.

Ontonagon River

Walleye in the Ontonagon River spawn 40 km upstream from Lake Superior, below Victoria Dam on the west branch. There is an isolated sport fishery near the river mouth in late May, but the overall run has dropped off in recent years (Ray Juetten, Michigan DNR, pers. commun.). Walleye from the western Lake Superior stock have been caught in the Ontonagon River (Schram et al. Wisconsin DNR, unpubl. data).

Lac La Belle

Small numbers of walleye inhabit Lac La Belle but no specific spawning areas have been identified. A fingerling stocking program was started in 1985 to increase the size of this population (Ray Juetten, Michigan DNR, pers. commun.).

Keweenaw Bay

Walleye from the Keweenaw Bay stock spawn in three locations in the Sturgeon River:

1) 13 km upstream from Portage Lake,

2) below the dam at the outlet of Otter Lake, and

3) another 32 km upstream below the Prickett Dam.

They spend the summer months in Portage bake and Keweenaw Bay, and are gillnetted by tribal fishermen off Baraga in late September. Some fish return to the Sturgeon River in October and November to overwinter. Since 1985, an average of 30,044 walleye fingerlings (38-51 mm) have been stocked in 3,398 ha Huron Bay at the rate of 8.8 fingerlings/ha. Initial results indicate excellent survival and growth. Huron Bay has an abundant shiner (*Notropis* spp.) and mayfly (Ephemeroptera) population and the area is not utilized by tribal fishermen (Ray Juetten, Michigan DNR, pers. commun.).

Whitefish Bay

A single walleye stock is thought to inhabit Whitefish Bay with spawning occurring where suitable habitat exists. Spawning runs in the Tahquamenon and Waiska Rivers have declined in abundance. Beginning in 1985, fall fingerlings have been stocked annually in Waiska Bay to augment the fishery. Construction of a spawning reef is proposed for an area offshore from Cedar Point (John Schrouder, Michigan DNR, pers. commun.).

Ontario

Four major walleye stocks are thought to inhabit the Canadian waters of Lake Superior:

1) Whitefish Bay (including Batchawana Bay, Goulais River and Bay),

2) Nipigon Bay,

3) Black Bay, and

4) Thunder Bay (including spawning in the Current, Kaministiguia, Pine, and Pigeon Rivers).

The identification of these stocks is based on available data and the opinion of local managers. Walleye are also found in Michipicoten Bay, Jackfish Lake, Montreal River, and other river mouths or embayment areas, but it is not known if they represent separate stocks or strays from other areas of the lake.

All Ontario stocks except Thunder Bay have collapsed recently. In Thunder Bay, stocks have supported a limited sport fishery, usually during the spawning run. Lake Superior did not have a closed season for walleye, but did have a daily bag limit of six. Significant commercial fisheries existed in Black Bay, Nipigon Bay, and Whitefish Bay. The Black Bay commercial harvest exceeded the rest of Lake Superior from the late 1800s to 1965, when it collapsed (Baldwin et al. 1979). Commercial walleye harvest quotas have been eliminated in most areas of Ontario.

In response to reduced walleye stocks, the Ontario MNR instituted a reduced daily bag limit of three walleyes for Lake Superior and known walleye spawning tributaries to Lake Superior in 1989. A closed season from April 15 to the Friday prior to the third Saturday in May was also applied to Lake Superior, and a closed season from April 15 to June 30 was applied to selected Lake Superior tributaries with high walleye spawning potential. In addition, Nipigon Bay and the Nipigon River were closed to walleye fishing until 1992. Consumption guidelines in Ontario begin with walleye 45 cm long. Walleye over 55 cm from Pine Bay and Goulais Bay, and over 65 cm from Batchawana Bay carry an advisory not to eat them.

Whitefish Bay

Until the 1960s, the Goulais River contained a walleye spawning population. The population began declining in the 1970s. By 1984, three trapnets at the mouth of the Goulais

River, set from April 19 to May 28, caught only five walleyes (Rose and Kruppert 1984). A creel census in 1984 also revealed few walleye.

Batchawana Bay walleye spawn in the Batchawana River and were considered rare by 1970. It was unknown if these fish were discrete from the Goulais River population. The reasons for declining walleye numbers were assumed to be:

1) overfishing,

2) effects of sea lamprey control, and

3) competition and predation from exotics.

Once reduced in numbers, the incidental catch from a high-pressure sport fishery targeting on other species may have been enough to prevent walleye rehabilitation. An average of 331,000 walleye fry have been stocked annually in the Goulais River from 1984-85 and 1987-88. In 1985, 50 adult walleyes were also tagged and released in the Goulais River.

Nipigon Bay

Large spawning runs of walleye existed in the Nipigon and Jackfish Rivers and were heavily fished by local anglers. The stock collapsed in the 1960s with commercial harvest declining from near 12,000 kg in 1958-62, to 1,000 kg ten years later (Fig. 4). Ryder (1968) suggested pulp mill effluent as the reason for stock reduction, however MacCallum and Selgeby (1987) suggested overexploitation as a contributing cause. The rehabilitation effort was concentrated at the mouth of the Jackfish River where approximately one million eggs were stocked annually from 1978-83. An average of 1.7 million fry were stocked annually from 1984-86. In 1985, 2,000 fingerlings were stocked. From 1986-88, an average of 546 adults were stocked annually. Index nets in 1983 and 1985 sampled only eight walleyes and electrofishing in 1986 failed to capture a walleye. The program to translocate adults is continuing.

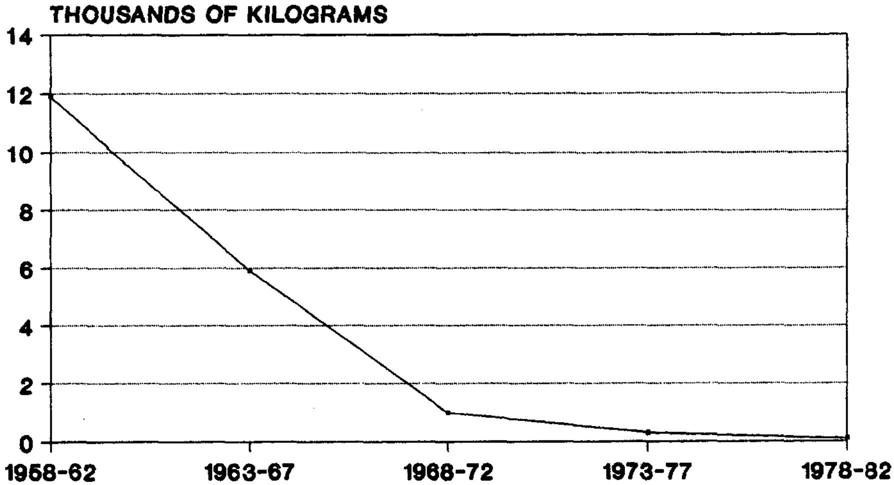

Fig. 4. Commercial walleye harvest from Nipigon Bay, 1958-82.

Black Bay

Between 1956 and 1968, approximately 90% of the Lake Superior walleye harvest came from Black Bay. The commercial catch peaked in 1966 and then declined sharply. The decline of older fish in the catch indicated the population was being harvested before reaching maturity, and was subsequently unable to replace itself. Overexploitation was cited as the most probable cause of the collapse (Colby and Nepszy 1981). Assessment nets set in Black Bay by the Ontario MNR substantiated the decline. Catches of walleye ranged from 52 in 1969, to 19 in 1971 (Ball 1988a).

In an effort to rehabilitate the walleye population, 1,032 adult walleyes were captured and transferred from the Current and Pigeon Rivers to Black Ray in September 1972. Sampling that fall indicated that most walleye remained at the northern end of Black Bay. By 1973, 51% of the walleye recaptured still remained in the stocking area, but 34% were also recaptured at the mouth of the Current River (Ball 1988a). Brousseau (pers. commun.), as reported in Colby and Nepszy (1981), suggested transferred walleye homed to the Current River. Ball (1988a) suggested there was no strong evidence of homing and there was no clear evidence why the program did not meet its goal.

Thunder Bay

Walleye are known to spawn near the mouths of the Current, Kaministikwia, Pine, and Pigeon Rivers. The discreteness of these stocks is unknown. All populations appear stable and are lightly fished by anglers (Ball 1988b). Habitat loss along the shoreline within the city of Thunder Bay may limit stock increases.

DISCUSSION

Overfishing has been identified as the primary reason for declining Lake Superior walleye abundance (Table 4). Slow-growing stocks, dominated by old individuals, were unable to withstand high levels of exploitation. Commercial exploitation by Native Americans in U.S. waters must be carefully monitored so adequate protection is given remaining healthy stocks. In the absence of commercial exploitation, abundance levels have stabilized in the western Lake Superior and Thunder Bay stocks.

Table 4. Summary of management problems and strategies for major Lake Superior walleye stocks.

Stock	Management problem	Management objective	Agency strategy	Results
western Lake Superior	Exploitation on old stock; high mercury levels	Maintain stock size	Close spawning area to fishing	Stock remains status quo
Kakagon Slough	Overfishing	Provide sport and tribal fishery. Control overabundant perch	Fry and fingerling stocking	Good survival and growth on fingerlings
Bad River	Presumed overfishing; tack of data	Acquire data	Not known	Not known
Ontonagon River	Reduction in size of spawning run	Acquire data	Monitor spanning activity	*Not known*
Lac La Belle	Lack of data	Provide sport fishery	Fingerling stocking	**Inconclusive**
Keweenaw Bay	Overfishing; lack of data	Provide sport fishery	Fingerling stocking in adjoining bay	Good survival and growth
Whitefish Bay	Overfishing; lack of data	Provide sport fishery; rehabilitate stock	Fry and fingerling stocking; build spawning reef	Inconclusive
Nipigon Bay	Paper mill effluent; overfishing; lack of data	Rebuild stock	Fry, fingerling, and adult stocking; close fishery	Failed to establish
Black Bay	Overfishing; lack of data	Rehabilitate stock	Adult transfer	Failed to establish
Thunder Bay	High contaminant levels; habitat loss	Maintain present fishery; rehabilitate habitat	Protect existing habitat	Status quo

There are several potential but undocumented adverse impacts from exotic species. Sea lamprey predation has only been quantified in the Nipigon Bay (Ryder 1968) and western Lake Superior stocks (Schram et al. Wisconsin DNR, unpubl. data). In both studies, predation was not an apparent problem and considered a minor component of natural mortality. Seelye et al. (1987) found that early life stages of walleye were considerably more resistant than sea lamprey ammocetes to the lampricide TFM, and concluded it would be unlikely walleye would be adversely affected by standard stream treatments to kill sea lamprey ammocetes. Rainbow smelt have coexisted with several stocks for many years and do not appear to have had an adverse impact. Rainbow smelt were the main food item for western Lake Superior walleye (Swenson 1977). Coho salmon (Oncorhynchus kisutch) and chinook salmon (Oncorhynchus tshawytscha) have co-existed with walleye in Lake Superior for over 20 years, yet there is no evidence that salmon have had an adverse impact on walleye. It is possible that changes in stock parameters are not detectable with present monitoring programs: or salmon may not be directly competing with walleye since they have a different seasonal distribution. The European ruffe (Gymnocephalus cernua) was discovered in the St. Louis River estuary in 1987. Several year-classes have been documented and the species appears to be permanently established. Predation and/or competition exists as a possible threat to walleye. Indirect adverse effects on important prey species may also develop. New regulations, designed to suppress the ruffe population, went into effect in 1989 for the St. Louis River boundary waters. The minimum size limit for walleye is 381 mm with a daily bag limit of two, and a season from the Saturday nearest May 15 to March 1.

Contaminant levels on larger fish have exceeded recommended consumption guidelines for several years in Thunder Day, Goulais Ray, and western Lake Superior. In some cases, the health advisory can act as an upper length limit and may protect large spawners. There is also circumstantial evidence in Wisconsin that large walleye purge mercury when migrating in open lake waters (Wisconsin DNR, unpubl. data). Continued monitoring of all stocks is imperative.

Despite its secondary role and overall reduction in abundance, Lake Superior walleye are still actively sought by anglers. Agencies have responded to the demand for walleye fishing and are attempting to rehabilitate stocks through regulations and stocking. Commercial fishing is now eliminated except for a small incidental quota in Ontario and a Native American fishery in U.S. waters. Reduced bag and size limits are in effect in Ontario. Fingerling stocking programs in Wisconsin and Michigan have been successful in terms of survival and growth, while adult transfer programs in Ontario have failed to rehabilitate stocks.

MANAGEMENT NEEDS

Walleye distribution and abundance in Lake Superior will continue to be limited due to the lack of suitable habitat. If managers are attempting to rehabilitate walleye stocks, collection of data will be the primary objective in most cases. Except for the western Lake Superior stock, limited lakewide data sets preclude analysis of stock problems. Once population parameters are described and sources of stress identified, a management plan can be developed. If depressed stocks once consisted of a spawning population with characteristics similar to the western Lake Superior stock, then it may take a combination of stocking and conservative regulations to increase abundance to former levels.

ACKNOWLEDGEMENTS

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WALLEYE REHABILITATION IN LAKE MICHIGAN, 1969-1989

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ABSTRACT. All three major walleye (*Stizostedion vitreum vitreum*) in Lake Michigan had been reduced to remnant levels by the mid-1960s. In the early 1970s, they were restored by intensive fingerling and fry stocking programs. By 1988, northern Green Bay had received three million fingerlings and 24 million fry, and the southeastern shoreline of the main basin had received 2.2 million fingerlings and 72 million fry. Additional stocking is still planned. Stocking was discontinued in southern Green Bay in 1984 when the cumulative total reached 3.5 million fingerlings and 86 million fry. For the lower Fox River, extensive improvements in water quality were also important, enabling stocked walleye to thrive and spawn successfully in a formerly highly polluted environment. Important sport fisheries were reestablished in all areas and became so intensive in

the Fox River that special regulations were needed to protect spawning walleye. Yields from northern Green Bay and southeastern stocks are still well below historic peaks. Continued high growth rates in all areas suggest that much higher populations could be sustained. Biological characteristics of restored stocks are similar to native stocks except that stocked fish are less migratory. Some natural reproduction has occurred, but not at the desired level. Factors once believed to be preventing strong native year-classes (insufficient brood stock, high densities of alewife (Alosa pseudoharengus) and rainbow smelt (Osmerusmordax), contaminants and poor-quality spawning substrates) no longer seem to be major constraints. Good reproduction may still be constrained by suboptimal thermal regimes in most years.

INTRODUCTION AND HISTORICAL PERSPECTIVE

Walleye (Stizostedion vitreum vitreum) stocks in Lake Michigan, like those of other native fishes, experienced drastic changes from 1930-70 as the entire fish community was destabilized (Schneider and leach 1979; Wells and McLain 1973). Factors involved were:

1) successive invasions of rainbow smelt (Osmerus mordax), sea lamprey (Petromyzon marinus), and alewife (Alosa pseudoharengus),

2) local deterioration of water quality, and

3) intensification of fishing.

Major declines in walleye began in the 1950s; and by the mid-1960s, all walleye stocks had been reduced to remnant levels and were in serious trouble. Commercial walleye fisheries also collapsed, and have been banned in Michigan waters since 1969, and in Wisconsin waters since 1978. Fingerling and fry stocking began **in the 1970s, and by the** 1980s substantial stocks and sport fisheries had been reestablished. In this report we will:

1) document the changes in these stocks and the fisheries on them,

2) compare the biological characteristics of restored and native stocks, and

3) discuss the progress of the restoration programs and possible constraints to their success.

The history of each Lake Michigan walleye stock prior to 1975, along with possible causes for its demise, was given in detail by Schneider and Leach (1979). Pertinent background information is summarized below to provide a historical perspective.

The largest walleye stocks existed in northern and southern Green Bay and along the southeastern shore near the Muskegon River: only small populations were associated with river mouths in other areas (Fig. 1). Peak commercial yields were 589 mt for northern Green Bay, over 80 mt for southern Green Bay, and 22 mt for the southeastern shore.

The northern Green Bay stock, which was comprised of many discrete river- or reef-spawning populations, increased about sixfold during the 1940s. The phenomenal increase was traced to an exceptionally strong year-class in 1943, plus strong year-classes in 1950, 1951, and 1952. very weak cohorts were produced every year thereafter, causing the population to decline to a very low level by the mid-1960s. The primary cause for the decline was suspected to be competition and predation effects of expanding populations of exotic alewife and rainbow smelt on larval walleye.

The southern Green Day stock, which was comprised of several spawning populations, declined more gradually beginning in the 1920s. Pollution of the bay and of the Fox River spawning ground were the most likely causes. However, large populations of rainbow smelt and alewife developed after that and may have hindered walleye recovery.

The southeastern Lake Michigan stock spawned primarily in the Muskegon River, but the St. Joseph, Grand, and other rivers may have contributed some recruits from their resident populations prior to the 1920s. Recruitment of walleye from the Muskegon River apparently was enhanced by the construction of the Newaygo Dam in 1900. A large spawning run soon developed which, as late as 1954, was estimated at 139,000 adult walleyes. By the early 1960s, both the spawning run and the offshore commercial fishery had declined drastically. By 1975, the run contained only about 2,000 adults and many of those lived in the river year-around. The decline was primarily attributed to presumed negative effects of alewife on larval walleye in the Muskegon bake nursery area.

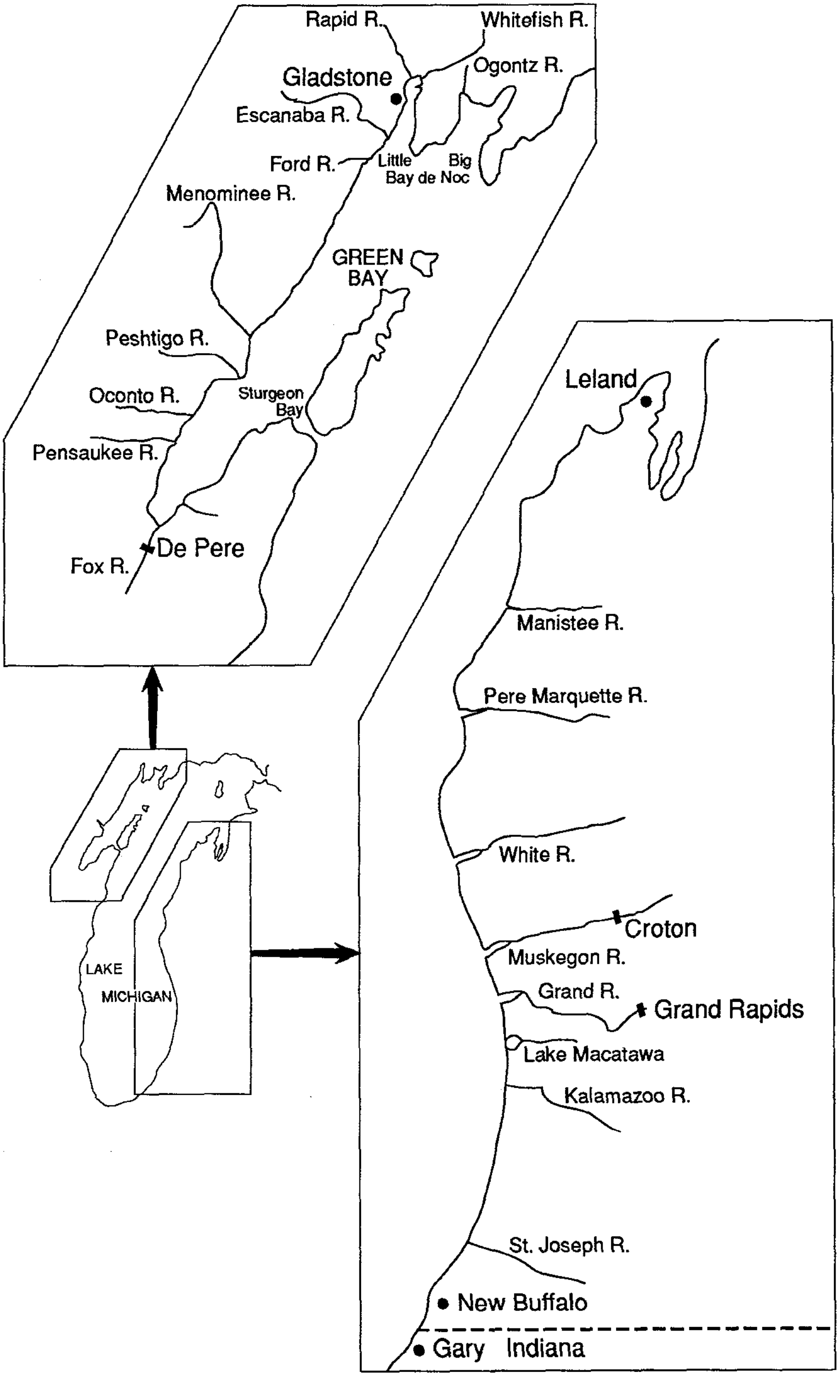

Fig. 1. Lake Michigan with enlarged maps of Green Bay and the southeastern shoreline.

INFORMATION SOURCES

Much of the recent information in this report has been derived from unpublished sources including agency files, ongoing studies, and long-term observations and experiences of the authors. Northern Green Bay has been studied and managed since 1970 by Jerry Peterson (and the late Bill Bullen) and Phil Schneeberger. Southern Green Bay has been studied and managed since 1981 by Terry Lychwick, Wisconsin DNR at Green Bay. The southeastern Lake Michigan stock has been jointly managed since 1969 by John Trimberger (assisted in recent years by Rich O'Neal), Michigan DNR at Grand Rapids, and Dave Johnson, Michigan DNR at Plainwell. Extensive current data on walleye sport catch in Michigan waters were supplied by Jerry Rakoczy and Dick Rogers of Michigan DNR in the form of agency reports and updates.

NORTHERN GREEN BAY

Management

Management actions in Michigan waters of Green Bay have been directed at reducing exploitation to conserve remnant populations and stocking small walleye to circumvent the recruitment problem. The primary objective has been to reestablish natural reproduction rather than provide an immediate fishery. Exploitation was reduced by:

1) banning commercial harvest (since 1969),

2) raising the minimum size limit on sport-caught walleye from 13 to 15 inches (since 1976), and

3) delaying the annual opening of the walleye sport-fishing season from late April to mid-May (since the late 1960s).

These regulations were not specifically targeted at the northern Green Bay stock, but were enforced in all of Michigan's Great Lakes waters to conserve all walleye stocks. The regulations helped protect the spawning stocks in northern Green Bay but, as will be discussed later, no noticeable improvement in recruitment can be attributed to them. To some extent, their potential beneficial effects were offset by a tribal commercial fishery that operated from the late 1970s until 1985.

An ongoing program of walleye fingerling and fry stocking began in 1971. The stocking rate was gradually increased to 0.5 million fingerlings and four million fry per year (Fig. 2). By 1988, a total of three million fingerlings and 24 million fry had been stocked. Most were released at the northern end of Little Bay de Noc, some off the Ford River, and some in Big Bay de Noc (Fig. 1). Eggs and sperm for the stocking program have been obtained almost solely from native ripe adults netted off the mouth of the Whitefish River. Many of the resulting fry were reared in ponds then stocked back into the bay at average lengths of 43 to 58 mm.

Density and Yields

The recovery of the stock as a result of the stocking program has been reflected by an increase in the spawning run. Prior to the maturation of the first stocked cohort, it was very difficult to obtain enough eggs from native fish to start the rearing program. In spring 1972, only 18 native spawning walleyes were caught in four trapnet lifts. Catches of ripe adults steadily increased after the mid-1970s, enabling the stocking program to expand to the full capacity of the rearing ponds, and even providing excess eggs for stocking other waters. Since 1988, Michigan's entire Upper Peninsula walleye rearing program has been supported by this ready source.

The buildup of the stock also has revitalized the sport fishery in northern Little Bay de Noc above Gladstone. Statistics on the sport fishery date back to the 1940s. In 1942-45, walleye comprised 14% to 70% of the total annual catch, and angler catch rate varied from 0.12 to 0.72 per hour (Roelofs 1946). The peak sport (as well as commercial) fishery reportedly occurred from the mid-1940s to the mid-1950s (mainly due to the extraordinary 1943 year-class), but no sport statistics were collected during that period (Crowe et al. 1963). In 1958, the waning yield for all of northern Green Bay was estimated at over 0.5 million walleyes-420,000 by sportsmen plus 119,000 by commercial fishermen (Crowe et al. 1963). By 1965, the population had reached an all-time low: only three walleyes were observed during a random creel census covering the northern end of Little Bay de Noc and the total walleye catch was estimated at less than 25 fish in 7,000 angler hours (Wagner 1968). Stocking began in 1971, and by 1976 a May-July fishery had developed which produced about 3,000 walleyes in 18,000 hours (Michigan DNR, unpubl. data). By the mid-1980s, the sport catch in Little Bay de Noc had increased to about 20,000 walleyes per year and effort had increased to about 350,000 angler hours per year (Table 1). The fishery remains concentrated at the northern end and some fish are caught there year-around. Annual catch rate averages about 0.05 walleye per hour. This figure is relatively low because the yellow perch (*Perca flavescens*) is the primary sport species in this area and Michigan's minimum size limit on walleye (15 inches) is relatively high. The catch rate is about three times higher at the best sites in the best months (May-July).

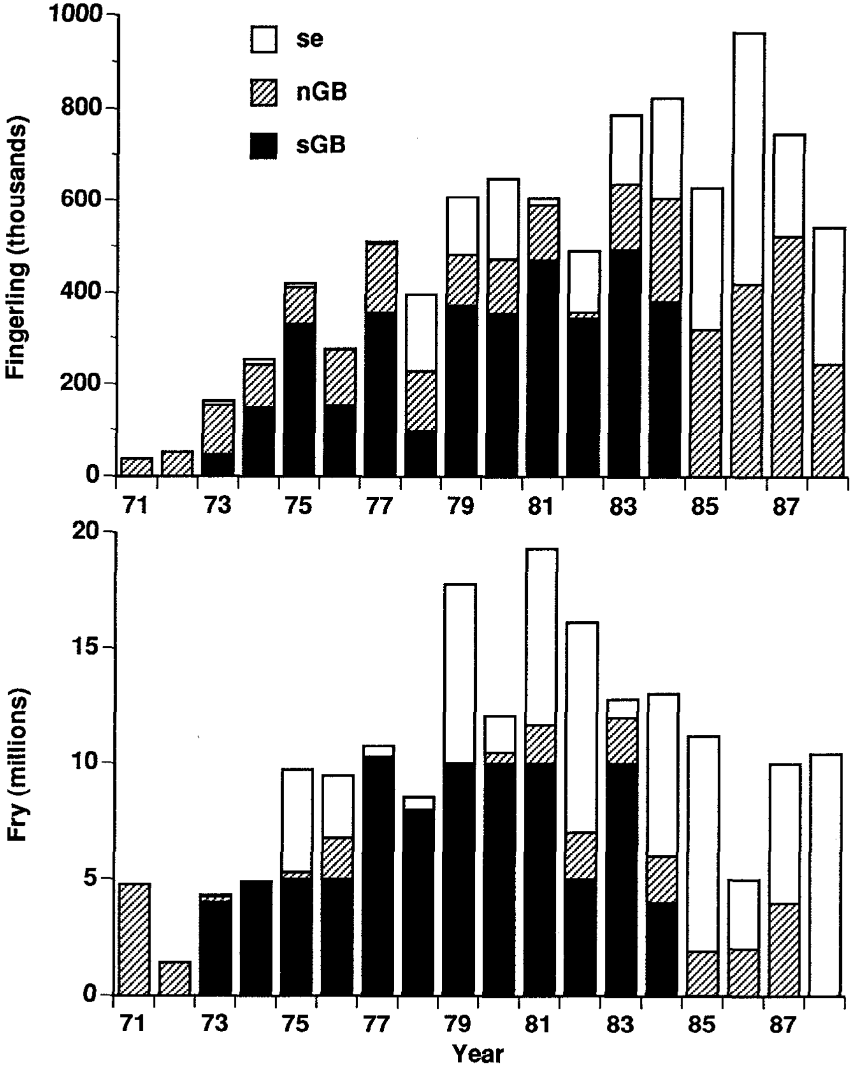

Fig. 2. Number of walleye fingerlings (upper panel) and fry (lower panel) stocked in southern Green Bay (sGB), northern Green Bay (nGB), and along the southeastern shore (se), 1971-88. For example, in 1988 no fingerlings were stocked in southern Green Bay, 245,000 in northern Green Bay, and 300,000 along the southeastern shore.

Walleye fisheries in other parts of northern Green Bay are very small. In Big Bay de Noc, which was not heavily stocked until 1986, no walleye were recorded in a January-October 1987 creel census and only 518 walleyes were estimated to have been caught in May 1986. No walleye were taken along the western side of northern Green Bay in 1986 or 1987 except near Menominee. There, estimated harvests were 278 in 1986 and 854 in 1987, all in May-July.

Table 1. Monthly estimates of walleye harvested and total angler hours for the Little Bay de Noc sport fishery, 1985-87. Data from Rakoczy and Rodgers (1987, 1988).

	Walleye harvested			Angler hours		
Month	1985	1986	1987	1985	1986	1987
Jan	2,758		2,343	116,085	---	113,128
Feb	2,132	---	1,410	131.558	---	97,663
May	6,750	15760	---[a]	32.975	60,324	11517
Jun	1,886	1,516	---[a]	35,673	32,013	12,468
Jul	3,163	4539	2,886	18,887	34,405	32,623
Aug	1,475	733	6,285	23,633	52,784	33,357
Sep	273	50	321	13,674	5,398	22,082
ckt	126	---	298	2,204	4,525	8,158
Total	18,563	19,598	13,543'	374,689	189,449	330,996

[a] Estimates for May and June, usually the peak months, were unreliable. Consequently annual total catch was probably in excess of 20,000 walleyes in 1987.

Population Characteristics

Movements. Walleye stocked in northern Little Bay de Noc do not disperse widely. In 1977-78, 2,049 of these walleye were marked with Floy anchor tags while spawning at the northern end of the bay. Recapture data indicated little movement: 54 were retaken north of Gladstone and one was retaken from the Escanaba River. Monel jaw tags were affixed to another 2,496 adult walleyes in April 1988.

Similarly, most (66%) were recaptured within eight km of the tagging site and the maximum dispersed distance was only 19 km. This pattern reflects where the sport fishery is concentrated. However, many of the larger walleye move to deeper waters. This became apparent in 1983-85 when tribal gillnets took many large walleye (26,800 kg in one year) from the central part of Little Hay de Noc. The original stock may have been more migratory than the present one. Of those tagged in 1957-60, 1.1% were recovered in the central or southern parts of Green Hay (Crowe et al. 1963). The Menominee River stock now appears to be isolated from walleye in northern Green Hay but has some interchange with stocks in southern Green Hay.

Growth. Growth has varied according to sex, time period, and population density (Fig. 3). Growth was relatively slow when the population was high (1949-51) and relatively fast when it was rebuilding (1976-81). The most recent data (1988) indicate growth has begun to slow, probably an indication that population density is starting to approach the capacity of the forage base.

Maturity. Restored spawning runs contain very few mature males shorter than 356 mm (total length) or younger than age 3, and very few mature females shorter than 483 mm or younger than age 5 (Table 2 and Michigan DNR, unpubl. data). These samples may be tentatively compared to samples collected directly from the bay by Hatch (1952) during the period of high population density and slower growth. The comparison suggests that the maturity pattern was similar for males but females now mature at a larger size. Balch (1952) reported that more than 50% of the 432-482 mm females were mature.

Recruitment. Natural recruitment of walleye in Bay de Noc has been very low since 1953. Recruitment was poor even though the native stock was supported by numerous discrete and widely dispersed spawning populations (Crowe et al. 1963); this indicates the problem was not localized. Fingerlings stocked in 1971 established a modest cohort (Table 2). Large schools of these fish were observed several times during 1971 and they began to renew the sport fishery the following year. Subsequent additions of fingerlings also clearly made a large contribution, but the success of stocked fry is unknown.

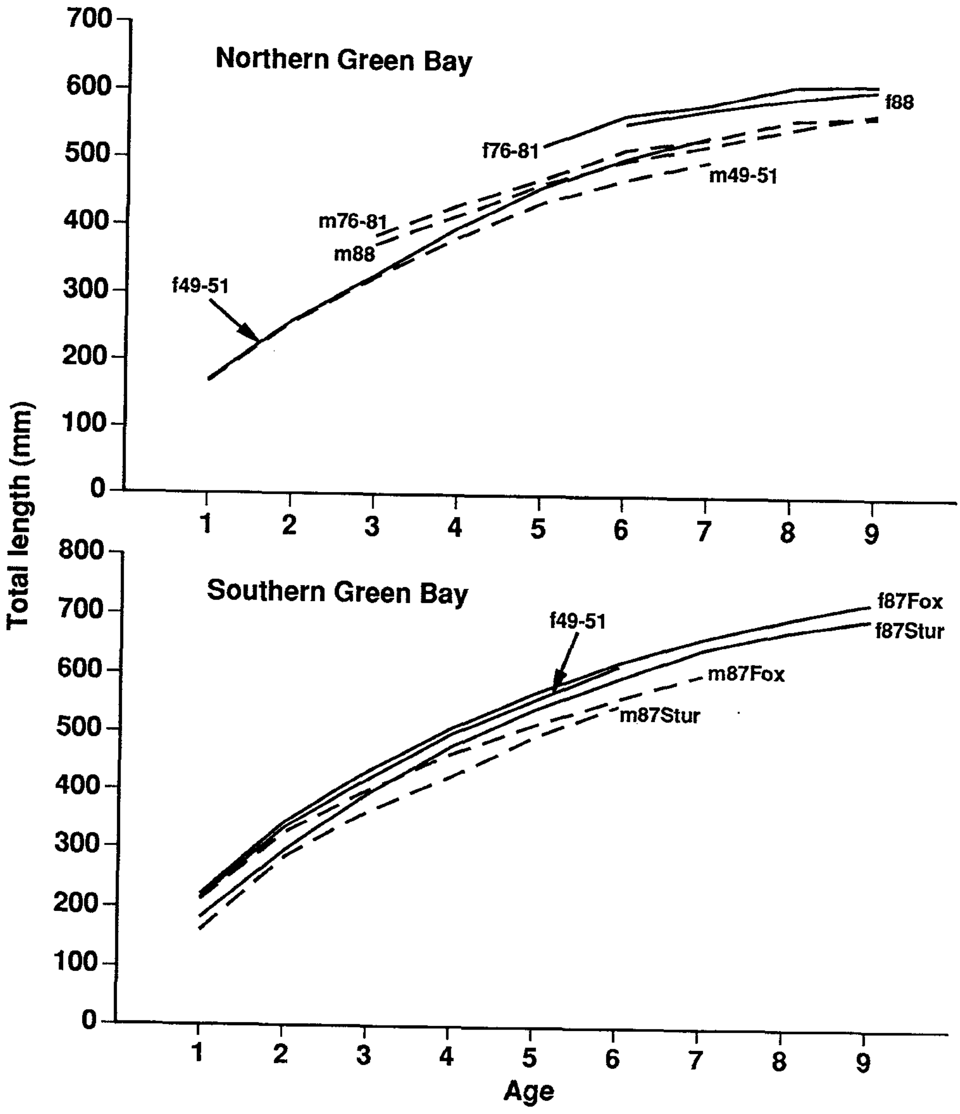

Fig. 3. Length-at-age for male (m, dashed lines) and female (f, solid lines) walleye from northern Green Bay (upper panel) and southern Green Bay (lower panel) in early (1949-51) and recent (1976-81, 1987, 1988) years. For southern Green Ray, 1987 samples were from populations in the Fox River ("Fox") and Sturgeon Say ("Stur"). The curve for southern Green Bay males in 1949-51, ages 1-3, is not shown because it overlapped the "m87Fox" curve.

Table 2. Age composition (percent) of the walleye population in Little Bay de Noc. Spring samples (sp) are from trapnetted spawners near the Whitefish River; summer samples (su) are from gillnets set in the bay proper. N = sample size; T = <0.5%.

Sex, year, season	N	Age 1	2	3	4	5	6	7	8	9	10+
Male											
1976 sp	61			29	61	5	2	3			
1977 sp	70			3	51	31	10		3		2
1978 sp	7.5			11	33	50	5	1			
1979 sp	325			11	34	24	27	3	1		
1980 sp	281			4	28	28	15	20	4	1	
1981 sp	218		1	2	26	6	20	17	20	6	2
1988 sp	242		T	39	22	13	10	4	5	3	3
Female											
1977 sp	17					29	65				6
1978 sp	33					43	21	18	3		15
1979 sp	76				3	7	75	12	2		1
1980 sp	35					8	20	49	14	3	6
1981 sp	80				1	8	10	31	21	14	15
1988 sp	73				2	1	21	14	5	1	56
Both sexes											
1966 su	35	6	3	6	12	3	46	9		3	12
1967 su	31	3	7	16		3	3	26	36	3	3
1972 su	6	67	17						36	16	
1973 su	25		100								
1975 sp	88		5	80	11	2					2
1976 sp	61			29	61	5	2	3			
1977 sp	91			2	43	31	21		2		1
1977 su	32		16	6	34	38				6	
1978 sp	109			7	23	47	10	6	1	1	5
1979 sp	401			10	28	21	36	4	1		T
1980 sp	316			3	25	26	16	23	5	1	1
1981 sp	298		T	1	19	7	18	21	20	8	5
1988 sp	315		T	32	19	11	12	6	5	2	13

Spawning now occurs at many of the traditional sites. In Little Bay de Noc, the Whitefish River once again receives a heavy run (thousands of adults) and many shoreline reefs are also used. In Big Bay de Noc, the Ogontz River receives a token run and spawning has been observed on several reefs. Observations were made at several reefs in the Rapid River area of Little Bay de Noc in 1978 and 1979. Many walleye eggs were found but a very low percentage of them were alive. Poor egg survival appeared to have been due to siltation and extensive growths of periphyton. Observations were made on the Whitefish River in 1983. There the substrate was in good condition, eggs were viable, and some walleye fry were collected; but fry numbers were relatively sparse. No abrupt increases in the adult walleye stock or fishery have yet occurred that cannot be logically attributed to fingerling stocking: however, modest numbers of native fingerlings were collected off the mouth of the Whitefish River in 1988.

The viability of early life stages is of some concern. Little Bay de Noc walleye eggs, routinely incubated in the Thompson State Fish Hatchery (W. Yoder, Michigan DNR, pers. commun.), experience a lower hatching rate (approximately 30%) than eggs from inland lakes (approximately 45%). However, survival of fry to fingerling size in rearing ponds has been good, usually 23% to 45%.

Survival. Survival of stocked walleye to adult size has not been estimated. However, survival must have been high because a sport harvest of about 20,000 adults per year resulted from additions of about 100,000 fingerlings per year plus a small amount of natural recruitment. The contribution from the relatively small numbers of fry stocked in some years was probably insignificant.

Good survival of walleye adults is evidenced by the frequency of old fish in the spawning run--up to age 15 based on dorsal-spine sections collected in 1988. An annual survival rate of 60% was calculated for both males (ages 3-11) and females (ages 6-11) from age-frequency samples in 1988 (Table 2) by the Robson-Chapman method (Ricker 1975). This is a considerable improvement over the 35% survival rate estimated for the period from the late 1950s to the mid-1960s (Schneider and Leach 1979).

Exploitation. As mentioned earlier, commercial fishing was banned after 1969 and a tribal fishery ended in 1985. Sport-fishing exploitation has been low but is increasing as the fishery continues to expand. Anglers reported the recapture of only 1.8% of the adult walleye tagged in 1977 (in the following 27 months), and just 1.4% of the fish tagged in 1978 (over the following 15 months). In 1988, 7%

of the jaw-tagged walleye were returned by fishermen within the first 12 months. Given the usual amount of tag nonreporting and some shedding of the anchor tags, these numbers suggest low exploitation. First-year returns from tagging in 1957-63 were also low (2% to 6%) but a much higher exploitation rate is suspected (Schneider and Leach 1979).

Community and Habitat Trends

The walleye has been restored as the top predator in Little Bay de Noc, now comprising 72% of the piscivore sport catch. Smallmouth bass (*Micropterus dolomieui*) and northern pike (*Esox lucius*) remain the predominate piscivores in the Big Bay de Noc fishery. Ten species contribute to these fisheries.

The fish community of Bay de Noc has experienced other important changes. The alewife stock has been much lower since the mid-1970s and rainbow smelt declined dramatically in the mid-1980s; their densities no longer seem to pose threats to walleye recruitment. Yellow perch stocks, which were depressed in both bays during the early 1970s, rebounded by the late 1970s. A tribal fishery and an illegal commercial fishery temporarily depleted the yellow perch stock in Big Bay de Noc in the early 1980s, but now this stock is in excellent condition. Stocks of northern pike, smallmouth bass, common carp (*Cyprinus carpio*), and sucker seem to have been stable over the last 20 years. White perch (*Morone americana*) have appeared in southern Green Bay and one was found in northern Green Bay in 1989. The threespine stickleback (*Gasterosteus aculeatus*), a species not previously documented in northern Green Bay, was captured in Big Bay de Noc trawl samples in 1988.

Diet information for yellow perch and walleye has been updated for the first time since the mid-1960s (Schneeberger 1989 and unpubl. data). Stomach contents from 1,164 yellow perch were examined during 1988. Diet from June through August included the usual items such as amphipods, midge larvae and pupae, mayflies (including *Hexagenia*), caddisfly larvae, and fish. During September and October, the exotic cladoceran *Bythotrephes cederstroemi* (BC) was found in 30% of the yellow perch collected from Little Bay de Noc and 4% of the yellow perch from Big Bay de Noc. From 1 to 120 (mean = 16.7) BC were counted in individual stomachs of 76-213 mm yellow perch. Caudal spines of BC substantially clogged intestines of at least seven yellow perch. Of 39 other fish species caught and examined, trout-perch (*Percopsis omiscomaycus*) had the greatest degree of diet overlap with yellow perch, but rock bass (*Ambloplites rupestris*) was the only other species found to have ingested

BC. Only 21 walleye stomachs were examined and most were empty. Of those containing food, alewife and rainbow smelt were the prominent items.

Water quality has not changed perceptively but, as noted above, it may be limiting walleye spawning success in the Rapid River area. Contaminants are not considered to be a major problem in this area as compared to southern Green Bay, but further study is needed to determine if contaminants might be related to the mediocre eye-up rate of walleye eggs and continued low natural recruitment. Human consumption advisories are in effect for walleye over 560 mm long (mercury >0.5 ppm) and large salmonids (PCBs >2 ppm).

SOUTHERN GREEN BAY

Management

The major objectives of walleye management in the Wisconsin waters of Green Bay have been to:

1) increase the standing crop of walleye in suitable parts of southern Green Bay and its tributaries to ten adults/ha, and

2) restore a self-sustaining stock.

The southern Green Bay stock had deteriorated to the point where only the Menominee River still supported a spawning population (Fig. 1). Management activities have included stocking small walleye and, in recent years, implementing more restrictive fishing regulations.

Stocking began in 1973 with the introduction of walleye fry and fingerlings into the Sturgeon Bay area (Fig. 2). The Fox River was added as a planting site in 1977, and several other sites have been also been stocked. By 1984, a total of 3.55 million fingerlings and 86 million fry had been released. Stocking was discontinued after 1984 so the magnitude of natural recruitment could be evaluated better.

Walleye for the stocking program were obtained from various inland lakes in northern Wisconsin. Eggs were cultured in the state hatchery system and fingerlings were reared in ponds to lengths of 33-86 mm before release into the bay or its tributaries.

Commercial harvest of walleye was banned after 1978, but mortalities from incidental catches increased as stock was built up. By 1984, it was estimated that nearly 10,000 walleyes were killed incidentally by gillnet (8,300) and dropnet (1,100) fisheries targeting yellow perch. Following the implementation of a perch harvest quota, which led to an increase in yellow perch abundance and to a reduction in the amount of gear deployed, the incidental walleye kill was reduced to 1,700 in 1986.

Concern about high sport catch led to more restrictive regulations. Daily bag limit was reduced from five to three walleyes in 1983. Beginning in 1989, a trophy fishery was established in the Fox River from March 1 to the first Saturday in April because approximately 50% of the annual harvest was being taken during the spawning run. Restrictions are a 711 mm (28 inch) minimum size limit and the daily bag limit is one.

Intensive sampling was begun in 1976 to evaluate the restoration program. A variety of survey techniques were used including:

1) electrofishing along the shoreline and in the Fox River in fall or summer,

2) gillnetting in fall,

3) shoreline seining in June-July,

4) bottom trawling in August-September,

5) fyke netting in spring, and

6) monitoring of catches by commercial perch fishermen.

Walleye with a total length of 300 mm were marked with Floy anchor tags and fin clipped at the Sturgeon Bay and Fox River sites, the ones sampled most intensively. Index stations, established along both the eastern and western shores, were sampled less intensively. A contact-type creel census was begun in 1983. The sampling program has produced data on walleye density, distribution, survival, movement, age composition, year-class strength, spawning areas, amount of natural recruitment, and angler harvest.

Yields and Density

The restoration program has reestablished a significant walleye sport fishery in local areas. A major fishery developed in the Fox River below De Pere Dam, a good fishery developed at Sturgeon Bay, and small fisheries developed near other planting sites. By the mid-1980s, the annual harvest from the Fox River at De Pere had risen to over 30,000 in some years (Table 3). Peak catches were made during the spring spawning run and during the fall, but fish were available in the river year-round. Catch rate was remarkably high, O-3-0.4 walleye per angler hour, which allowed anglers the luxury of sorting their catch. Net samples also indicate there are large numbers of unexploited walleye available off the mouth of the Fox River. Estimates of walleye sport catch from other areas have not been completed at this time.

Table 3. Monthly estimates of walleye harvested, walleye harvested per angler hour, and angler hours for the Fox River sport fishery at De Pere, 1983-85. Dash indicates no census was taken.

	Walleye harvested			Walleye per hour			Angler hours		
Month	1983	1984	1985	1983	1984	1985	1983	1984	1985
Jan	---	580	212	---	0.15	0.18	---	3,959	1,158
Feb	---	619	82	---	0.12	0.14	---	4,981	599
Mar	---	5,370	7,663	---	0.37	0.33	---	14,477	23,224
Apr	---	14,953	7,360	---	0.33	0.27	---	45,283	27,706
May	798	3,841	3,581	0.04	0.33	0.33	18,413	11,517	11,034
Jun	777	1,600[a]	2,487	0.07	0.24	0.41	10,848	6,650[a]	6,126
Jul	158	---	224	0.07	---	0.05	2,376	---	4,422
Aug	---	25″	854	---	0.08	0.35	---	315	2,412
Sep	4,507	5,077	1,992	0.53	0.62	0.44	8,508	8,232	4,566
Oct	19,681	5,517	4,661	0.91	0.66	0.60	17,977	8,378	7,764
Nov	2,680	808	28	0.75	0.62	0.07	3,566	1,300	384
Total	28,601	38,390	29,144	0.46	0.37	0.33	61,688	105,092	89,395

a Incomplete: no Census June 24-August 25, 1984.

Mark-and-recapture population estimates have been made in conjunction with tagging or fin clipping on the Sturgeon Bay spawning grounds since 1976 (Table 4). This population increased from zero to approximately 1,800 in 1976 as the first cohort of stocked walleye started to mature. Since then, estimates have ranged between 6,500 and 23,500, with the exception of a peak of 42,000 in 1980. The average population, about 10 walleyes/ha, met the goal of the restoration program.

Table 4. Spring fyke net catches and population estimates for walleye in Sturgeon Bay, WI, 1976-88.

Year	Sex percent			Total catch	Population	
	Male	Female	Unknown		Estimate	95% limits
1976	95.8	0.3	3.9	306	1,840	860-3,600
1977	69.7	13.9	16.4	1,719	6,500	4,500-9,300
1978	84.3	10.2	5.5	1,817	16,400	11,200-24,200
1979	76.5	19.4	4.1	1,426	11,100	7,692-16,666
1980	81.5	17.6	0.9	2,541	42,000	31,707-55,722
1981	60.9	34.4	4.7	4,042	17,800	16,250-19,600
1982	66.1	33.8	0.1	2,280	8,466	7,438-9,740
1983	49.8	46.7	3.5	2,661	13,270	11,678-15,217
1984	55.8	42.3	1.9	2,675	20,944	17,906-24,501
1985	44.1	55.0	0.9	2,314	17,187	15,00519,894
1986	40.0	59.8	0.2	2,433	23,470	19,76S-27,363
1987	58.6	38.8	2.6	1,480	8,595	7,278-10,741
1988	67.5	32.3	0.1	2,870	14,602	13,674-16,295

Population Characteristics

Movements. Tagging studies and density patterns indicate populations remain within rather small areas and are quite discrete. For Fox River walleye tagged in the springs or falls of 1981-83, 823 returns were made through 1984. Most (91%) were caught just below De Pere Dam or within 29 km (lower river and tip of the Bay), 3.5% moved up through the lock and were recaptured above the dam, 2.8% were found in Sturgeon Ray, and 2.9% were caught near Menominee. For walleye tagged in Sturgeon Bay in the springs of 1984-87, 163 returns were reported by anglers as of April 30, 1988. Most (94%) were caught within a 19 km radius of the tagging site, 1.8% moved to the Menominee River, and 1.2% were recaptured near the Oconto River.

Growth. Growth of walleye has been very rapid throughout southern Green Bay but especially in the Fox River area (Fig. 3). For example, in 1987 the average total length of age-5 females was 571 mm in the Fox River and 543 mm in Sturgeon Ray. A comparable figure for the northern Green Bay population is about 500 mm. These rates greatly exceed the Wisconsin and Michigan state averages. Growth has been consistent with 1949-51 samples (a period of low density) and has not yet declined in response to increasing density.

Maturity. Because of rapid growth, most male walleye are mature at age 3 and most females at age 4 or 5 (Table 5). Most males 360 mm or longer are mature, whereas few females (generally less than 5%) mature before reaching 470 mm.

Recruitment. Spawning populations have been restored in the Fox, Oconto, Peshtigo, and Pensaukee Rivers due to stocking and improved water quality, but only the Fox River is known to be producing significant numbers of young. A successful reef-spawning population was established in Sturgeon Bay where none ever existed, as far as is known. The only other known spawning site is in the Menominee River, which has continually sustained a modest population for over a century. It is anticipated that shoal-spawning populations will eventually be established in the lower bay to supplement the Fox River spawners.

The relative strength of walleye year-classes in Sturgeon Bay and the Fox River were ranked to determine the importance of natural recruitment and the contribution of stocked fry and fingerlings (Table 6). For Sturgeon Bay, the best index of cohort density was obtained from spring fyke net data by multiplying annual population estimates by age composition (percent) then adding for ages 3-6 to smooth out sampling variations (Tables 4, 5). An index based on age 3 only was also used because it provided a way of ranking the strength of more recent cohorts. For the Fox River (Table 7), annual total catch in electrofishing surveys was multiplied by age composition to obtain density indices by age, then these were ranked within each age group. Cohorts with consistently high or low ranks could then be identified.

Table 5. Age composition (percent) of the Sturgeon Bay walleye spawning population, 1976-88. N = sample; T = <0-5%.

Sex, year, season	N	Age 2	3	4	5	6	7	8	9	10+
Male										
1976	293	1	99							
1977	1,199	2	82	18						
1978	1,531		72	26	2					
1979	1,091	4	28	42	15	2				
1980	2,070		55	18	18	8	1			
1981	2,460		37	30	23	9	2	T		
1982	1,507	46	15	18	12	6	3	T	T	
1983	1,325	8	44	12	15	12	8	1	T	
1984	1,490	T	39	21	11	6	16	S	1	T
1985	1,020		8	28	25	14	10	10	3	5
1986	973	1	2	10	40	22	12	9	3	2
1987	867	17	24	22	24	11	2			
1988	1,938	1	50	23	14	11	1	T	T	T
Female										
1976	1									
1977	238		2	98						
1978	185		1	66	33					
1979	276			45	45	10				
1980	448			12	53	25	10			
1981	1,391			26	46	18	9	1		
1982	773			39	41	11	8	2		
1983	1,243		4	19	36	24	15	2	1	
1984	1,025			31	24	22	15	S	2	1
1985	1,273			26	30	8	17	13	3	3
1986	1,455		T	18	30	16	7	14	8	7
1987	574	1		9	43	24	17	4	1	1
1988	932	T	5	20	13	30	25	5	1	T
Both sexes										
1976	294	1	98							
1977	1,437	1	67	31						
1978	1,716		64	31	6					
1979	1,365	3	30	42	21	4				
1980	2,518		45	17	24	11	3			
1981	3,851		24	28	31	12	4	1		
1982	2,280	31	10	25	22	7	4	1	T	
1983	2,568	4	27	15	25	17	12	1	1	
1984	2,515	T	23	25	17	13	16	5	1	1
1985	2,293		4	27	28	10	14	12	3	2
1986	2,428	T	1	16	34	18	9	12	6	5
1987	1,441	10	15	17	32	16	8	2	1	T
1988	2,870	1	35	22	13	17	9	2	1	T

Table 6. Relative strength of walleye year-classes in Sturgeon Bay (based on spawning-run population estimates) and the Fox River (based on fall electrofishing CPUE) compared to stocking rates.[a]

	Sturgeon Bay					Fox River	
	Estimated number by age			Walleye stocked			
Year class	X(3-6)	3 only	Strength rank	Fingerlings (thousands)	Fry (millions)	Strength rank	Fry stocked (millions)
72 and older	0	0	0	0	0	Very low	0
1973	5,160	1,809	Low	46	0	Very low	0
1974	16,272	4,381	Medium	1.50	4	Very low	0
1975	27,521	10,480	High	331	5	Very low	0
1976	16,844	3,341	Medium	134	5	Very low	0
1977	28,225	19,068	High	248	5	Medium	---[b]
1978	11,905	4,236	Medium	57	9	Medium	8
1979	7,533	838	Low	333	0	High	10
1980	16,950	3,530	Medium	0	0	Medium	10
1981	17,785	3,867	Medium	472	0	Medium	10
1982	---	619	Low	0	0	High	5
1983	---	70	Lowest	0	0	Medium	6
1984	---	1,255	Low	382	0	Low	4
1985	---	7,154	Medium	0	0	Low	0
1986	---	---	Low	0	0	Low	0
1987	---	---	---	0	0	Very low	0

[a] Natural recruitment possible in sturgeon Bay since 1977 and in the Fox River since 1981.

[b] 58,850 fingerlings were stocked in 1977 rather than fry.

Table 7. Age composition (%) of walleye collected during fall electrofishing surveys at Fox River, De Pere 1981-88. N = sample size: T = <0.5%.

Sex, year,		Age								
season	N	0	1	2	3	4	S	6	7	8+
1981	2,184	T	24	62	10	3	1			
1982	1,688	1	10	48	36	4	1		T	
1983	2,756	T	69	5	11	13	1	1	T	T
1984	**1,868**		1	85	7	4	2	1	T	T
1985	1,536		1	51	37	10	1	T		
1986	483	T	3	15	24	33	21	3	T	
1987	3,954	T	54	23	11	7	4	1	T	
1988	3.850		1	65	22	8	3	1		

For Sturgeon Bay, no cohorts were found prior to 1973, the first year stocked (Tables 5, 6). Relatively strong year-classes occurred in the mid-1970s and relatively weak ones developed in the 1980s. Year-class strength was correlated with fingerling stocking rate up through the 1978 year-class: however, very large additions in 1979, 1981, and 1984 produced only low to medium cohorts. Fry stocking, made concurrently in most years, was probably less successful (Kernan, Wisconsin DNR, unpubl. data). Natural reproduction could have begun in 1977 when most females in the 1973 cohort matured (age 4). Clearly, substantial numbers of native recruits were produced after 1980 in years when no walleye were stocked: however, these year-classes were of low to medium strength relative to all others. Electrofishing surveys at Sturgeon Bay index stations, initiated in 1983, confirm that the 1983 cohort was very weak and that the 1982 and 1984 cohorts were of similar (low) strength.

Relatively weak recruitment since 1979 appears to be due to:

1) poor survival of stocked fingerlings because they were relatively small (less than 50 mm), and

2) mortality of eggs and fry caused by intrusion of cold Lake Michigan water onto the spawning reefs.

In some years, wind-driven seiches cause temperatures to drop below 10°C during the incubation and hatching period, a shock that is likely to affect walleye survival (Hokanson and Lien, U. S. Environmental Protection Agency-Duluth, unpubl. data).

For the Fox River-De Pere population, very few walleye (migrants from upriver populations) existed prior to the onset of stocking in 1977 (Tables 6, 7). Medium to high cohorts were produced by adding five to ten million fry from 1978 to 1983. Natural reproduction probably began in 1981, and was clearly apparent in 1985-87 when no stocking took place. However, these native cohorts and the last stocked one in 1984 appear to be relatively weak. Good spawning substrate is relatively scarce below the dam, and may never supply enough recruits to saturate the entire lower bay with walleye. The success of fry stocking in the Fox River compared to Sturgeon Hay is attributed to the turbid, warm, productive character of the river.

Low recruitment in the lower Fox River cannot be attributed to any single factor. The major spawning area is located over rock and gravel substrate along a 0.3 km section of the eastern shoreline immediately below De Pere Dam, and many of the naturally spawned ova were developing satisfactorily in 1985 (Halter et al., University of Wisconsin, unpubl. data). Egg quality and water purity appear to be adequate because hatching rates as high as 61% were obtained in special incubators (Auer and Auer 1987). On the other hand, Hokanson and Lien (U. S. Environmental Protection Agency-Duluth, unpubl. data) observed a negative relationship between larval survival and female size and inferred a minor contaminant problem in the eggs of larger females. Overall, it appears that low reproduction is due to the limited amount of spawning substrate. Also, survival of embryos and larvae may be impaired by contaminants, sedimentation, fungal infections, and unfavorable temperatures.

Survival. Survival rates for fingerlings stocked in Sturgeon Hay in 1973, 1974, and 1975 were calculated from population estimates at age 4 and fingerling stocking rates (recall that fry survival was negligible and natural recruitment could not have begun until 1976). The estimates, considered to be maximal, were 4.4%, 3.3%, and 1.4% for those respective years. As indicated above, survival of subsequent stocked fish had to be much less. Survival of fry stocked in the Fox River cannot be estimated directly but must have been greater than 0.3% because stocking rates of about ten million per year were producing fisheries in excess of 30,000 adults per year.

Annual survival of adult walleye was calculated from tagging data and subsequent recaptures by anglers using

Ricker's (1975) large-sample formula. For the Sturgeon Bay population, estimates were 68%, 55%, and 90%, for 1984, 1985, and 1986, respectively. For the Fox River population, survival was much lower: 33%, 20%, 21%, 20%, and 15%, for 1981 through 1985, respectively. Both sets of estimates take into account tag-shedding rates of 40% to 60% in the first year, as determined by double marking with Floy anchor tags and fin clips. Oddly, the estimates of survival may be slightly biased by well-intentioned anglers who reported recaptures, but removed tags and released fish instead of harvesting them.

Exploitation. Much of the difference in adult survival between these two populations can be attributed to exploitation. For Sturgeon Bay, annual tag-return rate by anglers varied from 2% to 5%, and given typical rates of tag shedding (50%) and nonreporting (50% assumed), the true exploitation rate was probably about 10%. For the Fox River, an intensive sport fishery developed that removed about 35,000 walleyes per year from this relatively small area and necessitated the restrictions discussed earlier. Voluntary tag returns by anglers were 5% in 1982 and 7.2% in 1983, then increased to 8.5% in 1986 and 8.9% in 1987 when a $3.00 reward was offered for tags by the Stroh Brewery Company. With adjustments for tag shedding and nonreporting, the best estimates of the true exploitation rate are 19%, 29%, 34%, and 35% for 1982, 1983, 1986, and 1987 respectively.

Community and Habitat Trends

The habitat and fish community of southern Green Bay and its tributaries are in the process of change. Improvements in water quality since the mid-1970s have improved walleye spawning habitat and, through reduction in eutrophy, may be triggering other walleye-beneficial changes in the ecosystem (Leach et al. 1977). The yellow perch stock has rebounded, and rainbow smelt and alewife stocks have decreased.

Walleye predation could have played a minor role in these community shifts. In 1977 at Sturgeon Bay, Kernan (Wisconsin DNR, unpubl. data) found that the bulk of the walleye's food was rainbow smelt in spring and fall, and alewife plus rainbow smelt in July. These were the most abundant forage species in the area. Common fishes such as yellow perch, white sucker (*Catostomus commersoni*), and brown bullhead (*Ictalurus nebulosus*) were not eaten. This suggests some selectivity for rainbow smelt and alewife and that these species buffer the others from walleye predation. Similar selectivity for soft-rayed forage fish has been observed in western bake Erie and Saginaw Bay walleye (Knight et al. 1984; Mrozinski et al., in press). At present, in the Sturgeon Bay area, the predominant species are walleye, yellow perch, alewife, and rainbow smelt, and during spring and fall, various salmonids. In the Fox River and the lower end of Green Bay, the predominant species are walleye, yellow perch, and gizzard shad (*Dorosoma cepedianum*). Common carp, brown bullhead, and white sucker are also abundant; rainbow smelt and alewife move in seasonally. The white perch is a recent, unwelcome, addition to the complex.

Contaminants, particularly PCBs, have continued to persist in all fish species despite cleanup efforts. Beyond the obvious health considerations to man from the consumption of these fish, contaminants may be affecting reproduction of large walleye throughout southern Green Bay (Hokanson and Lien, U. S. Environmental Protection Agency-Duluth, unpubl. data), thereby hampering the walleye rehabilitation program by making it heavily dependent upon the reproductive success of small walleye.

SOUTHEASTERN SHORE

Management

Walleye stocks along the southeastern shore of Lake Michigan (Fig. 1) have been managed by the Michigan DNR like those in northern Green Bay. Commercial exploitation was banned after 1969 and angler exploitation was reduced (statewide increase in minimum size limit and delayed season) to conserve the remnant fish. Fry and fingerling walleye were stocked to circumvent the recruitment problem. The stocking program has been targeted primarily at developing fisheries and secondarily at developing self-sustaining populations. All six of the major river-lake drainage systems along the southeastern shore have been stocked. However, the Muskegon and St. Joseph Rivers have been the major walleye areas in the past and received the primary focus (Figs. 1, 2). From 1973 through 1988, a total of 2.25 million fingerlings and 72 million fry were stocked, with 47% of the fingerlings used to build up the Muskegon River spawning run. Remnant native walleye from this run were the primary source of eggs for the stocking program, but walleye from New York, Pennsylvania, and Ohio were added to the Grand River and Lake Macatawa in the earliest years. It is clear that some New York fish survived, raising the possibility that their genes were added to the gene pool. Typically, the fingerlings have been 35-75 mm long when stocked.

Density end Yields

An increase in the Muskegon River spawning run and a dramatic improvement in the sport fishery of each drainage system are proof of the success of the stocking program. The Muskegon River run increased from roughly 2,000 adults in the mid-1970s (an all-time low) to roughly 40-100 thousand adults in the mid-1980s. In 1953-54, a period of high abundance, the spawning run was estimated at 114-139 thousand fish (Crowe 1955). Walleye catches with electrofishing gear, which has been used below the lowermost dam (Croton) to obtain eggs and sperm for the rearing program, also demonstrate the marked improvement in walleye density from 1975 (mean = 15 per day) to 1981 (mean = 123 per day).

Local sport fisheries have been created or rejuvenated but a significant offshore stock and fishery in Lake Michigan has not been reestablished to date. It appears that relatively few of the stocked walleye migrate to Lake Michigan; however, this is difficult to evaluate because offshore sport fisheries target salmonids or yellow perch, and commercial netting has been greatly reduced. The CPUE for walleye in commercial trapnets off Muskegon was less than two fish per lift in 1985-86 (Smith 1988), compared to 37 per lift in 1953-54 (Michigan DNR, unpubl. data). In both periods, lake whitefish (Coregonus clupeaformis) were the primary species sought by commercial trapnetters.

Creel census estimates of annual walleye sport catch for ports from New Buffalo to Muskegon range from 1,300 to 12,900 for 1983-87. However, nearly all of these walleye were caught inside of, or very near, stocked drainages. Creel data for the inland portion of these drainage systems are incomplete. For 1987, we judge that the St. Joseph River produced about 10,000 walleyes (0.015 per hour), the Muskegon river-lake system yielded several thousand (as compared to about 9,000 in the early 1950s (Crowe 1957)), and the other drainage systems yielded lesser amounts. The grand total is probably in the 20-30 thousand range. By comparison, the peak commercial yield in the past was 20 mt, or about 17,000 walleyes (Schneider and Leach 1979), and total yield was probably about 30,000 walleyes.

Population Characteristics

The population spawning below the lowermost dam (Newaygo Dam prior to 1969, Croton Dam after 1969) has been monitored extensively. Some sampling and tagging has also been done in Lake Macatawa.

Movements. Historically, the Muskegon River spawning run was composed of large numbers of adfluvial migrants from eastern Lake Michigan, small numbers of walleye native to the river or Muskegon Lake, and some migrants from other drainage systems (Schneider and Crowe 1977). When the adfluvial stock was high in 1948-54, tagging studies found that nearly all spent adults had left the Muskegon river-lake system by July 1. As a result, the inland fishery was highly seasonal and a relatively high fraction (16.8%) of all tag returns came from offshore sites or other drainages (Table 8). When the adfluvial stock was low in 1975-76, the native component predominated, and only 0.7% of the tag returns were from outside the Muskegon River drainage (one fish went to southern Green Ray). In 1981-87, following the stocking program and an increase in the adult stock, outside returns remained low (4.5%) and a higher proportion of the returns (28.2%) came from Muskegon Lake. This has been reflected in the establishment of a good year-round fishery in Muskegon Lake and a summer fishery just off its outlet in Lake Michigan.

Table 8. Recapture location of spawning jaw-tagged walleye in the Muskegon River in 1948-54 (high density, adfluvial population), 1975-76 (low density, resident population), and 1981-87 (medium density, stocked population).

			Percent of recaptures by area		
Tagging year	Number tagged	Number recaptured	Muskegon River	Muskegon Lake	Elsewhere [a]
1948-54	2,159	435	77.7	5.5	16.8
1975-76	444	135	92.6	6.6	0.7
1981-87	4,058	309	67.3	28.2	4.5

*Includes the eastern shore of Lake Michigan from as far south as Gary, Indiana, to as far north as Leland, Michigan. The only recapture from the west shore came from southern Green Bay in 1976. In addition, fish have reappeared in every river between the St. Joseph and the Manistee. In the 1980s, walleye were recaptured from the Grand River (10), the Kalamazoo River (1), White Lake (1), and Pere Marquette Lake (1). Furthermore, walleye tagged in Lake Macatawa have been recaptured in the Muskegon River system and elsewhere, and 2-RP clipped fingerlings stocked in the Grand River in 1976 were recaptured in the Muskegon River in 1979 and 1988.

Adult walleye caught in Lake Macatawa, near the Black River, were jaw tagged in 1979, 1983, and 1984 (Table 9). Surprisingly, just 49% of the returns have been from the same system and 51% have been from other drainages or Lake Michigan proper.

Table 9. Numbers of spawning jaw-tagged walleye near Lake Macatawa and returns by anglers in subsequent years.[a]

Release data			Number of returns by calendar year after release					
Year	sex	Number	Same	1	2	3	4	5
1979	Male	33	1					
	Female	66	1					
	Unknown	1						
	All sexes	100	2					
1983	Male	207	12	9	7		1	1[b]
	Female	20						
	Unknown	2						
	All sexes	229	12	9	7		1	1[b]
1984	Male	0						
	Female	62	1					
	Unknown	318	20	7	2	2	2[b]	
	All sexes	380	21	7	2	2	2[b]	

a Returns came from Lake Macatawa (27), Kalamazoo River (15), Lake Michigan (5), Muskegon River (4), St. Joseph River (1), Spring Lake (1), White Lake (1), and Manistee Lake (1).

[b]Recaptured with electrofishing gear from the Muskegon River spawning run.

Growth. Generally, growth of walleye in the Muskegon River population has varied inversely with population density (Fig. 4). Growth was relatively slow in the 1950s (a period of high density), and it was relatively rapid in the 1970s (a period of low density). This is most evident for age-6 and older walleye, which have been well-represented in the spawning run and are most likely to have lived in the forage-rich waters of Lake Michigan or Muskegon Lake. The surprisingly slow growth of younger ages apparent during the 1970s (despite low density) is attributed to a higher proportion of river-dwelling native walleye which didn't have access to large numbers of alewife, rainbow smelt, or gizzard shad.

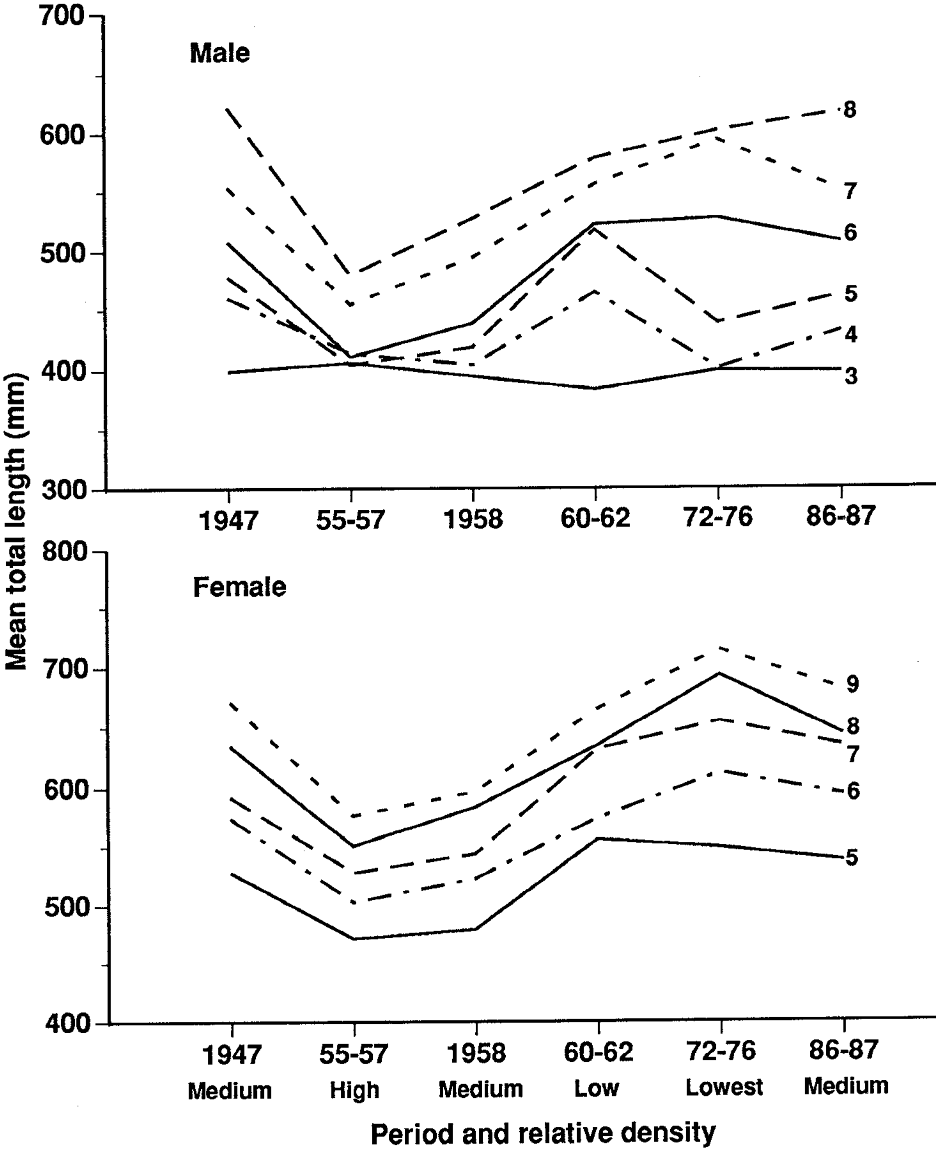

Fig. 4. Mean length-at-age for male (ages 3-8) and female (ages 5-9) walleye in the Muskegon River spawning run for six time periods and population densities.

Maturity. Traditionally, the Muskegon River walleye spawning run has been composed of relatively large and old fish but there have been marked shifts in age and size frequency (Figs. 5, 6). In 1947-55, when the adfluvial subpopulation predominated and recruitment was good, modal age was 5-6 and modal lengths were 400 mm for males and 500 mm for females. In the 1950s, the effects of poor recruitment began to appear as a shift towards older and larger adults. In the 1970s, the weak run appeared bimodal due to a higher proportion of small, young river residents and a lower proportion of large, old lake residents. In 1981, a large portion of the run was composed of age-3 males due to heavy stocking in 1978. By 1983-87, stocked walleye cohorts were well-established and the maturity pattern shifted back to large, old fish. (The shift during the 1980s was not as extreme as Fig. 5 indicates because large fish were favored for egg-taking).

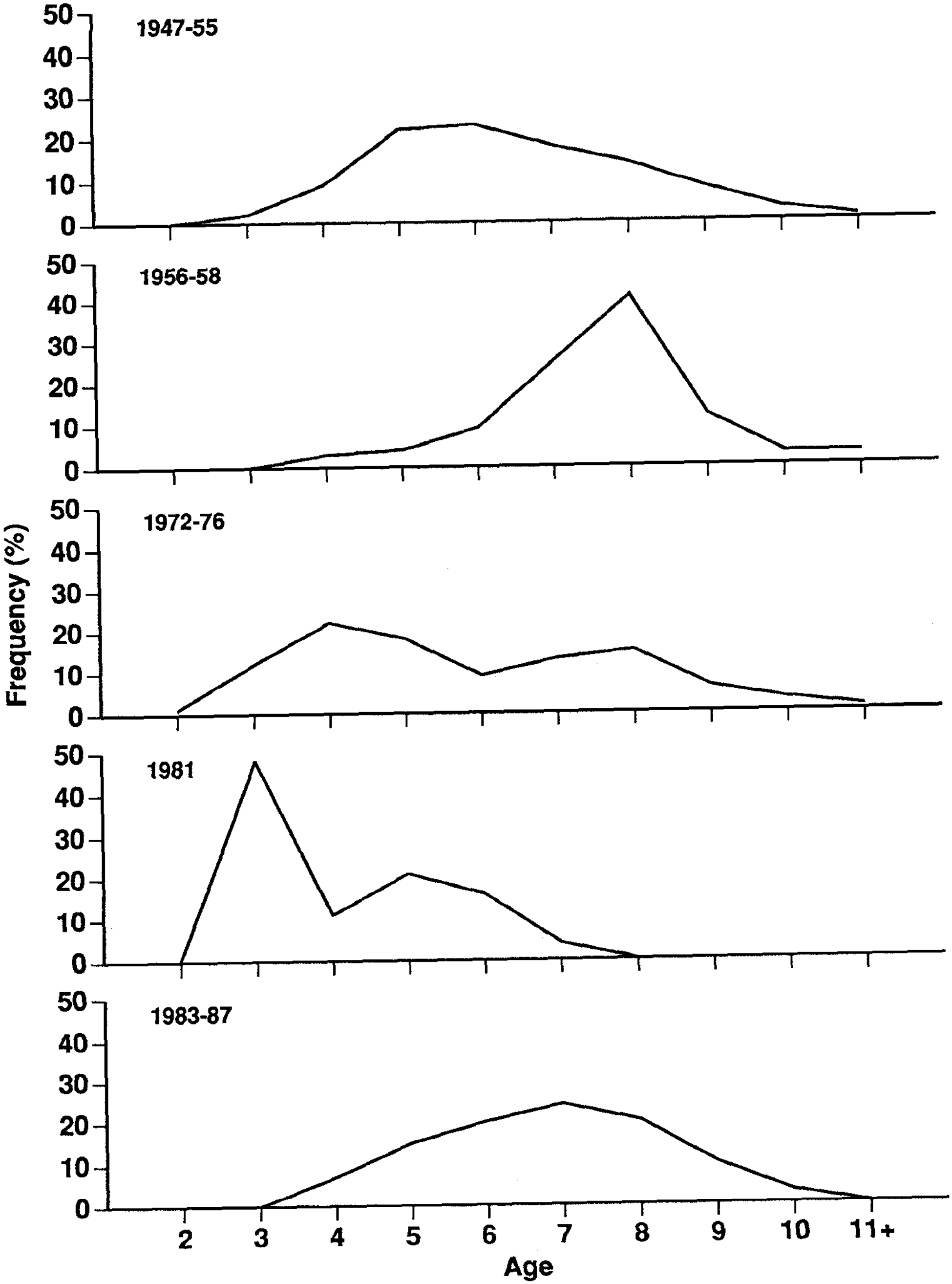

Fig. 5. Age-composition data of the Muskegon River walleye spawning run in five periods (data for 1947-76 from Schneider and Leach 1979).

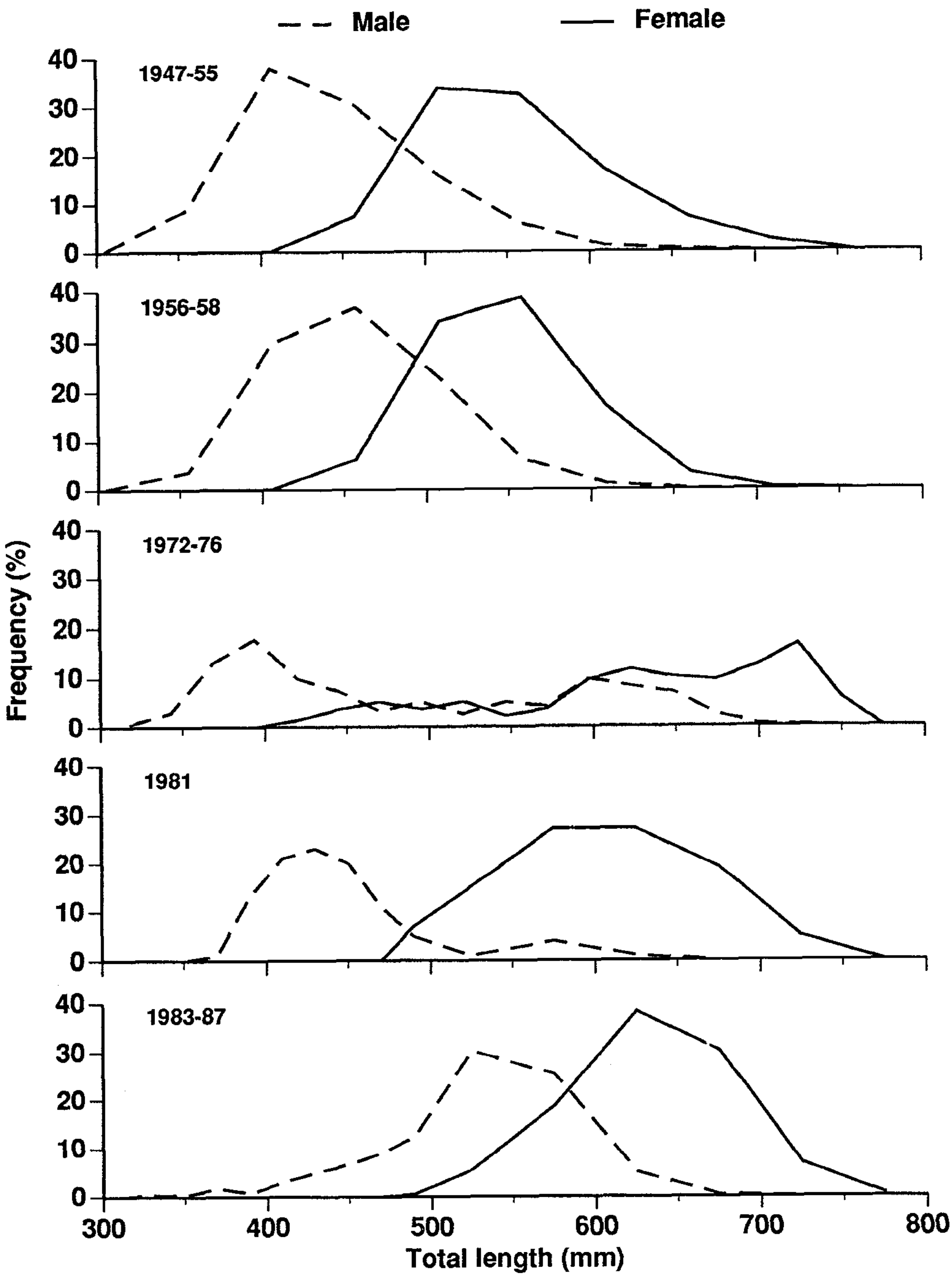

Fig. 6. Length-frequency distributions of male and female walleye in the Muskegon River spawning run in five periods (data for 1947-76 from Schneider and Leach 1979).

Recruitment. Some natural recruitment has taken place in the lower Muskegon River every year but there hasn't been a strong native year-class since 1955 (Schneider and Leach 1979). Recruitment is supplied by spawning below the lowermost dam and also by migrants from upriver impoundments (Schneider and Crowe 1977). However, it is clear that stocked fingerlings are responsible for the increase in this stock. Light additions (<8,000 fingerlings) in 1974 and 1975 did not cause significant increases in the run or alterations in age composition, but the first heavy stocking, in 1978, was prominent in the 1981 run. Conversely, the 1981 and 1982 cohorts were expected to be very weak, yet have been well-represented in recent runs; this could be due to improved natural reproduction and/or straying from other stocking sites.

Reproductive success may be constrained by the cool character of the river. Schneider (Michigan DNR, unpubl. data) noted water temperatures were less than laboratory optima for egg incubation and fry feeding in 1975 and 1976. He collected small numbers of newly hatched fry below Croton Dam but none in downriver areas. Similarly, in 1987 many fry were collected near the spawning ground but very few in the lower river and Muskegon Lake, the presumed nursery areas (R. Day, Michigan DNR at Lansing, pers. commun.). Consequently, years of exceptionally warm spring weather are most likely to produce strong walleye cohorts. Indeed, the two warmest years (May-August) since the mid-1940s were 1949 and 1955, and both probably produced major year-classes (Schneider and Leach 1979). Temperatures have not been exceptionally warm since 1955, corresponding to the long slump in walleye recruitment.

The lower ends of the other drainage systems along the southeastern shore had insignificant levels of natural recruitment and small adult populations for decades prior to recent stocking. Tagging studies and synchronous fluctuations in abundance indicated most of the walleye were strays from the Muskegon River population. Modest numbers of spawners now congregate in each planted drainage, but their spawning success is unknown.

The St. Joseph River has been heavily stocked with fry since 1981 and with fingerlings since 1982. An excellent sport fishery developed in 1984 and continues to improve. The relative success of fry versus fingerling stocking there is unknown.

Lake Macatawa has been stocked with mixtures of fry and fingerlings since 1973. Small walleye appeared in fall 1974 surveys and all sizes have become abundant since then. Both fingerlings and fry seem to be thriving in this turbid, enriched environment. The cohort established in 1973 can be traced to fingerling stocking (New York source) and the 1979 cohort is either due to fry stocking, limited natural reproduction, or straying.

The Grand River has long supported a small native walleye population: but, during the 1950s, walleye became rare in the river-bayou complex below the first dam. Fry stocking began in 1975 and fingerling stocking began in 1978; however, there was no evidence of survival prior to the 1979 planting (mostly fry). By the mid-1980s, a good spring and fall fishery developed below the dam.

The Kalamazoo and White River systems also contained only stray walleye until recently. Regular stocking of fry and fingerlings began in the Kalamazoo River in 1979 and it now supports an attractive fishery. White Lake has been stocked with fingerlings since 1981 and a modest fishery is developing.

Survival. Survival rates of stocked fry and fingerlings are unknown but the annual survival of adults can be estimated from one set of tagging data (Table 10). For native adults tagged in 1975 and 1976 combined, the number of recaptures by electrofishing in each of the subsequent five years was 30, 11, 10, 5, and 4, respectively. A survival rate of 0.62 was calculated from the logarithms of this progression by the least squares method.

Table 10. Spawning walleye tagged below Croton Dam, Muskegon River, and number returned by anglers (A) and recaptured during electrofishing surveys (E) in subsequent years.

Release data			Number of returns by calendar years after release												
			Same	1		2		3		4		5		6	
Year	sex	Number	A	E	A	E	A	E	A	E	A	E	A	E	A
1975-76	Male	290	8	2 4	4	8		8	1	5		1	2		
	Female	100	2		52			212				3			2
	unknown	54	3	1	1	1									
	All sexes	444	13	30	7	11	1	10	1	5		4	2		2
1981	Male	434	62		29				1		1			2	
	Female	60	7		2		1		2						
	Unknown	6													
	All sexes[a]	500	69		31		1		3		1			2	
1982	Male	352	37		6		3		1		1				
	Female	229	7		4					3					
	All sexes	581	44		10		3		1	3	1				
1984	All sexes	291	1	1	1		1		1						
1985	Male	83	4	1											
	Female	475	2	2											
	All sexes	558	6	3											
1986	Male	411	46	6	8										
	Female	719	34	5	6		7								
	Unknown	32	7	1											
	All sexes	1,162	87	12	14										
1987	Male	528	39	11											
	Female	433	12	4											
	All sexes	961	51	15											

[a] Includes 17 walleyes tagged in Muskegon Lake in early spring 1981.

Exploitation. Exploitation of this stock is low to moderate and much less than for the Fox River stock. About 4,500 walleyes spawning in the Muskegon River between 1975 and 1987 were marked with jaw tags (Table 8). Minimum exploitation rates, based on reported recaptures by anglers within the first year after tagging, were:

1) 2.9% for 1975 and 1976 combined,
2) 21.4% for 1981,
3) 7.6% for 1982,
4) 0.3% for 1984
5) 1.1% for 1985,
6) 7.5% for 1986, and
7) 5.3% for 1987.

A comparable figure (except that it includes both sport and commercial returns) for 1948-54 tagging was 8.7%. The 21% return rate for 1981 was bolstered by extensive publicity and the chance to win a $2,000 lottery prize: consequently it is probably the best estimate of the true exploitation rate during the 1980s. For tagging at Lake Macatawa, first-year tag returns by anglers ranged from 2.0% to 5.5% (Table 9).

Community and Habitat Trends

Fish communities in southeastern Lake Michigan and the lower ends of these drainage systems seem to be in better balance and health in recent years. Post-1973 trends in various species were documented by Eck and Wells (1987) and the U.S. Fish and Wildlife Service (unpubl. data). The rainbow smelt stock was relatively stable except for a peak in 1981-83. Alewife abundance gradually declined during the 1970s, fell to a very low level in 1982-86, then began to recover in 1987. Bloater (*Coregonus* hoyi) and yellow perch responded by returning to relatively high densities. Walleye recruitment success was also expected to increase when the alewife stock was reduced in the Muskegon Lake nursery area (Schneider and Leach 1979); however, under the present intensive stocking Program, this cannot be verified. Water quality has generally improved in all these river systems and we are optimistic that they will develop self-sustaining populations in the near future. The contaminant burden is relatively low in walleye in this portion of Lake Michigan (no health advisory), and with improved culture techniques, the eggs hatch at a very good rate, approximately 60% (J. Copeland, Michigan DNR, Wolf Lake State Hatchery, pers. commun.).

DISCUSSION

Remnant walleye stocks have been built up since the early 1970s by extensive fry and fingerling stocking programs in all three areas of Lake Michigan that were historically important--northern Green Bay, southern Green Bay, and the southeastern shore. Protective fishing regulations alone were not sufficient to induce strong native year-classes but helped to conserve the remaining brood stocks. Generally, survival of large (>50 mm) fingerlings was higher and more consistent than survival of small fingerlings (<50 mm) or fry. However, fry additions were very successful in the Fox River and probably were successful in Lake Macatawa; both have turbid and productive water. Stocking is continuing in northern Green Bay and along the southeastern shore but was discontinued in southern Green Bay after 1984 to evaluate the extent of natural recruitment.

Important local walleye stocks and sport fisheries have been rejuvenated or newly established near every stocking site. In Sturgeon Bay, a good population and a good fishery were established where virtually none ever existed. An important fishery was reestablished in Little Bay de Noc, but it is more concentrated than before and yields are still far short of the high levels of the 1950s. Along the southeastern shore, the Muskegon River spawning run is approaching the level which existed during the 1950s. Also, fisheries in companion drainages are better now than ever before. In the lower Fox River, a superb sport fishery developed which produced record yields. There, concern about low adult survival (15% to 33% per year as compared to 60% or more in other areas) and maintaining a large brood stock prompted special restrictions during the spawning season. The philosophical dilemma confronted was one common to all rehabilitation programs: should fisheries be promoted, or even tolerated, until stocks become self-perpetuating? This is a politically hot issue in each area of Lake Michigan because sport fishermen made major contributions of money and labor to the stocking programs.

The biological characteristics of stocked walleye differ somewhat from those of native walleye. Generally, at all locations, stocked fish seem to be less migratory than native walleye had been, but this difference seems to diminish as population density increases. A similar tendency was observed in Saginaw Bay (Mrozinski et al. in press), and suggests some imprinting and homing may be associated with stocked fingerlings. This cannot be readily attributed to genetic differences because native walleye were the primary source for northern Green Bay and southeastern stocking programs. In general, growth has varied with population density, but only in northern Green

Bay is there recent indication that growth has begun to slow in response to rehabilitation. This indicates there is still potential for expansion of every population. Maturity patterns have shifted in response to weak-strong cohorts but have generally returned to the norm.

Natural recruitment has not been fully evaluated but is known to be substantial in Sturgeon Bay and in the Fox, Whitefish, and Muskegon Rivers. Moderate sized native cohorts were established in southern Green Bay in the 1980s, but nowhere do they appear to be high enough yet to maintain stocks at as high a level as fisheries managers would like. Therefore, rehabilitation of these stocks is not yet complete.

Factors still limiting good natural reproduction and the total rehabilitation of these stocks are not fully understood. An obvious possibility, that egg production had fallen below some threshold level, has been eliminated by building up adult numbers to levels well above historic lows. Contaminants and foul spawning substrates remain a concern in Green Bay, but eggs exhibit moderately good viability and some natural reproduction is occurring. Ironically, the best recruitment is taking place in southern Green Bay where environmental problems are still the worst. It may be significant that this stock was built up by an infusion of new genes from inland Wisconsin populations rather than from remnant natives.

Alewife and rainbow smelt densities no longer seem high enough in any area to significantly reduce survival of walleye fry either directly by predation or indirectly by overgrazing zooplankton populations. Indeed, other sensitive species, such as yellow perch and bloater, have responded with improved recruitment as predicted (Eck and Wells 1987). Fish communities now have improved diversity and predator-prey ratios and that should foster large, self-sustaining walleye populations.

Climatic influences may be constraining spawning success in each area. Large, essentially random fluctuations in walleye recruitment were characteristic over the last 100 years. This is an indication that these stocks have always been very sensitive to environmental fluctuations and may still be. Worldwide walleye literature contains many examples of possible weather effects (Koonce et al. 1977). We noted possible links between recruitment and warm temperatures for the Muskegon River and Sturgeon Bay spawning populations. Consistently, for northern Green Bay and Saginaw Bay, the exceptionally strong 1943 year-class also developed in a year of above average (but not exceptional) May-August air temperatures. A prolonged series of years of cool to near-average weather, coupled with the relatively cool character (marginal trout water) of important spawning rivers such as the Muskegon and the Whitefish, probably contributed to low recruitment from 1956 to 1987. During this May-August period, air temperatures were relatively warm for only 1960 and 1970, and no outstanding year-classes of walleye were produced. However, in 1988 there was a favorable combination of high brood stock and relatively warm temperature which could have triggered a strong native year-class. Preliminary indications are that good reproduction occurred in the Whitefish River in 1988, but it is too early to confirm that.

Over the long term, improved natural recruitment is anticipated at all locations because of increased egg production, improved balance in fish communities, and continuing improvements in water quality.

ADDITIONAL RESEARCH

Current information is needed on the amount of natural recruitment in northern Green Bay and southeastern stocks to determine if additional stocking is necessary. The most direct method, to simply stop stocking (as done in southern Green Bay), would be very unpopular among anglers who are deeply involved with rearing programs. This problem is presently being addressed in northern Green Bay by checking for native fry and fingerlings and by varying stocking location to create missing year-classes. More importantly, factors that still limit reproduction in all areas need to be evaluated. Possible limiting factors include genetics, contaminants, spawning substrates, and temperature.

ACKNOWLEDGMENTS

The dedicated efforts of many Wisconsin DNR and Michigan DNR staff contributed to the rehabilitation effort and collection of data assembled in this report. They have made a valuable contribution to resource management. Roger Knight reviewed the manuscript and provided many helpful suggestions and Alan Sutton prepared the graphics.

REHABILITATION OF WALLEYE IN SAGINAW BAY, LAKEHURON

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ABSTRACT. The walleye (Stizostedion vitreum vitreum) population of Saginaw Bay, historically the second largest in the Great bakes, collapsed in the late 1940s due to poor reproduction and other factors. It did not recover on its own and the commercial fishery has been closed since 1970 to protect the remnant brood stock. Stocking of walleye fingerlings, and to a lesser extent fry, began in the mid-1970s with the goal of establishing large self-sustaining populations. By 1988, 5.55 million fingerlings had been planted. Stocked fingerlings survived and grew very well on diets of extremely abundant soft-rayed forage fishes. Tagging studies indicate there is some interchange with walleye in other areas, especially Lake St. Clair and Lake Erie. By 1988, a good year-around sport fishery had developed which yielded 134,000 walleyes, one-sixth or less of the bay's biological potential. Spawning runs developed in the Tittabawassee River and other tributaries. Successful spawning has been documented but self-sustaining status has not yet been achieved.

INTRODUCTION

Saginaw Bay is a fertile, 2,960 km^2 extension of Lake Huron (Fig. 1). It is equally divided by a broad, shallow constriction into a shallow inner bay (mean depth 4.6 m) and a deeper outer bay (mean depth 15.6 m) (Beeton et al. 1967). The bottom substrate is mostly composed of sand, clay, and mud; areas of gravel and rock are not extensive. The inner bay has been enriched with industrial, urban, and agricultural waste and runoff, primarily from the Saginaw River, the major tributary (Freedman 1974). Changes in the biological and chemical characteristics of Saginaw Bay have been most apparent in the last fifty years:

1) basic fertility of the bay has increased measurably,

2) turbidity has increased to a level which has eliminated aquatic plants in some areas,

3) density and composition of phytoplankton have changed, and

4) the benthic community has shifted to more pollution-tolerant species.

The fish community has also been drastically altered during the past 150 years by factors such as commercial overexploitation, deterioration of water quality, invasion or introduction of exotic species, destruction of wetlands, and the damming and degradation of tributary streams. Nearly all of thevaluable fish stocks were reduced, including those of the walleye (Stizostedium vitreum vitreum).

Historically, Saginaw Bay supported the second largest population of walleye in the Great Lakes. An extensive commercial fishery began in the 1830s and soon reported catches were often in excess of one million pounds per year (Schneider 1977). Walleye were captured by seine when in or near certain rivers, fyke net from the Saginaw River, commercial spear fishermen through the ice of the inner bay, and pound net and trapnet from offshore waters.

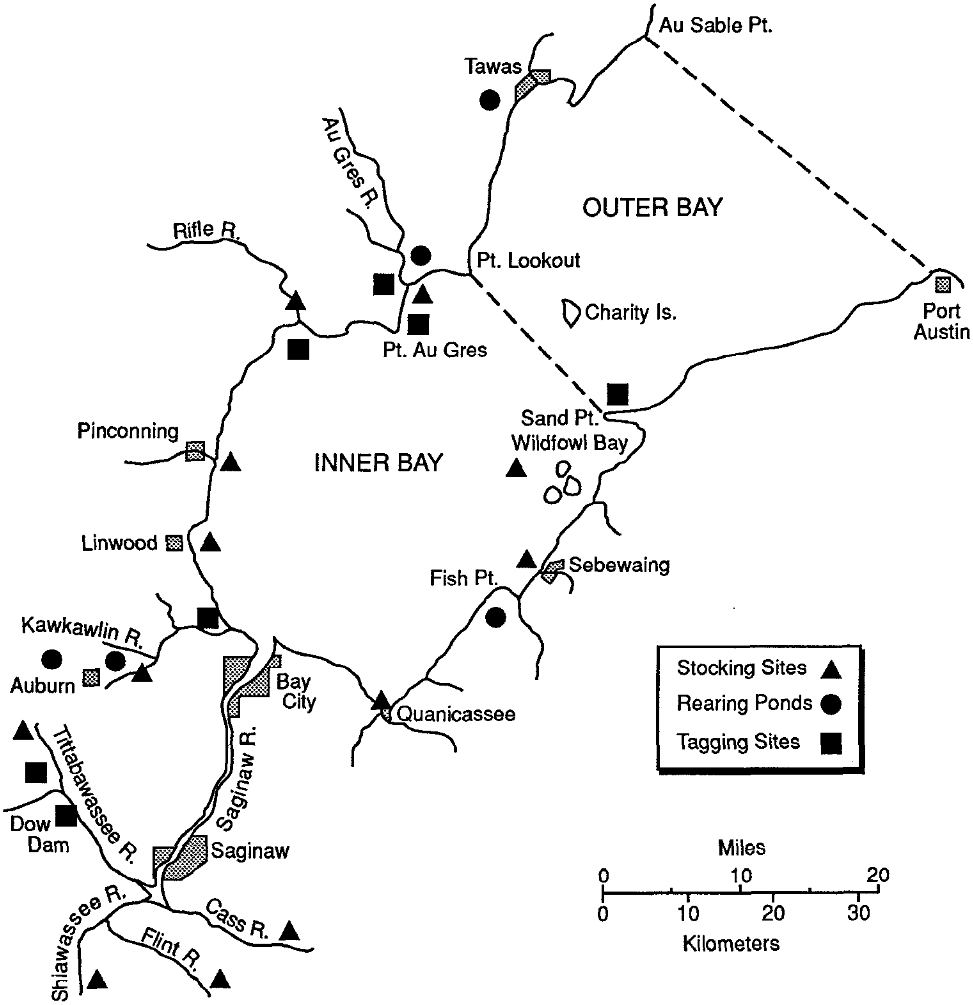

Fig. 1. The Saginaw Bay region of Lake Huron, showing walleye rearing, stocking, and tagging sites.

The first three types of fisheries had dwindled to insignificance by the turn of the century. The trapnet fishery expanded, peaked in 1942 with a landing of two million pounds, then collapsed abruptly in the late 1940s (Baldwin et al. 1979). The population did not recover and the commercial walleye fishery has been closed since 1970 to protect the remnant brood stock.

Several explanations of the walleye collapse in Saginaw Bay have been proposed (Keller et al. 1987; Schneider and Leach 1979; Hile and Buettner 1959). These include:

1) sea lamprey (Petromyzon marinus) predation,

2) cessation of walleye stocking,

3) competition and predation from rainbow smelt (Osmerus mordax) and/or alewife (Alosa pseudoharengus),

4) overfishing, and

5) environmental degradation.

We now comment on some of these proposed explanations.

Lamprey predation has never been substantiated as a major cause for walleye decline in Saginaw Bay or elsewhere (Schneider and beach 1979; Ryder 1968). The incidence of lamprey wounds on Great bakes walleye was low even in years when lamprey abundance was very high.

The Bay City State Fish Hatchery closed in 1945, just prior to the collapse of the walleye population. However, Hile and Buettner (1959) and Dymond (1957) concluded that the release of walleye hatchery fry had been unimportant.

It is suspected that alewife and rainbow smelt may have hindered walleye recruitment in recent years but that these species were not the primary cause for the decline (Schneider and Leach 1979). The last strong walleye year-class (1943) was hatched the spring following the massive die-off of rainbow smelt (Van Oosten et al. 1947). However, only weak walleye year-classes were produced the next six years even though smelt abundance remained low. Alewife first reached a substantial level in Saginaw Bay in the early 1950s and soon became extremely abundant.

Commercial exploitation of Saginaw Bay walleye in the years preceding the collapse was heavy. Record landings were achieved only three years before the collapse occurred (Baldwin et al. 1979). The size limit was lowered twice from 1932-38, and growth increased from 1930-43 (Hile 1954). Consequently, the harvest of immature fish increased and the reproductive potential of the population decreased (Schneider and Leach 1979). Even after the collapse was evident in 1947, no attempt was made to close the fishery for another 22 years.

Environmental degradation occurring during this same period may have made the stock less resilient to exploitation. Schneider (1977) concluded that the spawning substrate may have been fouled enough by the accumulation of organic materials to hinder egg survival.

Rehabilitation began during the 1970s and improvements in the stock and sport fishery soon became evident. This report will:

1) document the methods used for rehabilitation,

2) describe changes in the stock and fishery, and

3) discuss the problems yet to be resolved.

INFORMATION SOURCES

Much of the recent information in this report has been derived from unpublished sources including files of the Michigan Department of Natural Resources, ongoing studies or monitoring, and long-term experiences and observations by the authors. Leo Mrozinski managed the Saginaw Bay fishery from 1970 to 1988. Raymond Shepherd, involved with Saginaw Bay management since 1976, took charge in 1988. Robert Haas has monitored and studied Saginaw Bay fishes since 1970. James Schneider has been involved with walleye research in Saginaw Bay and other areas of the Great Lakes since 1975.

An extensive tagging program has been ongoing since 1981, and a total of 30,222 walleyes had been tagged as of May 1988. The primary capture site has been below Dow Dam on the Tittabawassee River at Midland, where a spawning run developed (Fig. 1). Walleye were collected with a 230 V DC electrofishing boat, measured, sexed, and examined for dermal lesions. Serially numbered monel metal tags were attached to their maxillary jaw bones and the walleye were released at the tagging site. As many as 1,000 walleyes could be collected in a six-hour period during the peak of the run in mid-April. The numbers tagged each year do not closely reflect the magnitude of the runs. Smaller numbers of walleye were tagged at several other sites, mostly during April. The principal sites were Kawkawlin River, Au Gres River, and several locations in Saginaw Bay proper including Point Au Gres, Sand Point, and "the catfish hole" (off the mouth of the Rifle River).

The tagging program has had minimal publicity and not all recaptures have been reported. Persons reporting tags are sent an informational letter and, in recent years, the Saginaw Bay Walleye Club has provided a complimentary lure to all anglers reporting tags. In the first few years of the program several tags were reported by commercial fishermen, but now none are received. Many other tags have been recovered by Michigan DNR biologists during fisheries surveys.

A major fish community and diet study was conducted from 1986-88. Samples were collected at 11 sites in the inner bay with trawls and gillnets on a 24-hour basis, May through October. Additional studies are ongoing.

REHABILITATION EFFORTS

The goal of the Saginaw Day walleye rehabilitation effort is to reestablish self-sustaining populations capable of providing an annual sport fishery harvest of 600,000 fish (about 600,000 kg). This is a reasonable goal compared to historic production and Lake Erie production. Major steps taken to accomplish this goal were:

1) protecting adults from commercial exploitation, and

2) stocking small walleye to build up a large population.

We anticipated that a larger brood stock, coupled with continued improvements in water quality, would overcome constraints on natural reproduction.

Stocking began in 1972 (Fig. 2). In that year, 50 million walleye sac fry were stocked and an equal number were stocked in 1973. They were put directly into the inner bay at Wildfowl Ray. Few, if any, of these tiny fish survived in the presence of dense populations of alewife and other planktivores.

A fingerling stocking program began in the mid-1970s with the rearing of small numbers of walleye in ponds or roadside gravel borrow pits. This attempt was inspired by successes at southern and northern Green Bay (Schneider et al, in press). In 1977, a 5.7 ha drainable pond was constructed on the site of a highway borrow pit near Kawkawlin. This pond produced 25,000 fingerlings in 1978 and 330,000 fingerlings the following year. In subsequent years, additional ponds were constructed at Au Gres (2.6 ha in 1981), Fish Point (2.2 ha in 1981), Auburn (two at 4.4 ha each in 1983), and Tawas (2.8 ha in 1984). The Au Gres and Tawas ponds are cooperative ponds constructed by sport-fishing groups such as the Arenac County Natural Resources Committee and Walleyes for Iosco County. The other facilities are either owned by, or leased to, Michigan DNR and receive support from the Bay County Natural Resources Association and the Saginaw Bay Walleye Club in the form of fertilizer and manpower.

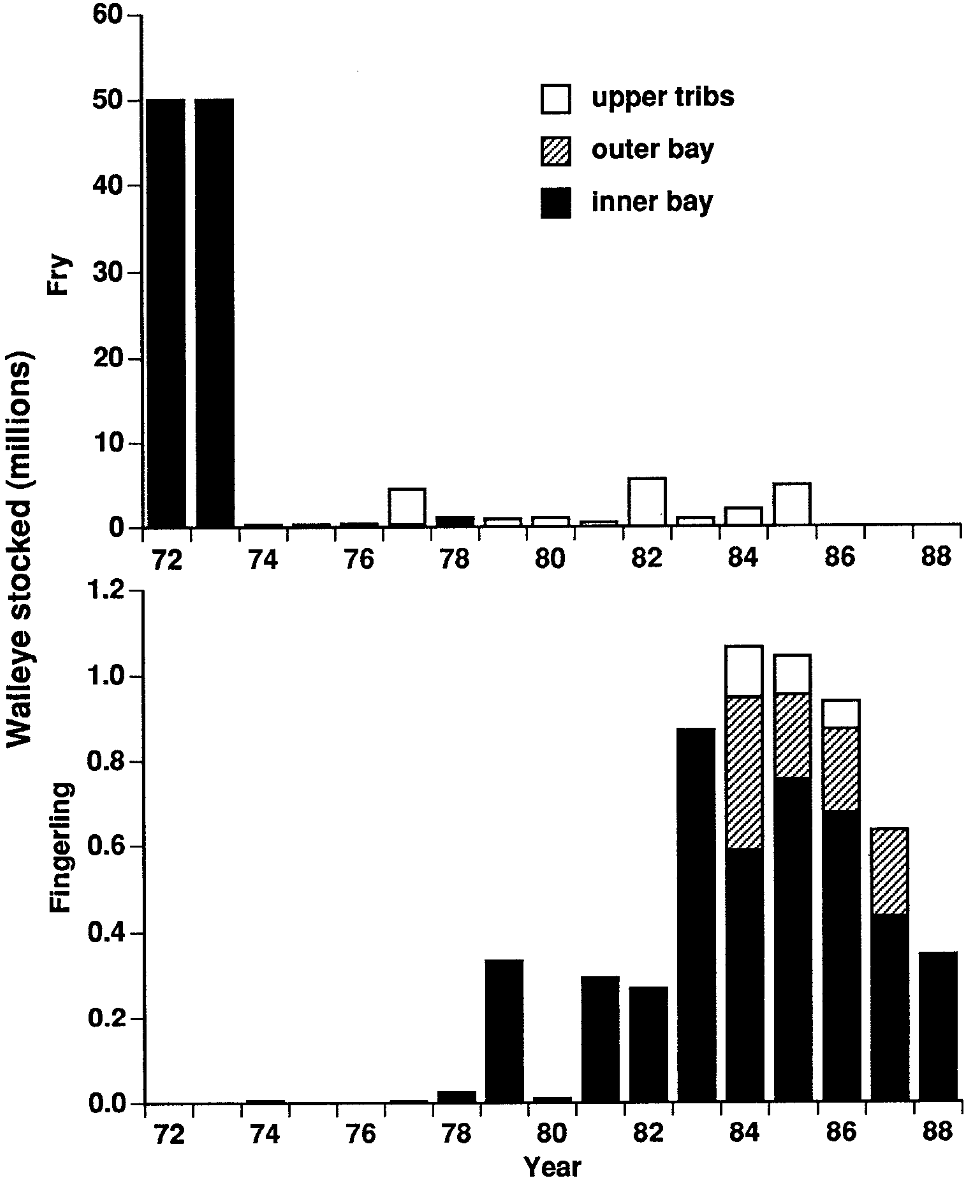

Fig. 2. Number of walleye fry and fingerlings stocked in the Saginaw Bay area: inner Saginaw Bay (and the lower reaches of its tributaries): outer Saginaw Bay; and the upper reaches of its inner bay tributaries.

A total of 5.6 million fingerlings have been stocked into Saginaw Bay and its lower tributaries (Fig. 2). The fingerlings, usually 40-60 mm long, are reared at a cost of approximately three cents each. We anticipate stocking a minimum of 500,000 fingerlings annually into Saginaw Bay until substantial natural reproduction can be documented. Total yearly cost of the walleye rehabilitation program is about $25,000.

Fingerling walleye have been stocked at several locations in the Saginaw Bay area (Fig. 1). The largest numbers have been stocked at sites near the rearing ponds to reduce stress caused by high water temperatures at the time of harvest (mid-June to early July). In addition, both fingerling and fry have been stocked into impoundments on the upper reaches of the Saginaw River system. Ordinarily, few would survive and migrate down to the bay. However, survival was unusually good in the late 1970s because stocking followed fish removal projects at three of the reservoirs.

STATUS OF REHABILITATION

Population Size

In 1979, we began to receive reports of an increase in the number of small walleye. By 1981, the incidental walleye catch in commercial trapnets had increased eight fold. Anglers also reported an abrupt increase in both the bay and the Tittabawassee River. Electrofishing surveys of the Tittabawassee River in fall 1980 and April 1981 revealed the unusual presence of several thousand walleyes. Although the bulk of the fish were from the 1979 year-class, a significant number belonged to the 1977 cohort and were probably the result of fry stocking in upstream impoundments on the Tittabawassee River. We believe these fish had emigrated to Saginaw Bay and were returning to spawn.

The walleye population continued to build up as more fingerlings were stocked into Saginaw Bay but it seemed to reach a plateau by the mid-1980s. Continued monitoring of the Tittabawassee River suggests that the spawning run may exceed 250,000 adults. Creel census and tag-return data suggest that the entire Saginaw Bay adult walleye population has probably reached 1-2 million fish.

The Fishery

The walleye is an extremely popular fish and substantial sport fisheries have been created in Saginaw Bay and its larger tributaries where virtually none had ever existed. The open-water fishery primarily occurs in the vicinity of the Charity Islands, outside the islands of Wildfowl Bay, near Fish Point, off the mouth of the Saginaw River, and along the western shoreline near Linwood and Pinconning. The bulk of the catch occurs in July. Walleye are often taken in the deeper outer bay incidental to fishing for Pacific salmon (Oncorhynchus, spp.). An important riverine fishery has also developed in the Tittabawassee and Saginaw rivers. This fishery begins in September and continues through the close of the season on March 15. It starts again when the season opens on the last Saturday of April and tapers off in mid-May when most of the fish have left the system. October and April are the peak months. The winter offshore ice fishery is still in the early stages of development and presently occurs along the western side of the bay. As with any developing fishery, anglers are constantly refining techniques and locating new concentrations of fish.

The offshore sport fishery of Saginaw Bay has been monitored by creel census since 1983 (Table 1). The number of walleye harvested increased from virtually zero in the 1970s, to about 2,000 in 1983, to about 105,000 in 1988. An ice fishery developed in January-March 1987 and the harvest expanded to about 4,600 walleyes by 1988. Average walleye catch rates improved to 0.01-0.02 walleye per hour, and would be much higher if effort directed at other species was excluded.

Table 1. Creel census estimates and 95% confidence limits of walleye harvest (numbers) and catch rate (number harvested per total angler hour) for Saginaw Bay and the Tittabawassee River, 1983-89. Data from Ryckman (1986) and Rakoczy and Rogers (1987, 1988, and Michigan DNR, pers. commun.).

		Walleye harvested		Walleye/hour/angler	
Year	Month	Estimate	95% limits	Estimate	95% limits
Saginaw Bay [a]					
1983	May-Nov	2,128	±1,450	0.003	±0.002
1986	Apr-Oct	59,268	±25,319	0.030	±0.010
1987	Jan-Mar	636	±388	0.001	±0.001
	Apr-Oct	63,691	±12,061	0.034	±0.007
1988	Jan-Mar	4,658	±4,617	0.017	±0.017
	Apr-Sep	100,129	±25,077	0.070	±0.019
1989[b]	Jan-Feb	17,184	±11,575	0.136	±0.102
Tittabawassee River					
1986	May	14,643	±14,901	0.069	---
1987	Apr-Dee	21,428	±4,625	0.108	±0.030
1988[c]	Jan-Mar	8,226	5,100	0.076	±0.054
	May-Jun	31,363	±17,084	0.247	±0.166

a Area from Port Austin to Tawas, except in 1983 the census was from Port Austin to the Iosco-Arenac county line.

[b] Pinconning area only and probably an underestimate.

'Includes the lower Saginaw River.

New walleye sport fisheries developed on the Tittabawassee River and the lower Saginaw River as well (Table 1). The annual catch now approaches 30,000 walleyes. A significant ice fishery developed during the winter of 1986-87 which, by the following winter, yielded about 8,200 walleyes at a rate of 0.07 per hour.

Natural Reproduction

Significant runs of spawning walleye developed in the Tittabawassee-Saginaw river system and in other tributaries to Saginaw Hay including the Rifle, the Au Gres, and the Kawkawlin Rivers (Fig. 1). Most other streams and drainage ditches tributary to the bay also have spawning runs. Fry have been collected from the Tittabawassee and Rifle Rivers: spawning success in other rivers is not known. Good spawning substrate is lacking in most of the tributaries. Historically, only the Saginaw River system was reported to have a large spawning run. In this century, virtually all spawning occurred on offshore reefs (Schneider 1977).

In 1982, it was established that contaminants in walleye eggs and sperm were not so high as to preclude successful reproduction. In that year, eggs collected during the Tittabawassee River run were artificially fertilized and cultured in a hatchery. The eggs developed normally and 66% hatched. Fry reared in ponds survived well and attained a length of 62 mm.

Natural reproduction was first documented in 1985 when a few fry were collected with lighted fry traps and drift nets in the Tittabawassee and Rifle Rivers. Survival to the fingerling stage was documented the same year by trawling in Saginaw Hay near the Saginaw River and the Quanicassee River prior to stocking pond-reared fish. Ten-minute tows caught up to three young-of-the-year (YOY) walleye. Trawling in other areas of the Hay did not produce any fingerlings. Similar trawling in 1986 failed to collect any native YOY walleye.

The relative contribution of natural reproduction to the adult walleye population is under study by D. Jude (University of Michigan, unpubl. data). He attempted to mark the otoliths of stocked walleye by:

1) subjecting fry to water temperature manipulations in 1987, and

2) immersion in a solution of tetracycline in 1988.

Neither produced a discernible mark. However, it appears that pond-reared fingerlings have a slower growth pattern and a discernible "check" when stocked into the bay. These characteristics may be useful in distinguishing them from fast-growing native fingerlings. Jude collected many naturally produced larvae from the Tittabawassee and Saginaw Rivers in 1987-88, but few native fingerlings were collected in those years by Michigan DNR personnel.

Movements

Following stocking, little is known of the distribution of juvenile walleye until late summer when they are often found gilled in commercial trapnet leads in the inner bay. Some enter the Saginaw and Tittabawassee Rivers in the fall. Sport anglers catch numerous 200-280 mm YOY through the ice on the lower Au Gres River.

Adult walleye movements can be deduced from shifting patterns of the fisheries, netting, and tag-return information. After spawning, the majority of spent fish leave the tributaries and reenter the bay by mid-May. Fish exiting the Saginaw River system appear to move along the eastern shoreline. By mid-June, fish are abundant in the vicinity of the Charity Islands. By late July, some fish are found farther offshore in deep water. However, even in mid-summer large numbers of fish remain in the inner bay. This behavior differs from that reported previously. Prior to the collapse of the native stock, adult walleye left the inner bay during summer (Hile 1954); and from June-September, both undersized and adult walleye were plentiful in outer bay trapnets set as deep as 37 m (Van Oosten et al. 1947).

During the winter months, adult fish gather in increasing numbers in the inner bay. There appears to be a general movement of fish along the western side of the bay towards the mouth of the Saginaw River. By mid-March, large numbers of fish have ascended 88 km up the Tittabawassee River and congregated below Dow Dam. Some pass this low-head dam and move another 22 km to Sanford Dam. By early April, when spawning usually peaks, adult walleye are found in many, if not all, tributaries to the bay. Monitoring of commercial trapnets indicates that some adult walleye remain in the inner bay and may spawn there.

An unusual feature of the Saginaw River walleye run is that many adults enter the river as early as September. Apparently, they move in to feed on tremendous numbers of small gizzard shad (Dorosoma cepedianum) which are present at that time.

Most tag recaptures have been made relatively close to the tagging sites but some fish wandered far and interchanged with other walleye stocks (Fig. 3). Of 25,569 spawning walleyes tagged in the Tittabawassee River, 1,154 have been recaptured. Most (65%) of the recoveries came from the Tittabawassee and Saginaw Rivers, 21% came from the inner bay, and 6% came from the outer bay. Another 4% had moved northward, especially to the Au Sable River. Less than 0.5% were recovered from Michigan waters of southern Lake Huron. Approximately 1% of the recoveries were reported outside the

Lake Huron basin (St. Clair River, Lake St. Clair, Thames River (Ontario), Detroit River, and Lake Erie). The most distant recoveries were 400 km to the north (Echo River, Ontario) and 500 km to the south (Maumee River, Ohio).

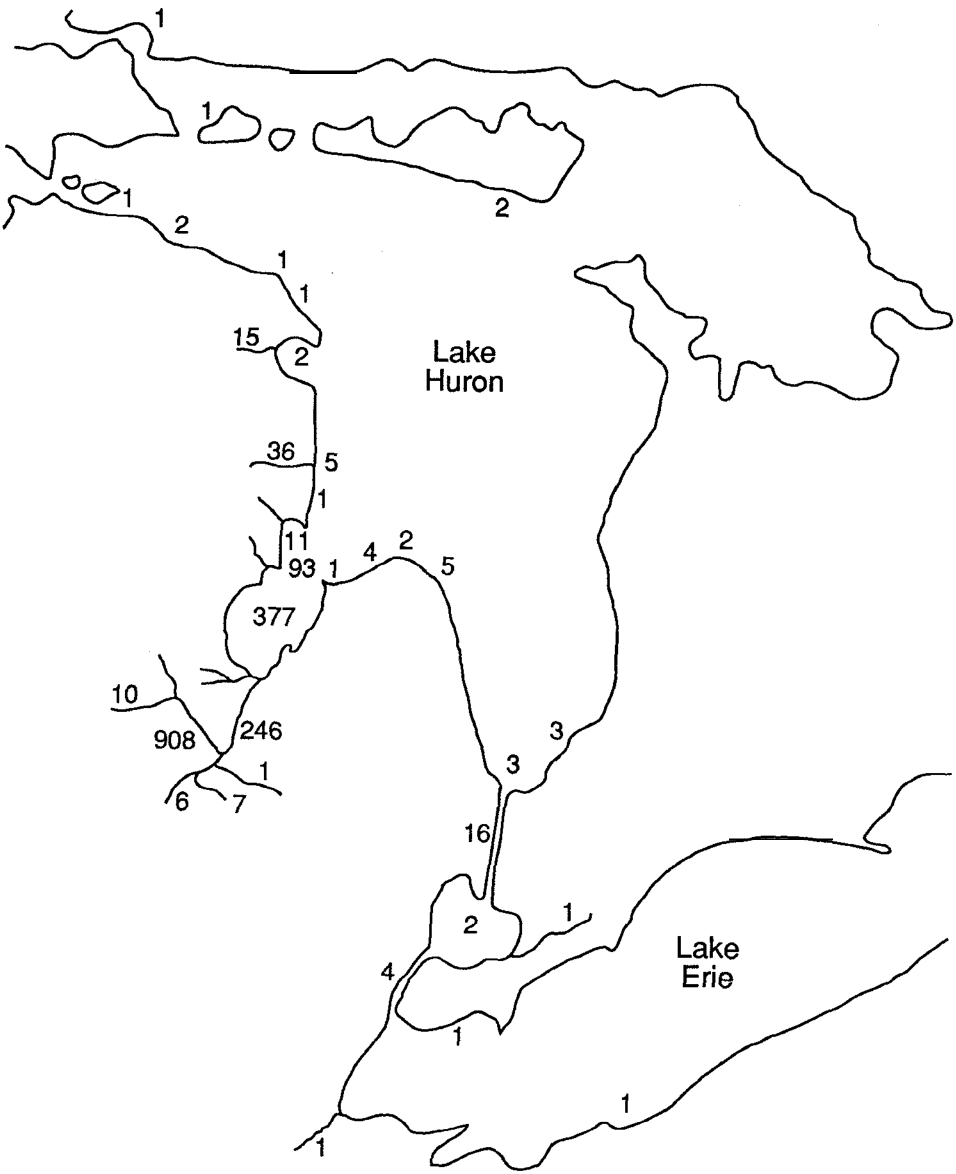

Fig. 3. Location of angler recoveries from 25,569 spawning-run walleyes tagged in the Tittabawassee River, 1981-88.

Behavior of walleye tagged at other sites in Saginaw Bay was similar except for those released near Sand Point (Table 2). None of the Sand Point walleye were recovered from the Tittabawassee River and 79% of the recoveries were from outside the basin. This suggests there may be a higher exchange rate between outer bay stocks and stocks in the southern Lake Huron-western Lake Erie complex.

Table 2. Number, by location, of angler tag recoveries of walleye tagged at various locations in Saginaw Bay and tributaries, 1983-88. Number of walleye tagged is in parentheses.

	Tagging location				
	Sand Point (1,204)	Kawkawlin River (296)	Pt. Au Gres (855)	Au Gres River (508)	"Catfish Hole" (1,568)
Tittabawassee River	--	3	2	1	8
Saginaw River	--		4	--	1
Kawkawlin River	--	3	1	--	2
Inner Saginaw Bay	4	5	6	9	8
Charity Islands	1	1	1	1	4
Au Gres River	1	--	--	1	--
Tawas River	--	--	2	--	--
Tawas Bay	--	--	2	1	2
Au Sable River	--	--	2	1	1
Southern Lake Huron	2	--	--	--	--
Eastern Lake Huron	1	--	--	--	--
St. Clair River	12	1	2	--	--
Lake St. Clair	3	--	1		--
Detroit River	2	--	--	--	1
Thames River Ontario	1	--	--	--	--
Western Lake Erie	2	--	--	1	
Total	29	13	23	15	27

Survival

Exploitation of walleye by anglers has been low. Through the end of 1988, 1,854 tags had been reported (Table 3). This accounts for 6.1% of the total number of tagged fish. Tag-recovery rate has ranged between 1.3% and 3.2% per year, with an average of 2.4%. In a comparable study at Lake St. Clair in which reward tags were used, Haas et al. (1988) observed that actual recovery rate was about 1.5 times the reported rate. Thus, the annual exploitation of walleye in Saginaw Bay is probably about 5%.

Table 3. Number of adult walleye tagged in Saginaw Bay and tributaries and number reported by anglers, 1981-88.

	Year tagged								
	1981	1982	1983	1984	1985	1986	1987	1988	Total
Number tagged	441	727	3,566	4,152	4,10	4,631	8,448	4,151	30,222
Number reported									
1981	10								10
1982	3	8							11
1983	2	13	81						%
1984		6	54	73					133
1985	2	2	28	78	112				222
1986		6	32	71	96	115			320
1987		1	31	58	90	150	258		588
1988		2	17	47	43	60	173	132	474
Total	17	38	243	327	341	325	431	132	1,854
Percent reported	3.9	5.2	6.8	7.9	8.3	7.0	5.1	3.2	6.1

Adult walleye survival has averaged 63% per year. This estimate was calculated from 1982-88 tag-return data (Table 3) using a maximum likelihood procedure (Model 0 of Brownie et al. 1985). Since angler exploitation is light, natural mortality must be about 32% per year. Survival-rate estimates (Haas et al. 1988; Ryder 1968; Schneider and Leech 1979) for other Great Lake populations are:

1) Lake Erie - 61%

2) bake St. Clair - 53%

3) Nipigon Bay of Lake Superior - 45%

4) Northern Green Bay - 35%

Growth

Growth of walleye in Saginaw Bay is extremely rapid. Generally, they grow to 381 mm (15 inches, the minimum size limit for the sport fishery) in just two growing seasons. Walleye belonging to the 1979 year-class achieved the following mean total length-at-age:

1) 460 mm at age 3,
2) 536 mm at age 4,
3) 582 mm at age 5,
4) 638 mm at age 6.

Subsequent year-classes have demonstrated good growth also, but growth may have decreased slightly in recent years.

Community and Diet Studies

Prey species, especially yellow perch (*Perca flavescens*), have dominated the Saginaw Bay fish community since the 1950s and continue to do so (Table 4). It was hoped that restoration of the walleye would improve the predator-prey balance and, especially, improve the growth and size structure of the slow-growing yellow perch population (Keller et al. 1987). To date, these improvements have not occurred. White perch (*Morone americana*) first appeared in 1986 and by 1989 had become extremely abundant (3,000 per ten-minute trawl sample). They have not had an apparent effect on other species yet.

Table 4. Monthly trawl catch per ten-minute tow for all species in Saginaw Bay and Lake Huron during 1987. T = <0.5.

Species[a]	May	June	July	Aug	Sept	Oct	Mean
Yellow Perch	504	145	694	680	453	396	579
Spottail shiner (*Notropis hudsonius*)	121	90	564	491	531	445	374
Rainbow smelt	216	129	445	574	420	193	329
Trout-perch (*Peropsis omiscomaycus*)	112	236	352	196	250	168	221
Alewife	13	136	186	499	177	55	178
Gizzard shad	0	0	108	325	25	19	80
White perch	1	T	35	37	46	55	29
Emerald shiner (*Notropis atherinoides*)	1	1	17	16	27	47	18
White sucker *commersoni*)	34	17	9	2	8	6	13
Channel catfish (*Ictalurus punctatus*)	7	T	3	19	6	3	6
Freshwater drum (*Aplodinotus grinniens*)	1	T	11	2	7	4	4
Common carp (*Cyprinus carpio*)	1	2	4	6	5	2	3
White bass (*Roccus chrysops*)	T	T	1	8	5	1	3
Pumpkinseed (*Lepomis gibbosus*)	0	T	1	5	2	1	1
Johnny darter (*Etheostoma nigrum*)	T	T	T	2	3	2	1
Quillback (*Carpiodes cyprinus*)	T	T	2	T	2	2	1
Lake whitefish (*Coregonus clupeaformis*)	1	1	T	T	T	T	T
Black crappie (*Pomoxis nigromaculatus*)	T	0	T	T	T	T	T
Bluntnose shiner (*Notropis simus*)	0	0	0	0	1	T	T
Brown bullhead (*Ictalurus nebulosus*)	T	0	T	T	T	T	T
Round whitefish (*Prosopium cylindraceum*)	0	0	0	0	0	T	T
Goldfish (*Hypsypos rubicunda*)	0	0	0	0	0	T	T
Logperch (*Percina caprodes*)	T	0	T	T	0	0	T
Stonecat (*Noturus flavus*)	0	T	0	T	T	T	T
Bluegill (*Lepomis Macrochirus*)	0	0	0	0	T	T	T
Total catch	1,021	1,359	2,432	2,866	1,967	1,400	1,841
Number of tows	39	40	48	38	40	46	42

[a] Nomenclature follows Robbins et at. (1980).

Preliminary analyses of walleye diet show that alewife, rainbow smelt, and gizzard shad predominate. Some of the very abundant forage species (trout-perch, spottail shiner, and yellow perch) are being consumed at relatively low frequencies. These species are bottom oriented, a behavior which appears to buffer them against walleye predation.

Genetic Studies

Electrophoretic studies on Saginaw Hay walleye indicate they are not in genetic equilibrium, in contrast to walleye in Lake St. Clair and western Lake Erie (Haas et al. 1988). Samples of spawning walleye taken from the Tittabawassee River in 1983, 1984, and 1985 show significant differences in allele frequencies between sample years and year-classes, as well as significant departures from random mating expectations (T. Todd, National Fisheries Center--Great Lakes, pers. commun.). The extensive stocking of fingerling walleye into Saginaw Hay from diverse genetic stocks (primarily the Muskegon and Maumee Rivers) is the probable cause of the unstable pattern of genetic variability. It was expected that the 1979 year-class would consist almost entirely of the Muskegon River strain, however, genetic frequencies indicated more than one population was present. Simulations based on these data suggest that recruitment from endemic walleye contributed at least 50% of the 1979 year-class. Additional samples of walleye from the Au Sable River, Lake Gogebic, the Muskegon River, and the Tittabawassee River are being analyzed to resolve the question of natural vs. hatchery contribution to the walleye stocks of Saginaw Hay.

Disease

The incidence of dermal lesions (lymphocystis and/or dermal sarcoma) has been monitored for the Tittabawassee River spawning run since 1981 (Table 5). Incidence rate increased from 0.0% in 1981 to 12.4% in 1985, then decreased to 9.6% in 1988. Casual observations by Hile (1954) indicated an incidence of 6.6% for Saginaw Hay walleye collected in May 1943. It appears to be more common in males and larger individuals.

Table 5. Incidence of dermal lesions on spawning-run walleye from the Tittabawassee River and percentage of infected and noninfected walleye which were recaptured by anglers, 1981-88.

Year tagged	Number tagged	Percent infected	Percent of tagged fish recaptured	
			Infected	Noninfected
1981	400	0.0	---	4.2
1982	727	0.1	0.0	5.1
1983	3,430	1.7	8.8	6.9
1984	3,550	9.7	6.9	8.7
1985	3,872	12.4	8.7	8.5
1986	3,532	11.4	7.5	7.9
1987	6,022	10.3	5.5	6.8
1988	4,036	9.6	1.8	3.2
Total	25,569		6.2	7.4

Our data suggest dermal lesions have little or no effect on walleye survival. Infected walleye may recover, as evidenced by the recapture of healthy fish which had been infected when tagged one or more years earlier. Furthermore, there was no statistically significant difference in angler recapture rate of walleye which were infected when tagged (6.2%) compared to noninfected fish (7.4%).

Since 1981, over 29,000 walleyes have been examined. Only one walleye had a wound which appeared to have been caused by a lamprey.

DISCUSSION

The rehabilitation effort is generating an important sport fishery. The total catch from Saginaw Bay, the Tittabawassee River, and the Saginaw River was estimated at 134,468 walleyes in 1988. The value of the fishery can be estimated by multiplying the value of one angler day by the number of angler days targeted on walleye. The value of an angler day in Michigan is $34.00 (U.S. Fish and Wildlife Service 1989). In 1988, 205,373 angler days were targeted on Saginaw Bay walleye (G. Rakoczy, Michigan DNR, pers.

commun.) and the calculated value of the bay fishery was $6,982,600. In addition, 76,138 angler days were tallied on the Tittabawassee and Saginaw Rivers, and the calculated value of the river fisherywas $2,588,700. The total benefit for 1988 was estimated at $9,571,400. Since the annual rearing and management cost is approximately $25,000, the walleye rehabilitation program could have a cost:benefit ratio as high as 383:1 if natural recruitment is negligible.

Nevertheless, considerably more walleye could be produced in Saginaw Bay. In 1988, the sport fishery yielded 110,000 walleyes, or about 0.4 kg/ha. Historic commercial yields were about six times higher, usually 1.5 kg/ha/yr to 3 kg/ha/yr. The western waters of Lake Erie, which appear similar in basic productivity, are yielding about 14 kg/ha/yr (S. Nepsy, Ontario MNR, pers. commun.). In this context, the goal of redeveloping a Saginaw Bay yield of 600,000 walleyes per year (2 kg/ha/yr) is realistic.

However, without natural recruitment this goal probably cannot be achieved. Keller et al. (1987) mathematically simulated the buildup of the population and fishery from estimates of rates of exploitation, natural mortality, and stocking. They assumed that:

1) natural recruitment was insignificant,

2) fry stocked since 1977 did not contribute, and

3) an average stocking rate of one million fingerlings per year would continue.

Simulation results indicated the walleye population and fishery would reach a plateau by the mid-1990s, at a level only slightly above the 1988 level. Therefore, to make significant improvements in the fishery, stocking rates would have to be increased to several million fingerlings per year.

The simulation also suggested that the 1986 walleye sport catch should have been much lower than the estimated figure of 73,000. The most likely explanations included:

1) natural recruitment had taken place,

2) stocked walleye fry had made a large contribution,

3) fingerling survival had been extremely high, or

4) that there was substantial immigration of adult walleye from populations in southern bake Huron, bake St. Clair, or Lake Erie.

Since then, evidence for substantial amounts of natural reproduction and immigration have been found.

Three management options become available if self-sustaining status is not achieved:

1) The stocking program could be abandoned. This is unlikely to occur because of its favorable cost:benefit ratio and tremendous popularity with anglers.

2) The stocking program could be continued at the current level of up to 1,000,000 fingerlings annually.

3) The stocking program could be expanded to take full advantage of the walleye-producing potential of Saginaw Bay. New ponds would have to be developed and rearing costs would likely be much higher than those of the present program. However, the cost of an expanded program may still be justified provided fingerling survival and returns to the fishery remain high.

Contamination problems have plagued the fishery since the 1920s (Schneider 1977). In 1978, the Michigan Department of Public Health issued an advisory recommending that no fish be consumed from the Saginaw River system. Since the majority of walleye frequenting these rivers spend most of their life in Saginaw Bay, this was of major concern. Walleye were collected from the Tittabawassee River in August 1985 and analyzed for an array of contaminants (PCB, PBB, and dioxin). They were found to be within the standards established by the U.S. Food and Drug Administration for all contaminants tested, and the advisory on walleye consumption was lifted. An advisory remains in effect for common carp and channel catfish. Many anglers now consume walleye, but because of the poor environmental conditions that once existed in these rivers and occasional "off" flavors, other anglers are still suspicious and prefer to release their catch.

NEED

The greatest research need at this time is to determine the contribution of natural recruitment to the walleye population of Saginaw Bay and the factors limiting it. Some work is presently under way, but results are inconclusive and additional effort is needed to determine the amount of recruitment contributed by populations in various tributaries and over offshore reefs. It is not known if the historic reefs have regained spawning populations and if their polluted substrates can successfully incubate walleye eggs. The amount of quality spawning areas available should be determined and steps should be taken to improve and protect these areas where possible. It appears that the amount of good spawning substrate (rock-gravel) in the tributaries is limited and that restoration of offshore spawning reefs will be essential to total rehabilitation.

The burrowing mayfly (Hexagenia sp.) should be restored to the Saginaw Bay community if possible. It would improve the diversity of this ecosystem and supply an important food resource for yellow perch. Experiments along this line are under way (W. Bryant, Michigan DNR, pers. commun.).

The many complaints about the poor flavor of walleye caught from the Tittabawassee River should also be investigated. Few complaints are received after the fish leave the river and return to Saginaw Bay. Hopefully, the cause of the tainting can be isolated and eliminated.

The tagging and monitoring program for the Saginaw Bay walleye population should be continued to provide current information on growth, survival, natural recruitment, and exploitation. A reward tagging program should be initiated to provide a better estimate of exploitation rate. A small percentage of the annual tagging quota should be marked with special reward tags of significant value ($50-$100) to insure that most recovered tags would be reported. A sponsor may be needed to provide funding for such a project.

ACKNOWLEDGMENTS

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THE PRESENT (1989) STATUS OF WALLEYE STOCKS IN GEORGIAN BAY, NORTH CHANNEL, AND CANADIAN WATERS OF SOUTHERN LAKE HURON [1]

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ABSTRACT. The status of 14 stocks of walleye (Stizostedion vitreum vitreum) are discussed in relation to their present (1989) levels of rehabilitation, the techniques and methods used to rehabilitate the different stocks, their different habitats, the significant environmental factors impinging on them, and community dynamics where data are available. The areas covered include Georgian Bay the North Channel, St. Marys River and one group exploited in southern Lake Huron. Tagging studies indicate there may be a mixture of two or more stocks originating in the Thames River, tributary to Lake St. Clair, and from western Lake Erie, some fish possibly even from the Maumee River tributary to western Lake Erie. These stocks contribute to the walleye fishery of southern Lake Huron. Ten of the stocks inhabit shallow oligotrophic waters draining the Canadian Shield. The year-class strengths of these stocks appear to be under the control of environmental factors, principally river flow. The stocks inhabiting eutrophic waters show significant statistical relationships with community dynamics, principally abundance of prey species. The impact of different types of pollution are discussed. A set of testable hypotheses on the probable pathway of interactions of environmental factors on determining year-class strength is suggested. It entails variations in snowfall, spring air temperatures, rivervolume, and

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[1] Contribution 91-01 of the Ontario Ministry of Natural Resources, Research Section, Box 5000, Maple, Ontario, Canada LOJ 1EO.

detritus inputs to estuarine areas which stimulate blooms of herbivorous zooplankton, which in turn, provide good growth, feeding, and survival of young walleye. Long-term climatic trends are implicated in the changes observed over several decades.

INTRODUCTION

The habitat of walleye (*Stizostedion vitreum vitreum*) in Lake Huron is limited to the shallow waters (<20 m) which cover most of Saginaw Bay and the North Channel, but is only a relatively narrow fringe along eastern Georgian Bay and southern Lake Huron. Comparatively large yields were taken by commercial netting from the North Channel and Georgian Bay during the late 1800s and just past the turn of the 19th century (Fig. 1). These large initial yields from accumulated fish stocks occurred during the period of intensive forest harvests with the associated logging camps, lumber mills, and boom towns which soon grew up around them. Most of the boom towns were soon abandoned as the forests were rapidly depleted (Brown 1978). In the last 50 years, commercial walleye yields from Lake Huron have remained markedly below the initial yields of accumulated stocks and have slowly declined over time (Fig. 1). Water quality of these generally oligotrophic waters remains good, with small changes in primary parameters (Stevens et al. 1985). Within eastern Georgian Bay, which will receive the major emphasis in this paper, recent yields of walleye have fluctuated erratically but with a gradual declining trend (Fig. 1).

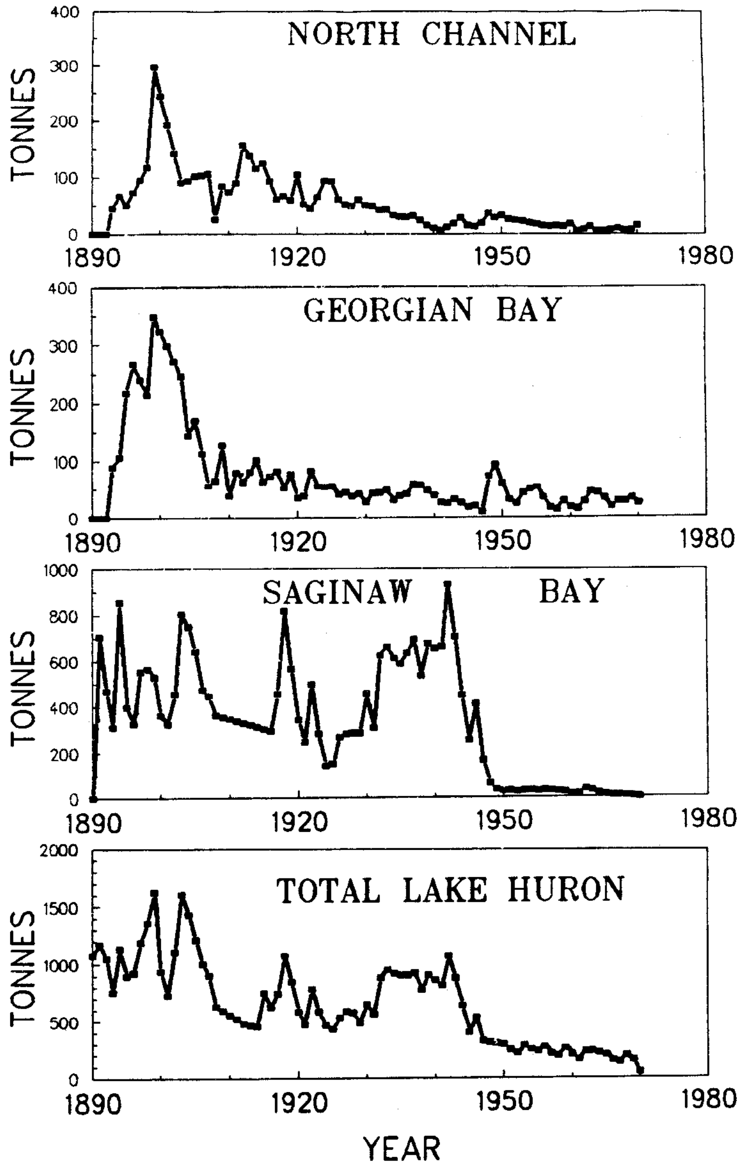


Fig. 1. Trends in commercial catches of walleye in various parts of Lake Huron (top three panels) and the totals for the whole lake (bottom panel). Note differences in scales for y-axis, North Channel and Georgian Bay are the same but Saginaw Bay and total Lake Huron cover much larger values.

Because walleye (called yellow pickerel or dore in Canada) are highly regarded by both commercial and sport fishermen, there have been many efforts of remedial legislation and rehabilitation programs for this popular species. This paper will review the status of known walleye stocks that inhabit the Georgian Bay-North Channel-St. Marys River areas. The stocks are mainly defined by their spawning runs into major tributaries, but some stocks also spawn on offshore shoals or reefs.

The status of walleye in Lake Nipissing, the headwater of the French River, and a major tributary to eastern Georgian Bay, is also included to provide contrast and additional information on walleye biology in this area. We will also examine the status of a mixed stock harvested in southern Lake Huron. This stock has its origins mostly in the Thames River, (a tributary to Lake St. Clair), and partly from western Lake Erie. Some fish might even be from the Maumee River in Ohio.

Also, in this study, we compare the significance of environmental and community dynamics on production of year-class strength of the different walleye stocks when there was a sufficient length of time-series data available.

INFORMATION SOURCES

Although a few of the walleye stocks were discussed in the PERCIS symposium (Spangler et al. 1977), many more are known to exist, but there is little published data to describe them. Much of the recent data used in the paper comes from research and management programs of the Ontario Ministry of Natural Resources conducted by biologists in the several districts surrounding Lake Huron. These reports are available at district offices of the Ontario MNR and at the Ministry Libraries either at Maple or Queens Park, Whitney Building.

Other data sources include unpublished material stored at the Lake Huron Fisheries Research Station at South Baymouth, e.g. gillnetting surveys (Harrison, Ontario MNR, pers. commun.), and the Lake Huron Fisheries Assessment Unit office at Owen Sound, e.g. commercial sampling records (Fergus, Ontario MNR, pers. commun.). Commercial catch records for early years are available from Annual Reports of the Department of Marine and Fisheries, Dominion of Canada from 1867-1900. Thereafter, we used annual reports of the Game and Fisheries Department of the Province of Ontario from 1900-44. The most recent commercial fish catches are summarized in five-year periods in a series of convenient booklets by J.I. Ridgley (though only two of the five bear her name, they are all listed under her authorship; 1972a, b, 1975, 1976, no date). Catches by species are summarized by statistical districts which materially aids interpretation.

A highly informative source of descriptions of the areas and efforts to manage fish, wildlife, parks, and timber resources is in the District History Series of the former Ontario Department of Lands and Forests (Ontario DLF, 1963a and b, 1964, 1965, and 1967). Records of fish plantings, commercial harvests, regulations for sport fishing, and much local history are contained in these reports. These histories are available at the Ministry libraries.

More recently, the Ontario MNR has gone through a long sequence of planning studies starting with Strategic Land Use Plans, band Use Guidelines, and District Fisheries Management Plans (Ontario MNR; 1980, 1987). These are the most up-to-date summaries of goals, objectives, perspectives, and descriptions of current and projected uses along with problems unique to each area. They include optional management strategies and tactics. Several are referred to in this paper.

BRIEF DESCRIPTION OF WALLEYE STOCKS

The specific sites of walleye stocks discussed in this paper are shown in Fig. 2. The same numbers are used in listing the status of these stocks (Table 1) and also list the type of spawning location used (swamp, river, shoal), and an indication of status (extirpated, depressed, rehabilitating, or rehabilitated).

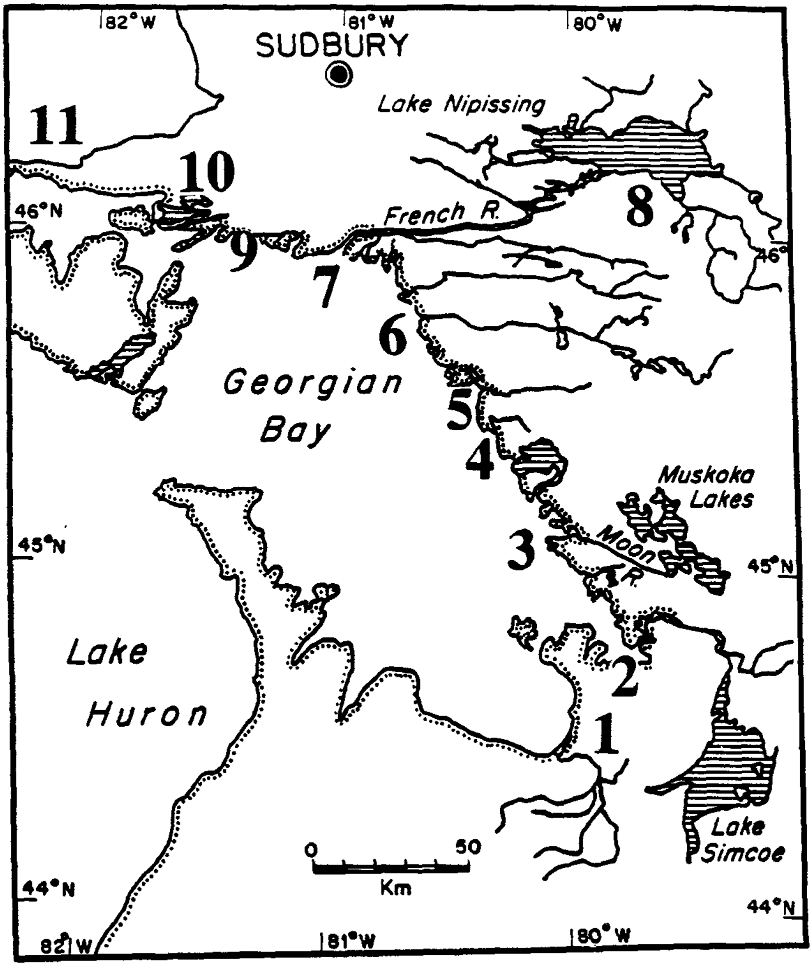


Fig. 2 Georgian Bay and the eastern North Channel with numbers indicating walleye stocks discussed in the text and listed in Table 1. Note that Sudbury is a major source of sulfur dioxide which falls to earth as acid rain. Stocks numbered 5, 6, 9, and 10 are particularly vulnerable because of poor buffering capacity.

Table 1. List and status of walleye stocks in Canadian waters of Lake Huron, Georgian Bay, and the North Channel. Characteristics of spawning sites, when known, are *also* indicated. Site numbers in this table also correspond to site numbers in Figure 2 in text.

Site "0.	Stock name	status	Spawning site
1	Nottawasaga River	low abundance	Minesing Swamp
2	Severn River	low abundance	Severn River
3	Moon River	increasing abundance	below Moon Falls and in Blackstone Harbour
4	Shebeshekong River	extirpated early in century	
5	Shawanaga River	low abundance	Shawanaga River and west side of Shawanaga and Hertzberg Island
6	Magnetawan River	low abundance	Magnetawan River and Magnetawan Ledges
7	Lower French River complex and Bustard Island	moderate abundance	Bad River Channel and Dalles Rapids sites are only ones sampled presently
8	Lake Nipissing	increasing	Wasi Falls, Duchenay Creek, South River, Sturgeon River, many other sites
9	Chikanishing River	extirpated due to acid rain	
10	McGregor Bay	low abundance	Pickerel Creek, Jumbo Island
11	Spanish River	increasing	below dam at Espanola
12	Mississagi River	low abundance	Mississagi River
13	St. Marys River	moderate abundance	Munuscong Lake
14	Southern Lake Huron portion of mixed stocks	high and stable	Thames River tributary to Lake St. Clair, Lake Erie, some from Maumee River, Ohio

Starting in the most southerly portion of Georgian Bay and moving northward, one of the most unusual walleye stocks enters the Nottawasaga River in late fall from southern Georgian Hay, over-winters in the river, and then spawns over flooded vegetation in the Minesing Swamp above Jack Lake. Minesing Swamp is a remnant of a previous lake formerly connected to Georgian Bay. It has gone through several stages of expanding and contracting (Fitzgerald 1985). It is possible that the stock has been modified from an earlier shoreline-spawning stock to a swamp-spawning stock through intensive homing as the lake and land elevations have changed.

The next distinctively recognizable stock we will examine is the Severn River stock which spawns below the last water-level regulation dam on the river. After their spawning run, this walleye population spreads out over Severn Sound. In contrast to all other areas, this relatively enclosed bay, with a set of smaller bays along its southern shoreline, is a eutrophic area with turbid, algae-laden waters heavily impacted by rapidly increasing human stresses. There is a second spawning area for walleye in the North River which also enters Severn Sound. Little is known of these fish except that they are vulnerable to poaching efforts. They add to the population in Severn Sound and may be included in the spring trapnet samples obtained in Sturgeon Hay from the southern end of the sound. Tagging studies at the spawning sites will be needed to determine their movements and exploitation rates. The eastern shoreline at Severn Sound has been investigated for the significance of nursery habitat for muskellunge (Esox masquinongy) (Craig and Black 1986). This high profile predator is an important component of the fish community.

Both the Nottawasaga and Severn Rivers drain from highly productive farmlands in central Ontario. Severn Sound, in particular, receives a high load of phosphorus from the Severn River (Sherman 1988). The source is largely from excessively fertilized Holland Marsh. This is an intensively used agricultural area with effluents to Cooks Bay in Lake Simcoe. This lake, the largest in the Trent-Severn canal system, then drains via Lake Couchiching and Sparrow Lake into Severn Sound. The phosphorus loads to Lake Simcoe from both point and nonpoint sources have recently been summarized by Johnson and Nichols (1989). They conclude that, "the 1982 P load to Lake Simcoe was the same as the load to Lake Michigan and Lake Huron circa 1970 (prior to P removal programs)" (Johnson and Nichols 1989). The surface area of these two lakes is 162 times the size of Lake Simcoe. Conversely, the phosphorus load to Lake Simcoe can be said to be 162 times more concentrated per unit area than in those much larger lakes. The city of Orillia, plus the densely packed cottages and resort lodges along both lake Couchiching and Sparrow Lake, at Big Chute and Port Severn, all add to the phosphorus load before it flows into Severn Sound. This high profile predator is an important component of the fish community.

The geology, geomorphology, water chemistry, and human stresses are all much different for most of the other river areas (except the Thames River stock), which all occur in the extremely old, well weathered Precambrian shield area.

Moving northward, the Moon River stock (possibly a set of stocks) will be the most intensively examined and described group in this status paper because of long-term studies and rehabilitation efforts in this area. Studies in two areas in particular, first the Shawanaga-Groundhog Island area and then the Moon River area, were subjected to detailed studies because of the classic report and recommendations by C. W. Douglas (pers. commun.).

The Shebeshekong River stock of walleye formerly existed north of Parry Sound but is now depleted. It was a recognizable group which was highly vulnerable to seining in large, sandy, shallow-water bays. It was overexploited near the turn of the century and has not recovered.

Further northward are the Bayfield Inlet stock and the mixed stocks of the Shawanaga River area. Here, as elsewhere, there exists a distinct river spawning group and another shoal spawning group, locally called the Groundhog Island (designated as Kiskadena Island on hydrographic maps) stock, which apparently spawns off the west side of Shawanaga Island. Confusion and conflicts between the "outside" commercial fishermen and the unsubstantiated concerns by "inside" sport fishermen that the commercial fishermen were intercepting spawners on their way to the Shawanaga River was the primary cause for scientifically studying the walleye stocks in eastern Georgian Bay.

More northerly, the Magnetawan River area also has a river-spawning stock and a "ledges" stock which are shoal spawners. In the northeast comer of the Georgian Bay coast is the lower French River complex with at least two distinct spawning sites at which walleye have been tagged. This multichannel outlet of both the large French and Pickerel Rivers presents a complex of possible spawning sites of which only two have been studied to date.

Any description of walleye stocks in this area would be incomplete without brief inclusion of the Lake Nipissing walleye stocks. Not only is Lake Nipissing the major source of the French River, it has long been one of the most important and heavily fished areas in northern Ontario. For this reason, it has shown indications of being fished excessively with markedly declining catch rates and other indices of overexploitation (Anthony and Jorgensen 1977). It is the site of the earliest Lake Management Unit established in Ontario. Because of the long-standing walleye studies, it is used by area biologists as a general indicator of likely walleye trends in other nearby areas.

Along the northern shoreline of Georgian Ray, the well-exposed geological bedrock consists of white quartzite formed in the mountain roots of a large mountain chain, now worn down after 1.5 billion years to the present low elevation La Cloche Mountains. This heavily eroded and weathered area has extremely low buffering capacity because of the predominance of quartzite that is quite pure. Unfortunately, the area is close to the highly developed heavy metal mining operations in the nearby Sudbury basin area approximately 60 km away. The sulfide ores of the Sudbury basin have been roasted to drive off SO_2 for many years and the effects of the sulfur dioxide emissions on biota have long been documented (Murray and Haddow 1945; Gorham and Gordon 1960; Conroy et al. 1978). Prevailing winter winds direct much of the sulfurous fumes toward the Killarney Provincial Park area of the La Clothe Mountains. For many years, regulations allowed much greater production of sulfurous fumes during winter because it was not a growing season, and it was believed that increased output would not be harmful. Strong sulfurous emissions during summer obviously killed many small trees, so regulations permitted greater roasting intensities during nongrowing periods, unaware at the time of the winter storage of acidic particulates that provided an acid shock during spring runoff.

There are numerous lakes in the La Clothe area which have been studied for many years to measure the effects of acid rain on fish and algae populations (Beamish and Harvey 1972; Harvey 1975; Beamish et al. 1975a and b; Sprules 1975). Heavy metals are also implicated as potential detriments, particularly nickel, copper, and selenium which are lost from the Sudbury area stacks (including the nearby Falconbridge and Coniston mining areas). One of the recent studies on effects of low pH on walleye, in some of the lakes and rivers of the area, concluded that sulphuric acid concentrations were sufficiently high to destroy formerly known walleye stocks (Hulsman et al. 1983). Therefore, the former Georgian Bay walleye stock that entered the Chikanishing River to spawn has been extirpated because of acid rain.

Moving westward into the transition zone between Georgian Bay and the North Channel area, the isolated McGregor Bay stock of walleye is considerably reduced from previous levels. The stock may also be subject to effects of acid rain affecting spawning streams, but there are apparently still lake-spawning fish that maintain a greatly reduced fishery. Also, perhaps atmospheric fallout of aluminum (Holtze and Hutchinson 1989), or mercury (Mathers and Johansen 1985; McMurty et al. 1989, or selenium (Wren and Stokes 1988) have detrimental effects on fish.

The next river westward, the Spanish River, has a major walleye stock which has long suffered from pollution from a pulp and paper mill at Espanola (Dymond and Delaporte 1952; Conroy and McGrath 1967; Bowman et al. 1988), and involved tainting of fish flesh so there was little fishing pressure. During installation of pollution control devices in July 1983, the river was impacted with a significant fish kill due to accidental leakage of toxic materials from the mill at Espanola. But most of the fish killed appeared to be suckers (Catostomidae) and other nongame fish of little value (Chevalier, Ontario MNR, pers. commun.). In July, adult walleye would have still been resident in the North Channel. They run into the Spanish River in fall prior to their spring spawning. Since 1983, rehabilitation efforts have been successful enough for this stock so that it now provides the major source of walleye eggs for stocking programs in the Espanola District (Hughson, Ontario MNR, pers. commun.) .

The last stock briefly reviewed from the North Channel is the Mississagi River stock discussed by Spangler et al. (1977). Little new information is available on this stock. Historically, the entire North Channel area produced a large commercial catch of walleye (Fig. 1) but, in recent years, the whole set of stocks in this area seems to have been reduced to exceedingly low levels.

Walleye within the St. Marys River, the connecting channel between Lakes Superior and Huron, have recently been tagged and their movements summarized (Liston et al. 1986; Duffy et al. 1987). The major impetus for extensive studies was the potential of winter navigation on this heavily used waterway, one of the busiest in the world. Changes in the St. Marys River situation during recent history have impaired the walleye stocks there. The changes range from both deliberate and inadvertent introductions of fish, to physical modifications of the rapids area, and include chemical changes due to pollution control (Table 2). This is a highly impacted area in which cause and effect may be difficult to distinguish.

Table 2. A list of fishery management efforts and physical changes in the St. Marys River area (Kriska 1989).

1) Stocking:
rainbow trout (steelhead) (<u>Oncorhynchus mykiss</u>), brown trout (<u>Salmo trutta</u>), lake trout (<u>Salvelinus namaycush</u>), chinook salmon (<u>Oncorhynchus tshawytscha</u>), Atlantic salmon (Salmo salar), walleye.

2) Inadvertent introductions:
smelt (<u>Osmerus mordax</u>), sea lamprey (<u>Petromyzon marinus</u>), alewives (<u>Alosa pseudoharengus</u>), pink salmon (<u>Oncorhynchus gorbuscha</u>), threespine stickleback (<u>Gasterosteus aculeatus</u>), white perch (<u>Morone americana</u>).

3) City-run fish hatchery established in Sault Ste. Marie, Ontario.

4) Partial lamprey control in small areas of river.

5) Water flow manipulation using 16 compensating gates.

6) Busiest shipping locks in the world through four U.S. locks. Canadian locks for pleasure craft presently shut down.

7) low-head height hydroelectric plants on both U.S. and Canadian shores.

8) Reduction in toxic contaminants and improved sewage disposal methods have led to benthic fauna recovery in lake George.

9) Spawning and nursery area modifications in the rapids area: berm constructed to prevent dewatering of critical habitat, plus installation of an inlet pipe to increase flows over rehabilitated spawning and nursery habitat. Fishway constructed in Potagannissing Bay at south end of river to allow northern pike (<u>Esox lucius</u>) better access to a spawning marsh. Routine dredging of shipping channels.

SUMMARY OF WALLEYE MANAGEMENT EFFORTS

Fishery management efforts have taken two forms:

1) mainly legislative, established regulations of seasons, creel limits, possession limits, fishing methods, establishment of fish sanctuaries, and boundary lines separating offshore commercial fishermen from inshore sport fishermen.

2) The primarily physical methods have included spawning area reconstruction with rocks and boulders, extensive planting of fry and fingerlings, and water flow agreements with Ontario Hydro so that certain river flows are maintained during spawning and incubation periods.

In many sites, the solid granite of the Canadian Shield grades into the water with sandy bottoms. Suitable spawning shoals are often limited, but usually are of ideal sized rocks and stones to be used in rock-filled, log-crib docks and breakwaters. Preservation of these extremely valuable sites from the highly motivated onslaughts of cottage owners is a major problem in the intensively used cottage country area around Parry Sound. One of the physical management schemes which has been recently initiated is the construction of rock and rubble spawning beds in suitable locations, such as in the Moon River downstream from the last impassable falls (Brown 1978).

In the past, planting walleye fry was commonly practiced. Most of the stocks received inputs from the Little Current hatchery until it was closed in 1966. Maximal plantings occurred during 1935 to the early 1940s (Ontario MNR, unpubl. data). More recently, Ontario has embarked on a Community Fisheries Involvement Program (CFIP), copied from the federal Public Involvement Program for Salmonid Enhancement on the west coast (OMNR, 1988a). In Ontario, funds are provided for local groups to construct facilities for raising fish. The province also provides eggs and some advice, but it is up to the local groups to supply manpower to raise the fish. Initial results have been variable. Some groups have quickly learned the appropriate fish culture techniques and the need for extensive care that is necessary to raise young fish successfully. While the CFIP program is only five years old, and growing rapidly in numbers of projects and funding, some initial successes are starting to appear in the form of increased fish abundance. The Moon River is one site in particular which has long been an area of considerable interest to walleye fishermen and a focus for both studies and management efforts by the province.

A summary of recent walleye plantings in the Moon River area is given in Table 3. The fry plantings were made in conjunction with estimation of natural fry production and most were dyed with a vital stain (Bismarck Brown Y) to permit population estimates of natural fry populations to be made from marked:unmarked ratios in fry samples (McIntyre, Ontario MNR, pers. commun.) In recent years, both Ministry and CFIP programs have provided several plantings per year of various sizes of fish (Mabee, Ontario MNR, pers. commun.: Thurston, Ontario MNR, pers. commun.) Two groups of fall fingerlings were fin clipped. These have provided an important source of verifiable planted fish with which to validate scale interpretations of planted fish in contrast to naturally produced progeny.

Table 3. Number of young walleye stocked in the Moon River area in recent years. Multiple plantings per year with different sized fish have occurred from 1983-87.

Year	Fry	Summer fingerlings	Fall fingerlings (fin clips)	weight (gms) Range (no. plantings)	Mean
1973	3,048,266				
1975	1,836,751				
1976	3,245,938				
1980			20,883 **(RV)**		4.9
1981			3,700 **(LV)**		a.7
1982		11,755			1.2
1983		59,068		(2)	0.4
1984		113,212		0.9-7.0 (7)	1.5
1984			1,388	11.6-25-O (2)	13.3
1985		160,418		0.4-1.6 (7)	0.6
1985			19,013	1.8-2.0 (2)	1.9
1986		146,414		0.7-3.6 (4)	0.9
1987		72,893		1.1-1.8 (3)	1.2
Total	8,130,955	563,760	44,984	Grand total 8,739,699	

MONITORING PROGRAMS AND THE STATUS OF STOCKS

In this section, both the details of monitoring methods and their results are described on a stock-by-stock basis rather than putting all methods in one section and all status results in another. This is done primarily because the coverage of walleye stocks is so variable from district to district and river to river within districts. The stock numbers refer to locales identified in Fig. 2 and Table 1.

Stock #1, Nottawasaga River

This stock has been monitored by spring trapnetting in Jack's Lake downstream of the main spawning grounds in Minesing Swamp. The overwinter residence in the Nottawasaga River has been followed by frequently monitoring the positions of walleye tagged in the fall with radio tags (Humeniuk, Ontario MNR, pers. commun.; Minor, Ontario MNR, pers. commun.) and their subsequent movement into Minesing swamp. The swamp-spawning behavior with eggs deposited on submerged vegetation is highly similar to walleye stocks in Wisconsin described by Rriegel (1970) and Niemuth et al. (1972). The trapnet program in Jack's lake sampled the downstream movement of adult walleye after spawning, since the upstream movement occurs under ice (Minor, Ontario MNR, pers. commun.). Trapping data are summarized in Craig (Ontario MNR, pers. commun.) and LaFrance (Ontario MNR, pers. commun.). In general, the Nottawasaga stock provided exceptionally good fishing during the mid- to late 1970s, due to the combined occurrence of three exceptionally strong year-classes (1974, 1975, and 1978). Since that time, spring water runoffs have been consistently lower so the stock has declined to unattractive fishing levels. Since there are other more attractive fisheries in the vicinity (a highly popular Georgian Hay shoreline fishery for rainbow trout) and the large run Of rainbows into the river in the spring, the Nottawasaga River walleye fishery has fallen to a very low intensity.

From the age-composition data in the spring trapnet fishery we have tested the effects of flow volume as a determinant of year-class strength. This relation was suggested by Winterton (1975) for the Moon River stock, and we have tested his thesis on other Georgian Hay stocks and found a similar relation for the Nottawasaga River stock (Fig. 3).

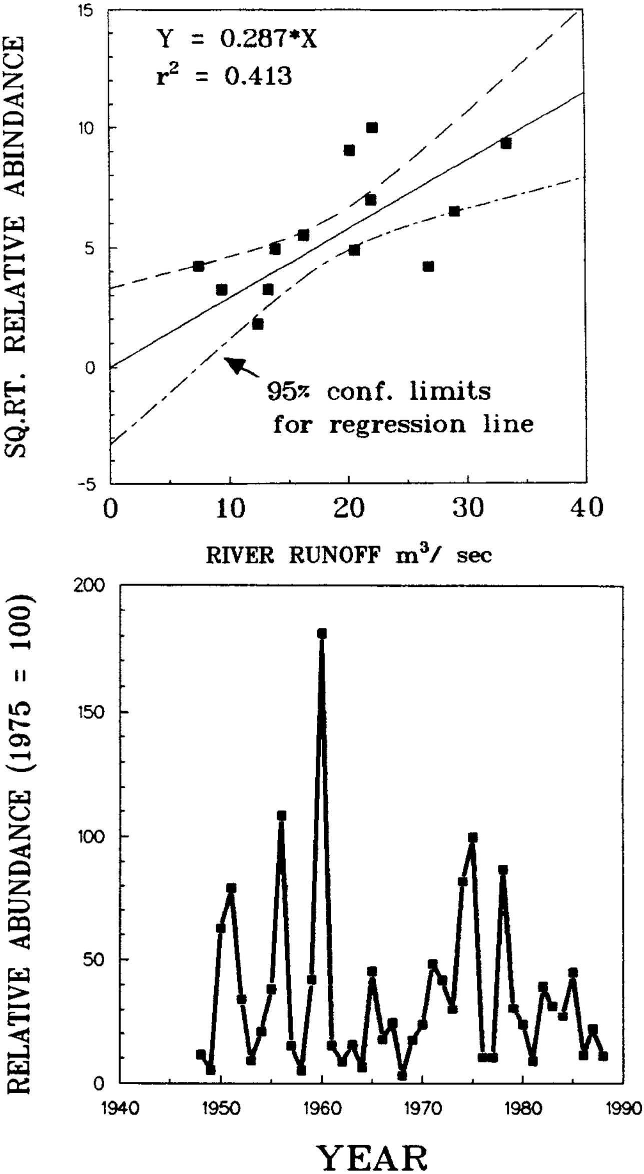


Fig. 3. The linear relationship of the mean Nottawasaga River flow during April and May with the square root of adult walleye abundance (top panel). This regression was then used to extend the times series of estimated year-class abundance based on river flows from 1948-89 (bottom panel).

A simple zero-intercept, linear regression was fitted to mean April-May flow volumes, reported by Environment Canada, and related to the square root of 13 ranked year-classes of Nottawasaga walleye (Fig. 3). The untransformed ranks displayed a curvilinear response. The estimated year-classes based on river flows were used to provide a much longer database than the 13 year-classes monitored in the trapnets. Then the individual year-class estimates were smoothed by a running average of five to simulate population trends of walleye assuming five year-classes dominate the fishery at any one time (Fig. 4). This model provides a much better appreciation of the decline of this stock of walleye. It is also a good example of the use of a proxy variable, a substitute that can provide at least an idea of long-term trends even though an extensive data series was not collected.

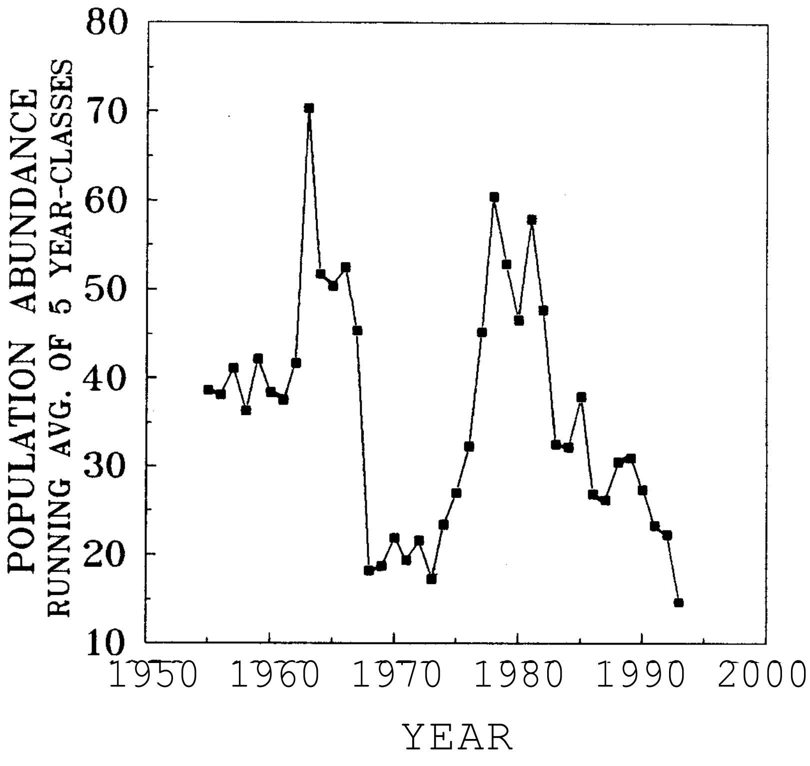


Fig. 4. Population trends of Nottawasaga walleye stock estimated by relation of year-classes to runoff (previous figure) and then smoothed by a running average of five successive year-classes assumed dominant in the fishery each year.

The Nottawasaga stock of walleye represent a simple case of an environmentally regulated stock in which high flow volumes are necessary for production of strong year-classes.

Stock #2, Severn River

The Severn River stock of walleye is severely depressed. The nearly enclosed nature of Severn Sound (Fig. 5), and the nutrient-laden inputs it receives from both fertile agricultural sources and sewage outfalls from several small cities, has led to excessive eutrophication problems in some of these smaller bays (Penetang Harbour, Midland Bay, Sturgeon Hay, and Hog Bay). Excessive algal blooms have long been a problem (Sherman 1988). In addition, the area has been invaded by Eurasian milfoil (Craig, Huronia District, Midhurst, Ontario, pers. commun.), a densely growing submerged aquatic plant that grows well in eutrophic situations. In consequence, spring trapping in Sturgeon Bay, directly south of the Severn River walleye spawning grounds, has shown a marked decline in walleye with a massive swamping of the fish community by black crappies (Pomoxis nigromaculatus) (Fig. 6). During 1980 and 1981, the percentage composition of this species exceeded 70% (LaFrance, Ontario MNR, pers. commun.). An intensive winter fishery developed. By 1982, in excess of 31,000 black crappies were taken primarily in the Honey Harbour area, as estimated by a winter creel survey (Craig, Ontario MNR, pers. commun.). By 1989, the winter catch declined to 8,800 crappies, a 72% decline. In the mid-1980s, there was an increase in other centrarchids, such as largemouth bass (Micropterus salmoides) and pumpkinseed sunfish (Lepomis gibbosus) (Fig. 6). Northern pike have also increased recently and attracted increased fishing pressure, particularly an ice fishery in the Waubaushene area. The northern pike increase may be a response to rising lake levels which peaked in 1986. In the most recent samples (1988 and 1989), brown bullheads (Ictalurus nebulosus) have shown an increased abundance (Fig. 6), but walleye remain scarce (Craig, Ontario MNR, pers. commun.). Studies in the Indian River chain of lakes in upper New York state show black crappies displaced walleye in the invasion of eutrophic lakes (Schiavone 1981, 1983, 1985). The percentage species composition of the fish community is summarized by ecological roles (pan fish, game fish, and benthic fish). Pan fish are black crappie, rock bass (Ambloplites rupestris), yellow perch (Perca flavescens), and pumpkinseed sunfish. Game fish include pike, walleye, smallmouth bass (Micropterus dolomieui), and largemouth bass. The benthic fish include white sucker (Catostomus commersoni), redhorse sucker (Moxostoma spp.) and bullhead. We conclude that changing water quality in the Severn Sound area has provided habitat more conducive to black crappies and they have displaced walleye. It will be interesting to see if rebounding northern pike abundance can restructure the fish community. At present, the fish community looks highly unstable. In addition, rapid expansion of boating facilities and the ever increasing greater interest in ice fishing, may attract greater numbers of anglers to the area with even greater stress on predator stocks. More stringent restrictions on harvest of predators may be needed to rehabilitate this stock. Improved water quality regulations will also have to be stringently enforced. Recent initiation of a Remedial Action Plan (RAP) study through the International Joint Commission (IJC) will likely aid the water chemistry problem which has already received several significant improvements through installation of modern sewage disposal plants. But with the major source of phosphorus from the Severn River, water quality improvements in Severn Sound are also highly dependent on reduced nutrient inputs from long distances upstream, such as the Lake Simcoe watershed. This whole area is an excellent example of the need for an ecosystem approach to rehabilitation. This includes solving problems in the entire watershed and integrating terrestrial and aquatic components at many levels of biological organization. The RAP approach, narrowly focusing on a small area may be effective in drawing attention and action to local areas, but is not comprehensive enough to solve some of the nutrient flow problems that stem from large areas of nonpoint source activities (PLUARG report, Berg and Johnson 1978).

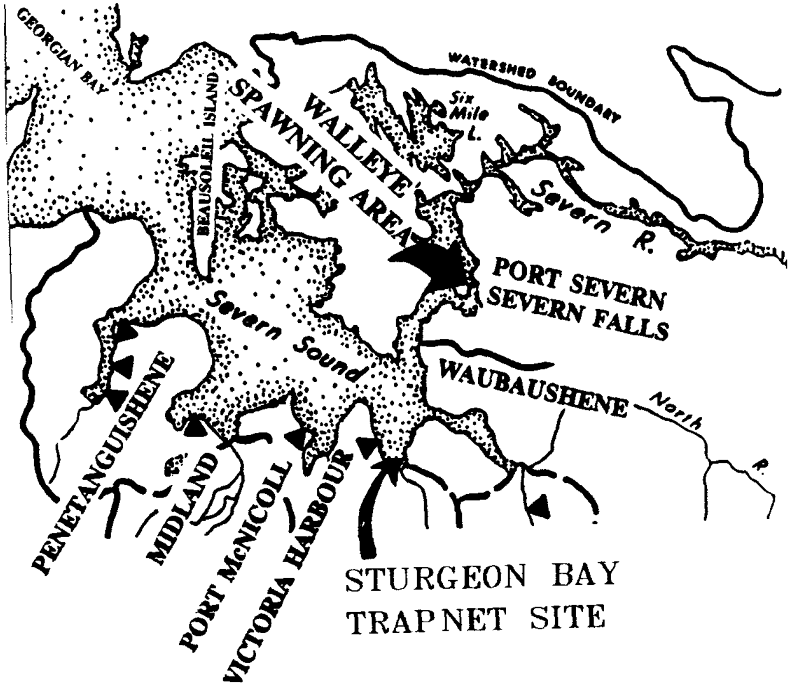


Fig. 5. The Severn Sound area with the location of sewage disposal plants of several small cities indicated with solid triangles. The greatest source of phosphorus is discharged by the Severn River (Sherman 1988).

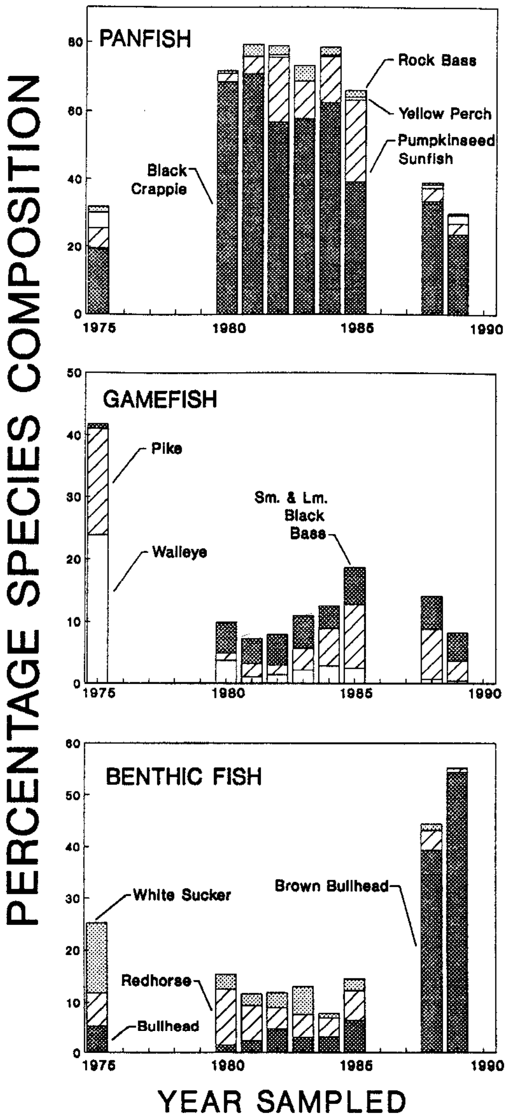


Fig. 6. Trends in species composition in Severn Sound as indicated by spring trapnet samples from Sturgeon Bay 1975-89 (samples were not taken every year). The percentage species composition of the fish community is summarized by ecological roles (pan fish, game fish, and benthic fish). Black crappie were dominant in the mid-1980s but brown bullheads now exceed 50% of the catch of this unstable community.

Stock #3, Moon River

The Moon River stocks have been monitored over 22 years by:

1) spring trapnetting of adults,

2) fall electrofishing of juveniles over the eight most recent years, and

3) occasional creel surveys, both summer and winter.

Recent measures of status are based on spring trapnetting in the Moon River (McIntyre, Ontario MNR, pers. commun.; Paus et al., Ontario MNR, pers. commun.) and fall electrofishing (McIntyre and Thurston, Ontario MNR, pers. commun.; Thurston, Ontario MNR, pers. commun.), and a recent (1984) daytime creel survey (Thurston, Ontario MNR, pers. commun.). The reason we stress the daytime nature of the sport-fishing survey is because of the habit of walleye, well known to anglers, to bite better at night (Linder et al. 1983). Winter-ton (1975) estimated that night catch rates were three to five times higher than day catches in the clean, clear, oligotrophic waters of the Moon River estuary. Smallmouth bass and northern pike dominated the sport catch. The third most abundant species was black crappie which are now expanding in the region (Thurston, Ontario MNR, pers. commun.). This is a worrisome trend in the light of experiences in New York (Schiavone 1983, 1985) and in Severn Sound.

Spring Trapnet Samples of Spawning Adults

During 16 years over a 22-year period (1968-89), trapnets have been set in the Moon River to sample the spring spawning run of adult walleye. Two to three nets have been used each year. Winterton (1975) sampled from 1968-72. Parry Sound District staff have also sampled in 1975, 1976, and 1980. The age-composition data have changed markedly over the decades and have been summarized annually (Table 4). Mean age of adults was 7.1 years. After that exceptionally good period, a series of poor recruitment years followed. By the period 1981-84, only old fish ages 10-15 dominated the samples with a mean age of 9.8 years. Catch per effort was extremely low at this time (Fig. 8). The sport fishery was depressed. During 1985-89, however, the initial effects of rehabilitation efforts began to strongly bolster the younger age groups and mean age in the catch dropped to 5.5 years (Fig. 7).

Table 4. Age-frequency of Moon River walleye (sexes combined) 1968-89.

				AGES SAMPLED												
YEAR	2	3	4	5	6	7	a	9	10	11	12	13	14	15	16	17 TOTAL
Winterton thesis study - two strong year-classes (1960 & 1965)																
1968	0	93	163	426	159	193	1733	267	67	50	72	40	25	6	1	1 3296
1969	0	66	2001	358	424	203	195	1397	345	88	77	63	59	20	5	1 5302
1970	0	161	296	1437	160	146	94	151	608	106	48	17	17	7	2	0 3250
1971	8	11	172	230	873	118	147	108	145	394	63	17	9	9	1	0 2305
1972	2	65	13	86	81	950	72	95	73	110	232	29	12	3	0	0 1823
Extremely poor years																
1981	0	0	2	6	3	0	2	3	5	15	8	8	8	1	0	0 61
1982	0	2	0	10	26	12	11	26	37	34	25	16	4	1	1	0 205
1983	0	1	6	5	9	19	11	16	25	44	28	26	15	3	0	0 208
1984	2	2	7	9	1	7	10	5	10	12	17	5	3	1	0	0 91
Initiation of rehabilitation																
1985	0	84	24	16	4	5	12	19	23	23	21	14	8	1	1	0 255
1986	1	124	223	24	14	9	7	31	38	50	40	21	11	3	0	0 596
1987	0	10	74	137	7	4	5	7	10	15	12	2	0	0	0	0 283
1988	1	0	672	152	121	123	14	22	22	27	16	16	4	2	0	0 1192
1989	0	147	602	125	24	36	9	9	6	6	6	3	2	0	0	0 975

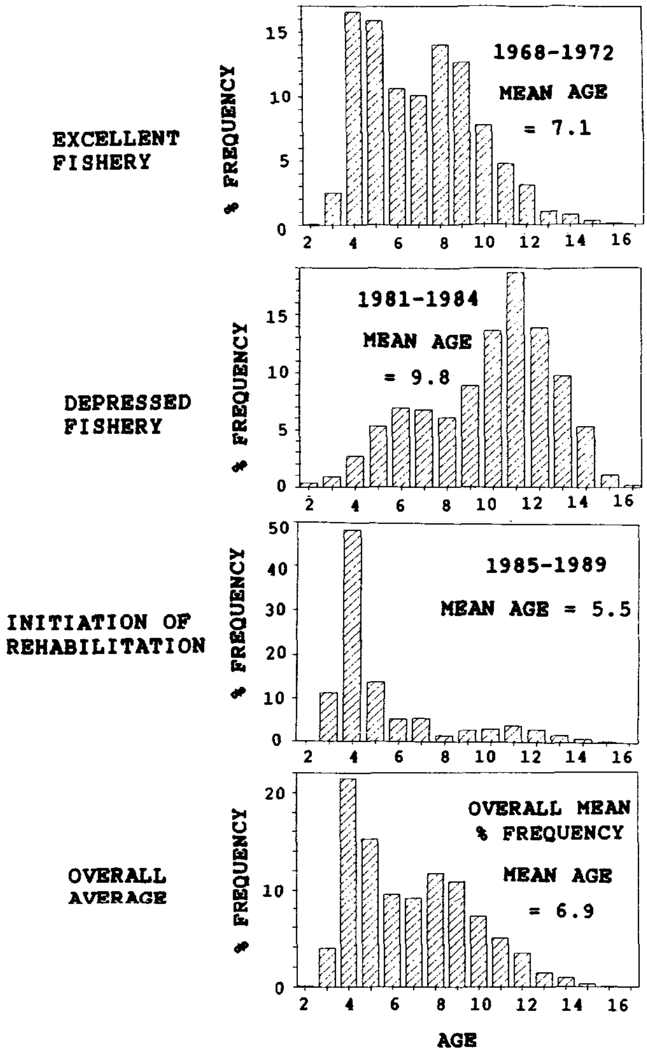


Fig. 7. Mean percentage age-frequency of spring spawning walleye (sexes pooled) sampled by trapnets in the Moon River over a 22 year period. Three distinctively different periods are shown and the overall average.

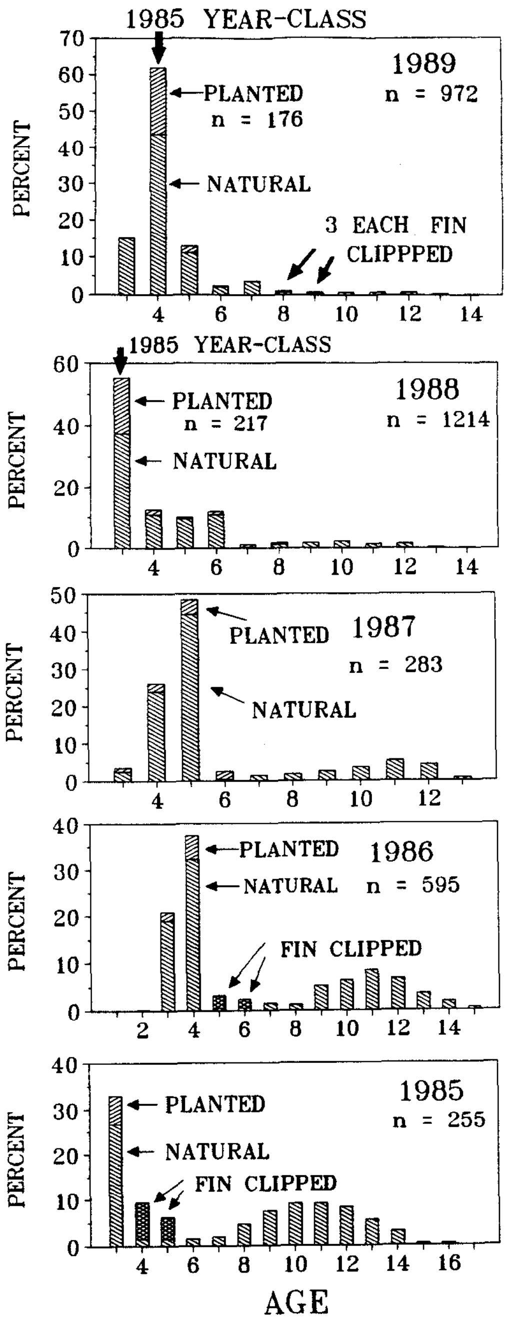


Fig. 8. Percentage age-composition of Moon River walleye samples during the initial phases of rehabilitation. Both fin-clipped, known-planted and fish assessed planted by scale-pattern analysis are shown relative to natural production.

More details of rehabilitation are plotted on a year-by-year basis showing recoveries of fin-clipped fingerlings, fish assessed as planted by scale-pattern analysis, and walleye assessed as natural (Fig. 9). Only 7.4% of the pond-reared fingerlings were clipped prior to planting (Table 2). But there is a distinctive check on the pond-reared fish due to crowding and handling during planting (Fig. 10). It occurs much closer to the focus than the first annulus. This naturally occurring mark has been used to estimate the numbers of planted fish recovered. For the extraordinarily strong 1985 year-class, in 1988 there were 176 assessed planted to 426 naturally produced (29.2% planted) while in 1989 there were 217 planted to 455 naturals (32.3% planted). Chi-square analysis was not significantly different between years sampled (chi-square = 1.39, 1 d.f., $p<0.01$), so that a combined average of 31% of 1,274 walleyes sampled were assessed as planted for the 1985 year-class. These recoveries were from the largest combined planting of summer and fall fingerlings in which 179,431 pond-reared fingerlings were stocked in nine separate plantings. Size at planting ranged from 0.2 to 2 gins/fish. Comparable figures for the earlier year-classes as estimated for ages four and five in the spring trapnet fishery are given in Table 5. The initial small numbers of large sized, fin-clipped, fall fingerlings indicated how greatly depressed natural reproduction had become for they contributed 82.6% and 75% of the spawning adults over ages four and five. The 1984 and 1985 year-classes were planted in much greater numbers of fingerlings and they made significant contributions to the spawning population by composing 21.5% and 30.9% of the adults in 1988-89. The marked changes in numbers planted provide an interesting range of values for testing the effects of planting intensity on subsequent contributions. Even more interesting will be the chance to see if the enhanced spawning population continues to provide increasingly greater numbers of naturally produced walleye (as they did in 1985) or if planting will have to be continued to maintain a fishery in an era of reduced spring runoffs. It can be concluded that initial plantings have markedly added to the adult spawning population and provided supplemental walleye for an interim fishery. Rehabilitation has been well initiated. Initial favorable trends may continue to revive this popular fishery.

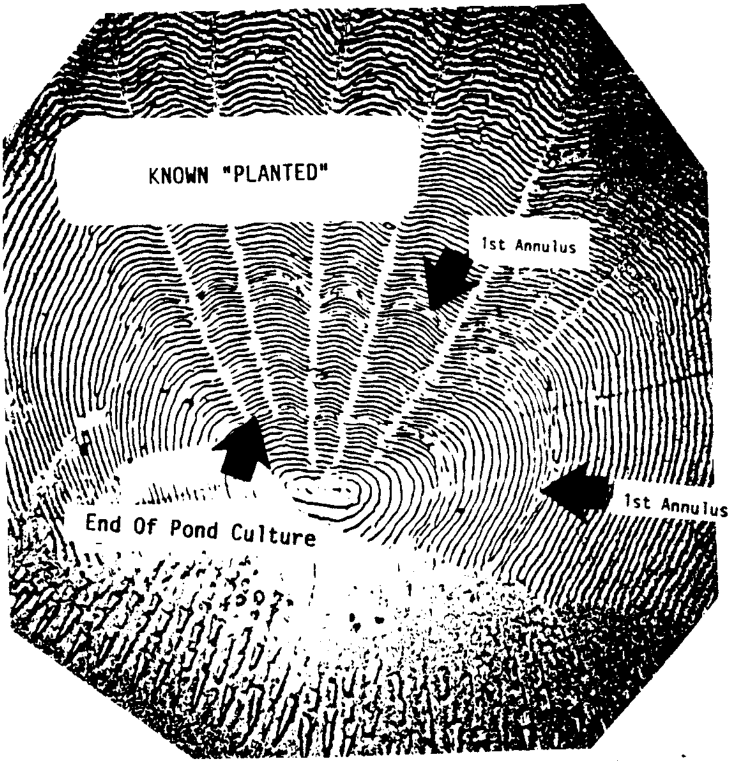


Fig. 9. A representative example of a scale from a fin-clipped, known-planted walleye used for scale-pattern analysis. The distinctive check formed at the end of pond culture occurs during handling and holding prior to planting. It is located closer to the focus than the first annulus.

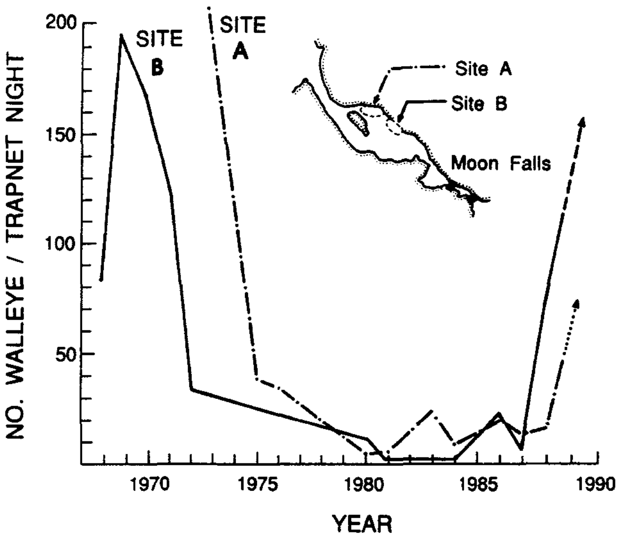


Fig. 10. Trends in spring catch/effort of spawning walleye in two trapnet sites in the Moon River. Steep declines follow the passage of two strong year-classes (1960 and 1965) through the fishery. The remarkably sharp increases due to rehabilitation are clearly evident. The arrows indicate the potentially greater catches anticipated in the near future.

Table 5. Summary of percentage contribution of planted walleye to adult spawning year-classes at ages four and five in relation to numbers and size at planting.

YEAR	NUMBERS (1000s)	MEAN WEIGHT (gms)	MEAN % (ages 4 & 5)	SAMPLE SIZE	NO. RETURNS/ 1000 PLANTED
1980	20.88	4.9	82.6	23	0.91
1981	3.70	8.7	75.0	48	8.92
1982	11.76	1.2	7.3	179	1.11
1983	59.07	0.4	6.2	145	0.15
1984	114.60	1.6	21.5	177	0.33
1985	179.43	0.7	30.9	1274	2.19
1986	146.41	0.9	(... results in 1991 . ...)		
1987	72.89	1.2	(.... results in 1992 ....)		

Electrofishing Surveys in the Moon River Estuary

The fall electrofishing program, conducted over eight years (1982-89), has provided useful information on both the relative contribution of planted walleye and fluctuations in the littoral-zone fish community.

The ratio of planted walleye to naturally produced fish estimated that planting averaged nearly 40% of the earliest age groups, 0+ to 2+ (Table 6). When the data are tabulated by year-class (instead of sampling year), the percent contribution by planted fish varies from zero to 88%. Plantings during the years 1981, 1984, and 1987 were particularly effective, since they contributed 88%, 60% and 59%, respectively (Table 7). Note that the naturally produced 1986 year-class is highly outstanding. The flow rates of the Moon River were exceptionally high in October 1986. Electrofishing samples were taken during high flows and likely provided exceptionally favorable collection conditions. In addition, some of the walleye planted earlier in the program were mature and added to the spawning population by spring 1986. This provided the initial rehabilitation of the stock through natural reproduction of planted fish.

Table 6. Samples of naturally produced (N) and planted (P) walleye in fall electrofishing surveys in the Moon River estuary and nearby Iron City Bay.

Area Year	(Hours of effort)	YOY N	YOY P	1+ N	1+ P	2+ N	2+ P	OLDER N	OLDER P
Moon River estuary:									
1982	(5.17)	1	11	1	9	2	0	13	0
1983	(4.64)	4	1	18	8	1	5	5	1
1984	(4.25)	5	20	12	13	18	7	3	2
1985	(5.02)	12	8	25	20	12	6	9	1
1986	(3.89)	75	5	9	7	3	10	38	11
1987	(3.00)	2	2	16	0	2	0	7	0
1988	(3.90)	4	1	5	8	19	0	11	3
subtotals	(29.87)	103	48	86	65	57	28	86	18
Iron City Hay:									
1985	(2.21)	20	30	1	0				
1986	(1.53)	0	0	1	1	0	1		
1987	(2.56)	6	11						
1988	(1.85)	0	0	3	0				
subtotals	(8.15)	26	41	5	1	0	1		
Overall ratios		129:89		91:66		57:29		86:18	
Grand totals (38.0 hrs.)		218		157		86		104	
Percent planted		40.8%		42.0%		33.7%		17.3%	

Sumoverages **0+ to 2+** Total = 461 N = 277 P = 184 = 39.9%

Table 7. Natural (N) and planted (P) walleye tabulated by year-class (across the diagonal of Table 6) and total effort over three seasons (0+ to 2+), where available.

Year-class	Total effort (hrs.)	N	P	sum	%P	CUE = No/Hr N	CUE = No/Hr P	CUE = No/Hr sum
1980	5.17	2	0	2	0	0.39	0	0.39
1981	9.81	2	14	16	88	0.20	1.43	1.63
1982	14.06	37	27	64	42	2.63	1.92	4.55
1983	13.91	28	20	48	42	2.01	1.44	3.45
1984	13.16	33	50	83	60	2.51	3.80	6.31
1985	11.91	23	15	38	39	1.93	1.26	3.27
1986	10.79	110	5	115	4	10.19	0.46	10.66
1987	6.90	7	10	17	59	1.01	1.45	2.46
1988	3.90	4	1	5	20	1.03	0.26	1.28
	Geometric mean CUE					1.73	1.11	3.00

The results from the outer portion of the complex estuary, called Iron City Bay, are particularly informative. There is no known spawning site in this area. Plantings of 174,600 young walleyes in 1985 and 67,400 in 1987 were followed by fall electrofishing catches with mean CUEs of 8.29 and 2.49 planted fish with few fish in 1984, 1986 and 1988, when no fish were planted in this area. The correlation coefficient between planting and mean CUE was a remarkable +0.996 (r^2 = 0.992). But for total CUE (13.90 and 4.54 for the 1985 and 1987 year-classes) the correlation is even higher at +0.997 (r^2 = 0.994). Sample sizes were 31 interpreted as naturals and 43 definitely identified as planted fish. If those 31 fish assessed natural were actually planted fish in which the planting check was not readily seen, then we have a worst case situation that the recognition rate for planted fish is only 58% (43/74). Expanding this rate over the combined samples of the whole lower Moon River estuarine complex, then we can estimate that 184 assessed planted/0.58 recognition rate = 317 planted walleyes or 68.8% of the total sample (461 fish) may have been planted fish. Once again, trapnet fishery sampling will shed greater light on this topic.

In conclusion, the planting program has been highly beneficial in the initial rehabilitation of the Moon River walleye stock. This study has provided a firm minimum estimate of at least 40% and a maximum estimate that 69% of the young walleye of ages 0+ to 2+ are of planted origin. We believe that from 1986 onwards, planted fish have contributed significantly to the spawning stock, producing increased successful reproduction. As the stock becomes more self-sustaining, one would expect the proportion of planted fish to decrease. However, for the initiation of rehabilitation, it appears that fingerling stocking is a useful remedial technique in the Georgian Bay area.

Sport-fishing success likely increased in 1987 and 1988, because of the abundance of the 1982 and 1984 year-classes. But there should be an even greater increase in fishing success when the exceptionally abundant 1986 year-class enters the fishery in 1989 and 1990. It will be 1990 or 1991 before enough of the young walleye sampled by electrofishing have fully entered the spawning-run samples. Then we can start to test for the accuracy of the fall electrofishing samples as predictors of the age composition in spawning samples.

Statistical analyses show that fall electrofishing catches were influenced by fall (October) river flows. The mean monthly flows have fluctuated from 0.98 to 46.5 m/sec. Adjustment of electrofishing CUEs to a common flow regime of 1 m/sec (simply by division) markedly improves correlation coefficients between geometric mean CUEs over ages 0+ to 2+ when compared to environmental variables. The best electrofishing sites for juvenile walleye tend to be in the narrow passages between islands where the conditions are highly riverine. Therefore, increased flows appear to attract more young walleye to the area where they are more vulnerable to sampling. Using CUEs adjusted for October flow rates (in comparison with various environmental variables) the abundance of seven year-classes available at present is most closely related to a slow, steady warming trend of maximum air temperatures. This is similar to the conclusion of Serns (1982), where low variability of temperatures (estimated by the coefficient of variation of mean daily air temperatures) was more important than the mean temperature itself. We tried Serns' method, but found that fitting regressions to the increasing minimum and maximum air temperatures gave better statistical descriptors in the form of both slope and residuals around the regressions for analyzing temperature effects.

Species Composition

The summary of percentage species composition (Fig. 10) for the years 1982-88 also provides some insightful views of significant community interactions in the littoral zone fish community of the Moon River estuary. The cyprinids (minnows) and yellow perch alternated years as the dominant component up until 1988 (Table 8). In two extraordinarily warm summers (1987 and 1988), smallmouth bass produced two strong year-classes and became the dominant species in fall 1988. Bass fishing should increase markedly in this area in 1991 and 1992. Notice that young walleyes have varied from 0.5% to 7.2% of the total and ranked eighth overall in average abundance. Clearly, there has been a substantial gain due to rehabilitation efforts.

Table 8. Percentage species composition in the Moon River estuarine complex of channels and bays obtained from night electrofishing surveys each fall 1982-89 (eight years). Species are ranked in descending order of overall average abundance. Underlined values are maximum for each year, note the oscillation between yellow perch and minnows for top spot for first six years.

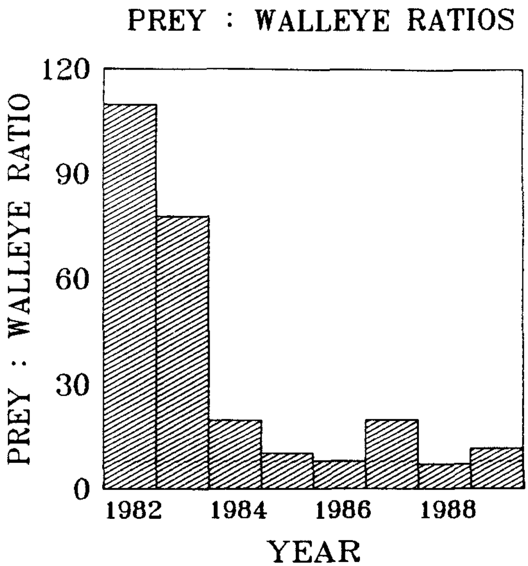
Species	1982	1983	1984	1985	1986	1987	1988	1989	Mean	Rank
Minnows <u>Cyprinidae</u>	**21.0**	**<u>20.6</u>**	**11.9**	**<u>24.6</u>**	**19.9**	**<u>18.6</u>**	**15.7**	**11.6**	**18.0**	**1**
Yellow perch	**<u>24.4</u>**	**13.5**	**<u>18.2</u>**	**16.2**	**<u>22.5</u>**	**16.9**	**13.6**	**7.4**	**16.6**	**2**
Alewife	**17.3**	**13.9**	**15.1**	**14.7**	**15.4**	**6.0**	**2.5**	**<u>21.1</u>**	**13.3**	**3**
Smallmouth bass	**12.1**	**12.3**	**8.7**	**10.4**	**8.9**	**16.1**	**<u>26.3</u>**	**10.4**	**13.2**	**4**
Rock bass	**10.9**	**17.4**	**12.1**	**11.4**	**10.1**	**15.6**	**15.6**	**7.7**	**12.6**	**5**
Brook silverside <u>Labidesthes sicculus</u>		**2.7**	**3.0**	**2.6**	**4.1**	**6.7**	**1.3**	**17.1**	**10.6**	**6**
Pumpkinseed	**5.7**	**7.6**	**14.4**	**6.6**	**5.1**	**6.1**	**6.4**	**8.4**	**7.5**	**7**
Largemouth bass	**3.7**	**6.1**	**6.8**	**1.3**	**1.4**	**3.4**	**7.0**	**3.1**	**4.1**	**8**
Walleye (Totals)	**0.5**	**0.8**	**2.9**	**6.0**	**7.2**	**2.8**	**6.2**	**4.3**	**3.8**	**9**
Logperch <u>Percina caprodes</u>			**1.2**	**2.8**	**1.8**	**2.9**	**1.4**	**0.7**	**1.8**	**10**
Black crappie	**1.8**	**1.0**	**1.9**	**0.6**	**0.6**	**0.6**	**1.1**	**1.5**	**1.1**	**11**
Brown bullhead	**1.3**	**0.5**	**1.7**	**0.9**	**0.4**	**1.7**	**0.8**	**1.3**	**1.1**	**12**
Sum (top 12)	97.4	95.8	96.1	97.1	97.0	95.7	97.1	94.6	96.4	

Electrofishing results also indicate one possible constraint to further buildup of walleye stocks. The different species have been grouped into ecologically similar roles (Ontario MNR, unpubl. data). We have used three categories (prey, predators, and others or mixed roles) as the major groups for classification of community roles. Comparing the ratio of abundance indices (no/hr) of prey species to young walleye through time, it becomes apparent that the ratio has fallen from 110 prey species to about 10 prey organisms per walleye with increased abundance of walleye (Fig. 10, Table 9).

Table 9. Summary of percentage by ecological role in the littoral-zone fish community of prey, predators, and those with mixed roles (e.g. yellow perch, black crappie, carp, bullheads) plus the ratios of prey to walleye and prey to all predators. Data from Moon River electrofishing surveys summarized in Table 8.

Role/year	1982	1983	1984	1985	1986	1987	1988	1989	Averages
Walleye	0.5	0.8	2.9	6.0	7.2	2.8	6.2	4.3	3.8
other predators	16.1	18.9	16.9	12.2	10.9	20.2	33.4	17.8	18.3
Total predators	16.6	19.7	19.8	18.2	18.1	23.0	39.9	22.1	22.2
Prey	54.9	62.1	57.6	62.7	56.4	55.9	43.1	51.1	55.5
Others (mixed roles)	28.1	15.4	22.4	18.1	23.7	19.6	16.2	26.7	21.3
Totals	99.6	97.2	99.7	99.0	98.2	98.4	99.2	99.9	99.0
RATIOS:									
Prey: walleye	109.8	77.6	19.9	10.4	7.8	20.0	7.0	11.9	33.1
Prey: predator	3.3	3.2	2.9	3.4	3.1	2.4	1.1	2.3	2.7

An initial ratio of 3.0-3.5 prey/predator has dropped very markedly in the last year to 1:1, after examination of the total community structure, including all predators (Fig. 11, Table 9). This may indicate a limit to further rehabilitation of predator stocks because of low prey abundance. The area is highly oligotrophic, draining ancient Precambrian granitic rock areas. Low productivity may restrict prey species to low abundance. Even when yellow perch were the dominant species, and they are classified here as being in the mixed-role group, they could achieve some sort of control over the cyprinids. This is evident from the alternate-year dominance of perch shown in Table 9. Additional buildup of full-fledged predators has depressed inshore prey stocks, and this might preclude additional increases in predator abundance. Unless prey abundance is greater in the unmonitored offshore areas, the inshore electrofishing results suggest that these low productivity waters may not have sufficient capacity to increase the predator component to a greater density. It is possible that the recent decrease in prey abundance led to the increased flurry of exceptionally large predators (muskellunge in particular) that have been caught in the area (O'Brien 1989). With strong year-classes of walleye and smallmouth bass, and low prey abundance in inshore waters, there may be some exceptional fishing in the Moon River estuary in the next few years.



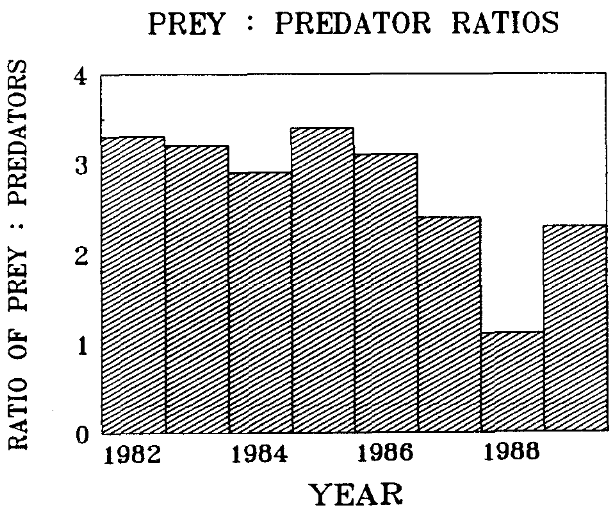


Fig. 11. Ratios of prey to walleye and the sum of all predators in the littoral zone of the Moon River estuarine areas. Data collected by night electrofishing during fall (mostly October) each year 1982-89. The low ratio of prey:predators in 1988 was accompanied by extremely good fishing for large predators, especially muskies.

Other Stocks

Other groups of distinctive walleye stocks likely exist in areas near Parry Sound. Only initial trapnetting or creel surveys have been conducted on some of these stocks. Other groups are likely to be described as additional sampling effort is concentrated in promising areas. Initial internal reports were written by Tomlinson (Ontario MNR, pers. commun.), McMillan (Ontario MNR, pers. commun.), Thurston (Ontario MNR, pers. commun.), Black (Ontario MNR, pers. commun.) and McIntyre (Ontario MNR, pers. commun.). There is still much initial discovery of spawning sites and initial description of small stocks that needs to be completed before we can be certain that all the walleye stocks have been described. But even the name applied to eastern Georgian Bay (Thirty Thousand Islands) implies the complexity of the area. This complexity, combined with the short spawning season when walleye can be sampled on their spawning sites, suggests it will be a long time before the goal of complete description is accomplished.

Stock #4, Shebeshekong River

This is a very short river which flows out of a lake of Shebeshekong Lake into Georgian Bay just north of Parry Sound (near the small village of Dillon). The river enters Georgian Bay behind Franklin Island which provides protection from strong storm winds. There are several sandy bays in the area which were used for seining by early fishermen. This population was destroyed by overfishing near the turn of the century when logging and lumbering were at their peak (Brown 1978). This provides an example of the permanent effects of excessive overfishing of a highly vulnerable stock.

Stock #5, Shawanaga River

This is another walleye stock from the next river northward which has also shown marked depletion from past levels. Because it formerly supported both an important controversial sport and commercial fishery, it was studied over six years. Olver et al. (1982) summarized data from studies by Leach (Ontario MNR, pers. commun.) and eight other studies by Zimmerman (Ontario MNR, pers. commun.) from 1964-67. Oliver et al. (1982) provided a table of age composition from 1962 to 1967 covering age groups 2 to 14. Recent studies have shown a paucity of successful reproduction. Spring trapnet surveys from 1982-84 indicated a small adult population with extremely high tag recapture rates (McIntyre, Ontario MNR, pers. commun.). From slightly more than 100 fish tagged/yr, recapture rates were 43% in 1983 and 49% in 1984. The 1983 spawning population estimate was 564 fish. Year-classes of 1979 and 1980 comprised 41% of the catch. Fall electrofishing surveys were completed from 1985-87 (Thurston, Ontario MNR, pers. commun.). These were conducted to monitor the relative success of several concomitant management efforts. These consisted of spawning shoal improvement in 1977, removal of 10.7 tonnes of white suckers over their spring spawning runs of 1982, 1983, and 1984 (4.2, 5.4, 1.1 tonnes/yr, respectively), and planting of young walleye by the local CFIP group. Planting rates were 31,600, 23,800, and 35,600 fish/yr from 1984-86, respectively. Initial recoveries indicate that 97% of the YOY in the 1985 year-class were planted fish. At age 2+, samples of the same year-class indicated 88% were planted. Samples of age 1+ walleye of the 1986 year-class provided an estimate of 92% planted. Fish cultural efforts seem extremely important to rehabilitation of this highly depressed stock. Reproductive failure may be partially due to acidic pulses during spring runoff in this river more so than any other in this area. During runoff periods of 1980-82, the pH of five rivers were monitored (the Moon, Sequin, Shawanaga, Magnetawan, and Pickerel Rivers (Table 10). Shawanaga consistently had the lowest values but even the lowest values observed during acid shock events are not excessively low (5.60, 5.45, 5.60 pH for 1980, 1981, and 1982 respectively. There may also be effects from dissolved metals (aluminum, mercury, copper, and/or other heavy metals) acting synergistically causing depressed reproductive success. The single small lake and limited drainage area of this system may make it more vulnerable to acidic precipitation.

Table 10. Late winter to early spring (Feb-May) pH values for five rivers along eastern Georgian Bay. June, July, and August values are given for comparison when available. Underlined values are extreme lows during acid shock events.

River	Item	1980		1981		1982	Means
Moon	**Mean**	6.39		6.29		6.20	6.26
	Min	6.20		5.20		5.90	
	Max	6.60		6.15		6.35	
	N	9		28		20	
	27 June	6.15	June (mean)	6.21			
	6 Aug	6.73	20 July	6.15	13 July	6.30	
Sequin							
	Mean	6.41		6.33		6.15	6.26
	Min	6.20		6.20		6.00	
	Max	6.60		6.45		6.25	
	N	9		12		7	
	27 June	7.03	18 June	6.20	13 July	6.30	
	6 Aug	7.00	20 July	6.32	24 Aug	6.45	
			19 Aug	6.62			
Shawanaga							
	Mean	5.98		5.88		5.72	5.86
	Min	5.60		5.45		5.60	
	Max	6.20		6.40		5.85	
	N	9		24			
	3 July	6.40	June (mean)	5.93	13 July	5.9:	
	8 July	6.68	20 July	6.05	24 Aug	6.30	
	6 Aug	6.39	19 Aug	5.18			
Magnetawan							
	Mean	6.44		6.31		6.26	6.35
	Min	6.15		6.15		6.10	
	Max	6.55		6.45		6.40	
	N	9		12		7	
	3 July	6.78	18 June	6.17	13 July	6.25	
	8 July	6.95	20 July	6.40	24 Aug	6.25	
	6 Aug	6.70	19 Aug	6.39			
Pickerel							
	Mean	6.46		6.34		6.23	6.34
	Min	6.20		6.10		6.10	
	Max	6.15		6.50		6.40	
	N	9		12		7	
	3 July	7.58	18 June	6.75	13 July	6.30	
	8 July	7.40	20 July	6.55	24 Aug	6.40	
	6 Aug	7.09	19 Aug	6.45			
Mean of means		6.34		6.24		6.11	6.21

Another informative item, from the standpoint of rehabilitation efforts, is available from this locale. The first CFIP planting consisted of very small fish 2128/pound = 0.213 g each. They have not shown up in any subsequent sample. In contrast, the second planting consisted of large fingerlings at 131/pound = 3.463 g each. The latter group is the 1985 year-class, which has shown in two subsequent electrofishing samples to comprise from 97% and 88% of the total year-class.

Stock #6, Magnetawan River

This relatively long river rises in the highlands near the edge of Algonquin Park, flows through the village of Burk's Falls on Highway 11, then receives the outflows of numerous large lakes. It then enters a long narrow bay, Byng Inlet, with the town of Britt on the north side and Byng Inlet on the south. The mouth is protected by Clark Island, Bigwood Island, and a complex glacier-scoured island cluster called McNab Rocks. Due south are the underwater Magnetawan Ledges.

There is insufficient data to compare year-class strength and flow data for this stock. This is unfortunate because the Burk's Falls site on the Magnetawan River has been monitored for longer than any other site, starting in 1916 (Fig. 12) (Environment Canada 1987). For many years, this walleye stock was considered to be in better shape than most other stocks in the area. Comparisons of catch rates in extensive creel surveys indicated this was true for a while. But increasingly greater complaints of poor fishing in recent years have suggested a major decline. An initial spawning-run survey in 1987 suggested that fluctuating water flows/levels during the spawning and egg incubation period are presently considered a major problem in the entire Magnetawan River system (Kujala, Ontario MNR, pers. commun.). The most recent netting data were from a trapnetting survey during the summer of 1980 (McMillan, Ontario MNR, pers. commun.). Among 10,080 fish caught in 221 trapnet nights, brown bullhead and rock bass were most common at 38.1% and 25.4% of the total catch, respectively. Sport fish only comprised 9.4% of the total, with smallmouth bass and northern pike more abundant than walleye. But the highest CUE values were from the Magnetawan River area (McMillan ibid). Other initial surveys have been completed for the Bayfield area, Nares Inlet and Lower Naiscoot River, Key River, and Boyne River sites (Thurston, Ontario MNR, pers. commun.; Black, Ontario MNR, pers. commun.; McIntyre, Ontario MNR, pers. commun.). These surveys identified some of the other areas and stocks that need additional study but are not considered further in this paper.

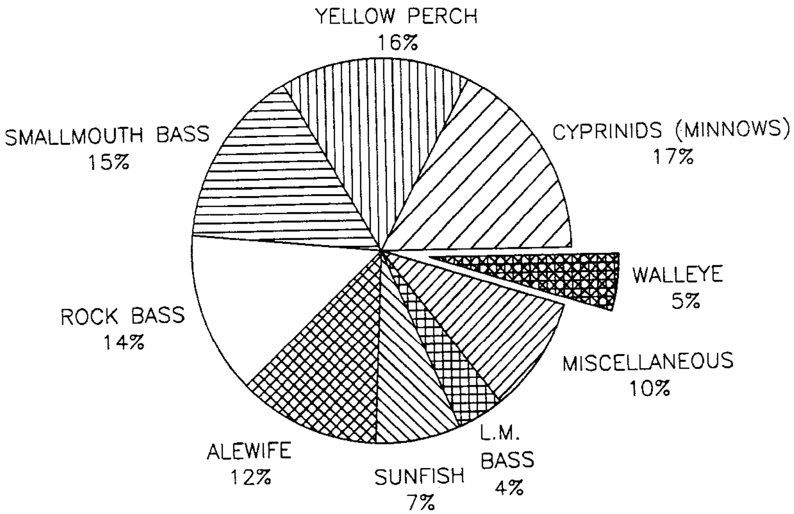
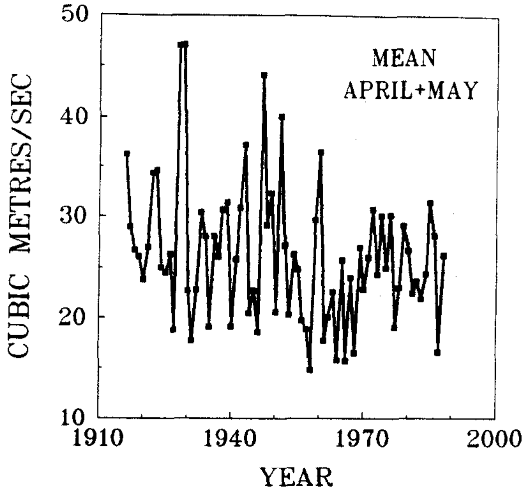


Fig. 12. Overall average species composition in the littoral-zone area of the Moon River estuarine complex of bays and channels. Data from night electrofishing surveys 1982-89.



POPULATION TRENDS

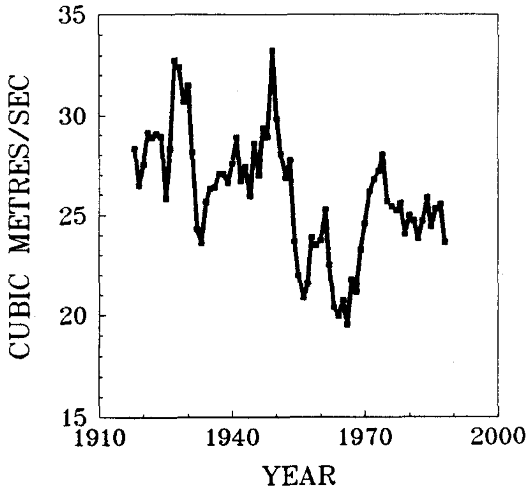


Fig. 13. Since the Magnetawan River has been monitored for a longer period than any other in the Georgian Bay area, the mean April-May flow rate was used as a proxy variable to simulate probable walleye year-class trends (top panel). These were smoothed by a running average of five to simulate five walleye year-classes at a time extant in a fishery (bottom panel).

Stock #7, The Lower French River Complex
and the Bustard Islands

The well known, historically important French River, a major route of the Voyageurs into the interior of Canada, is a large-volume river flowing out of Lake Nipissing. The flow is regulated somewhat by a steel dam at Dokis, Chauderie Dam, so that Lake Nipissing is drawn down during winter to act as a partial flood control storage area during spring runoff. Extreme high and low flows cause problems and controversy about regulation policies from both upstream and downstream inhabitants. The Lower French River system flows generally westward and, before it flows into Lake Huron, receives input from several other large river systems (the Restoule, Wolseley, Wanapitei, and Pickerel Rivers).

The remarkable boom and bust history of the forestry and fishing industries, and the towns that went with them, are particularly well documented in a publication narrowly focused towards northeastern Georgian Bay, particularly the French River complex (Campbell 1988). It is extensively filled with a large number of photographs that vividly show the massive changes that have occurred.

A series of multiple outlets exist in this complex. One example, from east to west, is the Pickerel River outlet which is cross connected to the Eastern Outlet, Main Outlet, and Western Channel. Some of these outlets have multiple channels such as the Bad River, Fort, and Voyageur Channels of the Western Channel, and these are linked by Cross Channel. There is a multitude of various sized islands and shoals in the many mouths of this system. Immediately off shore is the large complex of the Bustard Islands, which is heavily ice scoured with few trees. Within this bewildering array of flows and cross flows, two walleye spawning sites were sampled routinely from 1973-77 and large numbers of fish have been tagged (Gunn, Ontario MNR, pers. commun.: Olver et al. 1982). These two sites are the Bad River and Dalles Rapids in the Main Channel. Both trapnetting and creel surveys have monitored the 1968-74 year-classes. Once again, year-class abundance estimates were most closely related to the volume of river flow during April-May runoff (Ontario MNR, unpubl. data). Tag recaptures from a large-scale tagging project at the two sites show that there is considerable overlap in the areas where they are caught and even upstream movement of some tagged fish. In addition, there is some offshore movement to the Bustard Islands. It is highly likely that other spawning sites have not been sampled, but from these initial views, it appears there is a single, highly mixed stock within this lower river complex. The creel surveys, summarized from 1973-77, indicated that walleye made up 77% of the sport catch, smallmouth bass 13%, northern pike 6.6%, muskellunge 0.2%, and a miscellaneous mixture 3.4%. Day:night comparisons of walleye CUE were not different in this area (Gunn, Ontario MNR, pers. commun.).

Stock #8, Lake Nipissing

The main source of the French River complex is Lake Nipissing where the Fisheries Assessment Unit (Ontario MNR) for that lake has long been involved in intensive walleye studies (Jorgenson, Ontario MNR, pers. commun.: Anthony and Jorgenson 1977; Jorgenson, Ontario MNR, pers. commun.). Along with creel surveys, spring trapnetting of adults, and summer trapnetting for community indices, an index trawling program for YOY and yearling walleyes along with their forage base has also been maintained (Jorgensen, Ontario MNR, pers. commun.). The index trawling sites are fished during three replicate surveys per year. Using this approach, it has been demonstrated that there is a significant relationship between yearling walleye in trawl samples and those aged 4 and 5 from the same year-class taken in subsequent summer creel census samples (Jorgensen, Ontario MNR, pers. commun.). Regression takes the form Y = 940 + 77x, where y is the age-4 and age-5 index of summer harvest and x = the geometric mean catch (+ 1 to avoid log. zeros) of yearling walleye/half hour trawl tow, r = +0.5747, df = 10, P <0.002. Therefore, year-class strength is not determined in this population until the second summer of survival, as Forney (1976, 1977) determined for Oneida Lake walleye.

Lake Nipissing and Oneida Lake are highly similar, both being large, shallow, highly productive northern lakes with large populations of relatively slow-growing walleye that are heavily exploited. Detailed stomach analyses indicate that mayflies Ephemeroptera are important food items early in the year, but it is the availability of YOY yellow perch from mid-July to fall that is so important in producing strong year-classes of walleye (Jorgenson, Ontario MNR, pers. commun.). The relative significance of environmental and community dynamics using Jorgensen's data for Lake Nipissing has been tested. In this highly productive lake the effect of community dynamics, particularly fluctuations in the forage base, is more important than environmental factors in determining year-class strength. These results contrast with those for oligotrophic Georgian Bay stocks where the environmental factors seem more significant. The two different answers may be representative of the different trophic status of the different sites. In low productivity areas, environmental factors dominate year-class production. In highly productive waters, community factors dominate.

The primary management effort for rehabilitation of the Lake Nipissing walleye fishery has been a delayed opening of the angling season immediately after spawning when walleye were most vulnerable to angling. Angling surveys for some of the years prior to the delayed opening indicated up to 25% of the annual harvest of walleye were taken during the three-day opening weekend on Lake Nipissing (Jorgenson, Ontario MNR, pers. commun.). Annual surveys have indicated that 50% of the annual summer catch of walleye occurs prior to June 10. Tourist operators, camp owners, and sport fishermen were all aware of the rapidly declining fishery described in Anthony and Jorgenson (1977). It took the combined cooperation of all groups to implement the temporary restrictive measure (delayed season opening) that was necessary to prevent total collapse of the fishery. The recent increases in walleye abundance have led to the relaxation of the restrictive opening. The season now opens on the Queen Victoria holiday weekend in late May, the same as it was earlier. However, another stress is increasing. During years with extremely low snowfall, winter access over this large lake is easy for wheeled vehicles, and there are substantial increases in winter harvests of walleye at those times. Therefore, ice fishing efforts are being restricted to a single line per angler. Also, as the mature walleye concentrate prior to spawning, the late-winter fishery has been curtailed in those areas. The primary concern is that the increasing winter fishery may be reducing summer success rates. Restrictive harvest levels have worked to save the fishery, and may be needed again to maintain the high quality of this important stock.

Stock #9, Chikanishing River
Killarney Provincial Park

The area around Killarney Provincial Park has long been known as an important study area for investigating the detrimental effects of acid rain. The area is close to the Sudbury smelters and its position is directly downwind from them via prevailing winter winds. The nearly pure Lorrain quartzite which forms the well weathered, ancient (1.5 billion years) bedrock is a poor buffer (Beamish and Harvey 1972; Harvey 1972; Harvey and Lee 1980; Wales and Liimatainen 1987). Most of the lakes drain to Georgian Bay via the Chikanishing or Mahzenazing Rivers (Harvey and Lee 1980). Two of the lakes have been studied intensively. George and Lumdsen Lakes (both tributary to the Chikanishing River) and the river itself have had their walleye stocks destroyed (Hulsman et al. 1983). This study provides one of the few sets of experimental data on the effects of acid pulses in the area. Most acid rain studies have relied on correlations with declining pH values to suggest detrimental effects of lowering pH (Rahel and Magnuson 1983). There is a band of small lakes and short rivers along the northern Georgian Bay coast, all similar to the Killarney area, which may also have had former walleye runs that have now been destroyed.

stock #10, McGregor Bay

Further west along the northern shores of Georgian Bay, where an imprecise division with the North Channel occurs, is island-filled McGregor Bay (Fig. 14). The bay consists of a more open outer section and a more isolated inner section, formerly called North Bay but now named Iroquois Bay.

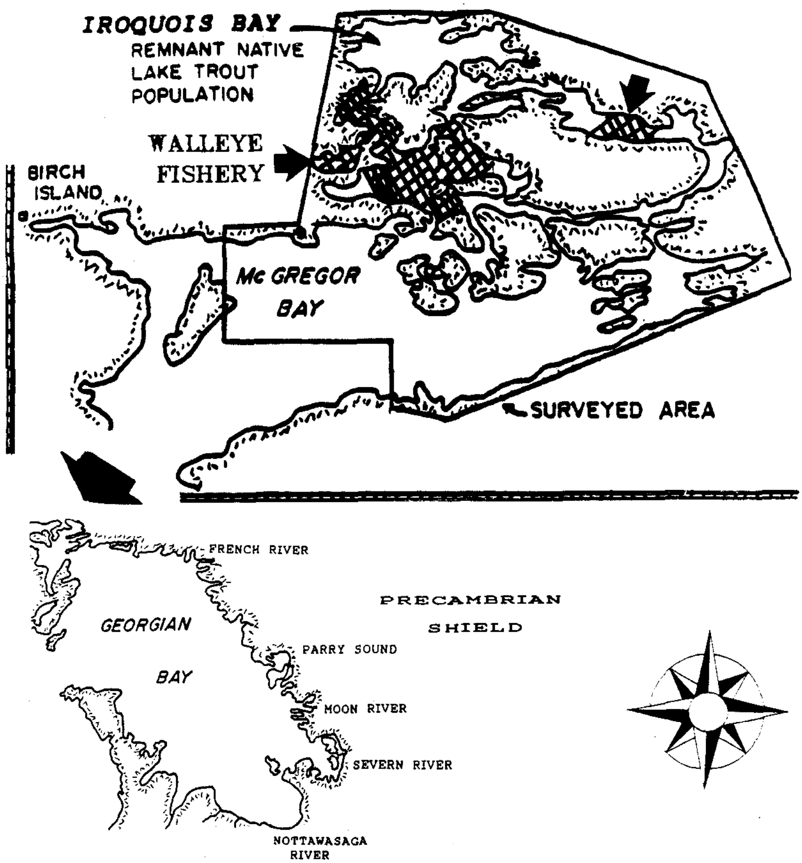


Fig. 14. The McGregor Bay area and Iroquois Bay (top panel), showing their position in the extreme eastern portion of the North Channel (large arrow) and adjacent to northwestern Georgian Bay (bottom panel). Georgian Bay has a much more reduced scale. Cross hatching indicates areas of walleye fishery.

Historically, local fishermen interviewedby Nees (1976) described the formerly dense concentrations of both river and shoal-spawning walleye. By the late 1960s, reproduction was apparently failing since only old fish remained in the sport fishery (Deyell, Ontario DLF, pers. commun.). This is the situation described by Beamish et al. (1975) as characteristic of acid rain effects. A declining fish population occurs through recruitment failure over an extended period. The result is a slowly aging extant fish population. In the creel census described by Deyell (Ontario DLF, pers. commun.), the areas of McGregor Bay that different species were caught in were described and plotted. Northern pike were caught in the shallowest areas, walleye in the intermediate depths (Fig. 14), and lake trout in the deepest areas, essentially Iroquois Bay.

Nees (1976), Olver et al. (1982) and many others have all blamed the heavy winter production of particulates of sulphur dioxides from the sulphide roasting ovens of the nearby Sudbury smelters for creating severe acid depressions in spring runoffs that led to the demise of the various stocks in the area. Heavy metal contamination may also have a synergistic impact to accompany the depressed pH (Hulsman et al. 1983). All of this is compounded by the extremely little buffering action from the well-weathered, extremely old quartzite rocks. Solutions to the acid rain problem have been slow in coming. In 1972, International Nickel Corporation installed a 381 m high-rise superstack into operation which disperses toxic gases over a much wider area. Long-term strikes and worldwide economic downturns, especially since 1981, have also markedly reduced outputs. As a result, there has been a major reduction in local sulphur fallout and marked improvement of water quality in acid-stressed waters in the Sudbury area (Keller and Pitblado 1986; Keller et al. 1986).

Rehabilitation efforts for McGregor Bay have been through a recent CFIP program. Area anglers have planted 50,000 walleye fingerlings in 1986 and 35,000 in 1987, along with one million fry each year (Stevens, Ontario DNR, pers. commun.). Across the narrow peninsula that separates McGregor Bay from the Bay of Islands to the west, 10,000 fingerlings and one million fry have also been introduced. These young fish are already showing up in bait seining efforts. The Bay of Islands area is far more eutrophic than deep McGregor Bay. The latter is one of two sites of residual native lake trout populations in Georgian Bay, along with Big Sound in the Parry Sound area.

Stock #11, Spanish River

The walleye stock in this area is in comparatively good condition, mainly because of long-term tainting problems in fish flesh due to effluents from a pulp and paper mill located about 29 km upstream from the mouth (Dymond and Delaport 1952; Conroy and McGrath 1967). Little specific study of walleye occurred until recently because of a fish kill during early July 1983 (Purych, Ontario MNR, pers. commun.; Powell, Ontario MNR, pers. commun.) and improvements in water quality. In the past, tainted fish flesh acted as a natural tag in commercial fisheries since buyers would reject the strongly flavored fish and send their rejection notices back to the fishermen who, in turn, sent them on to district offices. A pertinent section of a report by Conroy and McGrath (1967) is highly informative:

> The character of the river water below Espanola was reflected in the taste of yellow pickerel taken from the water in 1965. The samples showed that test fish from the Spanish River and the North Channel have an objectionable flavour. Samples analyzed 14 yrs previous (Dymond and Delaporte 1952) revealed that pickerel from the Spanish River had an objectionable taste, but little odor. The grade established was only 39% and was compared to a grade of 63% for control fish of the same species from Lake Mindemoya. The objectionable taste was reported to be suggestive of indol and protein decomposition.

In their study, Conroy and McGrath (1967) discussed the possibility that the tastes were due to phenolic compounds, tannins and lignins "associated with the decomposition of many different organic materials that might be present in these waters".

In July 1983 (during startup operations of new pollution control systems) pulp mill operators accidentally discharged toxic soap material into the Spanish River killing large numbers of fish, including sport fish. An estimated 50,000-60,000 fish were killed (Purych, Ontario MNR, pers. comm. 1983). Samples obtained by Conservation Officers indicated that most were suckers (72%), 7% were pickerel (walleye), and 5% were northern pike (Chevalier, Ontario MNR, pers. commun.). A fishery survey within a week of the kill indicated fish from the North Channel had moved upstream and repopulated the lower river and some had dropped down from a major tributary, the Aux Sables River. The greatest concentration of fish was found immediately below the dam at Espanola but upstream from the point in the river where the discharges occurred (Purych, Ontario MNR, pers. commun.). A second survey three months later showed a large run of walleye from the North Channel (believed to be from the Whalesback Channel area) had migrated to the Espanola dam area (Powell, Ontario MNR, pers. commun.). Powell also listed Birch Creek, Coles Rapids, and the Aux Sables River as *other* probable spawning sites. From 1984 to present, OMNR has stocked one million fry/yr as an aid to rehabilitation. With "significant improvements in water quality" (Bowman et al. 1988), interest in walleye angling rose rapidly and an alternate-year creel census was started in 1985 (Corbett, Ontario MNR, pers. commun.). The major spawning area immediately below the dam at Espanola was closed to angling and the fall fishing period shortened (Corbett, Ontario MNR, pers. commun.). Walleye abundance has rebounded to such an extent that this population is now the major source of eggs for CFIP programs in the Espanola District (Hughson, Ontario MNR, pers. commun.).

Stock #12, Mississagi River and Area

There is little new information to add (Spangler et al. 1977). Quota zones for commercial fishermen have been established. There is a winter sanctuary for walleye in the Mississagi River plus a water flow agreement with Ontario Hydro to maintain flows above 500 cfs during the walleye spawning period. Local CFIP stocking programs have centered on the Thessalon River and Brights Lake which enters the North Channel through Bolton Creek (Woodside, Ontario MNR, pers. commun.) . Commercial yields are low compared to historical peaks. Recent CFIP walleye stocking programs throughout the area are likely to have major impacts, since efforts now are primarily aimed at planting fingerling walleye of relatively large sizes compared to the fry plantings of the past.

Stock #13, St. Marys River

Walleye have been sampled throughout the St. Mary's River (Krishka 1989). However, tagging studies show a marked trend for walleye to concentrate *in Lake Munuscong* (Fig. 15) during winter (Duffy et al. 1987). This is the site of an important winter fishery, the Munuscong Bay Winter Walleye Festival (Krishka 1989).

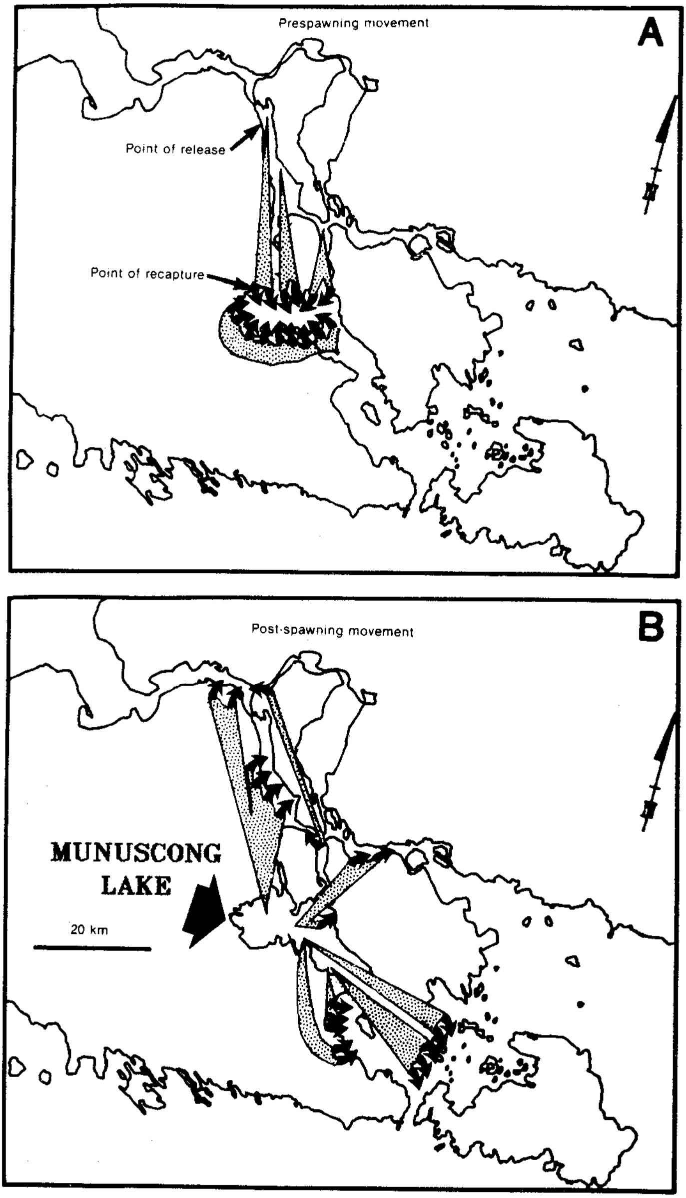


Fig. 15. Movement of tagged walleye in the St. Marys River in relation to Munuscong Lake. A) shows prespawning movements and B) shows post-spawning dispersal (Duffy and Batterson 1987).

Group #14, Southern Lake Huron
Harvests of Mixed Stocks

There is a moderately intensive trapnet fishery in Ontario waters in southern Lake Huron carried out by Purdy Fisheries. The Ontario MNR has sampled extensively since 1979.

> This has been a very stable and productive fishery. Landings essentially have matched allocations by management. CPUE values for the trapnet fishery were higher in 1985 and 1986 than in the preceding six-year period of relative uniformity (McNeil, Ontario MNR, pers. commun.).

The major source of these fish is probably not from Lake Huron, but may be a mixture of stocks from several sources. Tagging studies have shown that some fish tagged as yearlings along the southwestern areas of Lake Erie near Sandusky, Ohio, moved up the Detroit River to Lake St. Clair and then southern Lake Huron (Wolfert 1963). Subsequently, Ferguson and Dirksen (1971) described the complex set of movements which take portions of the spawning stock from the Thames River through two other rivers and three lakes (St. Clair and Detroit Rivers, lakes St. Clair, Erie, and Huron). Colby et al. (1979) provide a pair of diagrams summarizing the set of interlake movements of this stock. Biologists (Ontario MNR) have intensively tagged walleye in the Thames River. From a report to the Lake Erie Committee of the Great Lakes Fishery Commission meeting March 22-23, 1988 (OMNR 1988b), the fate of 23,191 tagged walleyes revealed the rate of movement and fishing pressure in the various areas (Table 11). Among the 3,900 recoveries to date (16.8% recaptured), the largest portion of the recoveries were within Lake St. Clair (40.7%). But 29.8% were recovered in the sport fishery as they were moving upstream towards Lake Huron, and 20.2% were recovered in southern Lake Huron. Summing these two sources indicates that 51.8% of the recaptured tagged walleyes moved northward from Lake St. Clair, while only 7.5% moved downstream and were caught, either in the Detroit River sport fishery (6.0%) or in Lake Erie (1.5%). Tagging studies by Michigan biologists (Bryant 1984) have shown that walleye tagged in western Lake Erie off Monroe, Michigan, moved both into the Maumee River tributary to western Lake Erie and the Thames River tributary to Lake St. Clair, but 9.0% were recaptured by anglers fishing the St. Clair River (7.0%) or southern lake Huron (2.0%). From walleyes tagged at two sites in Lake St. Clair, 32.2% moved upstream and were recaptured in the St. Clair River (27.7%) and 4.5% were caught in southern Lake Huron (Bryant 1984). Surprisingly, from walleye tagged in mid-summer off Lexington, Michigan in southern Lake Huron, only 10.5% of the angling recaptures were from the same area. The majority (82.1%) were recaptured in either the St. Clair River (53.7%), Lake St. Clair (16.8%), or the Thames River (11.6%). Therefore, the walleye fishery in southern Lake Huron may be based on stocks that spawn either in western Lake Erie, the Maumee River, or the Thames River and portions of the progeny move northward to southern Lake Huron. The relative stability of the southern Lake Huron fishery may be a result of the mixture of multiple stocks smoothing out interstock variability. Trapnet samples of young walleye in Lake St. Clair have been used to anticipate trends in year-class fluctuations in Lake Huron (D. Hughes, Ontario, pers. commun.) but these trapnet samples might also be a mixture from different stocks.

Table 11. Percentage of total recovered tagged walleye returned from various rivers and lakes from both sport and commercial fisheries. These rates are based on 3,900 recoveries from 23,191 walleyes tagged in the Thames River 1980-82. Walleye caught in commercial nets in Lake St. Clair are released.

Direction	Area	Type of fishery Sport	Commercial	Subtotals	Totals
Upstream	Lake Huron	1.8	20.2	22.0	
	St. Clair River	29.8	-	29.8	51.8
Lake St. Clair		35.7	4.9*	40.7	40.7
Downstream	Detroit River	6.0	-	6.0	
	Lake Erie	1.1	0.4	1.5	7.5
Totals		74.5	25.5	100	100

* Fish released.

FACTORS REGULATING YEAR-CLASS STRENGTH OF WALLEY

A thorough summary of published papers on the factors affecting walleye reproduction is contained in FAO Fisheries Synopsis No. 119 (Colby et al. 1979). For the Georgian Bay area, however, we will concentrate on the results of Winter-ton (1975), who found that the Moon River walleye year-classes were most closely correlated with spring runoff volumes. We have tested this theory with more recent data from the Moon River and on other river-spawning Georgian Bay stocks as well. Winter-ton's thesis (1975) has been confirmed during the present analysis with some modifications. The Nottawasaga River stock is more closely related to a transformation (square root) of ranked walleye year-classes in relation to mean April-May flow volumes. Hut the curvilinear response (before transformation) may be due to the flow characteristics of the swamp in which this group spawns. High flow volumes are likely needed to maintain sufficient water levels in Minesing Swamp for proper spawning activity, egg incubation, early growth, and then outward movement of fry into the river and then downstream to Georgian Hay. There is likely to be a minimum flow which is needed for basic survival of fry but, once that is exceeded, survival might increase proportionally with higher flows. Additionally, the whole swamp may tend to delay flows so there may be lag effects which higher flows may overcome more easily. The short time series from the French River also showed a significant relationship with flow volume and year-class strength of walleye, although it was a much weaker correlation. The large size of the French River and the fact that Lake Nipissing acts as a damper on extreme fluctuations because of its large storage capacity help even out flow volumes and reduce the variability of year-classes. For the Moon River, the concept was tested using the additional years sampled along with the previous trapnetting data. There were too few years to use a completely independent data set. In general, however, spring flow volumes have been confirmed as being a major factor regulating year-class strength of river-spawning walleye in the Georgian Hay area. Only in the more eutrophic areas, like Severn Sound and Lake Nipissing, are interactions with other species of greater statistical significance. Therefore, Winter-ton's thesis (1975) has been found to be more generally applicable throughout the Georgian Hay area.

A slightly more complex model than that of Winterton (1975) was derived by adding a few more variables. Since there was a slight curvilinearity to the plot of year-class rank versus spring river flow (as in the Nottawasaga River model) the square root statistically significant variables were added to the model, maximum mid winter snow depth and mean April-May air temperatures. These are both precursors to high flow volumes. April and May rainfall was found not to be related to year-class strength. The zero-intercept, three variable equation coefficients are listed along with the sums of squares and accumulative sums of squares in a modified analysis of variance table (Table 12). Note that river flow accounted for 84.5% of the year-class variability, the same as Winter-ton found (he reported the r^2 value as a proportional 0.84). The air temperature variable adds another 8% to the cumulative r^2, while deep snow adds a further 4.3%. These r^2 values are adjusted for small sample size. Though small additions, they are statistically significant as indicated by t-tests in analysis of variance (t = 9.37, 6.84, and -4.10, respectively) and their associated p values (Table 12). Therefore, we can now model Moon River year-classes with an accuracy of 97%.

Table 12. Best multiple regression for calculating the square root of Moon River walleye year-class rank from three variables FLOW, TEMP, and SNOW. This is a zero-intercept regression with correlation coefficients adjusted for small sample size. Overall R (adjust) = 0.984.

Variable definitions: TEMP = May air temperature (C)
SNOW = Maximum snow depth (cm)
FLOW = Mean April + May Moon River flow (m^3 sec^{-1})

Predictor variable	Regression coefficient	Sum of squares	Cumulative sum of squares	Cum. d.f.	Adjusted r^2 x 100 (%)	p
FLOW	0.0516	495.73	495.73	1	84.5	0.000
TEMP	0.4991	43.91	539.63	2	92.5	0.000
SNOW	-0.1452	22.34	561.97	3	96.8	0.002
Residual		14.63	576.60	14		

Residual mean square = 1.33

There is a high degree of intercorrelation and redundancy to these variables. We can statistically experiment by calculating partial correlation coefficients to estimate the effect of holding one, then two, of the variables constant and compare the effect of FLOW, TEMP, and SNOW are 0.943, 0.900, and -0.777, respectively. Therefore, river flow has the greatest impact, followed closely by temperature. Note that deep snow, holding temperature, and flow constant are actually detrimental as indicated by the negative sign. But in reality the deep snow provides a massive water storage volume for high flow discharge when combined with a warm spring. It is this combination of events that leads to strong year-classes. Weather trends over several decades have been in the direction of reduced snowfalls and milder winters with smaller volume of runoffs. This has produced declining year-classes of walleye. The planting of fingerling walleye has benefited the Moon River stock at a time when it was most vulnerable to collapse. If weather trends persist, fish cultural activities may also have to persist to maintain a strong fishery.

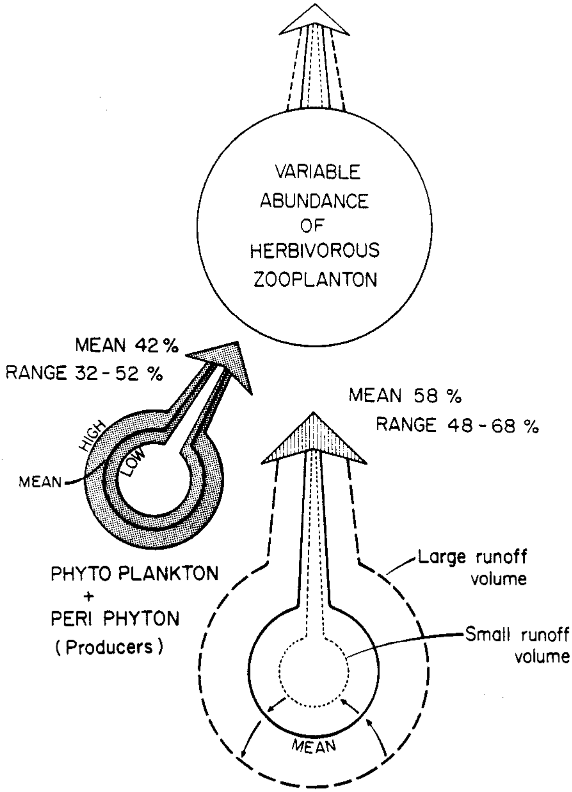
Table 13. Partial correlations between the square root of walleye year-class strength (where 1968 yr. cl. = 1.0) and three independent variables, first controlled for a single variable and then controlled for two variables. All correlations are zero-intercept models. N = 14, d.f = 12, significant r = 0.532, with two independent variables a significant r = 0.627.

Variable(s) controlled	Independent variable(s) coefficient	Partial correlation coefficient squared (%)	Partial correlation
TEMP	FLOW	0.842	71
	SNOW	-0.058 n.s.	5
SNOW	FLOW	0.812	66
	TEMP	0.646	42
FLOW	TEMP	0.737	54
	SNOW	0.225 n.s.	5
SNOW & TEMP	FLOW	0.943	89
SNOW & FLOW	TEMP	0.900	81
FLOW & TEMP	SNOW	-0.777	60

A testable hypothesis of the link therefore exists between the environmental trends and strong year-classes of walleye. As fisheries managers, river volume is a convenient proxy variable, a stand-in of sufficiently close relationship to the actual causal mechanism, to provide simple, useful predictive models for management purposes. Scientists, however, are curious to examine the probable causes in more detail and to suggest testable hypotheses which may fill in the sequences of events that can more fully explain the interconnected workings of the climate:river flow:year-class relationship in greater detail.

The link between river flow and year-class production must be mediated through a biological link. The main step

The link between river flow and year-class production must be mediated through a biological link. The main step in this link, perhaps, occurs through a variable sized pool of detritus which may act as the most important energy source to herbivorous zooplankton. Lindeman (1942) provided a significant impetus towards the concept of energy flows through ecosystems. Rich and Wetzel (1978) expanded Lindeman's (1942) concepts and emphasized the central role of detritus in the energy flows. In a highly enlightening study, the average concentrations of carbon and its rate of exchange through the epilimnetic waters of Lake Ontario were determined by Robertson and Scavia (1978) during the multifaceted, multiorganizational International Field Year of the Great Lakes (IFYGL). They found that a majority of carbon moved through the detrital pool rather than directly from producers. Their estimates were 3.9 $\mu g\ Cl^{-1}d^{-1}$ (42% of total) moved from producers to herbivorous zooplankters while 5.3 $\mu g\ Cl^{-1}d^{-1}$ (58% of total) moved from the detritus compartment to herbivorous zooplankton (Robertson and Scavia 1978). The model has been modified in the following manner. The suggested estimate of 5.3 $\mu g\ Cl^{-1}d^{-1}$ is not a fixed quantity but an annual variable. Within eastern Georgian Bay, similar carbon flows may be dependent on variable river runoff bringing in variable quantities of detritus from year to year. This is especially true when large runoffs wash out beaver dams with accumulated leaf litter and its detrital products, or flood broad river basins with nutrient-laden deposits. Therefore, the detrital pool is shown as a variable sized component which may make much larger contributions during years with large runoff volumes (Fig. 16). Conversely, low runoff might provide exceptionally small detrital input to the herbivorous zooplankton. Therefore, the zooplankton fluctuations are the final regulator of walleye year-class abundance, but the whole interconnected sequence of annual events is driven by winter snowfall accumulation and the spring runoff it produces. Recent ecological studies of the food webs in the St. Marys River lend credence to these concepts (Duffy et al. 1987). Earlier in this century, deep winter snowfall accumulations occurred with greater frequency, particularly 1928 and 1929, and again for four of five years during 1947 to 1951. These conclusions are based on the outflows of the Magnetewan River and the relationship between snow severity and river flow. The last exceptionally large snow accumulation and spring runoff occurred in 1960. Wildlife biologists have found significant relationships between snow severity and deer mortality (Passmore, Ontario DLF, pers. commun.). Both biologists and deer hunters in the eastern Georgian Bay area still remember the winters of 1958-59 and 1959-60 with their deep snows and large-scale starvation of many deer (Douglas, Ontario MNR, pers. commun.). But 1960 was also the last abundant year-class of walleye in this area. Since the east coast of Georgian Bay is a snow belt area, deeper than average snow accumulations are the norm. Variable winter accumulations and variable spring runoffs are probably the modulating factors controlling variable year-class strength of Georgian Bay walleye. Less snow during recent winters has led to a decline in walleye stocks and a marked resurgence in deer populations. Furthermore, the declining walleye stocks have been subjected to increasing stresses from other sources. Fishing mortality rates have likely risen, though there is little documentation of this factor. The depressed stocks have also been more greatly impacted by industrial pollutants, both directly through the river systems and through aerosols containing a variety of detrimental materials, both inorganic and organic. Again, winter accumulation of these materials in the snow pack are released in greater concentrations early in the annual runoff event. These may exceed the biological capabilities of eggs and larvae of walleye. Finally, in some areas, changing community structure, particularly in the form of new species such as black crappies, have significantly impacted depressed stocks. We have no data on the impact of smelt or alewives on walleye stocks prior to the impact of black crappies. Perhaps other areas have data that might shed light on the significance of these species. But the most significant factors appear to be environmental for the Georgian Bay area. Community changes seem to have greater impact in more eutrophic areas.



VARIABLE SIZED
DETRITUS POOL

Fig. 16. Modified portion of GLERL model of carbon flow through an epilimnion ecosystem described by Robertson and Scavia (1978). Here the variable sized pool of river-borne detritus, modulated by annual differences in runoff volume (depicted by expandable and contractible "balloons"), leads to annual variation in quantities of herbivorous zooplankton which, in turn, leads to variations in year-class abundance of walleye. This is the hypothesized pathway of causality linking the observed correlation between river flow and walleye year-class strength. The percentage values are based on μg C l^{-1} d^{-1} reported by Robertson and Scavia (1978).

RECOMMENDATIONS

Since each district in Ontario discharges its responsibilities toward Great Lakes waters and their fisheries to a different extent, it is difficult to generalize overall strategy. Certainly there should be additional stress on more tagging studies to delineate population boundaries of the many different local stocks.

Rehabilitation efforts through the CFIP approach have provided definite improvements in fish abundance and have strengthened weak spawning stocks. With the Ministry proposing even greater emphasis on partnerships with local interest groups, CFIP could be expanded even more.

Further research integrating the ecosystem concept as initiated in the St. Marys River studies, and testing the hypothesized pathways of year-class formation for oligotrophic Georgian Bay waters should also be implemented. We suggest the Moon River should be a candidate site because of the availability of extensive background material.

ACKNOWLEDGMENTS

We dedicate this paper to continuing the memory of Kauko Henry Kujala, 1947-87, highly dedicated and well-loved member of the Parry Sound District staff who died in a helicopter crash while photographing walleye spawning grounds near Serpent Rapids on the Sequin River. We acknowledge the information and data given freely and cooperatively by district staff, particularly Robin Craig, Huronia District; Karen Laws, Sudbury District: Don Hughson, Bruce Stevens, and Diane Corbett, Espanola District; Stan Woodside, Blind River District; and the highly mobile John Gunn, once again in Sudbury at Laurentian University. Fisheries Assessment personnel from the Lake Huron Unit (Bob Payne, Don Hughes, and Fergus McNeil) and from the lake St. Clair Unit (Don McLennan) have readily supplied useful data. Carsten Jorgensen has shared his extensive knowledge and data summaries for lake Nipissing with us. In addition, Wildlife Research colleagues Peter Smith and Fiona McKay, Southern Research Station, Maple, kindly provided snow severity data collected for deer studies. Keller (Ontario MOE Northeastern Regional Office, Sudbury) provided recent papers on the sulfur dioxide reductions in the Sudbury area. The critical editorial comments by Cheryl Lewis and Ken Muth are much appreciated. We also thank Audrey Chui who provided excellent drafting services and Mary Hirst who processed the manuscript several times while we were changing word processing programs.

WALLEYE IN LAKE ERIE AND LAKE ST. CLAIR[1]

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ABSTRACT. The history and current status of walleye (Stizostedion vitreum vitreum) stocks in Lake Erie and Lake St. Clair are reviewed in relation to their exploitation by commercial and recreational fishermen, environmental factors, rehabilitation efforts, and community dynamics. Management initiatives and stock recovery under these processes are outlined.

After the collapse of the fishery in 1957, the highly productive walleye stock of western lake Erie remained depressed through the 1960s, while the eastern basin stock remained stable. Closure of the fishery for walleye from 1970-73 because of mercury contamination provided an opportunity for the development of an international interagency management plan. With quota management, the walleye stock in western lake Erie responded well to limited exploitation, steadily increased, and expanded its range. As population expanded, growth began to decline and was more apparent in the young-of-the-year (YOY) in the 1970s, and in older walleye in the late 1970s and 1980s.

At the turn of the century, commercial harvest of walleye in lake St. Clair ranged from 12-127 tonnes annually. A relatively stable period from 1910-59 was followed by significantly increased harvests (100-150 t) in 1959-65. This increase was a result of increased commercial exploitation as well as an increased abundance of walleye. After the mercury contamination problem of 1970, angling effort and harvest was reduced but then gradually increased in Ontario waters from 37 t in 1973 to 62 t in 1988. The increased mean age of the stock during the early 1970s was due to a few strong year-classes (1970, 1972, and 1974) as well as a period of stable or reduced catch per unit effort. With the current mean age not reduced significantly, the stocks of walleye should continue to provide good yields.

INTRODUCTION

In this study of rehabilitation of walleye (Stizostedion vitreum vitreum) populations in Lake Erie and lake St. Clair, we will first describe the history of the extremely valuable commercial and recreational fisheries on walleye in those water bodies and the interconnecting Detroit and St. Clair Rivers. We will then describe fish community changes in those areas and the current status of populations. Finally, we will describe rehabilitation efforts and four ongoing management strategies:

1) management initiatives in western Lake Erie,

2) quota management of western Lake Erie walleye,

3) stock recovery under-management, and

4) unilateral management of eastern basin walleye in Lake Erie.

THE FISHERIES

Lake Erie

For over a century and a half, walleye have been a valuable and significant commercial and sport fish in Lake Erie (Fig. 1). In the western basin, commercial harvests fluctuated between 334 and 1,356 tonnes (t) from 1915-36, falling below 600 t in only four years. Harvest began to increase slowly in the 1940s (mainly in Ohio waters) after the loss of the valuable fishery for lake herring (Coregonus artedii). In the 1950s, catches rose rapidly as Ontario gillnetters greatly increased the amount and efficiency of their gear (Nepszy 1977). Harvest in the western basin peaked at almost 7,000 t in 1956 and more than 6,000 t were taken again in 1957. The stock then collapsed and commercial production dropped to only 274 t in 1962, rose to 1,130 t in 1963, and fell precipitously to 161 t in 1969.

In 1970, with the discovery of levels of mercury in walleye tissue that exceeded U.S. Food and Drug Administration guidelines (>0.5 ppm), the commercial fishery was closed in both the U.S. and Canadian waters of the western basin. Also, the retention of walleye caught by anglers was prohibited in Ontario and Michigan waters. With a decline in mercury contamination after 1972, the walleye fishery in Ontario was reopened to both sport and (limited) commercial use. However, in Michigan and Ohio, the renewed harvest was restricted to angling (Hatch et al. 1987).

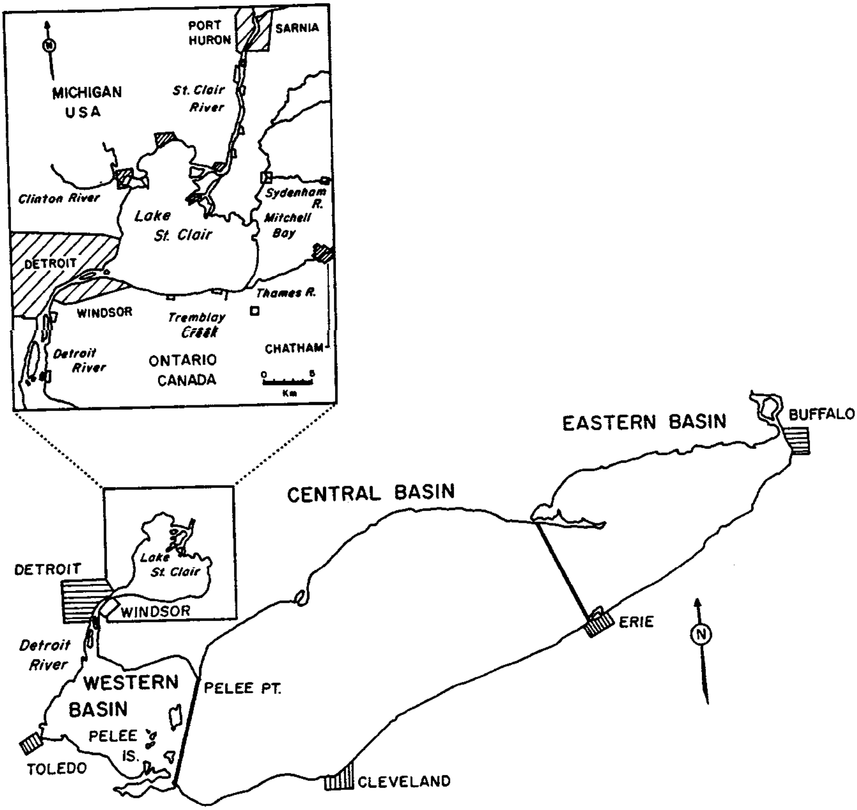

Fig. 1. Lakes Erie and St. Clair showing locations mentioned in text.

Under this multilateral ban on fishing, the innate resiliency of walleye stock was manifested. The fishable stock increased from about 83,000 walleyes in 1970 to nearly 14 million in 1976 (Hatch et al. 1987). Although walleye had always been prized by anglers, catch rates rarely exceeded 0.1 walleye per angler hour during the 1950s and 1960s (Keller 1964; Sztramko and Paine 1984). Catch per unit effort rose slowly during the early 1970s and then increased sharply from 0.16 in 1975 to 0.50 in 1976 in Ontario (Sztramko and Paine 1984), and from 0.12 in 1975 to 0.61 in 1977 in Ohio (Baker et al. 1979). Increased sport effort and high catch rate resulted in a dramatic increase in sport catch from an estimated 110,000 walleyes in 1975 to 2,164,000 in 1977 in Ohio waters alone. The Ontario commercial fishery reopened under a limited permit system in 1974 and expanded under an international quota system in

1976. The combined harvest of the three jurisdictions exceeded 2,500 t in 1977, 4,000 t in 1982 and 7,000 t in 1986 (Fig. 2).

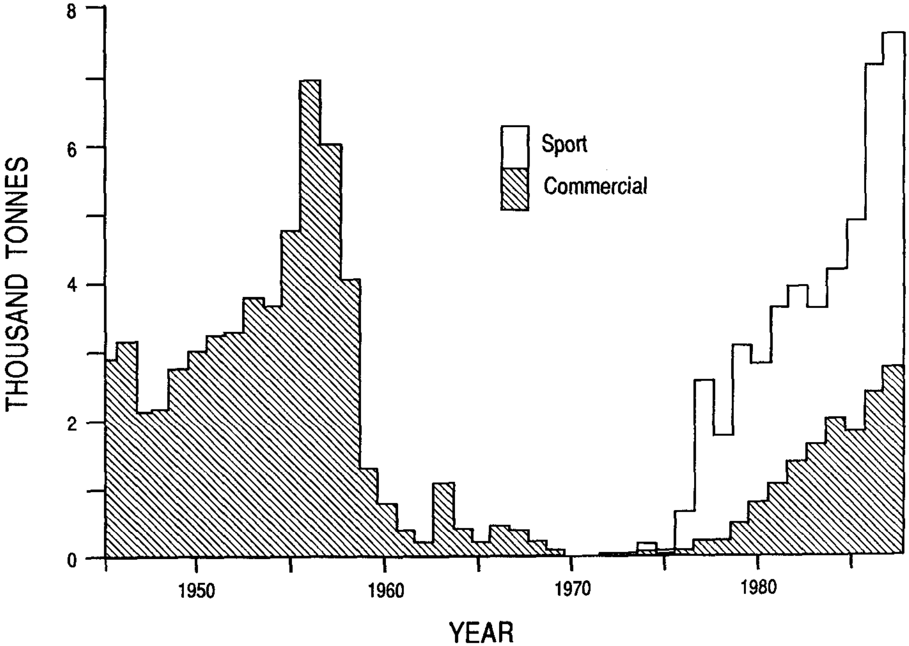

Fig. 2. bandings of walleye in western and central Lake Erie, 1945-87 (Hatch et al. 1990).

Although landings of walleye in Lake Erie's central basin had contributed up to 25% of Ontario's total landings during the 1950s, the harvest in Ohio did not exceed 5% of the western basin catch and angling pressure was also light (Keller 1964). Central basin landings collapsed simultaneously with those from the western basin. However, the recovery was not simultaneous. Several reasons have been suggested for continued low levels of abundance in the central basin, including:

1) changed limnological conditions,

2) pollution in spawning streams,

3) siltation of open lake spawning and nursery areas,

4) increasing populations of rainbow smelt (Osmerus mordax), and

5) a continuing small-mesh gillnet fishery for yellow perch (Perca flavescens) (Regier et al. 1969).

In the Ontario waters of the central basin, walleye catches of 2 t were a noticeable contribution to the 1980 commercial landings and this contribution continued to rise steeply through 1986. A catch of over 1,147 t in 1986 was attributable to a combination of greater abundance of walleye and increased effort directed at that species. Harvest by anglers also increased in both Ontario and Ohio waters of the central basin during the 1980s. Results from a 1984 Pacific salmon (Oncorhynchus, spp.) derby in Ontario waters showed a harvest ratio of one walleye to three coho salmon (Oncorhynchus kisutch). Walleye were rare in an earlier and similar survey. The snort catch from Ohio waters increased from 54,000 walleyes in 1982 to a record high of 1.1 million in 1988. Estimated catch rates were 0.12 per angler hour in 1975, 0.24 in 1983, 0.41 in 1986, and 0.33 in 1988 (Ohio DNR, unpubl. data). Until 1982, contributions of walleye by number harvested and by fishing effort were over 95% from the western basin. However, in 1983, a change occurred with an increasing proportion (12% to 14%) being taken from the central basin. This ratio for numbers of walleye harvested continued through 1987 and increased to 24% in 1988. The corresponding ratio for angler effort increased in 1984 and has remained greater than 20% to 1988.

The increasing abundance of walleye in the central basin is apparently due to dispersal from the western basin, but there is also a Possibility of a reproducing population in the central basin. The presence of mature, then spent, adults in May, larval walleye late in May, and juveniles in July indicated some degree of reproductive success in the western portion of the central basin (Timmerman and Dunlop 1985). The generally acknowledged paucity of prime spawning substrates on both shores of the central basin leads to the speculation that major contributions to the walleye population may be unlikely from these areas. Historically (1950s) there is some support for this speculation. Walleye were abundant outside the western basin only when populations were strong in the western basin.

A discrete population of walleye, confined to Lake Erie's eastern basin, has been recognized (Wolfert 1963, 1969; Wolfert and Van Meter 1978). After the collapse of the lake herring (*Coregonus artedii*) population in the mid-1940s, the commercial fishery concentrated on stocks of blue pike (*Stizostedion vitreum glaucum*) and lake whitefish (*Coresonus clupeaformis*) which supported the fishery until the late 1950s when both populations collapsed simultaneously. Prior to 1956, walleye was only an incidental species in the commercial fishery of the eastern basin. There were landings of only 1-4 t annually from New York waters (Wolfert 1981). After the collapse of the western basin stock in 1957, harvest from New York's eastern basin waters rose to 45 t in 1958 and ranged from 50 to 84 t from 1961-75. With the rehabilitation of the western basin stock in the late 1970s and 1980s, commercial landings from the eastern basin decreased to 32-47 t in 1976-1983 and then rose again, reaching 158 t in 1985 as the fishery expanded in the Ontario waters of the eastern basin.

The extent of the recreational harvest from the entire eastern basin is not known. However, a 1984 sport fishery assessment measured the recreational harvest in New York waters at about 22,000 fish (Lange et al. 1985). Since 1986, the harvest from New York waters has been restricted to angling. This sport harvest has been monitored annually since 1987.

Lake St. Clair

Commercial fishing was evident in Lake St. Clair (Fig. 1) from the days of the first settlers until 1970. After the mercury crisis, the commercial fishery was reopened in 1980 on a limited basis and continues to the present. However, no walleye have been allocated to this fishery. Total effort was extensive in both Michigan and Ontario waters in the late 1800s but declined substantially with the closure of the Michigan fishery in 1908. Commercial harvests of walleye in Ontario waters were variable from 1874-1910 and ranged from 12-127 t per annum (Fig. 3). For the next half century (1910-59) there was a period of relative stability with a mean harvest of about 25 t annually. A very significant change then occurred from about 1959-65 when walleye harvests and CUE from the commercial fishery increased progressively and substantially relative to the preceding 50-year period (Johnston 1977, Fig. 3). The increase in walleye harvested reflected both an increase in the commercial fishing effort and increased abundance based on catch per unit effort for trapnets.

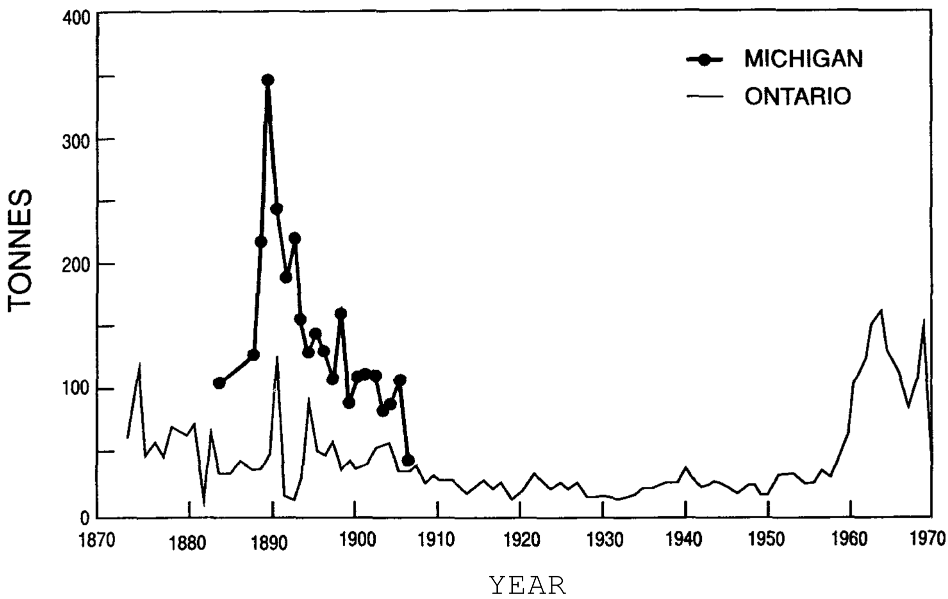

Fig. 3. Commercial fishery harvest of walleye from Lake St. Clair, 1870-1970.

In Ontario, the Thames River and to a lesser extent the Syndenham River, have provided a spring walleye fishery since early human settlement. This fishery became increasingly important to non-Indians, who used a variety of entrapment gear until 1950, when the fishery was restricted to angling. The Indian communities adjacent to the Thames River have been allowed limited access to the walleye spawning run with entrapment gear.

Recreational angling in the summer is lakewide, whereas winter fishing is concentrated in the more sheltered bays, on the lower Thames River, and along the southeastern shoreline. Data for the 1950s indicate a substantial winter fishery for walleye and yellow perch along the southeastern shoreline, for walleye in the Thames River, and for yellow perch in the bays along the northern shore.

The Michigan DNR estimated 78,000 walleyes caught from June to August 1966 and 96,100 from April to August 1967. Although no comparable data are available from Ontario waters, the summer fisheries for walleye in the center of the lake were extensive in those years.

Because of the mercury contamination problem in 1970, angling effort in Ontario waters dropped from 460,000 rod-hours in 1969 to 181,000 rod-hours in 1970. Effort increased to 461,000 rod-hours in 1974, but returned to normal in 1975 and again in 1977 (Table 1). Without the mercury contamination problem, it appears that angling effort in Ontario was about 300,000 rod-hours for the June to early September period and about 360,000 rod-hours for the extended May to early September period. Comparable data for this period are not available from Michigan waters.

Summer landings in Ontario waters varied from 18 t in 1970 to 37 t in 1973 to 62 t in 1988 (Table 1). The winter fishery for walleye is limited to the southeastern shoreline, the center of the lake, and the lower 10-15 km of the Thames River. A census of the river in 1973 indicated a substantial 7.5 t walleye fishery. Landings from the river increased to 15.8 t in 1982.

Table 1. Estimates of total angling **effort**[a] (thousands of rod-hours) for all species, angling yields and success **(CUE)**[b] for walleye in the Ontario waters of Lake St. Clair, June to August (data for 1969-75 from D. MacLennan, OMNR, pers. commun.; data for 1978-88 from Ontario MNR Report, 1989).

	Rod-Hours	Walleye		CUE
		No. x 10^3	Tonnes	
1969	460	37	25	0.169
1970	181	18	18	0.373
1971	286	25	25	0.342
1972	219	19	19	0.332
1973	337	37	37	0.286
1974	461	18	18	0.180
1975	387	21	21	0.152
1976	359		20	
1977	330		22	
1978	346	36	34	0.167
1979	335	96	34	0.376
1980	314	113	54	0.361
1981	292	82	51	0.299
1982	485	134	66	0.293
1983	324	65	34	0.230
1984[c]				
1985	264	78	42	0.385
1986	263	39	64	0.338
1987	289	115	59	0.385
1988	349	114[d]	62	0.497

[a] Survey period for 1969-77 was June-August; weekend survey only in 1977; May-August for 1978-88.

[b] Catch (observed number of fish kept) divided by effort (observed number of rod-hours spent seeking that fish).

[c] Survey not conducted.

[d] Incomplete values - July to August period only.

Detroit and St. Clair Rivers

The earliest record of commercial fishing in this system was the seining of lake whitefish in about 1830 at Ecorse, Michigan in the Detroit River. Eight species of fish were dominant in the harvest: lake whitefish, lake herring, walleye, lake sturgeon (Acipenser fulvescens), largemouth bass (Micropterus salmoides), muskellunge (Esox masquinongy), northern pike (Esox lucius) and common carp (Cyprinus carpio) (Edwards et al. 1987).

In the late 1800s and early 1900s, walleye still ranked second in market preference and fishermen actively sought spawning aggregations. For a number of years after 1880, personnel of the Sandwich, Ontario hatchery collected eggs from ripe walleye at Bois Blanc (Bob-Lo) Island and other locations in the Detroit River. It may therefore be inferred that spawning runs once occurred there, but were either small or did not persist long. The Detroit hatchery sometimes obtained eggs from the Canadian side of the Detroit River suggesting that walleye runs to the American shores near Detroit were also small (Goode 1884).

Harvest by anglers in Ontario waters of the lower Detroit River has been mainly of white bass (Morone chrysops) and walleye in the summer boat fishery. Although the CPUE for walleye has varied over the years, it remained stable from 1975-83, ranging from 0.134-0.175 fish per angler hour or 26-30 thousand fish (Sztramko and Paine 1984). The average annual harvest of walleye from Michigan waters of the Detroit River is estimated to be 15.3 $kg.ha^{-1}$, considerably higher than most other estimates reported in the literature. Colby et al. (1979) in their summary, estimated that good walleye waters yield about 5 $kg.ha^{-1}.y^{-1}$ to anglers.

The fisheries of the St. Clair River in the 1890s were small with few haul seines used while hand and troll lines were used primarily to capture walleye. Although walleye was the main species harvested, yellow perch, northern pike, and lake sturgeon were also taken in Ontario waters. At the turn of the century, walleye landings were in the range of 50-60 t annually.

From 1983-84, anglers expended an estimated 1.1 million hours of effort in the St. Clair River with an average catch of 0.24 walleye per hour (Haas et al. 1985). Estimated annual angler effort for all species was 281 hours/ha, a significant amount when compared to the average annual sport-fishing effort in inland lakes of 94 $h.ha^{-1}$ (Colby et al. 1979).

The harvest rate for all species in the St. Clair River was estimated at 32 $kg.ha^{-1}$ annually and the average annual harvest of walleye from Michigan waters was estimated to be 26.7 $kg.ha^{-1}$, again far superior to the yield recognized in good walleye waters.

FISH COMMUNITY CHANGES AND CURRENT STATUS

Western Lake Erie

Heavy fishing pressure in the 1950s greatly altered the age composition of the walleye population in western Lake Erie. This stock had always been subject to considerable variation in year-class strength (Deason 1936) but the scarcity of the older age groups became pronounced as the fishing-up process continued. Year-class variation has also been evident from recent measures of recruitment in this basin (Table 2).

Table 2. Comparison of adjusted YOY index (number per trawling hour) and interagency (Ohio-Ontario) yearling index (number per 1,000 feet of suspended gillnets) of walleye.

Year-class	Adjusted YOY Index	Yearling Index	Year-class	Adjusted YOY Index	Yearling Index
1959	13.2		1974	36.6	
1960	0.4		1975	15.3	
1961	7.8		1976	4.3	
1962	29.6		1977	105.1	
1963	1.5		1978	5.9	25.5
1964	3.9		1979	31.0	14.2
1965	11.1		1980	81.1	41.1
1966	0.6		1981	28.1	28.7
1967	3.4		1982	101.6	67.8
1968	1.7		1983	0.3	2.2
1969	5.2		1984	326	24.9
1970	21.4		1985	23.1	19.8
1971	2.0		1986	14.9	35.7
1972	32.2		1987	8.3	13.7
1973	8.3				

Growth

The decrease of average age during this period was accompanied by an increase in average size of walleye in the commercial catch. From 1943-54, walleye in fall samples averaged 366 mm in total length and 0.45 kg in weight; in 1955-62, respective figures were 406 mm and 0.74 kg (Parsons 1970). Hatch et al. (1987) found that as harvests of walleye increased during the 1940s and the larger and older fish were removed from the population, the mean length of age-3 fish seemingly decreased. Simultaneously, the mean length of age-1 and age-2 walleye began to increase (Fig. 4). This increase was reflected in the mean size at age 3 beginning in 1955. By fall 1960 (after the stock's collapse), the mean length of age-l walleye was roughly similar to the mean length of age-3 walleye in the mid-1940s. Growth rate continued to increase during the 1960s (Wolfert 1977) and mean length-at-age remained high with some fluctuations during this period of low population abundance (Fig. 4).

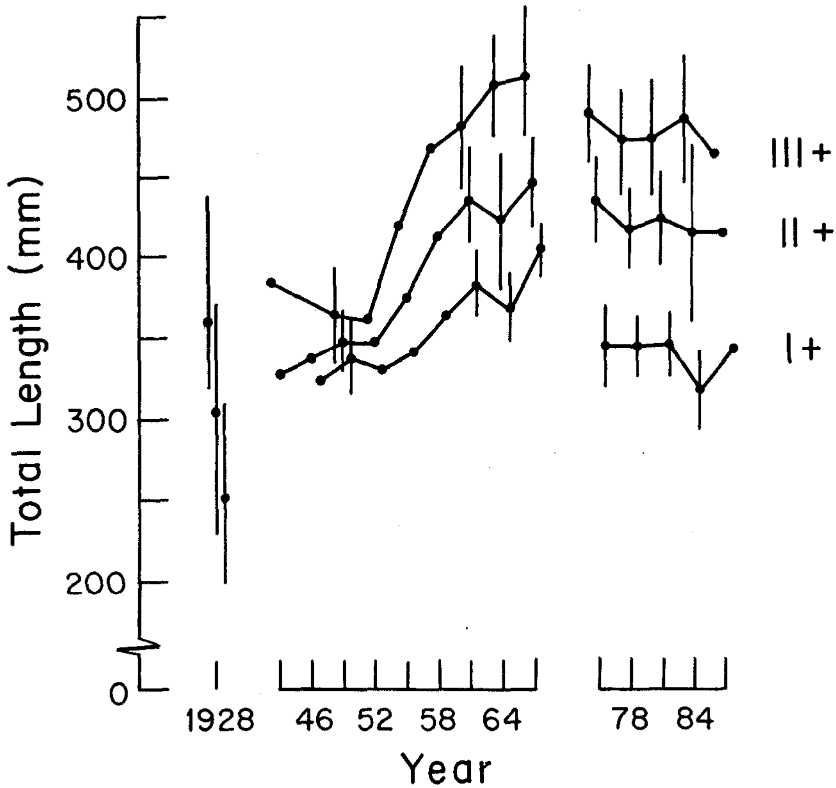

Fig. 4. Mean length of western basin walleye at the end **of** their second, third, and fourth growing seasons. Each point represents the mean length in net-run samples from Ohio commercial trapnets in three adjacent years. Vertical bars are one standard deviation above and below the mean (range for 1927-29 samples) for the samples where it could be determined (Hatch et al. 1987 with current years' data appended.).

Samples were unavailable from 1968-70, first due to low availability and then because of the mercury crisis **moratorium. However,** fall trawl samples of YOY walleye showed that first-year growth was nearly constant during the 1960s when the stock was depressed but declined progressively from the early 1970s as stock abundance increased gradually and then rapidly (Muth and Wolfert 1986; Hatch et al. 1987).

Walleye growth changes from year to year during the recovery period in the 1970s usually were small and decreases in growth for individual age groups were offset at times by slight increases in the following year. Decrease in growth was more pronounced after 1979 when stock abundance had increased. This decrease along with cumulative small growth losses in previous years resulted in a western basin walleye population that was dominated by young age groups that were smaller in 1983 than before stock rehabilitation. Hatch et al. (1987) examined the relationship between year-class growth and year-class abundance by comparing von Bertalanffy growth parameters by year-class. The comparisons, based on the product $K.L_\infty$, showed that beginning with the 1977 year-class (the first extremely large year-class) there was a sharp decrease in K and a concomitant increase in L_∞ for male walleye. The pattern in female walleye is less clear. Although no trend was obvious in either K or L_∞, the product $K.L_\infty$ showed a slight downward trend, although less pronounced than for males.

According to Hatch et al. (1987), weight-at-age followed a similar pattern but with more variation and there was a fluctuation of condition factors from 1964-83 (Muth and Wolfert 1986). The condition factor of yearling walleye declined slowly from 1976-80, but decreased rapidly from values between 0.96 and 0.99 to 0.91 in 1982 and 0.82 in 1983. Values for age-2 and age-3 walleye were also lower in 1983 than in previous years (although not as low as those for age 1) (Muth and Wolfert 1986).

Although no observations are available on weight or condition factors for YOY walleye, the accumulated data indicated that depressed growth in the first two growing seasons began in 1977-78 and that the effects persisted as the cohorts grew older (Hatch et al. 1987). These conclusions imply some increased competition for food at the abundance levels of walleye projected for 1977 and later, and that this competition was not overcome until fish became large enough to consume larger prey.

Maturity

Size and age at sexual maturity of walleye from the western basin also changed markedly after 1977 (Muth and Wolfert 1986). Females matured to a greater length in the 1980s than in the 1960s and 1970s and the increase in length at maturity was much more evident in male walleye. Age at maturity also changed. During 1964-66, 86.3% of the age-3 females were mature in the spring (Wolfert 1969). However, the anticipated maturity of fall-caught age-2 females decreased markedly in 1975 and again in 1982 to levels below 10%. Sexual maturity of age-4 walleye remained unchanged.

Nearly all age-4 walleye (98.6%) examined in 1964-66 were *mature* (Wolfert 1969) and in recent years, fall-caught age-3 females showed 100% anticipated maturity except in 1974 and 1983 when the proportion dropped to 87.5 and 94.4% respectively (Hatch et al. 1987; Muth and Wolfert 1986).

The decrease in average age at maturity of walleye since 1927-28 in the western basin has gone hand in hand with a large increase in the growth rate. The bulk of males reached maturity at 330 mm or age 3+ while females were not maturing before reaching 380 mm or age 4+. First-year calculated lengths in 1927-28 averaged 100 mm (Deason 1933) as compared to about 250 mm in 1964-66.

Eastern Lake Erie

Growth

Wolfert (1977) reported that during 1963-68 the major commercial fishing gear used in eastern and western Lake Erie differed, as did the age composition of the catches sampled from them. In the eastern basin, age composition of walleye caught in large-mesh gillnets (114 to 127 mm, stretched measure) changed little from 1963-68.

The age composition of walleye in the small number of large-mesh gillnet samples from the western basin was similar to that of fish in the eastern basin samples with age-3 group fish predominating. However, the overall average age was greater in the western basin (4.3 years) than in the eastern basin (3.7 years). Assessment netting by the New York State Department of Environmental Conservation during the 1980s showed that older individuals were well represented in the eastern basin walleye population (Lange et al. 1985, 1986; Einhouse et al. 1987, 1988).

Calculated total lengths of male and female walleye from each basin indicated faster growth in the western basin (Wolfert 1977). Annual growth increments of the same sex for each basin differed mainly during the first two years of life. Although the greater length attained by western basin females at the end of the first year (35 mm total length) was maintained, eastern basin females grew faster during the third year, and by the end of the fourth year the calculated length of eastern basin females exceeded that of western basin females. During this period, western basin male walleye were also larger than eastern basin fish during their first and second years. Accelerated growth of eastern basin males then reduced the differences, and at the end of the third and subsequent years, lengths of males of the same age from both basins were similar.

The calculated weights of walleye of the same sex differed in the two basins (Wolfert 1977). Females in the eastern basin were only about half as heavy as those in the western basin at the end of the first year. During the third and fourth growing seasons, eastern basin fish were heavier.

Eastern basin male walleye weighed only about half as much as those of the western basin after the first year, but they increased in weight faster than those in the western basin during the third and fifth years. By the end of the fifth year, males from both basins were almost the same weight.

Wolfert's (1977) study of walleye from the two basins indicated that at any given age during the first three years of life, females were longer than males and, generally, fish from the western basin were longer than those from the eastern basin. The greatest difference in growth of the same sex was apparent at the end of the first year, when fish from the eastern basin were only about half as heavy as those from the western basin. After the second year, relative growth in weight of eastern basin walleye improved. The weight of females exceeded those in the western basin by the end of the fourth growing season and the weights of males in the two basins were about equal by the end of the sixth growing season.

Maturation and Age at Maturity

Age at maturity varies considerably between walleye stocks and generally correlates inversely with growth rate which in turn is greatly influenced by energy availability.

Colby and Nepszy (1981) in their review showed that the environment greatly influences the rate of maturity of walleye. Walleye in northern stocks mature later and over a greater number of years than walleye in southern and heavily exploited stocks.

Female walleye from the eastern basin in 1964-66 were approximately 50% and 92% mature at ages 3 and 4 respectively. For comparison, western basin females were about 85% mature at age 3 and almost 99% mature at age 4. Females were about 25-38 mm longer at a given percentage maturity than those from the western basin. The smallest mature female was 433 mm while about 50% were mature at 450 mm and all were mature at 540 mm.

All age-2 males in 1964-66 were mature in the eastern basin although only 97% were mature in the western basin, even though the latter averaged 37 mm longer. In more recent years, the onset of maturity for male walleye in the eastern basin seems to be slightly delayed relative to Wolfert's (1977) findings. Assessment netting by the New York State DEC during the 1980s has found age-2 males to be 63% to 88% mature.

Fecundity

Fecundity of walleye is quite variable and probably reflects differences in population density and the subsequent availability of food. Walleye from the western basin were more fecund for any given length, weight, or age than those from the eastern basin (Wolfert 1969) (Fig. 5). Weight appeared to be the most accurate indicator of fecundity.

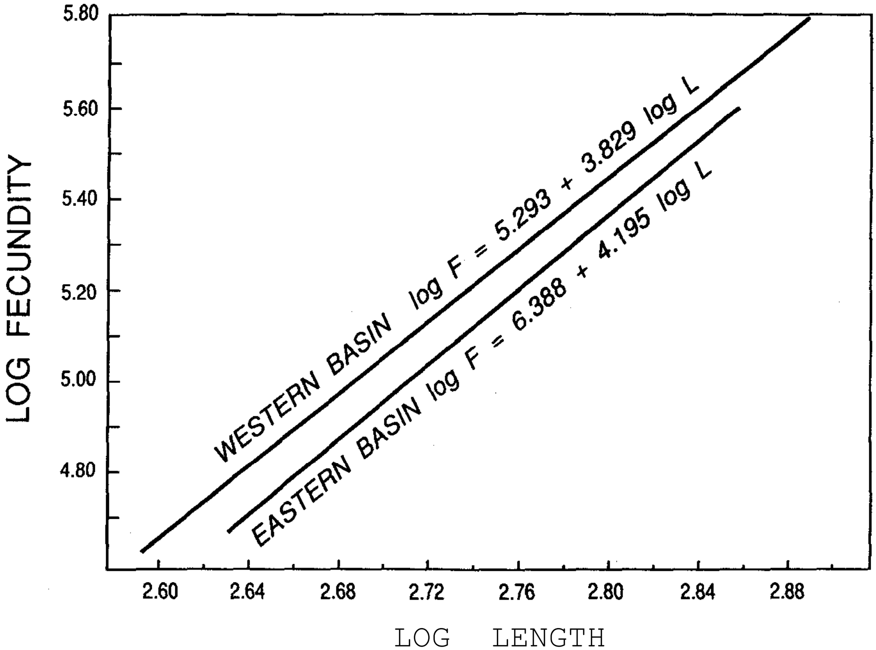

Fig. 5. Length-fecundity relationships of walleye from the eastern and western basins of bake Erie, March-April 1966 (Wolfert 1969).

In both basins, the relationship between number of eggs and length of fish was curvilinear. Wolfert (1969), in his analysis, showed that for the two data sets there was homogeneity of variance, although an F test of the intercepts of the two regression lines showed a highly significant difference (P = 0.01). Therefore, the average fecundities of western basin walleye were substantially higher than eastern basin walleye despite similarities in the average lengths of the individuals.

Even after adjusting mean values of length, weight, and ages and comparing to fecundity, the differences were still highly significant. Again, this clearly shows that fecundity of walleye was always higher in the western basin.

One hypothesis to explain these differences is that separate subpopulations inhabit the basins and the fecundity relationships diverged. It would seem apparent that in previous years the walleye stocks in the western and eastern basins of bake Erie were discrete populations and rarely mixed at any stage in life. Current expansion of walleye stocks from the western into the central basin may change this relationship.

Lake St. Clair

A large spawning aggregation of walleye is present in the Thames River, a tributary of bake St. Clair. Post spawning migration from here is to Lake St. Clair, the St. Clair River, lower Lake Huron and a small portion to western lake Erie (Ferguson and Dirkson 1971) (Fig. 1). Mean age data from walleye from various locations in Lake St. Clair (Table 3) gave some indications of subpopulations (Colby and Nepszy 1981). Walleye from Mitchell Hay with a consistently larger mean age may be prespawning migrants from the St. Clair River and lower bake Huron. The walleye at Tremblay Creek (south shore of Lake St. Clair), with a smaller mean age, may be prespawning migrants from western Lake Erie or Lake St. Clair proper. Following the closure of the fishery from mercury contamination in the early 1970s, the mean age of walleye from the south shore had increased suggesting a buildup of the brood stock. The increasing mean age during this period is largely a result of the dominant 1970, 1972, and 1974 year-classes in association with a period of stable or reduced overall CUE (Table 1). However, in more recent years (late 1970s and 1980s) the mean age of walleye has declined slightly but not significantly enough to indicate any decline in stocks. Since the mean age is still well above that of 3.0 (Table 3) suggested by Colby and Nepszy's (1981) crisis curve, these stocks should continue to provide good walleye yields.

Table 3. Mean age of walleye from various parts of western Lake Erie and Lake St. Clair, 1970-88. Data obtained from various agency reports.

	Lake St. Clair			Western Lake Erie				
	OMNR[a]			OMNR		Mich DNR[b]	USFWS[c]	
Year	Fall TC[d]	Index MB[e]	Summer Creel[f]	Comm. SPr	GN Fall	Spring Index	Comm. SPr	Trap Fall
1970	2.5	4.5						
1971	2.9	3.7						
1972	3.1	4.5						
1973	3.7	4.7					2.97	
1974	4.6	5.4					3.05	1.76
1915	4.5	5.5					3.38	1.27
1076	5.4	5.9					2.69	1.46
1977	4.6	4.9	4.57				2.70	2.19
1978	3.5	4.9	4.21	3.22	1.69	3.16	3.37	1.27
1979	3.8	5.1	2.20	3.18	2.15	2.39	2.92	2.11
1980	4.2	5.7	3.10	3.38	2.09	277	3.34	1.73
1981	3.8	5.5	3.80			3.04	3.70	1.87
1982	4.0	4.3	3.40	3.60	2.22	2.74	2.41	1.82
1983	3.1	4.2	3.00	3.44	2.76	2.76	2.38	1.21
1984	3.6	4.4		3.84	2.07	2.60	2.57	2.11
1985	3.9	5.1	3.20	2.94	2.88	3.20	3.24	1.71
1986	3.8	5.3	3.60	3.83	2.50	3.70	4.11	3.02
1987	4.0	5.4	3.00	3.91	2.62	3.80	3.54	1.73
1988	4.8	5.3	3.20	3.91	2.32	4.20	3.78	3.20

[a] Ontario Ministry of Natural Resources.

[b] Michigan Department of Natural Resources.

[c] United States Fish and Wildlife Services.

[d] Trembley Creek.

[e] Mitchell Bay.

[f] Combined lake creel.

MANAGEMENT STRATEGIES

Jurisdiction over fishery resources in Canada is divided between the federal and provincial governments; in the United States it lies with the individual states. Ontario's fisheries are licensed by the Province, but fishery regulations are enacted by the federal government. The regulations now are drafted by the Ontario Ministry of Natural Resources and passed by the Governor General in council, usually without revision. Management mechanisms vary somewhat among the various state organizations, but generally a natural resource agency formulates management plans and recommends the necessary regulations to an appointed commission for promulgation; however, action by a legislative body is sometimes necessary.

Acting through its bake Committees (Fig. 6), consisting of senior representatives of the resource agencies surrounding each lake, and by encouraging the formation of interagency groups to evaluate particular problems, the Great bakes Fishery Commission (GLFC) has fostered close cooperation among state, provincial, and federal fisheries agencies in the Great bakes area. The 1981 ratification of <u>A Joint Strategic Plan for Management of Great Lakes Fisheries</u> (developed under the auspices of the Commission) is an outstanding example of this cooperation. First among the strategies is "concensus must be achieved when management will significantly influence the interests of more than one jurisdiction."

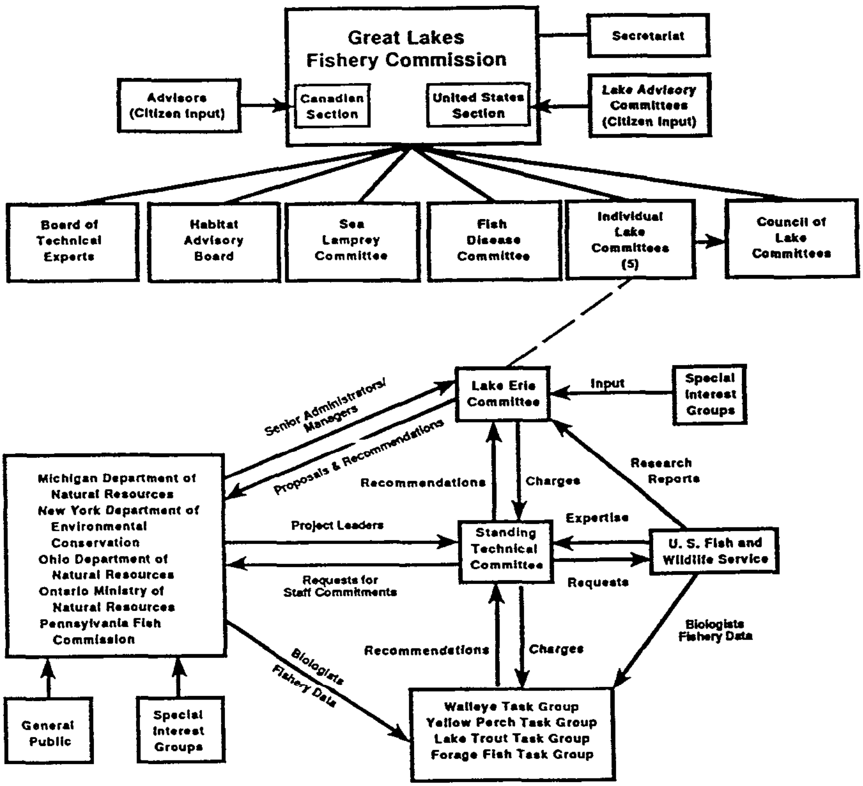

Fig. 6. Organization of the Great Lakes Fishery Commission and its Lake Erie Committee. Special interest groups include commercial and sport-fishing organizations, environmental organizations and public interest groups (Hatch et al. 1990).

Before 1970, commercial fishery regulations in Lake Erie were mostly those favored by politically active commercial fishery operators. Minimum size limits on walleye were in effect in Michigan, Ohio, and Ontario. Minimum gillnet mesh regulations governed the walleye fishery in all Lake Erie states, but not in Ontario. Extensive regulations governed trapnets in all jurisdictions. Generally there were no limitations on the number of licenses issued, total effort applied, or quantity of walleye landed.

Ontario's Lake Erie fishermen were given gradually increasing freedom in the 1900s, and by 1950 the fishery was generally unregulated. Commercial fishing regulations were rather closely enforced in Michigan and Ohio after 1945 and were conservative with respect to technological innovations.

Management Initiatives in Western Lake Erie

Angling became increasingly important in Lake Erie, especially on the United States side, but information on the extent of recreational catch was not available until after 1975 when Ontario and Ohio instituted comprehensive creel surveys. When walleye became scarce in the late 1950s, Ohio anglers intensified a campaign to further restrict the commercial fishery. In 1971, following a closure of the walleye fishery necessitated by mercury contamination, Ohio promulgated a five-year ban on commercial harvest of walleye that later became permanent and established a creel limit for walleye caught by anglers. Michigan developed a policy generally favoring the development of recreational fisheries.

In 1982, a new management plan representing the fishing industry was established for Ontario's commercial fisheries after negotiations between the Ministry of Natural Resources and the Ontario Council of Commercial Fisheries. Implementation of this plan began in 1984 with individual quotas for Lake Erie operators. Although government and industry agreed on the principle of individual quotas, problems arose in allocation among operators. Through negotiation, adaption, comanagement, and cooperation in enforcement, a workable plan was achieved in 2-3 years and remains in effect (Berkes and Pocock 1987).

In summary, walleye are now reserved for recreational harvest in Ohio and Michigan and shared between recreational and commercial interests in other jurisdictions. With the resurgency of walleye abundance, there has been a considerable shift of angling effort from yellow perch to walleye.

Quota Management of Western Basin Walleye

Recognizing the importance of continued protection of the still-depleted resource as the fishery reopened, the GLFC sponsored an international interagency meeting in March 1973 to discuss coordinated management of walleye in western Lake Erie. An international plan for conservation and rehabilitation of the walleye resource was formulated, accompanied by a recommendation for an interagency Scientific Protocol Committee to evaluate walleye population dynamics and develop forecasts of abundance. The plan was formally endorsed by the GLFC and forwarded to the respective government agencies in July 1973.

The Scientific Protocol Committee developed a system of quota management for the walleye fishery involving:

1) sequential projection of the fishable stock,

2) conservative exploitation rates to foster recovery of the resource, and

3) sharing of the quota among the several jurisdictions on the basis of lake surface area.

Each jurisdiction was to allocate its portion of the quota among user groups and be responsible for reporting all landings and enforcement of its portion of the overall quota.

The Scientific Protocol Committee pooled all existing statistical data for western Lake Erie walleye and concluded that the interval between 1963 and 1969 was the only one for which sufficient data were available to estimate the fishable stock. The second requirement for sequential projection, an index of recruitment, was available as a YOY index derived from assessment trawling. These data, combined with estimates of mortalities during the 1970-75 interval, formed a basis for estimation of the standing stock at the beginning of 1976, (Kutkuhn et al. 1976; Hatch et al. 1987). The Committee applied a conservative fishing rate of 10% to this standing stock to develop the initial quota in 1976, and quota recommendations were submitted annually to the interagency GLFC Lake Erie Committee in 1976-1988 (Fig. 6).

Stock Recovery Under Management

The innate resiliency of the walleye stock was quickly manifested under the multilateral ban on fishing instituted in 1970 because of mercury contamination. As estimated by sequential projection, the fishable stock increased from about 83,000 walleyes in 1970 to nearly 14 million in 1976. Angler interest expanded rapidly, and increased effort, coupled with a high catch rate, resulted in a marked increase *in* estimated sport catch that, in Ohio waters alone rose from 111,000 walleyes in 1975 to 2,194,000 in 1977. The combined harvest of the three jurisdictions exceeded 2,500 t in 1977, 4,000 t in 1982, and 7,000 t in 1986 (Fig. 2).

Quotas have been oversubscribed regularly (Hatch et al. 1987), due mainly to the inability to fully control the harvest from the recreational fishery. In 1984, it was the consensus of the Lake Erie Standing Technical Committee that the western basin walleye stock had been rehabilitated and that 20% to 25% exploitation was appropriate. Abundance of walleye in Lake Erie's central basin is increasing and the committee must now develop management policies suited to this expanding stock (Hatch et al. 1987).

The Lake Erie fish community is very unstable. Although the walleye resource in the western basin appears to be rehabilitated, the effects of eutrophication are still stressing the western and central basin fish stocks and invasions by new species continue.

Western basin walleye are examples of a common stock which has been exploited in several jurisdictions with differing management objectives. Historic declines in walleye stocks were related to overexploitation. The walleye stock rebounded when exploitation was controlled.

Interagency management of such transboundary stocks depends on a strategy that allows each jurisdiction to control exploitation in concert with its fishery management objectives. The adoption of agency quota allocations from shared stocks has proven to be an acceptable mechanism for agencies to maintain their options for management in their own jurisdictions. Resource agencies on the United States side of Lake Erie have encouraged recreational fishing at the expense of commercial production **as** a means of improving the economic efficiency of its intensive commercial fishery through individual quotas and industry self-policing.

Unilateral Management of Eastern Basin Walleye

Management of the smaller eastern basin walleye population has been on a unilateral basis by each of three bordering jurisdictions of Ontario, Pennsylvania, and New York. Concensus management has not yet been necessary in the eastern basin. Walleye tagging studies in New York's portion of this basin showed insignificant movements into bordering jurisdictions (Wolfert and Van Meter 1978; Einhouse and Shepherd 1988). Subsequently, this data may not necessarily justify viewing all walleye within Lake Erie's eastern basin as a shared resource.

Although the eastern basin walleye resource is much smaller than the western basin population, it appears stable and does support significant recreational and commercial fisheries in different areas. New York has recently allocated its walleye harvest entirely to recreational fishing. Ontario and Pennsylvania distribute harvest among both the recreational and commercial fishing interests.

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THE RESURGENCE OF WALLEYE IN LAKE ONTARIO

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ABSTRACT. The Day of Quinte walleye (Stizostedion vitreum) stock is the largest in Lake Ontario. The fishable population in 1958 was about 1,000,000. In the late 1960s and 1970s the population had declined to about 200,000 as a result of habitat deterioration. The population resurged with two successive strong year-classes in 1977 and 1978. The fishable population peaked at about 4,000,000 in 1980 when it was dominated by these two year-classes and has since declined because of a succession of smaller, but consistent, year-classes. Since 1985, this population has remained relatively constant at about 700,000. The resurgence of walleye appeared to be centered in the upper Bay of Quinte based on young-of-the-year (YOY) catches in 1977 and 1978. In later years, the lower Day of Quinte had higher densities of YOY. current estimates of total annual mortality of Bay of Quinte walleye are in the vicinity of 40%. Growth rates of walleye in the Bay of Quinte may be slightly lower in the 1980s compared with the 1960s. Density-dependent effects of the same year-class and the two previous year-classes on

these growth rates were detected. The female maturation schedule remains unchanged from the 1960s to the 1980s. However, the current maturation schedule of male walleye has increased in age to almost match the females. Recruitment of Bay of Quinte walleye over a broad spectrum of adult (age 4 and older) population size appears to be governed by density-dependent factors. However, since 1985 the population has stabilized to a rather narrow range, and within this range environmental or community factors seem to be more important determinants of recruitment. Mature walleye move from the Bay of Quinte to Lake Ontario after spawning during spring, and return to the bay during fall. This pattern of movement is reflected in angler harvest which concentrates on 3 and 4 year olds. The harvest since 1981 has typically been between 100,000 and 150,000 kg with a similar number of walleye harvested. Rates of catch and harvest recently have been near 0.3 and 0.4 fish per rod hour with average size in the harvest near 1 kg in the open-water angling fishery, indicating a high-quality fishery. Adult alewife (Alosa pseudoharengus) have been the major food item of walleye over 30 cm in the Bay of Quinte since the 1950s.

Other walleye stocks are also resurging in Lake Ontario. Among these, the New York Eastern Lake Ontario stock appears to hold the greatest potential for improvement because of available fry and fingerling nursery habitat which is uncommon throughout most of the lake. Angling for walleye has improved in the Black River, and index gillnets in nearby Lake Ontario have shown increases. In Port Bay, Little Sodus Bay, and the Niagara River, stocks have been bolstered by stocking and angling has improved.

INTRODUCTION

Walleye (Stizostedion vitreum) in Lake Ontario are locally abundant in only a few connecting bays and lakes, and in the shallow near-shore area of some portions of the main lake. The Bay of Quinte, East Lake, West Lake, Wellers Bay and the nearby shallow water of Lake Ontario provide habitat for the lake's largest populations, collectively termed the Bay of Quinte stock. Other smaller populations are associated with the Niagara, Black, and Oswego Rivers and small embayments such as Sodus Bay and Irondequoit Bay.

Historically, walleye and blue pike (*Stizostedion vitreum glaucum*) were of less importance to the commercial fishery than other species such as lake trout (*Salvelinus namaycush*), lake whitefish (*Coregonus clupeaformis*), ciscoes (C. spp.), and northern pike (*Esox lucius*) (Baldwin et al. 1979). From 1900 to 1950, walleye and blue pike production in Lake Ontario typically ranged from 50,000 to 150,000 kg per year (Fig. 1). Through this period, blue pike were generally more abundant in the catch than walleye. Also, blue pike catches were higher in U.S. waters and in the west, while walleye catches predominated in Canadian waters and in the east (Christie 1973; Baldwin et al. 1979). In 1951 and 1952, blue pike production rose to 203,000 and 295,000 kg, respectively, but thereafter declined drastically to less than 500 kg by 1962. Blue pike are now thought to be extinct in Lake Ontario. Nepszy (1977) implicated rainbow smelt (*Osmerus mordax*) in the extinction of blue pike in bake Erie. In Lake Ontario, rainbow smelt rose in abundance at the same time that blue pike declined (Christie 1973), consistent with Nepszy's hypothesis for their decline in Lake Erie. Although Christie (1973) surmised that blue pike in Lake Ontario originated in Lake Erie, the data that he presented were not consistent with this hypothesis. Christie (1973) stated that blue pike were recruited to the fishery two years later in Lake Erie than in Lake Ontario, and that this was consistent with the difference in growth rates between these lakes. However, the data presented by Christie (1973) shows that Lake Erie peaks in the fishery occurred about two years earlier or five years later than in Lake Ontario. Accordingly, we prefer to accept the simpler hypothesis that blue pike observed in Lake Ontario were produced in Lake Ontario. After the blue pike production dropped, walleye production in Lake Ontario continued to increase and exceeded 50,000 kg from 1954-62.

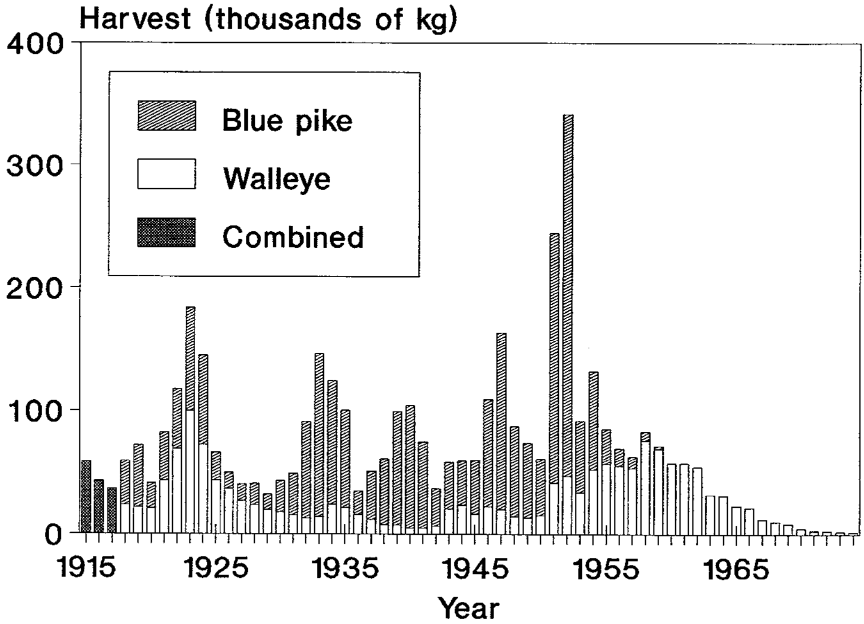


Fig. 1. Commercial harvest of walleye and blue pike in Canadian and U.S. waters of Lake Ontario, 1915-1974.

The Bay of Quinte walleye stock declined during the 1960s (Hurley and Christie 1977), but rebounded after 1977 (Hurley 1986a). This decline was concurrent with an increase in white perch (Morone americana), and excessive eutrophication, but was not believed to be the result of overexploitation (Hurley and Christie 1977). After improvements in domestic sewage treatment which reduced eutrophication, and after a winterkill of alewife (Alosa pseudoharengus), a strong year-class of walleyewas produced in 1977 (O'Gorman and Schneider 1986). A much stronger year-class was produced in 1978 after a large winterkill of white perch (Hurley 1986a). Although white perch, alewife, or eutrophication can be hypothesized as the agent responsible for the decline and subsequent resurgence of walleye in the Bay of Quinte during the 1960s, there has been no definitive answer to these questions.

Other walleye populations in Lake Ontario have also shown recent increases. For instance, angler catches of walleye in the Black River have increased in recent years and in the nearby part of Lake Ontario, walleye catches have increased in index nets (A. Schiavone, New York DEC, pers. commun.). Also, angler catches have recently increased at the mouth of the Niagara River (B. Lewies, Ontario MNR, pers. commun.), in Sodus Bay (G. LeTendre, New York DEC, pers. commun.), and at Pickering (McGary 1989).

This report provides a perspective of the past and current state of walleye populations in Lake Ontario. Most of the available data for walleye in Lake Ontario is based on the Bay of Quinte stock. Therefore, this report primarily describes the resurgence of this stock since 1977, and compares its current status with that of the late 1950s and early 1960s to provide some insights into this resurgence. In addition, we highlight information on other stocks to further our understanding of the resurgence in the lake proper.

INFORMATION SOURCES

The data used in this paper, mostly unpublished until now, come primarily from the fisheries assessment and research programs of the Ontario Ministry of Natural Resources (OMNR), Lake Ontario Fisheries Unit, Glenora. Additional information was provided by the New York Department of Environmental Conservation (NYDEC), Lake Ontario Fisheries Unit at Cape Vincent. A brief description of these programs follows.

OMNR Walleye Mark-Recapture Program

Mark-recapture sessions were run during spring and fall from 1985-87 and during the fall of 1988. All marked and recaptured walleye were caught in trapnets at various locations throughout the Bay of Quinte and in Lake Ontario adjacent to Prince Edward County (Fig. 2). Population estimates for each year-class used the Jolly-Seber method (Ricker, 1975) to provide age-specific estimates.

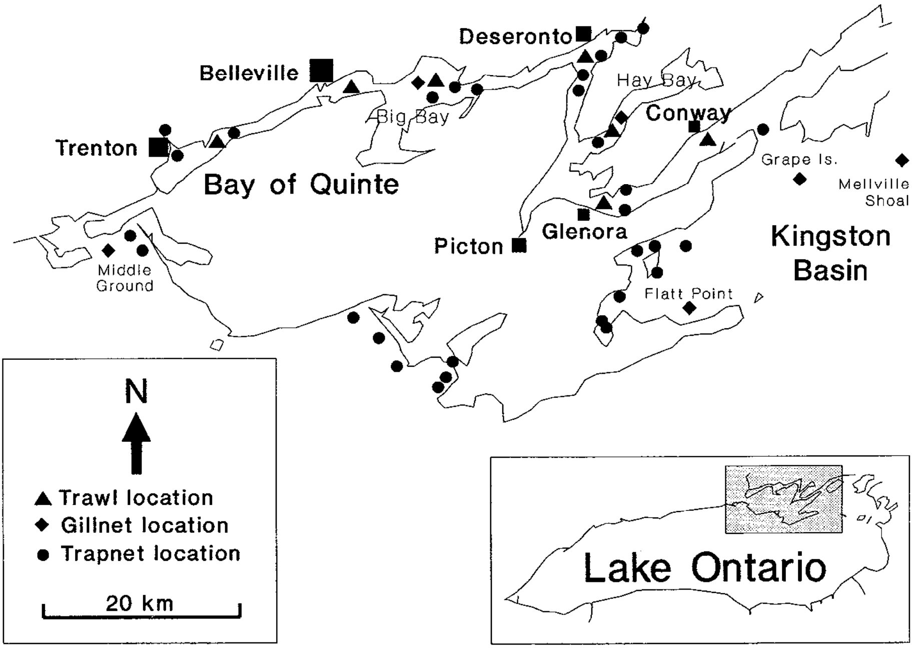


Fig. 2. Sampling locations of Ontario MNR trapnet, gillnet, and trawl programs in eastern Lake Ontario.

OMNR Near-Shore Gillnet Program

From 1977-85 this program was conducted at three sites in Lake Ontario (Fig. 2). Graded mesh series of gillnets (3.81 cm to 12.7 cm by 1.27 cm intervals) were set for one night of effort, 2-4 times from mid-July to the end of August, at a single depth between 5 m and 13 m. The Middle Ground site was continued from 1986-89. Also, from 1986-89 this activity was conducted at three sites in the Kingston Basin with a depth stratified design. Nets were set three times at 2.5 m to 27.5 m by 5 m intervals. A standard lift was calculated as the fish caught in one gang of gillnet composed of 100 m panels of each mesh.

NYDEC Eastern Lake Ontario Warmwater Assessment Gillnet Program

From 1976-79 this program was limited to two areas in the New York eastern basin of Lake Ontario. Nets were set at 9 m and at 3 m to 5 m above the thermocline. Since 1980, all areas of the New York eastern basin from 4 m to 31 m were sampled in a randomized, depth stratified design (Fig. 3). Depth strata were:

1) 4 m to 9 m,

2) 10 m to 15 m, and

3) 16 m to 31 m.

Sampling occurred in August. Graded mesh series of gillnets (5.08 cm to 15.24 cm by 1.27 cm intervals) were set for a period of one night. A standard lift was calculated as the fish caught in one gang of gillnet composed of 91.4 m panels of each mesh.

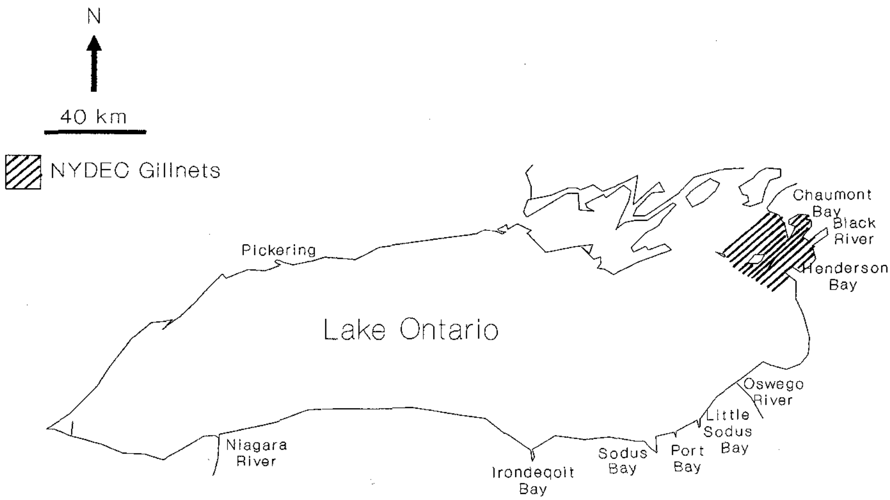


Fig. 3. Lake Ontario and sampling location of the New York Warmwater Assessment Gillnet Program.

OMNR Bay of Quinte Gillnet Program

A graded mesh series of gillnets similar to those used in the OMNR nearshore gillnet program were used, except the mesh depth was shallower to correspond to the shallower depths in the Day of Quinte. Data used here came from three sites (Fig. 2), and were collected during June, July, and

August. The site at Hay Bay has been sampled almost continuously from 1958 to present (except 1966). Big Day and Conway have been sampled since 1972 (except 1985). All lifts were adjusted to effort per night.

OMNR Bay of Quinte Trawl Program

Bottom trawls were made during August and/or September starting from 1972 to 1988 at three locations in the Bay of Quinte (Fig. 2). The net had an opening of 6 m and a cod end with 1.27 cm (0.5 inch) mesh. Tows were 400 m in distance at a speed of 1.1 m/sec.

OMNR Bay of Quinte Angling Surveys

Angling surveys during open water and ice cover have been conducted and completely analyzed on the Bay of Quinte from Trenton to Glenora for some years since 1957. These surveys have been markedly consistent. Fishing effort was estimated from stratified, random counts of anglers on the ice or in boats, and CPUE was determined from angler interviews. Stratification was by area, day type (weekends and weekdays), and season, to reduce the variance of the angling effort and harvest estimates.

Commercial Catch Data

Baldwin et al. (1979) published commercial walleye and northern pike landings from Lake Ontario up to 1977. Commercial landings after 1977 were obtained from lake Ontario Committee annual reports to the Great Lakes Fisheries Commission.

BAY OF QUINTE STOCK

Most walleye in Lake Ontario are associated with the Bay of Quinte (Fig. 2). It has a suitable habitat for all life stages and major spawning rivers that flow into the bay (Trent, Moira, Salmon, and Napanee Rivers). Walleye also spawn on shoals, in several smaller streams around the bay, and in West Lake, East Lake, and Wellers Bay. Historically, Hay Day had the greatest number of shoal spawners in the Bay of Quinte (Payne, 1963). More recently, large numbers of walleye have been observed spawning in Hay Bay (D. Jones, Ontario MNR Napanee District, pers. commun.). However, the current contribution of walleye from these shoals and smaller streams to the total lake population is, for the most part, poorly documented. Walleye-marking studies indicate considerable movement between the Bay of Quinte and Lake Ontario (recaptured from as far away as the St. Lawrence and Black Rivers, and Chaumont Bay in New York). Also, walleye marked during spawning at one river have been recaptured during spawning in another year at another river *(Ontario* MNR, unpubl. data). Based on these returns, we now treat walleye in northeastern bake Ontario and the Bay of Quinte as one large population with several rather loose components formed by fish that spawn in various places.

Population status

Since 1979, the fishable population of Bay of Quinte walleye (age 2 and older) has varied from about 700,000 to 4,000,000 (Fig. 4). These populations were backcast from the 1987 Jolly-Saber population estimates using a total annual mortality of 25% for two-year-old walleye and 40% for adult fish (see below). Population estimates for year-classes prior to 1977 were estimated with a regression using Hay Bay and Big Bay index gillnet catch per effort (CPE). The change in population is consistent with the pattern of year-class strength indicated by the catch of young-of-the-year (YOY) walleye in the Bay of Quinte bottom trawls (Fig. 5), the estimated number of two year olds (Fig. 6), and gillnet catch-per-effort indices (Fig. 7). Population estimates and CPEs indicated that the 1977 and 1978 year-classes were the largest in the last 25 years. The population peaked in 1979 when it was dominated by these two year-classes and has since declined because of a succession of a number of weaker year-classes. However, since 1985 this population has remained near 700,000 (Fig. 4). This does not differ greatly from the estimate of 1,000,000 older than age 2 in 1958 (Hurley and Christie 1977).

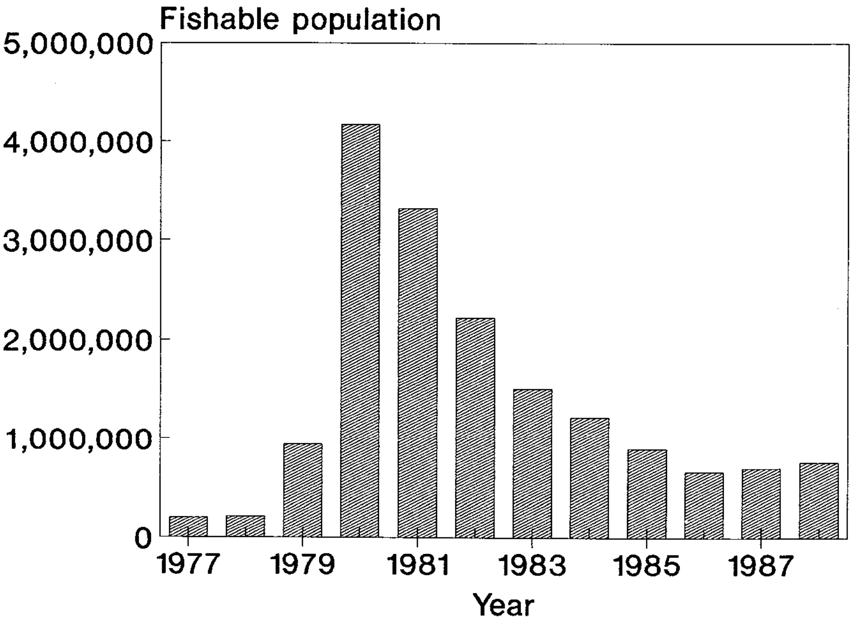


Fig. 4. Population estimates of two year old and older Bay of Quinte walleye during the fall, 1977-1988.

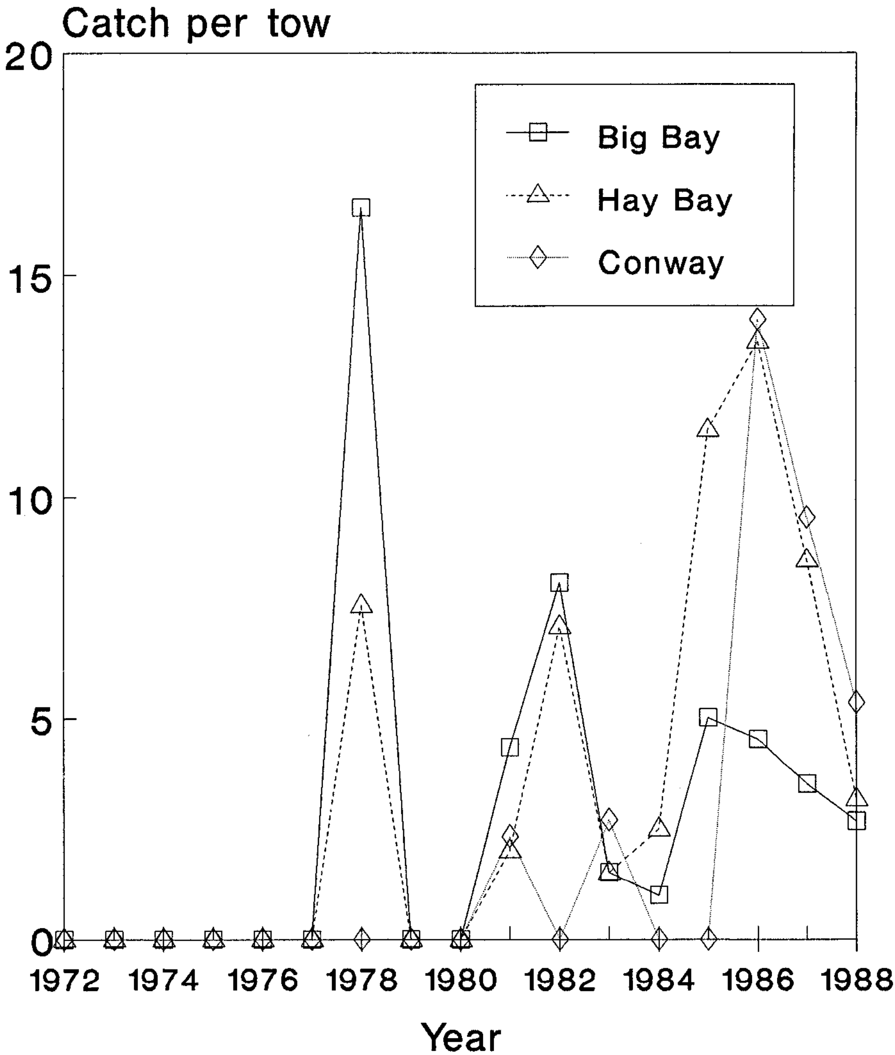


Fig. 5. Mean catch of YOY walleye in trawls in the Bay of Quinte during August and September, 1972-87.

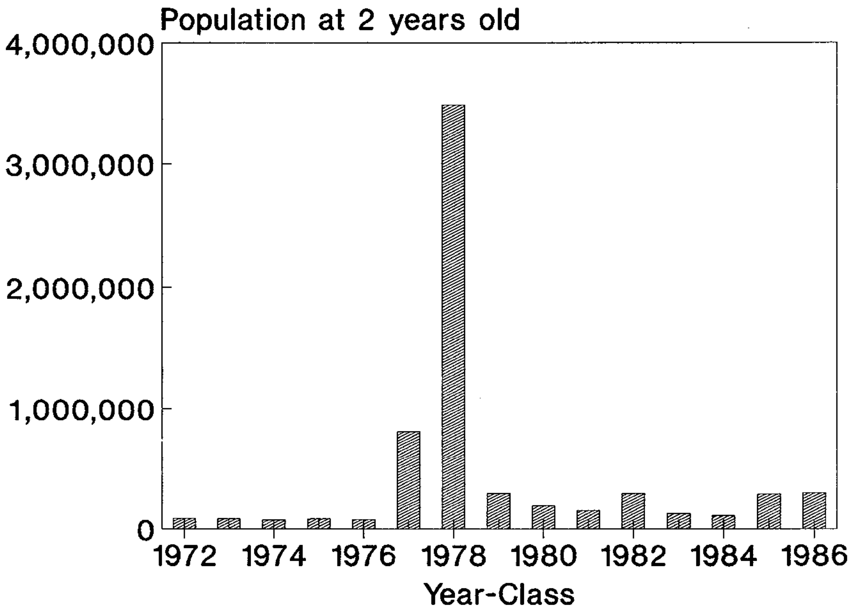


Fig. 6. Estimated population of two-year-old Bay of Quinte walleye for the 1977-86 year-classes.

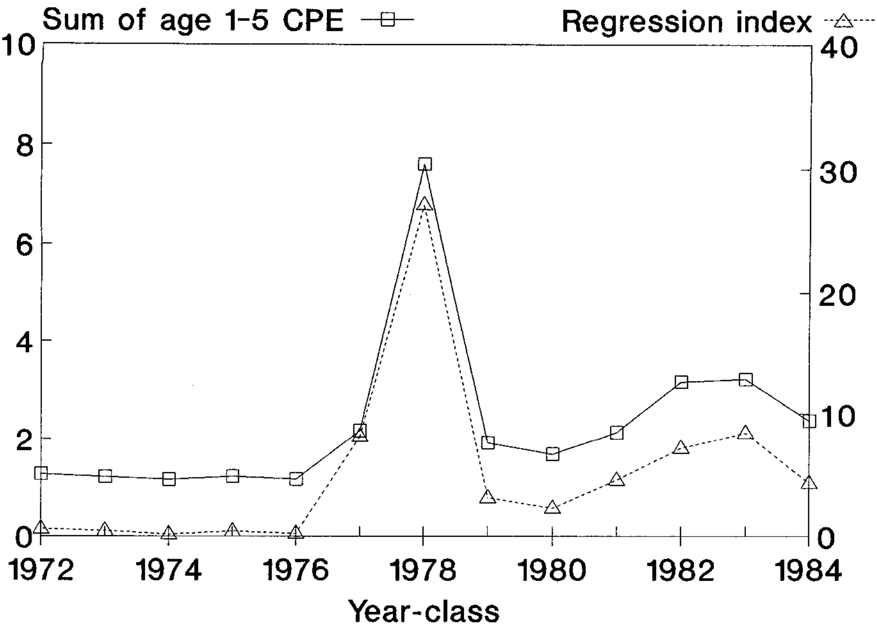


Fig. 7. Indices of year-class strength of Bay of Quinte walleye. The CPE index was calculated as the sum of CPE of standard gillnets for age-1 to age-5 walleye in the same year-class. The regression index was the intercept in a regression of CPE of standard gillnets for age-2 to age-5 walleye in the same year-class.

In addition, CPE in Hay Bay index gillnets indicate that walleye populations during the late 1950s and early 1960s were of the same order of magnitude compared with the more recent populations (Fig. 8). These nets also document the decline in the population during the late 1960s and the low population throughout most of the 1970s.

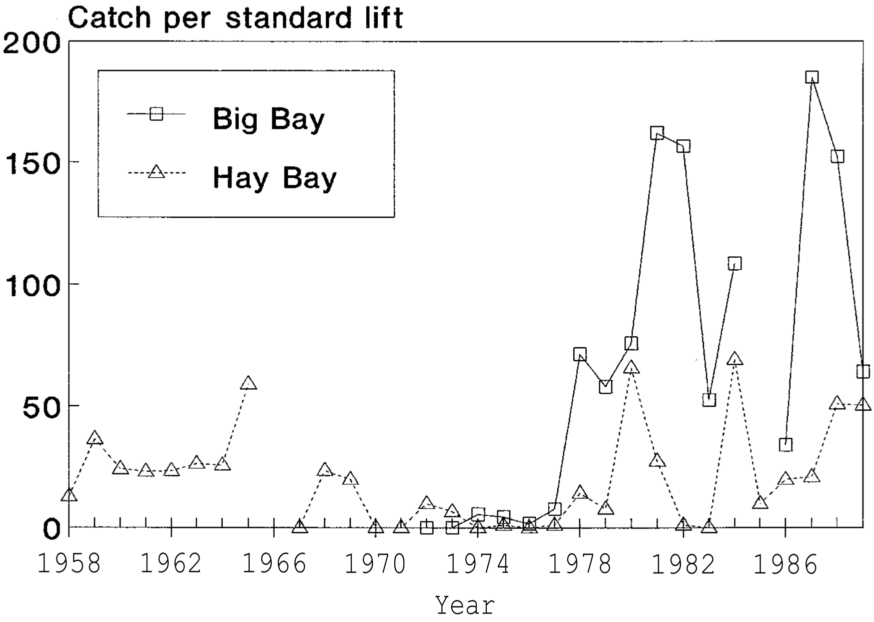


Fig. 8. Trends in walleye catch in index gillnets in the Bay of Quinte for June and August combined, 1958-89.

Total Mortality

Estimates of total annual mortality of Bay of Quinte walleye were in the vicinity of 40% (Table 2). Younger walleye likely have lower total mortality because most one- and two-year-old walleye are released by anglers and immature walleye are not subject to spawning-related mortality (natural and poaching).

Table 1. Estimates of instantaneous total mortality (Z) and actual annual mortality (A) of Bay of Quinte walleye based on cohort-specific Jolly-Seber population estimates.

Collection period	Z	A
Fall 1985 - 1987	0.63	0.47
Spring 1986 - 1987	0.44	0.36

Growth and Maturity

Growth rates of Bay of Quinte walleye (Fig. 9) are quite similar to faster growing stocks in Lake Huron (Spangler et al. 1977). Payne (1963) found that walleye from the upper Bay of Quinte (Trenton to Deseronto, Fig. 1) grew slower than those from the lower bay, particularly Hay Bay (Fig. 9). Because the size at age is parallel in these two areas, the differences in growth rate of walleye from these areas must be set during the first year of life. More recent data integrates these areas but shows relatively little difference between the historic and current growth rates (Fig. 9). Earlier data (1957-62) were collected during spring, whereas the later data (1987-88) were collected during fall. One year of age was added to fall data for direct comparison to spring data on the assumption that seasonal growth had ceased by the time the fish were sampled. However, if this assumption is false, then slight differences between the historic and more recent data might be reduced, particularly among the immature age-classes where gonadal growth does not take a precedent during fall.

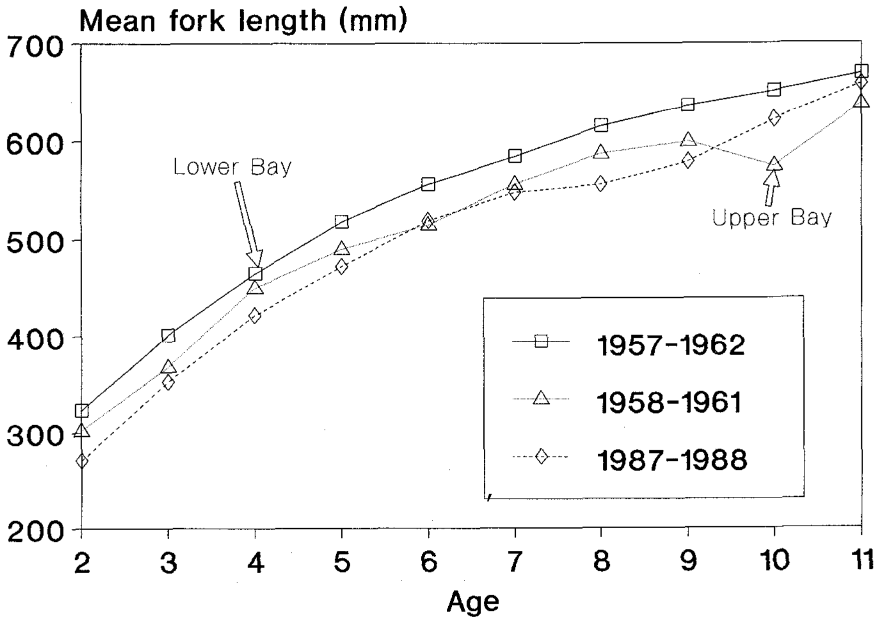


Fig. 9. Length-at-age of walleye taken in trapnets in eastern Lake Ontario. The 1957-62 (Lower Bay) data were collected primarily from Hay Bay, and the 1958-61 (upper Bay) data were collected from Belleville to Trenton (Payne 1963). The 1987-88 data were collected throughout the Bay of Quinte and in eastern Lake Ontario (Fig. 1).

The growth rate of walleye in a particular year-class was a function of the densities of the same year-class, and the two previous year-classes. To determine this relationship, the mean length-at-age of walleye caught in fall 1987 in trapnets was fit to the von Bertalanffy growth equation (Ricker, 1975) as follows:

$$\text{fork length} = 875.6(1-e^{-0.1096(\text{age}+3.038)})$$

$$(R^2=0.999;\ F=1636,\ P<0.0001)$$

Multiple linear regression indicated that the residuals from this equation were related to the density of YOY walleye in trawls from Hay Bay for the same year-class, the previous year-class, and the year-class two years previous. The previous year-class had the greatest depressing effect on growth rate, followed by the year-class two years previous, and the same year-class (Table 2).

Table 2. Density-dependent effects on growth of Bay of Quinte walleye caught during fall 1987 in trapnets in eastern Lake Ontario. The multiple regression explained 85% of the variation in the residuals from the growth equation (F = 9.22, P = 0.018).

Source variable	Regression	F	P
Same year-class	-1.199	4.58	0.043
Previous year-class	-3.307	13.52	0.007
Year-class two years previous	-2.687	8.76	0.016

Most female and male walleye in the Ray of Quinte are mature by age 4 (Fig. 10). Payne (1963) also found that, in the Bay of Quinte, most female walleye matured by age 4, but most males matured by age 3. Most of these fish originated from Hay Ray. This apparent increase in the age of maturity of males is consistent with the differences in growth rates observed between the 1957-62 (mostly Hay Ray walleye) and 1987-88 data. Whether these differences represent spatial or temporal differences in growth and maturity must await further analyses.

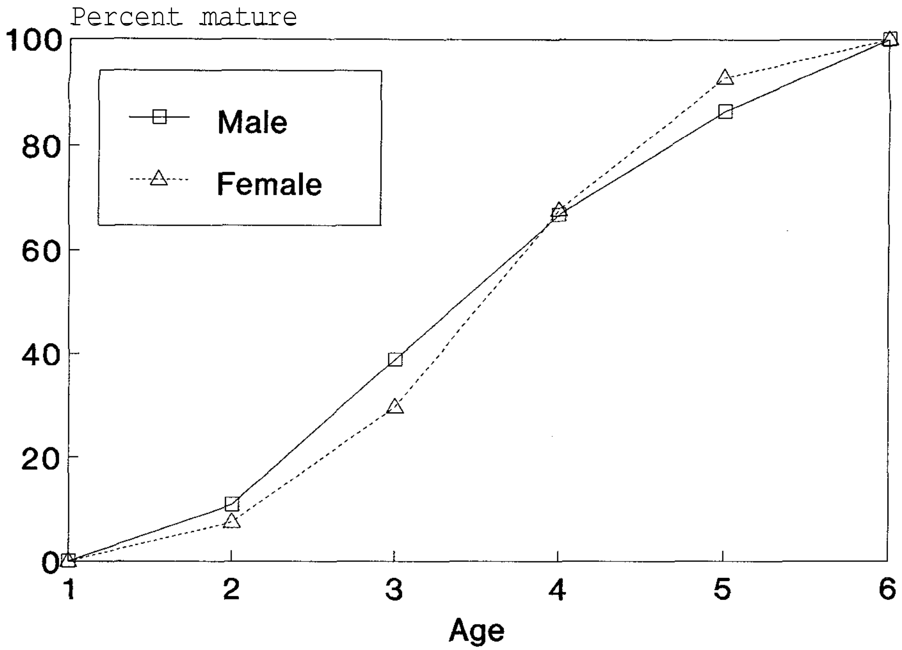


Fig. 10. The percent mature walleye by age and sex in the Bay of Quinte. Samples were from May-August in 1987 and 1988.

Recruitment

Recruitment of Bay of Quinte walleye over a broad spectrum of an adult (age 4 and older) population appears to be governed by density-dependent factors (Fig. 11). The recent resurgence of walleye has provided a large variation in adult population which is rarely available to adequately test for such a relationship. Since 1985, the adult population has stabilized to a rather narrow range, and within this range the recruitment model explains little compared to other sources of error. We suggested that the two preceding year-classes influenced growth of walleye, but the analysis here does not consider their effect on recruitment. Hurley (1986a) has suggested that the density of white perch may influence year-class strength of walleye in the Bay of Quinte. Weather patterns and water temperatures near the time of hatch also have a strong influence on walleye recruitment (Colby et al. 1979). Hurley (1986a) found no relationship between walleye year-class strength and spring water temperature conditions in the Bay of Quinte. However, combining the environmental effects with the population and community effects might reveal these relationships.

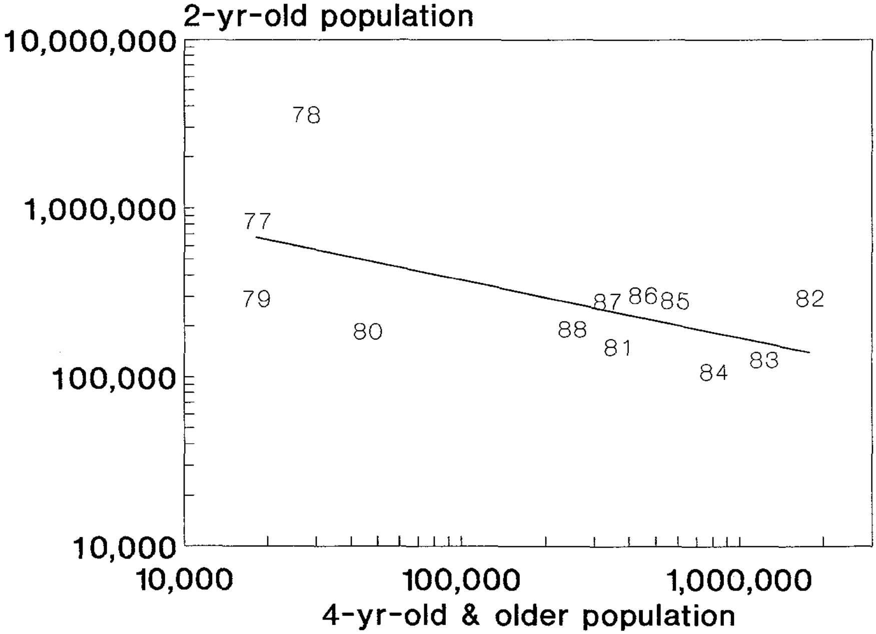


Fig. 11. Recruitment of two year old walleye from the adult walleye (age 4 and older) population two years previous.

Food

Adult alewife are the major food item of walleye over 30 cm in the Bay of Quinte (Table 3). Rainbow smelt became more important in the diet during the late 1970s when the alewife population was low (Ridgway et al. 1989), particularly in the deeper areas east of Glenora. For the most part, however, the walleye diet has changed little through time.

Table 3. The percent occurrence of food in Bay of Quinte walleye during summer. The numbers in parentheses indicate the sample size of walleye stomachs examined.

Food item	1958-1962[a] (721)	1977-1981[b] (589)	1987 (112)	
Alewife	52.1	28.5	48.2	
Rainbow smelt	1.9	15.6	1.8	
Yellow perch (*Perca flavescens*)	0.4	3.9	-	
White perch	0.1	1.2	0.9	
Minnow (Unidentified *Cyprinidae*)	0.1			
Johnny darter (*Etheostoma nigrum*)		0.7		
Gizzard shad (*Dorosoma cepedianum*)		0.7		
Mottled Sculpin (*Cottus bairdi*)			0.2	0.9
Threespine stickleback (*Gasterosteus aculeatus*)			0.2	-
Unidentified fish	48.7	53.0	39.3	
Fish eggs	0.6			
Insects	0.3	3.9	16.1	

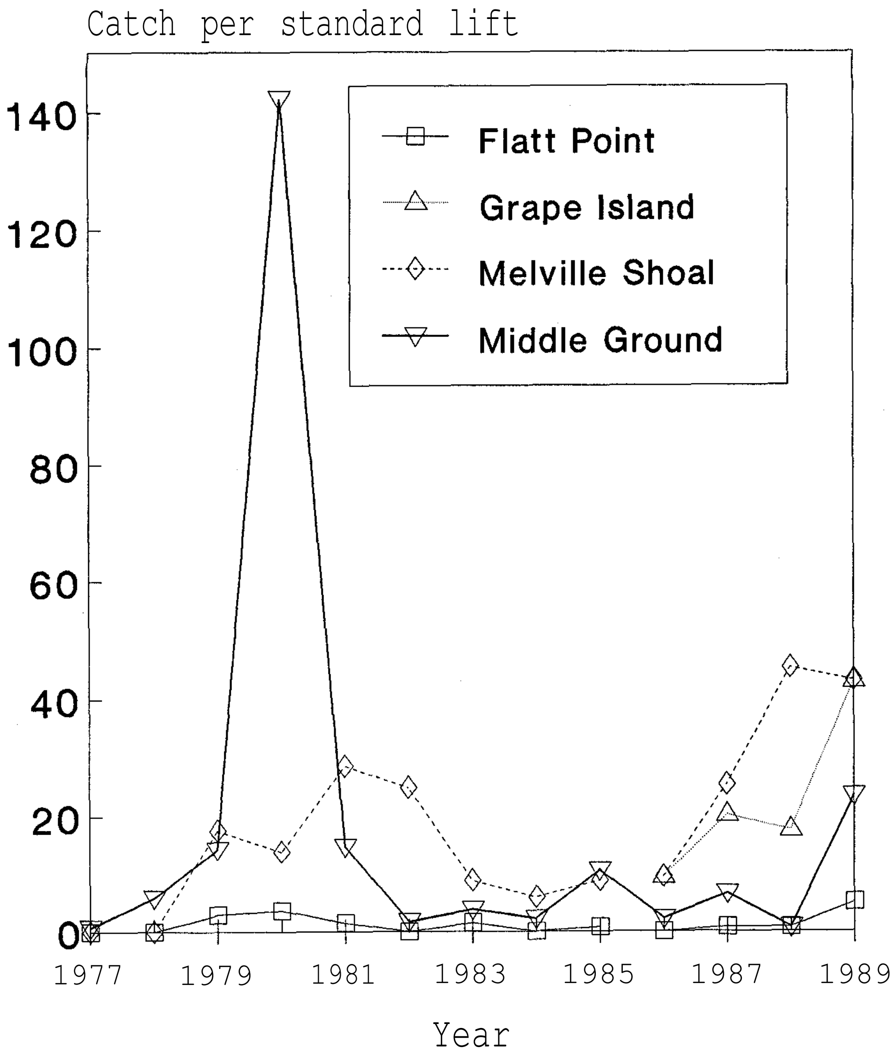
[a] Calculated from Hurley and Christie (1977).
[b] Hurley (1986a)

Distribution

The resurgence of Bay of Quinte walleye appeared to be centered in the upper part of the bay. In 1977 and 1978, the highest densities of YOY walleye were caught near Trenton and Belleville (Table 4). YOY densities were much lower at sites farther down the Bay. Densities in the lower Bay of Quinte increased in later years (Fig. 5). Recently, catches have increased at some Lake Ontario sites to similar levels as those found at Hay Bay (Figs. 8, 12).

Table 4. The mean catch per tow of YOY walleye in trawls in the Bay of Quinte during August and September.

Year	Trenton	Belle-ville	Big Bay	Deseronto	Hay	Glenora	Conway
1972	0.5	0.0	0.0	0.0	0.0	0.0	0.0
1973	0.5	0.0	0.0	0.0	0.0	0.0	0.0
1974	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1975	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1976	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1977	1.5	1.5	0.0	0.0	0.0	0.0	0.0
1978	47.5	86.5	16.5	36.0	7.5	1.0	0.0
1979	0.0	1.0	0.0	0.0	0.0	0.0	0.0
1980	0.0	0.0	0.0	0.5	0.0	0.0	0.0
1981	-	-	4.3	-	2.0	-	2.3
1982	-	-	8.0	-	7.0	-	0.0
1983	-	-	1.5	-	1.5	-	2.7
1984	-	-	1.0	-	2.5	-	0.0
1985	-	-	5.0	-	11.5	-	0.0
1986	-	-	4.5	-	13.5	-	14.0
1987	-	-	3.5	-	8.5	-	9.5
1988	-	-	2.7	-	3.2	-	5.3



Pig. 12. Trends in walleye catch in index gillnets in Lake Ontario for late July and August, 1977-89. Data for 1986-89 (except Middle Ground) are for the combined depths of 7.5 m and 12.5 m.

Payne (1963) suggested that mature walleye moved from the Bay of Quinte to Lake Ontario after spawning during spring, and returned to the bay during fall. These suggestions were supported by differences in summer and winter walleye age distributions indicating numerous older fish were present in the bay during winter but not summer (Payne 1963). Although we have made no rigorous analysis of movements, recent mark-recapture data and index gillnet data appear consistent with movement patterns suggested by Payne (1963). During summer, index gillnets in the Bay of Quinte failed to catch older walleye that were known to be in the population (Fig. 13). It was unlikely that this was a gear selectivity problem. This conclusion leads us to suggest that the older walleye had moved elsewhere. We have had tag returns of Bay of Quinte marked walleye as far away as the St. Lawrence River, the Oswegotchie River, Chaumont Hay, and the Black River (New York). Moreover, our mark-recapture data from spring and fall have regularly shown movements of walleye between the Hay of Quinte and Lake Ontario. Relatively little angling effort has been directed towards walleye outside the Hay of Quinte during summer, and so recapture information from Lake Ontario is minimal. Walleye may move out of the Hay of Quinte in response to food abundance in the upper bay (Ridgway et al. 1989), or perhaps in response to higher water temperatures in the bay (Hurley 1986c).

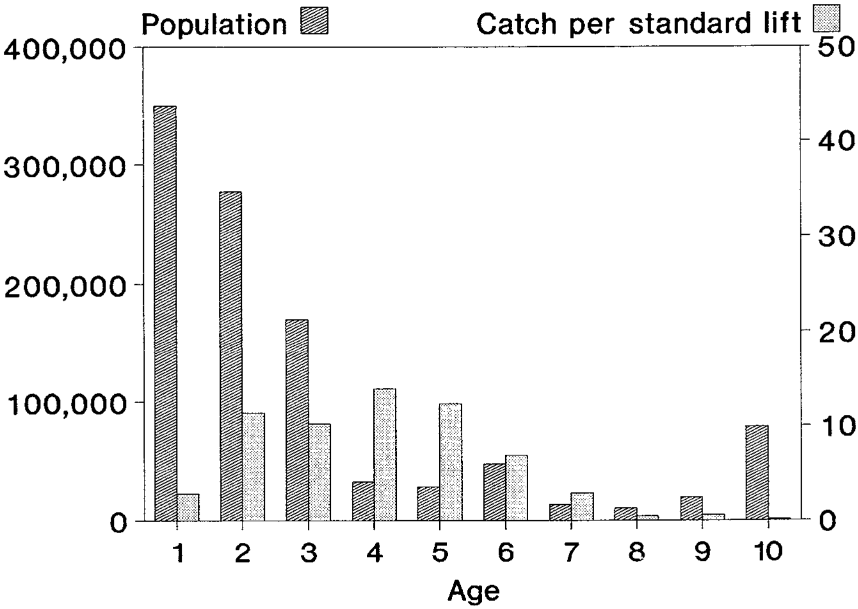


Fig. 13. Age distribution of the Bay of Quinte walleye population during 1988 from age-specific population estimates and from index gillnets.

Walleye in the Kingston basin of lake Ontario during August are more abundant at depths less than 15 m and at temperatures near 20°C (Fig. 14). Accordingly, outside the eastern basin and a few sheltered bays, most of Lake Ontario is considered unsuitable habitat for adult walleye.

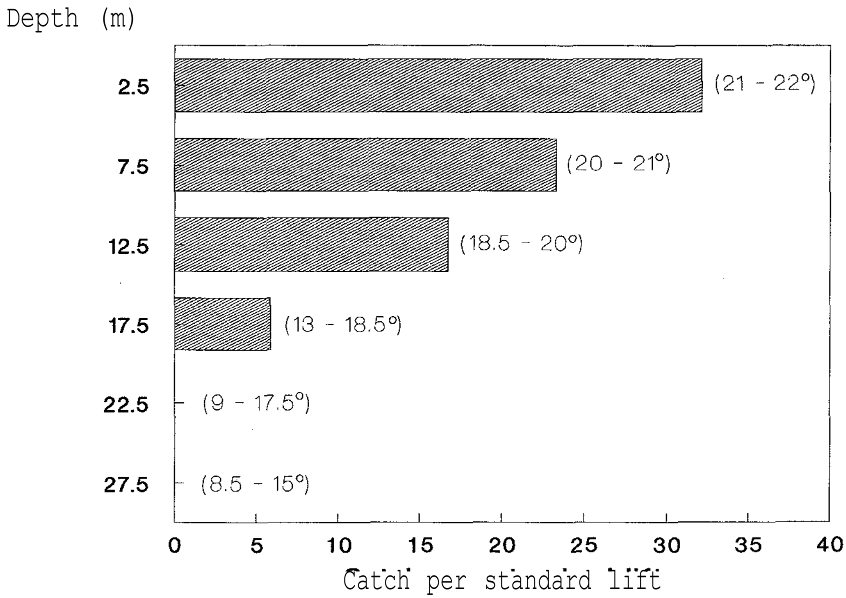


Fig. 14. Depth distribution of walleye at Grape Island, lake Ontario during August 1987. Numbers in parentheses are the temperature range for three samples.

Harvest

Angling and commercial fisheries have, at times, each been the major harvester of Bay of Quinte walleye (Fig. 15). Prior to 1970, commercial harvest dominated, but since the resurgence of the walleye population, angling harvest has dominated the fishery. This change, in part, has been the result of regulations to limit the catch of walleye by the commercial industry (Table 5). In 1981, commercial fishermen were given a small quota to cover incidental catch of walleye in gear targeted towards other species, but otherwise were restricted from catching walleye. Since 1984, walleye quotas for the commercial fishery have been set to zero and angling has become the single legal means for harvesting walleye. However, a small commercial harvest took place in 1989. Poaching, incidental catch by commercial fishermen, and native harvests are largely unquantified but are probably less than 5% of the adult walleye population (based on estimates from R. Baldwin, Ontario MNR, pers. commun.).

Table 5. Changes in the Ontario fisheries regulations since 1967 for walleye in eastern Lake Ontario aimed at protecting the declining and resurging populations (Wood 1984).

year	Regulation change
1967	4.5 in. gillnets banned west of Glenora in the Bay of Quinte, and this yardage was converted to 3-3.25 in.
1979	All gillnets, other than 8 in., were banned west of Glenora in the Bay of Quinte.
1980	4.5 in. gillnets banned.
	75,000 lb. of walleye allocated to commercial fishery for incidental catch.
	Brighton area closed to gillnets in August because of high walleye harvest.
	Angler possession limit changed from six to four walleyes.
1981	11,000 lb. of walleye allocated to commercial fishery for incidental catch.
1982	4.5 in. gillnets allowed for lake whitefish in areas already designated for gillnets.
	11,000 lb. of walleye allocated to commercial fishery for incidental catch.
1983	11,000 lb. of walleye allocated to commercial fishery for incidental catch.
1984	1,000 lb. of walleye allocated to commercial fishery for incidental catch.
	In June, the walleye quota was set to 0.
1989	30,000 lb. of walleye allocated to commercial fishery, in entrapment gear only: season from May 15-June 23; slot size limit from 18 in. to 24 in.

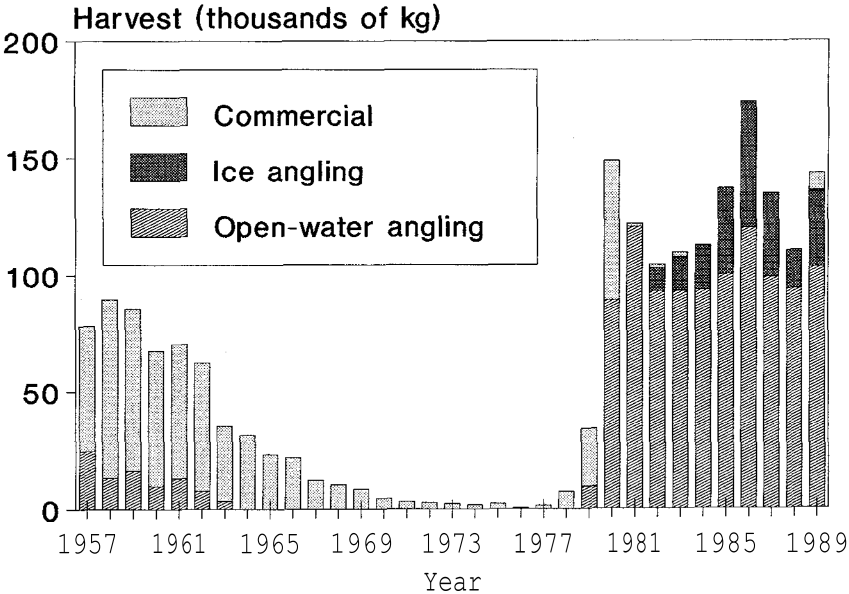


Fig. 15. Harvest of walleye by Canadian commercial and angler fisheries in Lake Ontario, 1957-87. For angling fisheries that were not surveyed in 1983, 1985, and 1987 (Table 1), the catch has been interpolated from the previous and the following year.

Walleye angling in eastern Lake Ontario has been restricted almost entirely to the bay of Quinte. Anglers in the Bay of Quinte have shown a very strong preference for walleye although they sought a wider variety of species during the years of low walleye abundance. Angling effort has grown dramatically since the early 1980s (Fig. 16). The bulk of the angling harvest currently takes place in the open-water fishery, and since 1982 has remained relatively constant near 100,000 walleyes annually. Prior to 1980, angling effort was restricted to the summer only (W. J. Christie, Glenora, Ontario, pers. commun.), but an ice fishery has since grown gradually and currently takes about 20,000 walleyes annually. Recent harvests per effort are similar to the late 1950s (Fig. 17) and are typically in the range of 0.2 to 0.3 fish per rod-hour. Angler catches and CPE are slightly higher because they release most of the walleye that are two years old and younger. Colby et al. (1979) consider a CPE of greater than 0.3 to indicate a good walleye fishery.

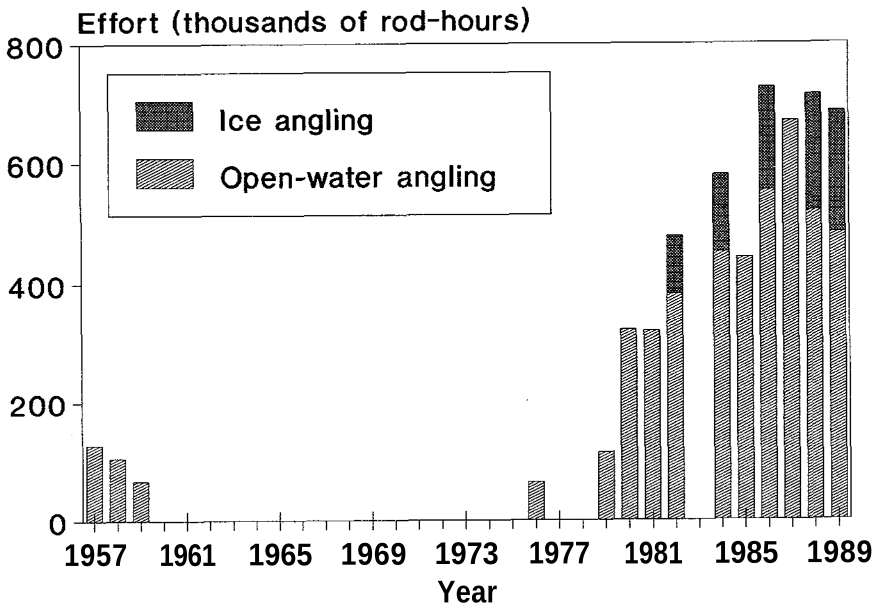


Fig. 16. Angling effort during open-water and ice fisheries in the Bay of Quinte, 1957-88. Where no (0) effort is indicated, the effort has not been measured (Table 1).

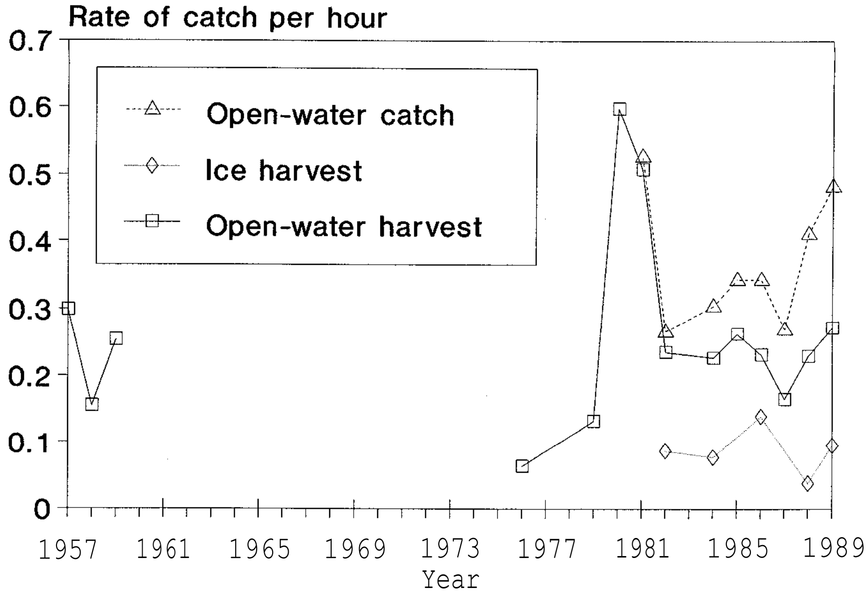


Fig. 17. Angling catch and harvest rates during open-water and ice fisheries in the Bay of Quinte, 1957-88. Where no rate is indicated, the rate has not been measured (Table 1).

During the open-water fishery, angling harvest is generally highest for the three- and four-year-old fish. Typically, about 70% of the harvest is made up of these age-classes. This is because three- and four-year-old walleye have higher selectivity than other ages (Fig. 18), and because younger fish are often released when caught. TWO-year-old fish are caught in large numbers by virtue of their abundance, but in 1988, 62% of them were released. In 1980, large numbers of four year olds were not abundant and so two year olds made up 89% of the harvest. During the ice fishery angling, selectivity is lower and more evenly distributed across all age groups (Fig. 18). The seasonal difference in angler selectivity is likely due to habitat shifts in the older fish. barge walleye move out to the lake during summer and are not vulnerable to the fishery. However, they move back into the bay of Quinte during the fall and are caught in the ice fishery.

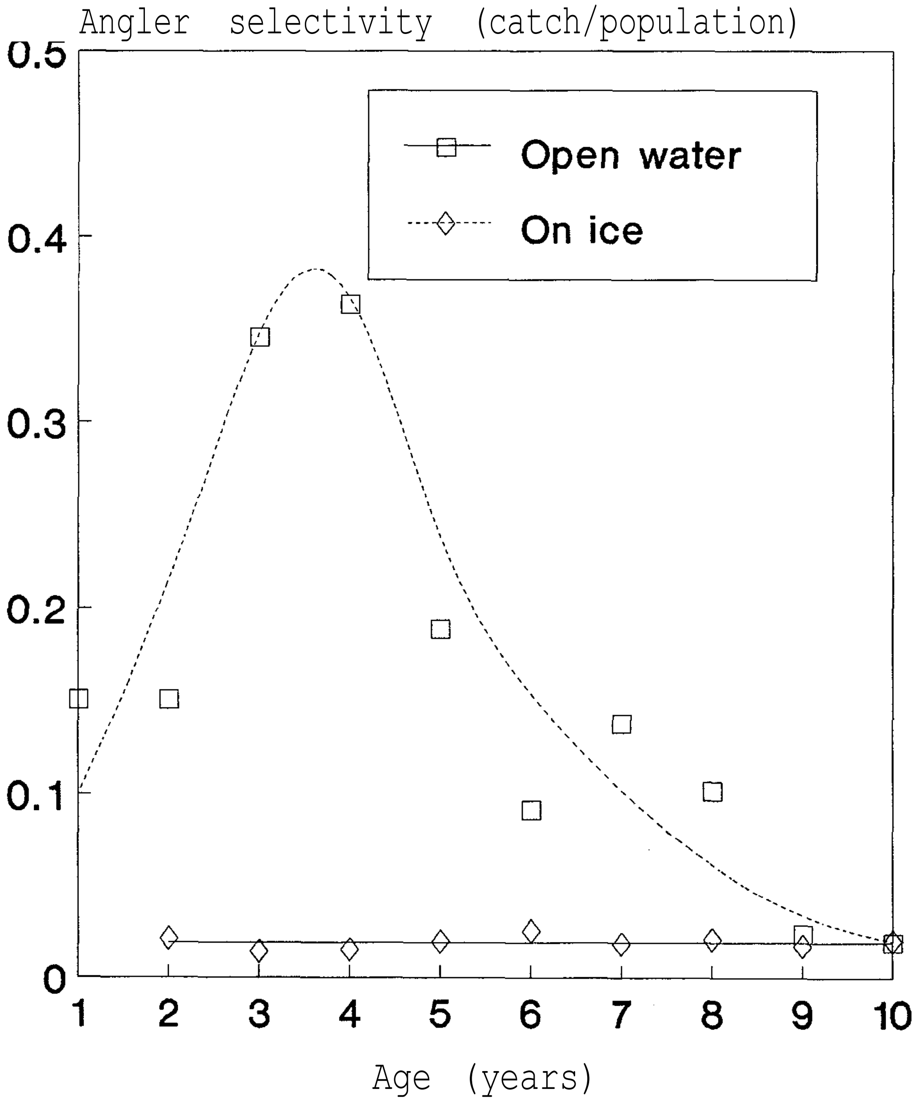


Fig. 18. Selectivity of walleye by age for open-water and ice angling fisheries in the Bay of Quinte, 1986-88. Curves are fit by eye.

Community Interactions

Ridgway et al. (1988) provided convincing evidence for top-down control of adult alewife abundance in the upper Bay of Quinte. The abundance of adult alewife declined in the

Bay of Quinte (Fig. 19) and throughout bake Ontario as a result of winterkill in 1976-77 (O'Gorman and Schneider 1986). Alewife abundance has since rebounded to former high levels in Lake Ontario except in the Bay of Quinte where their abundance is kept down by walleye predation (Ridgway et al., 1989). Also, these authors note that YOY alewife currently are higher in abundance than before the resurgence of walleye in 1977 and 1978. Ridgway et al. (1989) suggest that these higher levels of YOY alewife are maintained indirectly by walleye through reducing cannibalism by adult alewife. Trout-perch (Percopsis omiscomaycus) show a trend similar to adult alewife (Hurley, 1986a) and may also be controlled by walleye predation. Trout-perch are commonly observed in the walleye diet during winter (D. Walsh, Ontario MNR, pers. commun.) when alewife are not available in the Bay of Quinte.

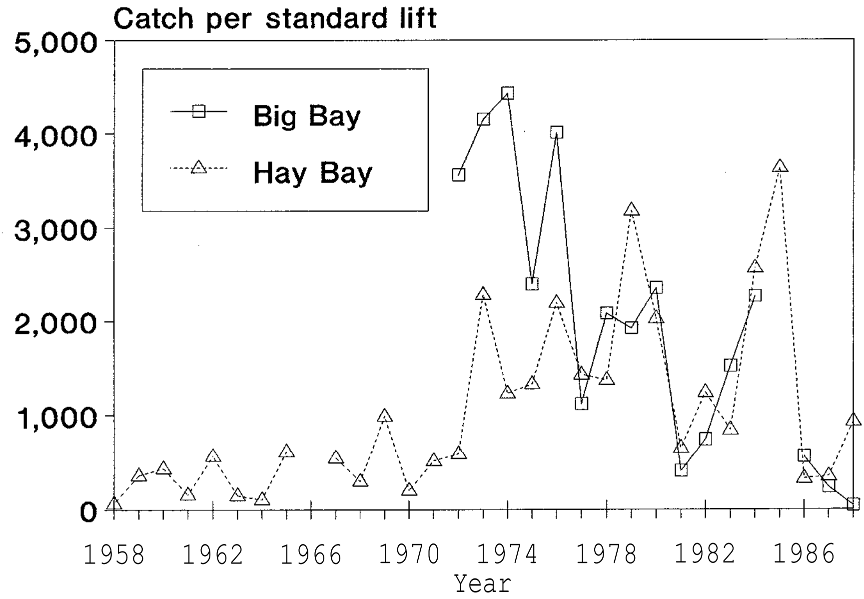


Fig. 19. Trends in alewife catch in index gillnets in the Bay of Quinte for June to August combined, 1958-88.

White perch increased dramatically in the Bay of Quinte after walleye declined in the 1960s (Hurley and Christie 1977). In 1978, populations declined drastically due to winterkill (Hurley 1986a), but have only partially rebounded since then (Fig. 20). Competition with, or predation by, walleye and other piscivores has been suggested as a major influence in controlling white perch populations in the Bay of Quinte (Hurley and Christie 1977; Minns and Hurley 1986). The competition hypothesis seems unlikely because the growth rates of walleye are high and density-dependent effects on walleye growth, although detectable, are small. Moreover, Minns and Hurley (1986) report that growth rates of white perch were much higher at walleye population peaks than during periods when walleye populations were lower. Also, diets are much different between these two species (Hurley 1986a; 1986b). The larval stages of white perch and walleye do not overlap in size in the Bay of Quinte (Leslie and Moore 1985) and therefore are unlikely to compete for food. We were unable to reject the predation hypothesis. Walleye are by far the dominant piscivore in the bay of Quinte and the most likely candidate to control white perch populations. barge walleye prey upon white perch to some extent (Table 3). Unfortunately, most of our diet samples were taken in the few months after the seasonal alewife migration into the Bay of Quinte. White perch may very well increase in prominence in the walleye diet during the seasons which we have not sampled.

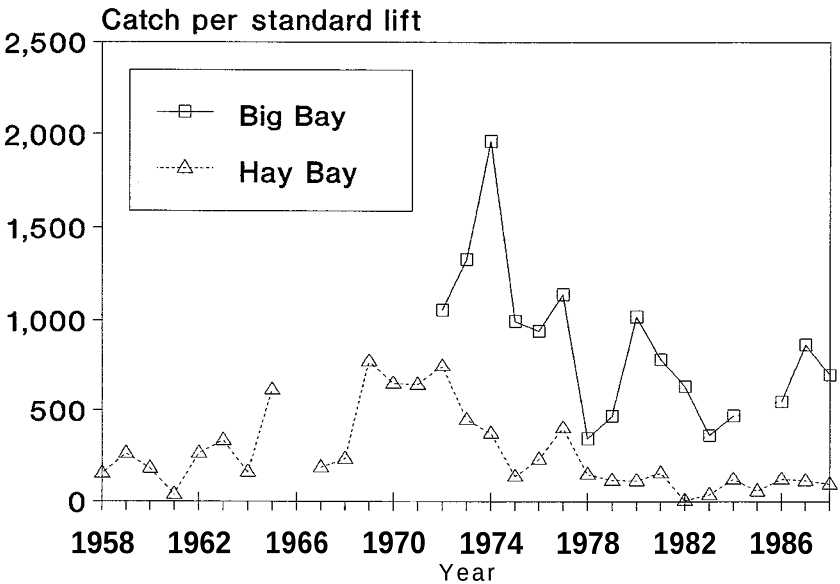


Fig. 20. Trends in white perch catch in index gillnets in the Bay of Quinte for June to August combined, 1958-88.

The reverse effect of competition or predation by white perch in determining walleye populations is not known. With the decline in walleye after the invasion of white perch (Christie 1973) and with the occurrence of the strong 1978 year-class coinciding with the winterkill of white perch, it is tempting to postulate some strong effects of white perch on walleye. However, the strong 1977 year-class of walleye was produced in the Bay of Quinte in the face of large white perch numbers. In addition, white perch were unable to displace walleye after invasion of West bake (Hurley and Christie 1977) and Oneida Lake (Forney 1977).

Abraham (1983) has suggested that a strong 1978 year-class of yellow perch in Sodus Bay, Lake Ontario resulted from reduced predation of pelagic larvae by alewife as a result of winterkill of the alewife. In a study at North Sandy Pond, Lake Ontario, Brandt et al. (1987) found that inshore movement of alewife for spawning corresponds with the hatch of yellow perch. In the two weeks following hatch of yellow perch in 1985 and 1986, 30% and 41%, respectively, of the alewife captured in the limnetic zone at night contained larval yellow perch. Larval walleye are similar in size to larval yellow perch during May in the Bay of Quinte (Leslie and Moore 1985). They, therefore, may be susceptible to predation by alewife. Stronger year-classes of walleye in 1977, 1978, 1982, and 1986-88 (Figs. 6 and 7) have occurred during periods of lower alewife abundance in the Hay of Quinte (Fig. 19). Accordingly, the strong year-classes of walleye may have benefited from reduced alewife predation on walleye larvae. Alternatively, reduced competition for zooplankton between walleye larvae and alewife might contribute to higher year-class strength of walleye.

Historically, northern pike were more abundant in the Bay of Quinte (Hurley and Christie 1977). Commercial harvests of northern pike far exceeded those of walleye in the early 1900s, but increases in walleye harvest during the 1920s and 1950s have coincided with decreased northern pike harvest (Fig. 21). It is tempting to suggest community interactions between these species. Hurley and Christie (1977) argued that the decline in northern pike population resulted from overfishing and low water levels, and moreover, that walleye benefited from a competitive release. We suggest that the current conditions of decreased water clarity (Robinson 1986) and decreased macrophytes (Crowder and Bristow 1986) favors walleye competitively over northern pike. This condition may be preventing a recovery of northern pike to former levels. If, for whatever reason, the northern pike population in Lake Ontario recovers to historical levels, then we should expect to see a decline in walleye.

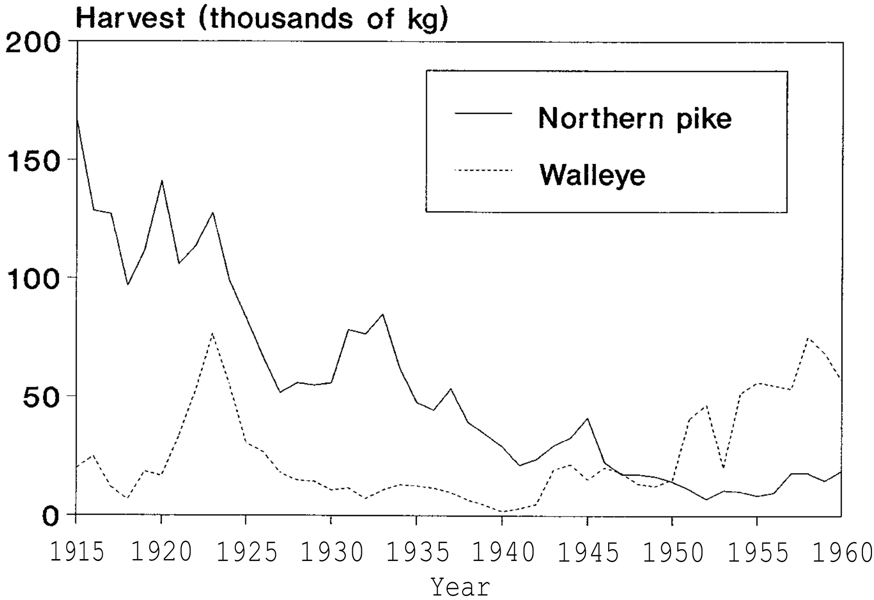


Fig. 21. The commercial harvest of northern pike and walleye in the Canadian waters of Lake Ontario, 1915-60.

NEW YORK EASTERN LAKE ONTARIO STOCK

Angling catches of walleye in the Black River have increased in recent years and the fishery is developing rapidly (A. Schiavone, NYDEC, pers. commun.). Currently, New York DEC is attempting to determine movements and exploitation of walleye in the Black River. Increased catches of walleye have also been observed in index gillnets in nearby parts of the eastern basin of Lake Ontario (Fig. 22), but as yet the densities are still lower than at some locations in the Ontario part of the basin.

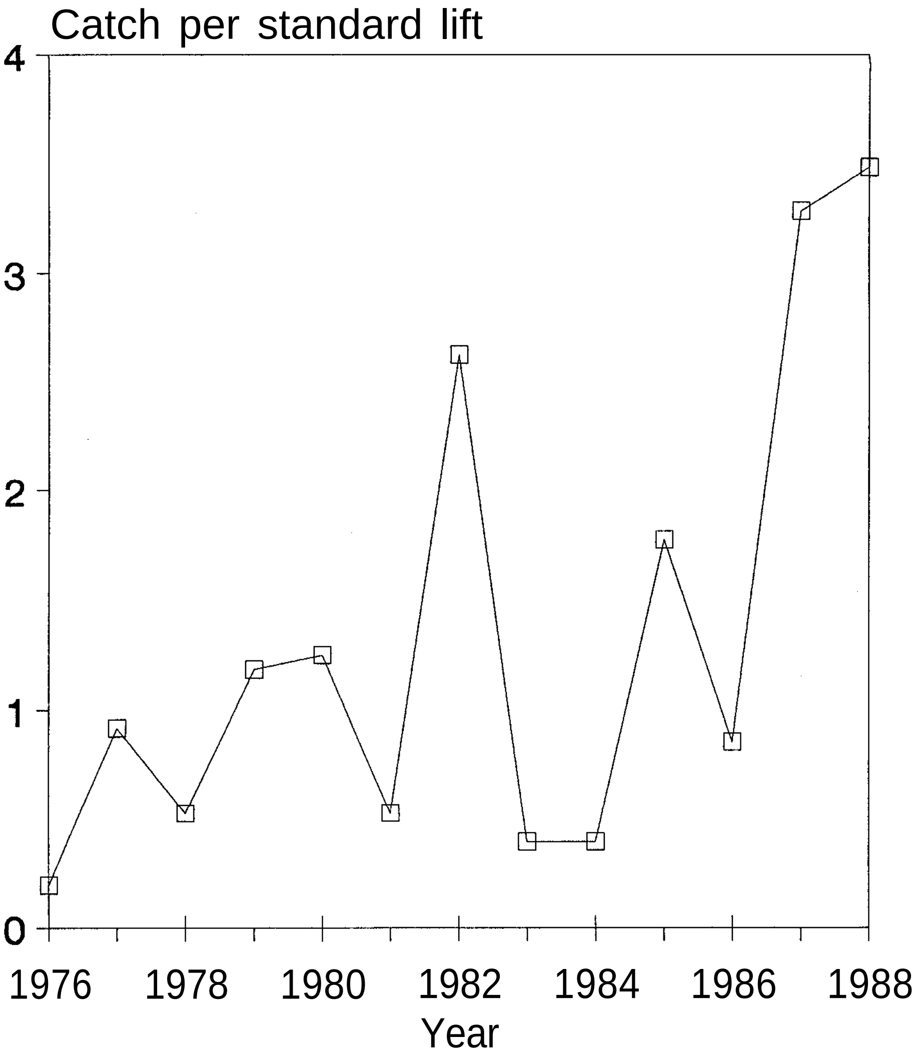


Fig. 22. Average number of walleye caught per gillnet life in the New York waters of the eastern basin of Lake Ontario, during August, 1976-88. (These numbers can be multiplied by two for a very rough comparison with Figs. 8 and 12.)

Nursery habitat appears to be available for this stock in Chaumont, Black River, and Henderson Bays and, based on this, we expect this stock to continue to resurge. Although walleye are rarely targeted, in May 1989 we had reports of two anglers reaching their catch limit in Black River Hay.

OTHER AREAS OF LAKE ONTARIO

Along the south shore of Lake Ontario there are several small embayments that have remnant populations of walleye. Also, the Oswego River has a remnant fishable walleye population that could provide the nucleus for future rehabilitation (G. LeTendre, NYDEC, pers. commun.). The near-shore area of this part of Lake Ontario contains numbers of warmwater species such as smallmouth bass (Micropterus dolomieui), white perch, and yellow perch which use these and other embayments, rivers, and creeks for spawning and nursery. Although there is little historical data available on the fish populations in these areas, they are thought to be capable of producing more walleye.

In 1939, walleye were a significant part of the angling catch in Irondequoit Hay (Ode11 1939). The stock has since declined and, prior to 1985, was considered absent from the bay for two decades (Lane 1986). However, although no walleye were caught in a trapnetting and electrofishing survey of the bay during spring 1985, Lane (1986) was encouraged by the reappearance of walleye in angler catches in the bay and in Irondequoit Creek.

In 1988, angler groups raised 33,700 walleye fingerlings and stocked them in Little Sodus Hay and Port Bay (Table 6). The NYDEC regards walleye stocking as a method to enhance brood stock for rehabilitation of the population to levels that might result in significant natural reproduction.

Table 6. Information on walleye stocked in Lake Ontario (Savoie and LeTendre, 1989).

location	Date	Age in months	Size (cm)	Number
Lower Niagara River	1986			20,000
Lower Niagara River	1987			3,000
Lower Niagara River	July 1988	4	6.4	29,580
Niagara River mouth	July 1988	4	8.5-35.6	1 7 0
Little Sodus Hay	July 1988	4	3.8-5.1	14,000
Little Sodus Hay	July 1988	4	7.6	4,200
Port Hay	July 1988	4	5.1	15,000
Port Hay	October 1988	7	7.6-25.4	500

Angler groups have stocked small numbers of walleye fry into the lower Niagara River from 1986-88 (Table 6) to bolster natural population. Angling for walleye has apparently improved in the lower Niagara River (B. Lewies, Ontario MNR, pers. commun.), but it is unclear whether improvement can be attributed to stocking or increased awareness of walleye.

OMNR gillnets set near Grimsby during the walleye spawning season from 1980-84 regularly caught small numbers of walleye. Potential spawning and nursery areas for these fish are the Niagara River, Hamilton Harbour, and the lower portion of the Old Welland Canal.

The warmwater outflow of the Pickering Nuclear Station attracts extremely large walleye (>5 kg) and a trophy fishery has developed (Dawson 1989; McGary 1989). However, the OMNR salmonid access creel conducted at major launch sites from Port Dalhousie to Port Darlington in 1988 (Stewart and Savoie 1989) observed only one walleye at Whitby.

DISCUSSION

The decline in walleye populations in the Bay of Quinte during the 1960s was most likely due to cultural eutrophication (Hurley and Christie 1977). The reasons for the subsequent resurgence of the Bay of Quinte walleye stock are difficult to attribute to any one cause. The initial resurgence began with the 1977 year-class. Certainly, the resurgence corresponds in time to phosphorus control at sewage treatment plants in the Bay of Quinte (Minns et al. 1986), but, oxygen concentration and oxygen depletion rates showed no improvements on a macrohabitat scale in the Bay of Quinte (Minns and Johnson 1986). However, oxygen levels in the microhabitats occupied by walleye eggs and YOY were not measured. A winterkill of alewife in 1977 and of white perch in 1978 may have had beneficial effects on walleye populations. If alewife have a negative effect on walleye recruitment, then the intensive salmonid stocking program (eight million yearling salmonids stocked annually since 1984) should be a positive influence on walleye abundance (Savoie and Letendre 1989).

However, community interactions may not be the main driving force of the resurgence. Perhaps as important as any other reason was the low adult population. Our analyses suggest that recruitment of the 1977 and 1978 year-classes benefited from density-dependent factors (Fig. 11). Certainly, all of these factors are confounded and it may not be possible to determine the driving force of walleye resurgence in the Hay of Quinte.

The Bay of Quinte walleye stock appears to be fully rehabilitated. The fishable population appears to have stabilized near 700,000 after declining from higher levels in the early 1980s. The age distribution (Fig. 13) and several indicators of year-class strength (Figs. 5, 6, and 7) indicate consistent reproduction. Moreover, walleye growth rates (Fig. 9) and indices of population size (Figs. 8 and 17) show rather minor differences between the early 1960s and present. Furthermore, other fish populations in the warmwater community, of which walleye in Lake Ontario are a component, have stabilized (Ontario MNR, unpubl. data). In addition, the expansion of the population may be near an end because the available suitable habitat in the eastern basin appears to have reached densities of walleye similar to the Bay of Quinte.

Current exploitation of walleye in the Bay of Quinte is high. Close to 40% of the three- and four-year-old walleye are harvested in the angling fishery (Fig. 18). However, effort appears to have stabilized (Fig. 16). Perhaps the reason that this stock is able to withstand such high exploitation on these age-classes is due to the lower exploitation on older age-classes (Fig. 18). Alternatively, if recruitment is density dependent (Fig. 11), then this alone provides a degree of stability to the population. If this relationship is true, then greater harvest might be possible at lower populations than we currently observe. The benefit of past fishing restrictions in light of such a stock recruitment relationship are difficult to assess. However, for safe management, some further confirmation of this relationship should be undertaken before more liberal regulations might be applied.

Currently, there are efforts being made through Remedial Action Plans (under the aegis of the International Joint Commission) to improve water quality in the Bay of Quinte. If these efforts are successful, then we should expect to see increased water clarity in the bay. Also, the probable invasion of the bay by zebra mussels (Dreissena **polymorpha) in the near future may result in increased water** clarity. An increase in water clarity would be followed by an increase in aquatic macrophytes. These habitat changes are likely to favor northern pike, with the result of a possible decrease in walleye abundance.

Other walleye stocks are also resurging in Lake Ontario. Among these, the New York Eastern Lake Ontario stock appears to hold the greatest potential for improvement because of the availability of preferred habitat (Fig. 14) which is uncommon throughout most of the lake. In Port Bay, Little Sodus Bay, and the Niagara River, walleye populations have been bolstered by stocking. Western Lake Ontario appears to hold potential for more walleye, because, historically western Lake Ontario supported a fishery for blue pike (Christie 1973). However, if rainbow smelt or alewife are capable of controlling year-class strength of walleye, then larger populations of natural reproducing walleye in the main part of Lake Ontario may not be a realistic goal for managers. The best approach for further walleye rehabilitation in Lake Ontario may be to continue management efforts on the adjoining rivers and embayments.

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REFERENCES

Abraham, W. J. 1983. Assessment of the 1982 year-class of yellow perch associated with Sodus Bay, Lake Ontario. Ann. Rep. NY Dept. Env. Cons.

Anthony, D. D., and C. R. Jorgenson. 1977. Factors in the declining contributions of walleye (Stizostedion vitreum vitreum) to the fishery of Lake Nipissing, Ontario, 1960-76. J. Fish. Res. Board Can. 34: 1703-1709.

Auer, N. A., and M. T. Auer. 1987. Field evaluation of barriers to walleye egg and larva survival in the lower Fox River, Wisconsin. Am. Fish. Soc. Symp. 2: 93-101.

Baker, Jr., C. T., M. R. Rawson, and D. L. Johnson. 1979. Ohio's annual Lake Erie creel census. Ohio Dept. Nat. Res., Wildl. Div., Lake Erie Res., Fed. Aid Prog. F-35-R, Study No. 3, Final Rep. 104 p.

Balch, R. C. 1952. The age and growth of the yellow pikeperch (Stizostedion vitreum) (Mitchill) in the Green Bay waters of Lake Michigan. M.S. thesis, Michigan State Univ., East Lansing, MI. 75 p.

Baldwin, N. S., R. W. Saalfeld, M. A. Ross, and H. J. Buettner. 1979. Commercial fish production in the Great Lakes, 1867-1977. Great Lakes Fish. Comm. Tech. Rep. No. 3. 187 p.

Beamish, R.; and H. H. Harvey. 1972. Acidification of the Lacloche Mountain Lakes, Ontario, and resulting fish mortalities. J. Fish. Res. Board Can. 29: 1131-1143.

Beamish, R., W. Lockhart, J. VanLoon, and H. Harvey. 1975a. Long-term acidification of a lake and resulting effects on fish. Ambio 4: 98-102.

Beamish, R., G. A. McFarlane, J. C. VanLOon, and J. Lichwa. 1975b. An examination of the possible effects of Sudbury nickel mining and smelting operations on fishes and the water chemistry of lakes within the Whitefish Lake Indian Reserve. Dept. Env., Fish. Mar. Serv., Res. Dev. Directorate Tech. Rep. No. 579.

Beeton, A. M., S. H. Smith, and F. F. Hooper. 1967. Physical limnology of Saginaw Bay, Lake Huron. Great Lakes Fish. Comm. Tech. Rep. No. 12. 56 p.

Bennett, E. B. 1978. Characteristics of the thermal regime of Lake Superior. J. Great Lakes Res. 4(3-4): 310-319.

Berg, N. A., and M. G. Johnson. 1978. Environmental management strategy for the Great Lakes system. Final Report from the International Reference Group on Great Lakes Pollution from Land Use Activities, PLUARG, to the International Joint Commission, Windsor, Ontario.

Berkes, F., and D. Pocock. 1987. Quota management and "people problems": a casehistory of Canadian Lake Erie fisheries. Trans. Am. Fish. Soc. 116: 494-502.

Bowman, B. 1988. Status Report, Spanish River-Harbour area remedial action plan (RAP). Queen's Printer for Ontario.

Brandt, S. B., D. M. Mason, D. B. McNeill, T. Coates, and J. E. Gannon. 1987. Predation by alewives on larvae of yellow perch in Lake Ontario. Trans. Am. Fish. Soc. 116: 641-645.

Brown, R. 1978. Ghost towns of Ontario: Vol. 1, Southern Ontario. Stagecoach Publ. Co., Langley, British Columbia.

Brownie, C., D. R. Anderson, K. P. Burnham, and D. S. Robson. 1985. Statistical inference from band recovery data: a handbook. U. S. Fish Wildl. Serv. Resour. Pub. 156. 305 p.

Bryant, W. C. 1984. Status of the walleye in Michigan waters of bake Erie and connecting waters, 1980-1983. Mich. Dept. Nat. Res., Fish. Res. Rep. No. 1918.

Campbell, W. A. 1988. Northeastern Georgian Bay and its people. Journal Printing, Sudbury, Ontario. 168 p.

Christie, W. J. 1973. A review of the changes in the fish species composition of Lake Ontario. Great Lakes Fish. Comm. Tech. Rep. No. 23. 65 p.

Colby, P. J., and S. J. Nepszy. 1981. Variation among stocks of walleye (Stizostedium vitreum vitreum): management implications. Can. J. Fish. Aguat. Sci. 3812: 1814-1831.

Colby, P. J., R. E. McNicol, and R. A. Ryder. 1979. Synopsis of biological data on the walleye (Stizostedion vitreum vitreum) (Mitchill). FAO Fish. Synp. 119. 139 p.

Conroy, N., and R. McGrath. 1967. Water quality evaluation of the lower Spanish River. Ont. Water Resour. Comm., Toronto, Ontario.

Conroy, N., K. Hawley, and W. Keller. 1978. Extensive monitoring of lakes in the greater Sudbury area, 1974-1976. Sudbury Env. Study Rep., Water Res. Ass., Northeast Region, Ont. Min. Env., Sudbury, Ontario.

Craig, R. E., and R. M. Black. 1986. Nursery habitat of muskellunge in southern Georgian Bay, Lake Huron, Canada. Am. Fish. Soc. Spec. Pub. 15: 79-86.

Crowder, A., and M. Bristow. 1986. Aquatic macrophytes in the Bay of Quinte, 1972-82. p. 114-127. In C.K. Minns, D. A. Hurley, and K. H. Nicholls [ed.] Project Quinte: point-source phosphorous control and ecosystem response in the Bay of Quinte, Lake Ontario. Can. Fish. Aguat. Sci. Spec. Pub. 86. 270 p.

Crowe, W. R. 1955. Numerical abundance and use of a spawning run of walleyes in the Muskegon River. Mich. Trans. Am. Fish. Soc. 84: 125-136.

1957. Movement and harvest of native walleyes from impoundments on the Muskegon River. Mich. Dept. Cons., Inst. Fish. Res. Rep. 1518. 9 p.

Crowe, W. R., E. Karvelis, and L. S. Joeris. 1963. The movement, heterogeneity, and rate of exploitation of walleyes in northern Green Bay, Lake Michigan, as determined by tagging. Int. Comm. N.W. Atl. Fish. Spec. Pub. 4: 38-41.

Dawson, J. B. 1989. The class of '78. Sci. Scan, Out of Doors. (In press)

Deason, H. J. 1933. Preliminary report on the growth rate, dominance and maturity of the pike-perches (Stizostedion) of Lake Erie. Trans. Am. Fish. Soc. 63: 348-360.

1936. Morphometric and life history studies of the pike-perches (Stizostedion) of Lake Erie. Ph.D. thesis, Univ. of Michigan, Ann Arbor, MI. 368 p.

Duffy, W. G., T. R. Batterson, and E. C. Pendleton. 1987. The St. Marys River, Michigan: an ecological profile. u. s. Fish Wildl. Serv. Biol. Rep. No. 85(7.10), Washington, DC.

Dymond, J. R. 1957. Artificial propagation in the management of Great Lakes fisheries. Trans. Am. Fish. Soc. 86: 384-392.

Dymond, J. R., and A. V. Delaporte. 1952. Pollution of the Spanish River. A Report to the Special Committee of the Research Council of Ontario, Ont. Dept. Lands Forests, Div. Res., Res. Rep. Tech. Ser. No. 25.

Eck, G. W. and L. R. Wells. 1987. Recent changes in Lake Michigan's fish community and their probable causes, with emphasis on the role of the alewife (*Alosa pseudoharengus*). Can. J. Fish. Aguat. Sci. 44 (Suppl. 2): 53-60.

Edwards, C. J., P. L. Hudson, W. G. Duffy, S. J. Nepszy, C. D. McNabb, R. C. Haas, C. R. Liston, B. Manny, and W-D. N. Busch. 1987. Hydrological, morphometrical, and biological characteristics of the connecting rivers of the international Great Lakes: a review. p. 240-264. In D. P. Dodge [ed.] Proceedings of the International Large River Symposium (LARS). Can. Fish. Aguat. Sci. Spec. Pub. 106.

Einhouse, D. W., F. C. Cornelius, P. E. McKeown, M. A. Wilkinson, J. P. Galati, and T. Heinrich. 1987. 1987 Annual Report to the Lake Erie Committee, Great Lakes Fish. Comm., NY Dept. Env. Cons., Albany, NY. 18 p.
1988. 1988 Annual Report to the Lake Erie Committee, Great Lakes Fish. Comm., NY Dept. Env. Cons., Albany, NY. 19 p.

Einhouse, D. W., and W. F. Sheperd. 1988. Distribution of marked walleye in New York waters of Lake Erie. NY Dept. Env. Cons. Spec. Pub., Albany, NY. 8 p.

Environment Canada. 1987. Historical streamflow summary, Ontario, to 1986. Inland Waters Lands Directorate Spec. Pub., Ottawa, Ont.

Ferguson, R. G., and A. J. Dirksen. 1971. Migrations of adult and juvenile walleye (*Stizostedion vitreum vitreum*) in southern Lake Huron, Lake St. Clair, Lake Erie, and connecting waters. J. Fish. Res. Board Can. 28: 1133-1142.

Fitzgerald, W. D. 1985. Postglacial history of the Minesing Basin, Ontario. In P. F. Karrow and P. E. Calkin [ed.] Quarternary evolution of the Great Lakes. Geological Assn. Can. Spec. Pap. 30: 133-146.

Forney, J. L. 1976. Year-class formation in the walleye (Stizostedion vitreum vitreum) population of Oneida Lake, New York, 1966-1973. J. Res. Board Can. 33: 783-792.

1977. Evidence of inter- and intraspecific competion as factors regulating walleye (Stizostedium vitreum vitreum) biomass in Oneida Lake, New York. J. Res. Board Can. 34: 1812-1820.

Freedman, P. L. 1974. Saginaw Bay: an evaluation of existing and historical conditions. U. S. Env. Prot. Agency, Rep. 905/9-74-003, Chicago, IL.

Goode, G. B. [ED.] 1884. The fisheries and fishing industry of the United States. Section 1, U. S. Comm. Fish., Spec. Rep. No. XXXIV. Washington, DC. 895 p.

Gorham, E., and A. G. Gordon. 1960. The influence upon the chemical composition of lake waters near Sudbury, Ontario, and upon the surrounding vegetation. Can. J. Bot. 38: 477-487.

Haas, R. C., W. C. Bryant, K. D. Smith, and A. J. Nuhfer. 1985. Movement and harvest of fish in Lake St. Clair, St. Clair River, and Detroit River. Final Report Winter Navigation Study, Mich. Dept. Nat. Resour. Fish Div., Mt. Clemens, MI. 610 p.

Haas, R. C., M. E. Fabrizio, and T. N. Todd. 1988. Identification, movement, growth, mortality, and exploitation of walleye stocks in Lake St. Clair and the western basin of Lake Erie. Mich. Dept. Nat. Resour. Res. Rep. No. 1954. 71 p.

Harvey, H. H. 1975. Fish populations in a large group of acid-stressed lakes. Verh. Int. Ver. Limnol. 19: 2406-2417.

Harvey, H. H., and C. Lee. 1980. Report to the Ontario Ministry of Natural Resources on the fishes of the LaCloche Mountain Lakes of Ontario, 1965-1980. Spec. Pub. Univ. of Toronto, Toronto, Ontario.

Hatch, R. W., S. J. Nepszy, K. M. Muth, and C. T. Baker. 1987. Dynamics of the recovery of the western Lake Erie walleye (Stizostedion vitreum vitreum) stock. Can. J. Fish. Aguat. Sci. 44 (Suppl. 2): 15-22.

Hatch, R. W., S. J. Nepszy, and M. Rawson. 1990. Management of percids in Lake Erie, North America. In W. L. T. van Densen, B. Steinmetz, R. H. Hughes. [ed.] Management of freshwater fisheries. Proc. of a symposium organized by the European Inland Fish. Adv. Comm., Goteborg, Sweden, 31 May-3 June 1988. 675 p.

Hile, R. 1954. Fluctuations in growth and year-class strength of walleye in Saginaw Bay. U. S. Fish Wildl. Serv. Fish. Bull. 91: 7-59.

Hile, R., and H. J. Buettner. 1959. Fluctuations in the commercial fisheries of Saginaw Bay, 1885-1956. U. S. Fish Wildl. Serv. Res. Rep. 51. 38 p.

Holtze, K. E., and N. J. Hutchinson. 1989. Lethality of low pH and Al to early life stages of six fish species inhabitating Precambrian shield waters in Ontario. Can. J. Fish. Aguat. Sci. 6: 1188-1202.

Hulsman, P. F., P. M. Powles, and J. M. Gunn. 1983. Mortality of walleye eggs and rainbow trout yolk-sac larvae in low-pH waters of the Lacloche Mountain area, Ontario. Trans. Am. Fish. Soc. 112: 680-688.

Hurley, D. A. 1986a. Fish populations of the Bay of Quinte, Lake Ontario, before and after phosphorous control, 201-214. In C. R. Minns, D. A. Hurley, and K. H. Nicholls [ed.] Project Quinte: point-source phosphorous control and ecosystem response in the Bay of Quinte, Lake Ontario. Can. Fish. Aguat. Sci. Spec. Pub. 86. 270 p.

1986b. Effect of nutrient reduction on the diet of four fish species in the Bay of Quinte, Lake Ontario, 237-246. In C. R. Minns, D. A. Hurley, and K. H. Nicholls [ed.] Project Quinte: point-source phosphorous control and ecosystem response in the Bay of Quinte, Lake Ontario. Can. Fish. Aguat. Sci. Spec. Pub. 86. 270 p.

1986c. Growth, diet, and food consumption of walleye (Stizostedion vitreum vitreum): an application of bioenergetics modelling to the Bay of Quinte, Lake Ontario, 224-236. In C. R. Minns, D. A. Hurley, and K. H. Nicholls [ed.] Project Quinte: point-source phosphorous control and ecosystem response in the Bay of Quinte, Lake Ontario. Can. Fish. Aguat. Sci. Spec. Pub. 86. 270 p.

Hurley, D. A., and W. J. Christie. 1977. Depreciation of the warmwater fish community in the Bay of Quinte, Lake Ontario. J. Fish. Res. Board can. 34: 1849-1860.

Johnson, M. G., K. H. Nicholls. 1989. Temporal and spatial variability in sediment and phosphorous loads to Lake Simcoe, Ontario. J. Great Lakes Res. 15: 265-282.

Johnston, D. A. 1977. Population dynamics of walleye (Stizostedion vitreum vitreum) and yellow perch (Perca flavescens) in Lake St. Clair, especially during 1970-76. J. Fish. Res. Board. Can. 34: 1869-1877.

Keller, M. 1964. Lake Erie sport-fishing survey. Ohio Dept. Nat. Resour., Div. Wildl. Pub. W-316. 19 p.

Keller, W., and J. R. Pitblado. 1986. Water quality changes in Sudbury area lakes: a comparison of synoptic surveys in 1974-1976 and 1981-1983. Water Air Pollut. 29: 285-296.

Keller, W., J. R. Pitblado, and N. I. Conroy. 1986. Water quality improvements in the Sudbury, Ontario, Canada area related to reduced smelter emissions. Water Soil Pollut. 31: 765-774.

Keller, M., J. C. Schneider, L. E. Morzinski, R. C. Haas, and J. R. Weber. 1987. History, status, and management of fishes in Saginaw Bay, Lake Huron, 1981-1986. Mich. Dept. Nat. Resour. Fish. Tech. Rep. 87-2. 42 p.

Knight, R. L., F. J. Margraf, and R. F. Carline. 1984. Piscivory by walleyes and yellow perch in western Lake Erie. Trans. Am. Fish. Soc. 113: 677-693.

Koonce, J. F., T. B. Bagenal, R. F. Carline, K. E. F. Hokanson, and M. Nagiec. 1977. Factors influencing year-class strength of percids: a summary and a model of temperature effects. J. Fish. Res. Board Can. 34: 1900-1909.

Kutkuhn, J. H., et al., (Chairman). 1976. First technical report of the Great Lakes Fishery Commission Scientific Protocol Committee on interagency management of the walleye resource of western Lake Erie. Great Lakes Fish. Comm. Ann. Mtg., Traverse City, MI. 32 p.. Appendix and Addendum 1. 12 p.

Lane, G. 1986. The importance of coves-wetlands to the Irondequoit Bay fish community, and some parameters associated with its populations. NY Dept. Env. Cons. Spec. Rep. to the Lake Ont. Comm. of the Great Lakes Fish. Comm.

Lange, R. E., F. C. Cornelius, D. W. Einhouse, P. E. McKeown, J. P. Galati, and T. Heinrich. 1985. NY Dept. Env. Cons. Ann. Rep. to the Lake Erie Comm. of the Great Lakes Fish. Comm. 22 p.
1986. NY Dept. Env. Cons. Ann. Rep. to the Lake Erie Comm. of the Great Lakes Fish. Comm. 23 p.

Lawrie, A. H. 1978. The fish community of Lake Superior. J. Great Lakes Res. 4(3-4): 513-549.

Lawrie, A. H., and J. F. Rahrer. 1972. Lake Superior: effects of exploitation and introduction of the salmonid community. J. Fish. Res. Board Can. 29: 765-776.

Leach, J. H., M. G. Johnson, J. R. M. Kelso, J. Hartman, W. Numann, and B. Entz. 1977. Responses of percid fishes and their habitats to eutrophication. J. Fish. Res. Board Can. 34: 1964-1971.

Leslie, J. K., and J. E. Moore. 1985. Ecology of young-of-the- year fish in Muscote Bay (Bay of Quinte), Ont. Can. Fish. Aguat. Sci. Tech. Rep. No. 1377. 63 p.

Lindeman, R. L. 1942. The trophic-dynamic aspect of ecology. Ecology 23: 399-418.

Linder, A., D. Csanda, T. Dean, R. Linder, B. Ripley, and D. Stange. 1983. Walleye Wisdom. Al Linder's Outdoor Inc., Brainerd, MN.

Liston, C. R., C. D. McNabb, D. Brazo, J. Bohr, J. Craig, W. Duffy, G. Fleischer, G. Knoecklein, F. Koehler, R. Ligman, R. O'Neal, M. Siamij, and P. Roettger. 1986. Limnological and fisheries studies in relation to proposed extension of the navigation season, 1982 and 1983. U. S. Fish Wildl. Serv. Rep. FWS/OBS-80/62.3. Washington, DC.

MacCallum, W. R., and J. H. Selgeby. 1987. Lake Superior revisited. 1984. Can. J. Fish. Aguat. Sci. 44(Suppl. 2): 23-36.

Margenau, T. L., S. T. Schram, and W. H. Blust. 1988. Lymphocystis in a walleye population. Trans. Am. Fish. Soc. 117: 308-310.

Mathers, R. A., and P. H. Johansen. 1985. The effects of feeding ecology on mercury accumulation in walleye (Stizostedium vitreum) and pike (Esox lucius) in Lake Simcoe. Can. J. Zool. 63: 2006-2012.

Matheson, D. H., and M. Munawar. 1978. Lake Superior basin and its development. J. Great Lakes Res. 4(3-4): 249-263.

McGary, B. 1989. The Pickering "nuke" for trophy walleye. Ontario Fisherman. April-May: 99-104.

McMurty, M. J., D. L. Wales, W. A. Scheider, G. L. Beggs, and P. E. Dimond. 1989. Relationship of mercury concentrations lake trout (Salvelinus namaycush) and smallmouthbass (Micropterus dolomieui) to the physical and chemical characteristics of Ontario lakes. Can. J. Fish. Aguat. Sci. 46: 426-434.

Minns, C. K., and D. A. Hurley. 1986. Population dynamics and production of white perch (Morone americana) in the Bay of Quinte, Lake Ontario. p. 215-223. In C. K. Minns, D. A. Hurley, and K. H. Nicholls [ed.] Project Quinte: point- source phosphorous control and ecosystem response in the Bay of Quinte, Lake Ontario. Can. Fish. Aguat. Sci. Spec. Pub. 86. 270 p.

Minns, C. K., G. E. Owen, and M. G. Johnson. 1986. Nutrient loads and budgets in the Bay of Quinte, Lake Ontario. p. 59-76. In C. K. Minns, D. A. Hurley, and K. H. Nicholls [ed.] Project Quinte: point-source phosphorous control and ecosystem response in the Bay of Quinte, Lake Ontario. Can. Fish. Aguat. Sci. Spec. Pub. 86. 270 p.

Minns, C. K., and M. G. Johnson. 1986. Temperature and oxygen conditions and oxygen depletion in the Bay of Quinte, Lake Ontario. p. 40-49. In C. K. Minns, D. A. Hurley, and K. H. Nicholls [ed.] Project Quinte: point-sourcephosphorous control and ecosystem response in the Bay of Quinte, Lake Ontario. Can. Fish. Aguat. Sci. Spec. Pub. 86. 270 p.

Mrozinski, L. E., R. Haas, J. C. Schneider, and R. E. Shepherd. Rehabilitation of walleye in Saginaw Bay, Lake Huron. (In Press)

Muth, K. M., and D. R. Wolfert. 1986. Changes in growth and maturity of walleyes associated with stock rehabilitation in western Lake Erie, 1964-1983. North Amer. J. Fish. Manage. 6: 168-175.

Nees, L. A. 1976. McGregor Bay, the quiet paradise. (No printer cited)

Nepszy, S. J. 1977. Changes in percid populations and species interactions in Lake Erie. J. Fish. Res. Board Can. 34: 1861-1868.

Niemuth, W., W. Churchill, and T. Wirth. 1972. The walleye, its life history, ecology and management. Wisc. Dept. Cons. Pub. No. 227-72. 20 p.

Nutte, G. L. 1944. Lake Superior. The Bobbs-Merrill Co., Indianapolis and New York. 376 p.

O'Brien, K. 1989. Moon River monster. Ontario Out-of-Doors 21(1): 15-17, 59-60.

Odell, T. T. 1939. Bays and ponds of the shore area. p. 82-97. In A biological survey of the Lake Ontario watershed. NY State Cons. Dept., Albany, NY.

O'Gonnan, R., and C. P. Schneider. 1986. Dynamics of alewives in Lake Ontario following a mass mortality. Trans. Am. Fish. Soc. 115: 1-14.

Ohio Department of Natural Resources. 1989. Status and trend highlights, Ohio's Lake Erie fish and fisheries. Ohio Dept. Nat. Resour., Lake Erie Fish. Unit, Sandusky, OH.

Ontario Department of Lands and Forests. 1963a. A history of Lake Huron Forest District. Dist. Hist. Ser. No. 3.

1963b. A history of Lake Simcoe Forest District. Dist. Hist. Ser. No. 7.

1964. A history of Parry Sound Forest District. Dist. Hist. Ser. No. 12.

1965. A history of Sault Ste. Marie Forest District. Dist. Hist. Ser. No. 20.

1967. A history of Sudbury Forest District. Dist. Hist. Ser. No. 21.

Ontario Ministry of Natural Resources. 1980. Background information Espanola District. Northeastern Region District land use planning program.

1987. Huronia District fisheries management plan. Background information summary report.

1988a. Community Fisheries Involvement Program (CFIP) Five Year Report 1982-1986. Ont. Min. Nat. Resour., Fish. Br., Toronto, Ontario.

1988b. Lake St. Clair Fisheries Report 1987. Ont. Min. Nat. Resour., Lake St. Clair Fish. Assess. Unit, Tilbury, Ontario.

Ontario Ministry of Natural Resources. 1989. Lake St. Clair fisheries report. Ont. Min. Nat. Resour., Mt. Clemens, MI.

Parsons, J. W. 1970. Walleye fishery of Lake Erie 1943-62 with emphasis on contributions of the 1942-61 year-classes. J. Fish. Res. Board Can. 27: 1475-1489.

Payne, N. R. 1963. The life history of the yellow walleye, (Stizostedion vitreum vitreum) (Mitchill) in the Bay of Quinte. M.S. thesis, Univ. of Toronto, Toronto, Ontario. 40 p.

Priegel, G. R. 1970. Reproduction and early life history of the walleye in the bake Winnebago region. Wisc. Dept. Nat. Resour., Tech. Bull. No. 45, Madison, WI.

Rahel, J. I., and J. J. Magnuson. 1983. Low pH and the absence of fish species in naturally acidic Wisconsin lakes: inferences for cultural acidification. Can. J. Fish. Aguat. Sci. 40: 3-9.

Rakoczy, G. P., and R. D. Rodgers. 1987. Sport-fishing catch and effort from the Michigan waters of Lakes Michigan, Huron, and Erie, and their important tributary streams, April 1, 1986-March 31, 1987. Mich. Dept. Nat. Resour., Fish. Div. Tech. Rep. No. 87-6a and b. 159 p.

1988. Sport-fishing catch and effort from the Michigan waters of lakes Michigan, Huron, Erie, and Superior and their important tributary streams, April 1, 1986-March 31, 1987. Mich. Dept. Nat. Resour., Fish. Div. Tech. Rep. No. 8a-9a and b. 185 p.

Regier, H. A., V. C. Applegate, and R. A. Ryder. 1969. The ecology and management of the walleye in western Lake Erie. Great Lakes Fish. Comm. Tech. Rep. No. 15. 101 p.

Rich, P. H., and R. G. Wetzel. 1978. Detritus in the lake ecosystem. Am. Natur. 112: 57-71.

Ricker, W. E. 1975. Computations and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191. 382 p.

Ridgley, J. I. 1972a. Ontario commercial fish industry statistics on landings, 1961-1965. Ont. Min. Nat. Resour., Comm. Fish. Fur Br., Div. Fish Wildl., Toronto, Ontario.

1972b. Ontario commercial fish industry statistics on landings, 1966-1970. Ont. Min. Nat. Resour., Comm. Fish. Fur Br., Div. Fish Wildl., Toronto, Ontario.

1975. Ontario commercial fish industry statistics on landings, 1956-1960. Ont. Min. Nat. Resour., Comm. Fish Fur Br., Div. Fish Wildl., Toronto, Ontario.

1976. Ontario commercial fish industry statistics on landings, 1971-1973. Ont. Min. Nat. Resour., Fish. Br., Div. Fish Wildl., Toronto, Ontario.

(No date) Ontario commercial fish industry statistics on landings, 1976-1980. Ont. Min. Nat. Resour., Fish. Br., Div. Fish Wildl., Toronto, Ontario.

Ridgway, M. S., D. A. Hurley, and K. A. Scott. 1989. The impacts of temperature and predation on the abundance of alewife (Alosa pseudoharengus) in the Bay of Quinte, Lake Ontario. J. Great Lakes Res. (In press)

Robertson, A., and D. Scavia. 1978. Ecosystem and water quality modelling during IFYGL. Verh. Int. Ver. Limnol. 20: 311-316.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooks, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. (Fourth Ed.) Am. Fish. Soc. Spec. Pub. 12. 174 p.

Robinson, G. W. 1986. Water quality of the Bay of Quinte, Lake Ontario, before and after reductions of phosphorous loading. p. 40-58. In C. K. Minns, D. A. Hurley, and K. H. Nicholls [ed.] Project Quinte: point-source phosphorous control and ecosystem response in the Bay of Quinte, Lake Ontario. Can. Fish. Aguat. Sci. Spec. Pub. 86. 270 p.

Roeloffs, E. W. 1946. A review of commercial fishing in Little Bay de Noc, with comments on its relation to sport fishing. Mich. Dept. Cons., Inst. Fish. Res. Rep. No. 1037. 8 p.

Rose, G., and G. Kruppert. 1984. An assessment of the walleye fishery and migration patterns of other species, Goulais River, spring of 1984. Ont. Min. Nat. Resour., Sault Ste. Marie Dist. 18 p.

Ryclanan, J. R. 1986. A creel survey of sport-fishing in Saginaw Bay, Lake Huron, 1983-84. Mich. Dept. Nat. Resour., Div. Fish. Tech. Rep. No. 86-4. 35 p.

Ryder, R. A. 1968. Dynamics and exploitation of mature walleyes (Stizostedion vitreum vitreum) in the Nipigon Bay region of Lake Superior. J. Fish. Res. Board Can. 25: 1347-1376.

Savoie, P., and G. LeTendre. 1989. Lake Ontario stocking and marking program. Report by Ont. Min. Nat. Resour. and NY Dept. Env. Cons. to the Lake Ontario Committee of the Great Lakes Fish. Comm.

Schiavone, A., Jr. 1981. Decline of the walleye population in Black Lake. NY Fish Game J. 28: 68-72.

1983. The Black Lake fish community: 1931-1979. NY Fish Game J. 30: 78-90.

1985. Response of walleye populations to the introduction of the black crappie in the Indian River Lakes. NY Fish Game J. 32: 114-140.

Schneider, J. C. 1977. History of the walleye fisheries of Saginaw Bay, Lake Huron. Mich. Dept. Nat. Resour., Fish. Res. Rep. No. 1850. 16 p.

Schneider, J. C., and W. R. Crowe. 1977. A synopsis of walleye tagging experiments in Michigan, 1929-1965. Mich. Dept. Nat. Resour., Fish. Res. Rep. 1844. 29 p.

Schneider, J. C., and J. H. Leach. 1977. Walleye (Stizostedion vitreum vitreum) fluctuations in the Great Lakes and possible causes, 1800-1975. J. Fish. Res. Board Canada, 34: 1878-1889.

1979. Walleye stocks in the Great Lakes, 1800-1975: fluctuations and possible causes. Great Lakes Fish. Comm. Tech. Rep. 31. 51 p.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Bull. Fish. Res. Board Canada. 184. 966 p.

Seelye, J. G., L. L. Marking, E. L. King, Jr., L. H. Hanson, and T. D. Bills. 1987. Toxicity of TFM lampricide to early life stages of walleye. North Amer. J. Fish. Manage. 7: 598-601.

Serns, S. L. 1982. Influence of various factors on density and growth of age-0 walleyes in Escanaba Lake, Wisconsin, 1958-1980. Trans. Am. Fish. Soc. 111: 299-306.

Sherman, K. (ED.) 1988. Severn Sound Remedial Action Plan. Part I. Environmental conditions and problem definition. (No publisher cited)

Smith, K. D. 1988. Evaluation of modifications to trapnets for reducing gilling in a commercial whitefish fishery. Mich. Dept. Nat. Resour., Inst. Fish. Res. Rep. 1953. 37 p.

Smith, S. H., H. J. Buettner, and R. Hile. 1961. Fishery statistical districts of the Great Lakes. Great Lakes Fish. Comm. Tech. Rep. No. 2. 24 p.

Spangler, G. R., N. R. Payne, and G. K. Winterton. 1977. Percids in the Canadian waters of Lake Huron. J. Fish. Res. Board Can. 34: 1839-1848.

Sprules, W. G. 1975. Midsummer crustacean zooplankton communities in acid-stressed lakes. J. Fish. Res. Board Can. 32: 389-395.

Stevens, R. J. J,. M. A. T. Neilson, and N. D. Warry. 1985. Water quality of the Lake Huron-Georgian Bay system. Inland Waters Directorate, Ont. Region, Water Quality Br., Sci. Ser. No. 143, Burlington, Ont.

Stewert, T. J., and P. J. Savoie. 1989. Western Lake Ontario harvest assessment, 1988. Annual report of the Ont. Min. Nat. Resour. to the Great Lakes Fish. Comm., Picton, Ontario.

Swedberg, D. V., and J. H. Selgeby. 1979. Biology, structure, and integrity of Chequamegon Bay walleye population. U.S. Fish Wildl. Serv., Great Lakes Fish. Lab. Admin. Rep., Ann Arbor, MI.

Swenson, W. A. 1977. Food consumption of walleye (Stizostedion vitreum vitreum) and sauger (S. canadense) in relation to food availability and physical condition in Lake of the Woods, Minnesota, Shageana Lake, and western Lake Superior. J. Fish. Res. Board Can. 34: 1643-1654.

Sztramko, L. K., and J. R. Paine. 1984. Sport fisheries in the Canadian portion of Lake Erie and connecting waters, 1948-1980. Ont. Fish. Tech. Rep. Ser. iii + 43 p.

Timmerman, A. J., and W. I. Dunlop. 1985. Evidence of yellow pickerel (Stizostedion vitreum vitreum) reproduction in the central basin of Lake Erie, 1984. Ont. Min. Nat. Resour., Lake Erie Fish. Assess. Unit, Rep. No. 1985-2. 42 p.

U. S. Fish and Wildlife Service. 1989. 1985 national survey of fishing, hunting, and wildlife-associated recreation, Michigan. 81 p.

Van Oosten, J., R. Hile, and F. Jobes. 1947. The whitefish fishery of Lakes Huron and Michigan with special reference to the deep trap net fishery. U. S. Fish Wildl. Serv. Fish. Hull. 40: 297-394.

Wagner, W. C. 1968. The sport fishery on Little Hay de Noc, 1965. Mich. Dept. Nat. Resour., Inst. Fish. Res. Rep. No. 1748. 20 p.

Wales, D. L., and V. A. Liimatainen. 1987. Preliminary assessment of the current impact and potential risk of acidic deposition on walleye populations in Ontario. Ont. Min. Nat. Resour., Ont Fish. Acid. Rep. Ser. 87-11, Toronto, Ontario.

Wells, L., and A. L. McLain. 1973. Lake Michigan: man's effect on native fish stocks and other biota. Great Lakes Fish. Comm. Tech. Rep. No. 20. 55 p.

Wilmot, S., and E. Harris. 1894. Report and review of the Dominion Fishery Commission on the fisheries of the Province of Ontario 1893. Printed by order of Parliament by S. E. Dawson, Printer to the Queen's Most Excellent Majesty, Ottawa, Ontario.

Winterton, G. K. 1975. Structure and movement of a spawning stock of walleye (Stizostedion vitreum vitreum) (Mitchill) in Georgian Hay, M.S. thesis, Univ. of Guelph, Guelph, Ontario.

Wolfert, D. R. 1963. The movements of walleyes tagged as yearlings in Lake Erie. Trans. Am. Fish. Soc. 92: 414-420.

1969. Maturity and fecundity of walleyes from the eastern and western basins of Lake Erie. J. Fish. Res. Hoard Can. 26: 1877-1888.

1977. Age and growth of the walleye in Lake Erie, 1963-1968. Trans. Am. Fish. Soc. 106: 569-577.

1981. The commercial fishery for walleyes in New York waters of Lake Erie, 1959-1978. North Amer. J. Fish. Manage. 1: 112-126.

Wolfert, D. R., and H. D. Van Meter. 1978. Movements of walleyes tagged in eastern Lake Erie. NY Fish Game J. 25(1): 16-22.

Wood, C. R. 1984. Some legislative changes for gillnet fisheries in eastern Lake Ontario, Hay of Quinte. Ont. Min. Nat. Resour., Lake Ontario Fish. Unit, No. 84-8, Picton, Ontario.

Wren, C. D., and P. M. Stokes. 1988. Depressed mercury levels in biota from acid and metal stressed lakes near Sudbury, Ontario. Ambio 17: 28-30.