GREAT LAKES FISHERY COMMISSION

REPORT OF THE

ST. MARYS RIVER SEA LAMPREY TASK FORCE

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TABLE OF CONTENTS

ABSTRACT

This report is an assessment of the role of the St. Marys River as a producer of sea lampreys to Lake Huron and of whether control measures in the river are warranted. The St. Marys River is known to harbor large numbers of sea lamprey larvae, and is the only such tributary to Lake Huron that is not treated with lampricides. Further, the frequency of occurrence of sea lamprey attachment marks on prey fish species is considerably higher in Lake Huron than in the other Great Lakes.

We estimated the adult stock of sea lampreys in northern Lake Huron at 248,000 individuals. The standing stock of sea lamprey larvae in the river is estimated at 6.8 million individuals not including the youngest age groups, which are inadequately sampled. Transformer production was calculated at 50,000 per year yielding 33,000 feeding phase adults, or 13% of the number in northern Lake Huron. However, these estimates as well as other conclusions in the report are based on incomplete data, and our inferences are subject to considerable error.

Sea lamprey activity is increasing in northern Lake Huron, but we could not demonstrate that this increase is related to greater numbers of larvae in the St. Marys River. We estimate that the total damage to the fisheries caused by sea lampreys in northern Lake Huron amounts to $2.6 million each year. The primary species affected are chubs, whitefish, lake trout and chinook salmon. Damage caused by sea lamprey amounts to 70% of the value of the fisheries for these species.

A conventional TFM treatment is the control measure that can most likely minimize the sea lamprey population in the St. Marys River. Preliminary calculations indicate that a conventional treatment would require 135,700 kg of TFM and cost $3.6 million. Nontarget effects of a TFM treatment would probably be acceptable. Hexagenia limbata, the species of most concern, would be depressed by 34% in Lake Nicolet, but the overall reduction in Hexagenia abundance is estimated at only 6.5%. Treatment costs figured on an annual basis ($450,000) exceed the annual damage caused by sea lampreys of St. Marys River origin ($344,000).

Increased sampling effort and improved sampling gear are needed to determine the source(s) of the sea lampreys in northern Lake Huron. Fishery losses caused by these sea lampreys are not acceptable. Our data can not implicate the St. Marys River as a major source and consequently control measures are not warranted at this time. However, more effective and intensive sampling may indicate that the St. Marys River is the major source, because transformers are difficult to recover with the existing sampling methods. Therefore, the St. Marys River should not be excluded from searches for the major sources of sea lampreys to Lake Huron.

INTRODUCTION

During the last few years a controversy about the role of the St. Marys River as a major supplier of sea lampreys to Lake Huron has intensified with affected fishery agencies and the public expressing increased concerns. Feeding-phase sea lampreys are far more abundant in Lake Huron than should be the case. All upper Great Lakes tributaries known to harbor significant numbers of sea lamprey ammocetes, excepting the St. Marys, are routinely treated with lampricides to suppress recruitment of sea lampreys to the lakes. Yet, recent assessments place the abundance of spawning-phase sea lamprey in northern Lake Huron at 248,000 whereas comparable figures for northern Lake Michigan and U.S. waters of Lake Superior are Only 79,000 and 62,000, respectively (USFWS, Marquette Sea Lamprey Control). Moreover, the frequency of occurence of sea lamprey marks and the incidence of observed attachments of sea lampreys on several fish species are much higher in Lake Huron than in the other upper Great Lakes. These observations taken together with the facts that sea lamprey ammocetes in the St. Marys River are abundant, widely distributed, and would naturally recruit to Lake Huron raise the question of the prospects and need for control measures on the river. Accordingly, the GLFC appointed a task force in May 1986 to assess the problem and make recommendations. This document is the report of the task force. We attempt to keep our report as brief as is reasonable, and considerably more data have been reviewed than are presented here. Definitive data are often lacking, however, and thus our conclusions are inferences subject to error and debate.

DESCRIPTION OF RIVER

The St. Marys River is the connecting waterway between Lake Superior and Lake Huron (Figure 1). The upper portion of the river extends about 24 km from Whitefish Bay to the St. Marys Rapids at Sault Ste. Marie. A series of works there, including compensating gates, shipping locks and power generating facilities, control the entire outflow of Lake Superior. The lower river, about 76 km in length, is broken into several channels and lake-like areas by three large and numerous small islands, and empties into both the North Channel and the main basin of Lake Huron. Total surface area of the river is about 732 km^2 of which 68% is in the U.S.A. and 32% in Canada. Most of the change in elevation between Lakes Superior and Huron (about 6.5 m) takes place at the St. Marys Rapids where the river drops 6.0 m over a distance of 1 km. Mean annual discharge for the river is 2,140 m^3/s (International Lake Superior Board of Control).

The limnology of the upper St. Marys River mirrors that of its source, Lake Superior. With an average spring surface temperature of 5^o C, the river is physically. suited to reproduction and development of sea lampreys, although the slow warming delays spawning until July, a month later than in other regional streams. Average levels of alkalinity, pH, and dissolved oxygen are 45 mg $CaCO_3$/1, 7.9, and 92%, respectively (International Joint Commission 1977). Superficial bottom sediments on the Canadian side are contaminated with oils, phenols, ammonia, cyanide, and heavy metals discharged in the past from industries in Sault Ste. Marie, Ontario. In the 1980s these pollutants do not appear to be limiting the distribution of ammocetes except in Lake George, which remains more contaminated because it served as a sink for industrial wastes released upstream. Otherwise, the superficial sediments in the river, which are mostly sand with mixtures of clay and silt, are not impaired as habitat for ammocetes. Ammocetes are most abundant in silt-sand mixtures, and the quantity and distribution of this substrate type are discussed later.

Spawning habitat (rocky-gravelly bottoms) for sea lampreys is located in the rapids below the compensating gates, below the power houses, and in the North Channel above Lake George. Spawning also occurs above the compensating gates along Point Louise and possibly in the channels below Lake Nicolet. A scarcity of spawning habitat below Lake George may account for the near absence of ammocetes in the East Neebish and St. Joseph Channels, which otherwise appear as suitable habitat for ammocetes. Sea lampreys also spawn in 15 streams tributary to the St. Marys. Two of these rivers, the Root and Garden (Canadian side) are major producers Of sea lamprey, some of which recruit to the mainstream.

The biota of the river is discussed later in relation to *non-target* effects of lampricide application.

HISTORY OF INVASION AND CONTROL

Sea lampreys were first observed in Lake Huron in 1932 (Smith 1972) and in the St. Marys River in 1962, when dredging operations revealed the presence of ammocetes and transformers below the Canadian lock. Exactly when the river was Colonized is not known, but the existence of transformers in 1962 indicates that substantial reproduction was underway at least by the mid-1950s, if not before. Sea lampreys were very abundant in Lake Huron by the late 1940s and actually declined in the late 1950s as they depleted their food supply. For instance, runs of spawning-phase sea lampreys in the Ocqueoc River, which flows into northwestern Lake Huron, peaked in 1949, and fell steadily thereafter, averaging less than 75% of the peak number by 1957-59 (Smith 1968).

Even though the abundance of spawning-phase sea lampreys in Lake Huron declined after the late 1950s, reproduction appears to have been adequate to saturate the tributary streams with ammocetes. Accordingly, some 96 streams were treated with lampricides from 1960-70, and this effort further reduced the abundance of parasitic and spawning-phase sea lampreys in the lake. How much the treatments reduced the adult stocks is not known. There were too few assessment barriers in the rivers to make accurate lakewide estimates, and the effects of treatment were obscured by declines caused by prey scarcity.

Control measures on the St. Marys River itself consisted of a total of 46 applications of lampricides on the Canadian side in 1972-85 to suppress sea lampreys. In all cases but one (where TFM was used) granular Bayer was applied. The total area treated was 88 hectares. Insomuch as 2,400 ha are infested with sea lamprey on the Canadian side, it appears doubtful that these treatments had any appreciable effect on sea lamprey populations. Treatments were discontinued after 1985.

POPULATION DYNAMICS

In this section we estimate the recruitment of St. Marys River sea lampreys to parasitic stocks in Lake Huron and analyze whether this recruitment is increasing. An understanding of the amount of recruitment is needed to assess potential benefits from any control activities in the river. Also, if recruitment appears to be increasing, concern for the fisheries is heightened. To address these questions we construct the size of the spawning runs in the river from 1964-86, develop a hypothesis that establishes our version of the dynamics of these sea lampreys, and estimate recent transformer production. A number of information gaps and sketchy data (identified where appropriate) causes us to acknowledge that our conclusions are approximations subject to large error.

Spawners

Abundance of spawning-phase sea lampreys in the St. Marys River appears to be edging upward in recent years after a period of' decline lasting from 1967 to the late 1970s (Figure 2). This time series was constructed by bridging between mark and recapture estimates made in 1985-86, trap catches made in 1976-86, and trawl catches of parasitic-phase sea lamprey made in the fall during 1963-81 (Appendix I). Figure 2 indicates that peak abundance of 90,000 spawners was reached in 1966-67, but it may have occurred earlier before sampling began. Insomuch as sea lampreys are not known to home, the spawning stock in the St. Marys would have its genesis from the St. Marys as well as from other regional streams. The available pool of spawners in the lake was declining in the late 1960s and early 1970s, because the first round of stream treatments WAS drying-up the supply of transformers. Also, those transformers that escaped treatment or that originated from untreated sources such as the St. Marys River faced a marginal supply of prey resulting in low growth rates (Heinrich et al. 1980) and presumably low survival.

After reaching a low of approximately 10,000 spawners in the late 1970s, the St. Marys River spawning runs appear to be increasing very gradually (the high catch in 1982 is an anomaly), averaging 20,000 individuals in 1985-86. This upswing is mirrored by the number of sea lampreys recovered by commercial fisheries in the Canadian waters of northern Lake Huron. Recoveries from large mesh fisheries averaged 328 in 1980-83, but increased to 955 in 1984-85, a three-fold increase (personal communication, Robert Payne, Ontario Ministry of Natural Resources, Owen Sound, Ontario). A similar increase was also reported for small mesh fisheries operating in the same area.

Our scenario on numbers of spawning sea lamprey in the St. Marys River suggests that, because spawning habitat is relatively restricted in the river, ammocete numbers may be unchanged in recent years even though the pool of spawners in northern Lake Huron is increasing. Thus, a substantial excess of spawners may also have existed in the past. Production of sea lampreys from the river appears to be limited by spawning habitat with the size of spawning runs reflecting some fraction of the overall pool of spawners in northern Lake Huron. The contribution of the St. Marys River to this pool is a function of abiotic factors that determine ammocete transformation rates in the river. Enough years have passed to allow ammocetes time to reach an upper limit.

As noted earlier, spawners must have been abundant in the river at least by the mid-1950s, and over 30 years seems like too long a period, even if growth is slow and age at transformation is high, for continuing increases in ammocete abundance. For example, only 12 years elapsed between the first observed spawning and the peak of spawner abundance in the Ocqueoc River (Applegate 1950).

Transformer Production

We estimate the annual production of sea lamprey transformers from the St. Marys River two ways. The first approach is empirical and is based on CPUEs of ammocetes during applications of Bayer 73 to survey plots on the river bottom. Transformer production is calculated by projecting the ratio of transformers to ammocetes in these collections onto an estimate of total ammocetes. Ammocete numbers are determined by multiplying the total area inhabited by ammocetes times average CPUEs after they are converted to density. This method yields an estimate of 44,000 transformers. In the second method transformer production is calculated from a model, which starts with estimates of the 1985-86 egg deposition and reconstructs the age distribution and transformation schedule of the population. The model gives a range of production of 25,000~85,000 transformers. Both methods are discussed below.

Two key requirements for estimating ammocete numbers empirically are a method for converting CPUES to ammocete density and an estimate of the area of ammocete habitat. CPUEs are the number of sea lamprey ammocetes recovered from the water surface per searcher hour following applications Of a ottom toxicant to survey plots. During 1983-86, 509 surveys were conducted on plots of 0.02-5.40 ha; total area surveyed was 160 ha. Since only a small fraction of the ammocetes in the survey plots swim to the surface, and not all of these can be recovered, CPUEs must be adjusted to quantify ammocete density. We developed a regression between ammocete CPUE and density from 28 mark and recapture assessments conducted by the Canadian agent in various sections of the river. American brook lamprey Lampetra appendix ammocetes were used as a surrogate for sea lampreys in the assessments except in four instances, when sea lampreys were also released. The following regression was used to convert CPUEs (N = 509) to ammocete density:

$$\text{nat.log ammocete density (No./ha)} = 2.8491 + 0.8714\ \text{Depth (m)} + 1.1488\ \text{nat.log CPUE (larvae/h)}$$

To determine the amount of habitat suitable for sea lamprey ammocetes in the St. Marys River, a map of the superficial bottom sediments was constructed (Appendix II). Bottom-type data (sand, silt, clay, gravel and mixtures) from benthic studies conducted by the sea lamprey control agents and Schloesser and Hiltunen (1986) were plotted on a map of the river, and areas of similar habitat were enclosed. Areas for five major habitat types were calculated for each of 14 divisions (zones) of the river (Table 1). Substrate types were lacking for extensive areas of the lower river, but ammocetes are not known to occur there, and accordingly, this deficiency is not important, Of the five habitat types, only the areas of sand and sand-silt mixtures (6,698 ha) were used in estimating ammocete numbers.

A total of 6.8×10^6 ammocetes was estimated to inhabit the St. Marys River. This number does not include the smaller size classes not readily captured in the surveys. The total was calculated by summing the products of average ammocete density from the regression and area o_ suitable habitat in each zone (Table 2). An empirically derived multiplier of 6.45×10^{-5}, the ratio of transformers to ammocetes in the surveys was then used to project annual transformer production (44,000).

Our estimates of transformer production are critical in determining the contribution of the St. Marys River to the parasitic population of sea lampreys in northern Lake Huron. Transformers are often difficult to locate in stream surveys because their distribution is patchy and their preference for habitat may not parallel that of ammocetes. Consequently, our empirically-based estimate of transformer production may be low because of sampling constraints.

The modelling approach (second method) for estimating transformer production is briefly discussed here and covered in more detail in Appendix III. Requirements for this method are typical of population models with estimates of fecundity, survival, growth, and transformation rate (analogous to fishing rate) being key parameters. From estimates of spawner numbers (Figure 2), sex ratio, mean length of females, and fecundity, egg deposition is estimated for 1985-86. Values of egg to fry survival (1-3%) used by Spangler and Jacobson (1985) are employed in the model. A length-frequency (Figure 3) of ammocetes and a Bertalanffy growth model are used to estimate age distribution (Figure 4) and mortality rate (slope of the right limb of the age distribution). Transformation rate is calculated from a survival model that assumes that increases in mortality after a length of 116 mm are due to outmigration of transformers. Growth and survival models were fitted to estimate transformer output. The best fit predicted 25,000-85,000 transformers, a first age at transformation of 7.9 years, and a transformation rate for ammocetes longer than 116 mm of 5.0% per year.

Values of transformer production are similar for the empirical (CPUE) and modelling methods (44,000 versus 25,000-85,000). The actual length frequency of ammocetes exceeding 116 mm suggests that 8.3% transform each year, which compares favorably with the 5.0% transformation rate generated by the model. These rates are in line with values for cold water populations. Purvis (1980) reported low transformation rates for the Big Garlic River (1%), Deadhorse Creek (4%), Marblehead Creek (4%), and

Hog Island Creek (0.2%). Rates were higher in fast growing populations, e.g. the Little Garlic (16%) and Potato Rivers (34%). All of these rates are for newly reestablished populations *following* control measures? and they may not be directly comparable to the St. Marys River where the untreated population would tend towards equilibrium.

DAMAGE ASSESSMENT

Sea lampreys from the St. Marys River comprise some fraction of the parasitic stock in the lakes, and likewise account for some proportion of the associated damage on prey fish stocks. Our approach will be to estimate damage for the total number of adult lampreys in northern Lake Huron. The damage caused by sea lampreys from the St. Marys River will follow as a simple proportion based on the ratio Of St. Marys to total sea lampreys. We assume that the feeding range of sea lampreys from the St. Marys River is restricted to northern Lake Huron, including the North Channel, and encompassing statistical districts MH-1, OH-l, and NC-l-3 (Figure 5).

The geographical bounds to the damage estimate are important because the value of fish destroyed by sea lamprey is a function of prey availability and for sport species of angler demand, which varies with location. Thus, whitefish are very important in a damage estimate in northern Lake Huron because large salmonines are relatively scarce in these waters. In central and southern Lake Huron we believe that the abundant stocks of Pacific salmon and lake trout would deflect sea lamprey predation away from whitefish. Actual feeding activity of St. Marys River sea lampreys outside of the northern area will not affect the damage estimate unless substantial numbers move far enough to gain access to different fish communities.

We can't conclusively say that large numbers of sea lampreys from the St. Marys River do not feed far from northern Lake Huron. However, the available data indicate that restricted movements are a reasonable assumption. Heinrich et al. (1985) found differences in size between parasitic-phase sea lamprey captured in north and south sections of statistical district MH-1. They also found that sea lampreys tagged in the north part of the district were more likely to spawn in northern streams, and that those tagged in the south tended to spawn in southern streams. These differences do not suggest a mass mixing of sea lampreys from different regions of the lake. Moore et al. (1974) also reported that most recoveries of tagged, adult sea lampreys were made in those areas of the lake where tagging occurred. Some tagged animals do move substantial distances (from lake to lake), but these movements are not the rule and they need not be accounted for in this analysis.

J. Heinrich (personal communication, USFWS, Marquette, Michigan) made a rough estimate of the numbers of spawning-phase sea lamprey in northern Lake Huron for this report. Not knowning the survivorship between parasitic and spawning-phase sea lampreys, but assuming that it is very high, his figure of 248,000 is the best available estimate of parasitic-phase sea lamprey in northern Lake Huron. Heinrich developed a regression between stream discharge and abundance of spawning-phase sea lampreys from mark and recapture studies in four northern Lake Huron streams in 1986. The regression was then used to estimate spawning runs in the other 31 streams where only discharge was known. Slope of the regression was 46 sea lampreys per cfs (the St. Marys River because of its size was excluded from the regression), Although 248,000 is a rough estimate, it is nearly identical to Heinrich et al. (1985) estimate of 250,000 from a marking study of parasitic-phase sea lamprey in northern Lake Huron made in 1981. Both estimates are admittedly very coarse. Nevertheless, the true number must be large as

Table 1. Areas of six substrate types for 14 zones of the St. Marys River (% within each zone in parenthesis);

		Area of Each Substrate Type (ha)					
Zone	Total Area (ha)	Clay	Silt and Silt-Detritus Mixtures	Sand and Sand-Silt Mixtures	Gravel and Sand-Gravel Mixtures	Stone and Rock	Unknown
1	8,726	632 (7.25)	0 (0)	4,381 (50.21)	3,713 (42.55)	0 (0)	0 (0)
2	2,096	0 (0)	132 (6.30)	1,453 (69.33)	300 (14.29)	211 (10.08)	0 (0)
3	637	411 (22.22)	16 (2.47)	346 (54.32)	0 (0)	134 (20.99)	0 (0)
4	4,387	2,310 (52.65)	0 (0)	1,745 (39.77)	41 (0.95)	291 (6.63)	0 (0)
5	1,057	498 (47.15)	0 (0)	473 (44.72)	0 (0)	86 (8.13)	0 (0)
6	1,342	0 (0)	0 (0)	a92 (66.46)	0 (0)	450 (33.54)	0 (0)
7	12,248	9,246 (75.49)	910 (7.43)	2,092 (17.08)	0 (0)	0 (0)	0 (0)
a	6,823	5,823 (85.34)	0 (0)	0 (0)	0 (0)	0 (0)	1,000 (14.66)
9	20,927	3,108 (14.85)	0 (0)	0 (0)	94 (0.45)	0 (0)	17,725 (84.7)
10	537	0 (0)	0 (0)	446 (83.05)	73 (13.56)	18 (3.39)	0 (0)
11	905	52 (5.77)	131 (14.42)	722 (79.81)	0 (0)	0 (0)	0 (0)
12	7,920	3,416 (43.13)	1,637 (20.67)	2,839 (35.84)	0 (0)	0 (0)	0 (0)
13	2,911	98 (3.37)	384 (13.19)	429 (14.72)	0 (0)	36 (1.23)	1,964 (67.45)
14	4,478	0 (0)	79 (1.76)	185 (4.13)	0 (0)	8 (0.18)	4,206 (93.93)
Total	74,994	25,324 (33.77)	3,289 (4.39)	16,003 (21.34)	4,225 (5.63)	1,262 (1.68)	24,895 (33.20)

Table 2. Average number of sea lamprey larvae by zone (ammocetes plus transformers) for U.S. and Canadian waters of the St. Marys River during 1983-86.

Zone	U.S.			Canada			Combined		
	Habitat (ha)	No. per ha	No.	Habitat (ha)	No. per ha	No.	Habitat (ha)	No. per ha	Total No.
1	74*	215	15,910	42*	215	9,030	116	215	24,940
2	735	47	34,766	718	310	222,580	1,453	177	257,346
3	137	424	58,080	209	3,248	678,832	346	1,960	736,912
4	1,745	1,548	2,700,736	0	0	0	1,745	1,548	2,700,736
5	473	73	34,548	0	0	0	473	73	34,548
6	482	1,362	656,715	401	102	40,902	892	782	697,617
7	90*	46	4,095	60*	35	2,100	150*	41	6,195
10	182	6,746	1,227,772	264	1,530	403,920	446	3,659	1,631,692
11	279	545.5	152,195	443	1,118	495,274	722	897	647,469
12	110*	41	4,466	180*	322	57,960	290*	215	62,426
13	0*			65*	11	715	65*	11	715
Total	4,307		4,889,283	2,382		1,911,313	6,698	1,015	6,800,596

*Restricted to areas actually inhabited by larvae.

the sum of the individual mark and recature estimates for just five streams (four streams used in the regression plus the St. Marys River) was 86,800 or 35% of the total estimate.

We employ an estimation scheme developed by J. Koonce (Case Western Reserve University) to calculate the damage caused by 248,000 sea lampreys feeding in northern Lake Huron (Appendix IV). This scheme is adapted from models that assume sea lamprey attacks follow a multiple species disk equation (Spangler and Jacobson 1985; Koonce et al. 1982). Key parameters used in the model are given in Table 3. Initially, we considered four prey species (chinook salmon, lake trout, whitefish, and chubs), but sea lamprey marking rates generated by the model were too high, particularly on whitefish, in comparison to actual data. This anomaly suggested that our estimate of sea lampreys was too high, our estimates of prey numbers were too low, or that we were erroneously excluding other important prey species. The latter seemed like the most reasonable cause because burbot, a species that suffered severe depletion when sea lampreys invaded the upper lakes (Smith 1968), have recovered in Lake Huron to a point where they could significantly influence sea lamprey prey selection. Accordingly, they were included in the analysis.

Table 3. Mean length, mean weight, value, stock size, probability of surviving a sea lamprey attack, and habitat overlap for five species of fish in northern Lake Huron (see text for sources).

Species	Mean length (mm)	Mean weight (g)	Comm. value ($/lb)	Angler value ($/ind.)	Stock size x 10^3	Attack survival	Habitat overlap
Chubs	284	192	0.90	-	11,300	0.00	1.0
Whitefish	487	1,120	0.53	-	2,800	0.10	0.5
Lake trout	497	1,200	0.51	12.96	69	0.25	1.0
Chinook	838	6,620	-	12.96	180	0.25	0.4
Burbot	533	1,660	0	0	1,000	0.00	1.0

A brief review of how standing stocks of the five prey species were determined follows. Numbers of chubs in MH-1 that were longer than 250 mm were obtained from R. Argyle (USFWS, NFC-GL, Ann Arbor, Michigan). Rate of exploitation was then calculated from landings for MH-1, and this rate was also applied to Canadian landings to estimate the number of chubs in Canadian waters. Whitefish numbers were calculated from 1985 catch and rate of exploitation estimates provided by the Technical Fisheries Review Committee (1985, 1986) and R. Payne (Ontario Ministry of Natural Resources, Owen Sound, Ontario). The Technical Fisheries Review Committee (1985, 1986) estimated the standing stock of lake trout at the beginning of 1985 in MH-1, the only area currently stocked with lake trout in northern Lake Huron. Chinook salmon numbers were determined by considering that combined catch and escapement (harvest weir) at Rogers City (located at the southern edge of MH-1) in 1986 represented the bulk of the stock in northern waters after predation by sea lampreys. Catch (19,000) and escapement (44,000) totaled 63,000 chinook at Rogers City (D. Nelson, Michigan Department of Natural Resources, Lansing, Michigan). This figure was adjusted upwards to approximately 100,000 to account for catch and escapement in other areas. The number of chinook in the stock before losses to sea lamprey occur was determined by iterations of our prey selection model. R. Argyle (USFWS, NFC-GL, Ann Arbor, Michigan) provided a coarse estimate of average burbot abundance in MH-1 during 1985-86. We doubled this number to account for burbot in Canadian waters.

Values of commercial species were obtained from records of the treaty fishery in Michigan's waters of northern Lake Huron. Sport value for chinook was estimated from the slope of the relation between stock and effort at Rogers City in 1985-86. This relation indicated that an increase in stock size of 36,000 fish (catch and escapement in 1986 less catch and escapement in 1985) resulted in an increased effort of 13,000 angler days. Therefore, each additional chinook produced 0.355 days of angling effort. We valued angling at $36.50 per day, the average expenditure for all Great Lakes angling (D. Talhelm, GLFC research completion report) Therefore, each chinook is worth $12.96. Lake trout were assumed to have the same angling value as chinook.

In addition to the numbers of each prey species and their mean size, the multiple species disk equation requires values for the probability that each species has of surviving sea lamprey attack and the amount of habitat overlap among the species. Koonce estimated that the survival probability for lake trout in Lake Ontario was 0.25, and we use this value for lake trout and for want of a better value for chinook salmon. Whitefish were assumed to be less resistant than lake trout and were given a value of 0.1. Chubs and burbot were given values of 0.0. Therefore, in the model the only sea lamprey marks produced on chubs and burbot are from ongoing attacks. Burbot are largely ignored in stock assessment in the Great Lakes so that it is difficult to make even educated guesses about their abundance and vulnerability to sea lamprey. On the other hand, we feel more confident that few chubs survive sea lamprey attack during the late summer to late fall period, when parasitic-phase sea lampreys reach their maximum size. Our analysis is restricted to this time interval, which amounts to 0.4 year.

Habitat overlap is a function of how much the distribution of each prey species overlaps the distribution of lake trout. We assume that chubs and burbot have complete overlap with lake trout, but that the overlap between whitefish and lake trout is 0.5 and overlap between chinook and lake trout is 0.4, These values are obviously subjective; marking data are given in Table 4 for comparison. Whitefish marking rates are always lower than rates for lake trout in mixed species assessments. Marking rates on chinooks and lake trout in Lake Huron are high, but the chinooks begin entering streams in September, and the larger, mature fish are absent from the lake in late fall, when sea lampreys are making their largest gains in weight. For instance, at the Swan River harvest weir near Rogers City, the chinook run began on 8 September 1986, peaked on 24 September, and was essentially over by 29 October (M. Schouder, Michigan Department of Natural Resources, Gaylord, Michigan).

Table 4. Sea lamprey marking rates (marks per 100 fish) on chubs, whitefish, lake trout, and chinook salmon in northern Lake Huron (year observed in parenthesis).

Species	US. waters (MH-1)	Canadian waters Main basin (OH-1)	Canadian waters North Channel
Chubs	1-7 (1984)	1-3 (1986)	20 (1986)
Whitefish	6 (1985)	2 (1985)	o-a (1985)
Lake trout	10-23 (1986)		
Chinook	15-30 (1986)	40-44 (1986)[1]	

1 From the St. Marys River.

Size is also a major determinant of prey selection in our model (Spangler and Jacobson 1985), which contains a relation between prey size and predator selection.

Larger prey are favored. Thus, attack rates per lamprey on each prey species are a function of prey size, prey abundance, and habitat overlap. Deaths in turn are a function of survival probability and predator abundance. Total deaths, marking rates, and value are final outputs of the model.

Key features of the prey selection model were compressed into a spreadsheet format so that iterations could be done quickly. Our values for habitat overlap and survival probability were determined in part from a series of iterations which allowed us to see the consequences (marking rates and deaths) of various levels Of habitat overlap and survival probability.

Our estimate of total damage caused by 248,000 parasitic-phase sea lampreys in northern Lake Huron is $2.6 million per year (Table 5), which in the aggregate amounts to 70% of the total value of the catch of the four species of concern (chubs, whitefish, lake trout, and chinook). Damage to chinook is highest at $1 million, but the whitefish loss is nearly as great-$950,000. Next in value are lake trout at $367,000 and chubs at $256,000. Burbot are considered worthless in terms of catch. Our damage estimate is admittedly coarse, but it is the best that can be made with the available data. Obviously, better assessments are needed on burbot, and more marking data on chubs and whitefish are also required. Overall, we suspect that we may have underestimated the damage to chubs, which are the most abundant prey fish.

Table 5. Estimates of sea lamprey attack rate, number of prey killed, marking rate, and damage (value lost) for five species of fish in northern Lake Huron preyed upon by 248,008 *sea* lampreys.

Species	Number (000's)	Attack rate	Thousands killed	Marks per 100 fish	Damage ($)
Chubs	11,300	0.06	674	0.6	256,000
Whitefish	2,800	0.33	725	6.1	947,000
Lake trout	69	0.71	28	22.6	367,004
Chinook	180	0.76	78	24.3	1,013,000
Burbot	1,000	‘0.84	570	7.9	0
					2,583,000

Assuming a transformer to parasitic phase survival rate of 66.3%, the same rate used for ammocetes, we estimate that the 50,000 transformers (average of our two estimates) produced by the St. Marys River result in 33,000 adult sea lamprey in northern Lake Huron. Therefore, we estimate that 13.3% (33,000 divided by 248,000) of the total damage or $344,000 per year is attributable to the St. Marys River.

CONTROL OPTIONS

TFM applications to streams are the mainstay of the sea lamprey control program in the Great Lakes, but barrier dams, bottom toxicants, and trapping and removal also serve as control measures. In addition, research on a sterile male approach (Hansen and Manion 1980) has progressed to a point where it could be implemented on the St. Marys River, if permits for the sterilant can be obtained from FDA. New bottom toxicants formulated from TFM rather than Bayer 73 are also in an advanced stage of research. We discuss the potential of these measures for controlling sea lamprey in the St. Marys River.

Barrier Dam

A barrier dam constructed to deny spawning-phase sea lamprey access to their spawning habitat is obviously out of the question for the St. Marys River. But, dams on the 15 sea lamprey producing tributaries to the St. Marys River could eliminate these streams as sources of larvae. These tributaries are routinely treated with TFM, but between treatments reinfestation occurs allowing emigration of larvae to the St. Marys River. However, the distribution of larvae in the St. Marys suggests that most larvae originate from spawning in the river, and thus barrier dams on the tributaries would have little impact on the sea lamprey population.

Sterile Male Release

Another GLFC task force is evaluating the St. Marys River as a potential additional site for release of sterilized male sea lamprey. Several factors favor the St. Marys River as a site: 1) release of sterile males would reduce the reproductive potential of sea lampreys in the St. Marys River, contributing to control in a very difficult situation; 2) the St. Marys River is centrally located and will be relatively close to whatever site is chosen for a sterilization facility; 3) an effective trapping program is already in place; and 4) because of the late timing of the spawning run in the St. Marys River, males trapped there could not be used elsewhere in the sterile male release program. Use of sterile males in the St. Marys River would probably not be as a demonstration project since the river is not a closed system (discrete stock). As a control option, sterile male release would probably be available only when permission to release sterile males has been granted and a demonstration project is concurrently underway.

The strategy for use of sterile males in the St. Marys River may have to be slightly different than in other areas in that all males to be sterilized may have to be trapped from the river. Because of the late timing of the spawning run in the river, we are not certain if males imported from other areas in the Great Lakes will compete successfully for nests and females. If importing males is desired, studies should be conducted to investigate this possibility. Availability of males from outside the St. Marys River will also depend on the need for sterile males at other sites.

The upper limit to the reduction of reproductive potential of sea lampreys through sterile male release in the St. Marys River may be dependent on trapping efficiency. The higher the trapping efficiency, the larger the number of females removed from the population and the larger the number of sterile males released into the population. Females removed from the population are a direct loss to reproductive potential. Assuming that sterile males are fully competitive in spawning with the remaining females, there is a further loss of reproductive potential equal to the proportion of sterile males. Trapping efficiency was 47% in 1985 and 31% in 1986. If all females were destroyed and all males sterilized and released, these trapping efficiencies would result in reductions of reproductive potential of 72% and 52%, respectively (Figure 6). If additional sterilized males are imported from other areas, further reductions are possible. Assuming for the time that we do not have that option, the possibility of increasing trapping efficiency should be explored in anticipation of sterile male releases in the river.

The effect of sterile male release on the production of transformers from the St. Marys River will also depend on two factors we may not be able to address adequately at this time. First, the effects of density on ammocete growth or survival are not well known. Because of that uncertainty, it is not clear that a reduction in reproductive potential would result in a proportional reduction in the number of transformers produced. If ammocete survival and growth are *not* independent of density, we cannot make accurate predictions of the magnitude and timing of effects from sterile male releases. Determining those relationships for the St. Marys River will probably not be possible. Second, it is also not clear how many of the spawning-phase sea lamprey running the St. Marys River in a typical year are from ammocete populations outside the river system. Although the presence of strays does not affect the size of the reduction in reproductive potential that can be attained each year, the number of spawners from outside the system will ultimately limit how far the production of ammocetes can be depressed. With annual releases of sterile males, the size of the spawning run would approach a lower limit slightly above the typical number of spawners from other sources.

Sterile male release needs to be part of a larger control strategy. The age at transformation in the St. Marys appears to be high and a large number of year classes may already be present. If other control methods were not used to reduce the size of existing year classes, continued transformation could make it 5 or more years after sterile male releases began before any decrease in the production of parasitic-phase sea lampreys could be expected. While we do not know whether ammocete survival at current population levels in the St. Marys is independent of density, reducing the ammocete population may favor success of the sterile male technique. The probability that reductions in reproductive potential will result in proportional reductions in the ammocete population increases as larval density is lowered.

The largest cost of sterile male release will be in the start-up of the project. These costs were estimated at over $300,000 by the Sterile Male Release Task Force. Assuming that facilities and equipment will have already been purchased in conjunction with a demonstration project, the cost of concurrent sterile male releases in the St. Marys River should be about $25,000 per year. The expected trap catch is 5,000 to 8,000. With 60% males there would be a total of 3,000 to 4,800 males to be transported to the sterilization site, sterilized, and returned to the river over a six to eight-week period. This would require three workers for about two months. Sorting and holding male lampreys at the traps should not add greatly to manpower requirements. Transportation costs would be approximately $1,000 and chemicals and supplies $1,000. Modest increases in the number of male sea lampreys handled due to increases in trapping efficiency should not increase costs appreciably.

Manpower (3 workers for 2 months or 0.5 FTE's)	$23,000
Transportation	1,000
Materials	1,000
Total	$25,000

Trapping and Attractants/Repellents

Trapping by itself may have some value as a control technique. Judging from the recovery rates of marked sea lampreys in 1985 and 1986 (47% and 31%), a third to a half of the spawning run was removed. Alone, trapping reduces reproductive potential by the proportion removed (Figure 6). Because of the uncertainty in whether production of transformers is proportional to reproductive potential, we do not know what effect removal of a given proportion of the run would have. However, it is certain that the higher the proportion removed, the greater the likelihood of an effect. As also stated relative to sterile male release, increased trapping efficiency is desirable.

Increasing trapping efficiency may not be as simple as adding more traps. Two traps added on the U.S. side in 1986 contributed a negligible portion of the catch. This implies that the task will be to find or create other effective sites in addition to increasing effort at existing sites.

Attractants or repellents could theoretically be used to increase efficiency, but none (except strong electric fields) have been consistently effective. Lighting of the traps increased the catch on the Cheboygan River (Purvis et al. 1985). However, attempts to use lights on traps at other locations have been generally unsuccessful. In 1986 researchers investigated the possibility that migrating spawning-phase sea lamprey might be attracted to odors given off by others already in the act of spawning. Spawning sea lampreys were taken off their nests in the Ocqueoc River and placed in the upper half of one of two experimental traps in the St. Marys River. The spawners were moved between the two traps weekly. The presence of spawners did not appear to increase catch over that in the empty trap. Research will continue, but attractants and repellents do not appear to be a viable option at this time.

Bottom Treatments

Assuming that chemical treatment will be a part of the control strategy for the St. Marys River, known areas of high ammocete density could be treated on a spatially limited basis with formulations releasing toxicant only near the bottom. This could be done either as an alternative to or, more likely, in conjunction with other approaches such as conventional TFM treatment or the release of sterile males. The feasibility of spot treatments rests on the effectiveness of the bottom-release formulations available, the size of the area which would need to be treated, spatial definition of that area, procurement of permits, environmental considerations, and cost.

The effectiveness of bottom-release formulations will undoubtedly vary with location in the St. Marys River. Under static laboratory conditions, bottom-release formulations of both TFM and Bayer 73 perform well. Bayer 73 has also proved effective in a number of field studies in lake and delta situations, producing 80% or greater mortality of caged ammocetes if 100 lbs. or more per acre of the 5% formulation were used. A bottom-release formulation of TFM under development at the Hammond Bay Biological Station has so far failed to produce reliable results under field conditions, although some tests have been promising. Observations made while testing bottom-release formulations of both TFM and Bayer 73 in Hammond Bay suggest that current and turbulence can substantially reduce their effectiveness. Observations on caged ammocetes treated in the St. Marys River with granular Bayer 73 also suggest a fairly wide range of effectiveness (3-75% during 1975-1977) depending on cage location. Ho and Gloss (1987) reported that concentrations of Bayer 73 varied by an order of magnitude during a treatment of Seneca Lake, New York. Before any largescale use of bottom-release formulations is considered, better understanding of the effect of current and turbulence on their performance is advised.

The areas to be treated on a spot basis could be limited to some extent based on surveys of larval density. If the distribution of ammocetes in the river is patchy enough, a small proportion of the total area infested may contain a relatively large proportion of the ammocete population. This concept deserves further development, particularly in terms of how much area would need to be treated to achieve an acceptable level of control. Furthermore, if the areas of higher density could be well enough defined, there could be a substantial reduction in chemical use by treating only the higher-density areas. The large-scale distribution of larvae in the river is generally well known, as discussed elsewhere in this report. In some sections, however, more small-scale sampling needs to be done to adequately define areas of higher density. Because of the cost of bottom-release formulations, it will probably be cost effective to do additional sampling to better define high density areas before attempting spot treatments. The areas which would be candidates for spot treatment will also depend on the specific mix of control measures in the treatment strategy.

Use of spot treatments will be at least partly dependent on securing the proper labels or permits to treat with a bottom-release formulation. Granular Bayer 73 could probably be used for spot treatments in Canadian waters of the St. Marys at 100 lb/acre under existing policy, but in U.S. waters the limit is 100 lb/acre for survey purposes only. To use granular Bayer 73 for treatment in the U.S. would require a new label permitting use for treatment or an experimental use permit. One other possibility is a state permit under section 24(c) of FIFRA, as was obtained by the New York Department of Environmental Conservation to treat two areas in Seneca Lake with granular Bayer 73 in 1982 and 1986. At present there is no label for the bottom-release formulation of TFM nor is one being sought.

Environmentally, spot treatments would have both positive and negative aspects. On the negative side there is a loss of selectivity inherent in the use of a bottom-release toxicant. Because bottom-release formulations must maintain a lethal concentration for some distance from each pellet or granule, concentrations near each pellet will be considerably higher than the LC 99.9 for sea lamprey. This would result in a higher loss of sensitive species of non-target benthic organisms in the treated area than with a conventional TFM treatment. One notable exception is Hexagenia limbata, a species of some concern in the St. Marys, which would suffer much lower losses if granular Bayer 73 were used. On the positive side, organisms higher in the water column would probably suffer lower losses. Any loss of selectivity may also be a reasonable tradeoff if a small enough portion of the river system were treated, perhaps killing a smaller total number of non-target organisms and leaving those in the remaining area for recolonization. Use of bottom-release toxicants would probably also reduce the total amount of chemical used.

Cost will be a factor in determining how spot treatments are incorporated into a control strategy. The current price for granular Bayer 73 is $2.45/lb. An experimental 2,500 lb batch of TFM pellets was recently produced for $3.10/lb, but if ordered in larger quantities, it would probably be similar in price to granular Bayer 73. Using $2.50/lb as an approximate cost for bottom-release formulations, chemical costs would be $250/acre if applied at 100 lb/acre and $500/acre at 200 lb/acre. These figures do not include the cost of application.

Application from small boats would be extremely labor intensive and not likely to be cost effective. Based on the experience of crews treating smaller test plots, a crew of four could treat approximately 25 acres per day. Treating a 100-acre plot would require a four-man crew for a week and the cost (including per diem and salaries) would be about $30 per acre. In comparison, the New York Department of Environmental Conservation contracted with an aerial applicator or "cropduster" to apply 100 lb/acre of granular Bayer over a 102-acre plot for $3,060. This required the assistance of two NYDEC personnel in boats to set buoys. The 100-acre plot required about three hours, suggesting that over 200 acres could be treated per day at a slightly higher cost of about $33 per acre (including salary and per diem for two workers), but with a much lower manpower commitment. This estimate could be high since the price per acre would be expected to decline with the size of the contract.

Assuming that application would be by airplane, the overall cost per acre would be about $280 if a bottom toxicant were applied at 100 lb/acre and between $530 and $555 if applied at 200 lb/acre.

Conventional Treatment

We are not certain that a conventional lampricide treatment of the St. Marys River with TFM or the TFM-Bayer mixture is feasible or whether it would be effective. Treatment strategies are usually predicated on flow studies and bioassays, which have not been conducted on the St. Marys River. However, for purposes of this report we speculate on how a treatment of the river would be conducted, what it might cost, and how effective it might be. For want of any data to the contrary, we assume optimal distribution of the chemical bank and complete mortality of larvae in zones targeted for treatment. Obviously, these are ideal events so in effect our estimate of cost is the minimum possible while effectiveness is overstated.

The logical application point for lampricides would be at the lock, power house, and compensating gate structures. These structures would ease the logistics of delivering a tremendous volume of lampricide. However, it may prove to be extremely difficult to pump lampricides from the compensating gates, which provide very little working space, so barges or other vessels may be needed. Ammocete density is greatest from immediately below the rapids to and including upper Lake George and Lake Nicolet so application above the rapids is critical for an effective treatment. We assume that the chemical bank would not have to be boosted in Lake Nicolet. If such a boost were needed, treatment costs would be much higher than estimated here.

Straight TFM rather than the TFM-Bayer mixture would probably be most economical to deliver. The mixture is most suited to harder water streams where the savings in chemical can be substantial. Static bioassays conducted with soft water (alkalinity 45 ppm) at Hammond Bay Biological Station indicated a minimum lethal concentration (99.9% mortality of sea lamprey) of 1.0 ppm (Figure 7). Addition of Bayer 73 could lower the MLC by about 30% but the increase in labor costs and complexity of the treatment incurred by applying two lampricides would not warrant the use of Bayer 73. Also, Bayer 73 tends to be less effective in areas of clay substrate, which is common in the St. Marys River.

As indicated earlier, the flow of the St. Marys River is regulated and fluctuates greatly (daily) with peak power demands. However, by treaty the minimum flow is not to fall below 1,570 m^3/sec (55,000 cfs). In 1986 flows were as high as 3,620 m^4 /sec and as low as the treaty minimum (Environment Canada, Inland Waters Directorate). Without flow studies indicating otherwise, it seems economical to apply at the treaty minimum flow. A higher flow increases the amount of chemical required, a much lower flow would cause problems in maintaining adequate dispersal of the chemical, and because of the frequent occurrence of flows at the treaty minimum, ammocetes would not inhabit the river bottom above the elevation associated with the treaty minimum. An agreement between the IJC and the GLFC would be needed to provide a constant, set flow for a treatment of the St. *Marys* River.

To maintain MLC through Lake Nicolet, which contains 40% of the river's ammocete population (Table 2), the application concentration of TFM must be higher than the LMC of 1.0 ppm. We estimate that the application concentration would be 1.5 ppm to achieve LMC in Lake Nicolet and that this concentration would have to be maintained for 16 hours. At a flow of 55,000 Cfs, 135,700 kg of TFM (active ingredient) costing $2.8 million would be required for the treatment scenario identified here. This amount is approximately equal to all the TFM used in the Great Lakes basin over a 2-year period. By way of comparison, the largest Stream ever treated with lampricides was the lower Nipigon River, which had a flow of 2,382 cfs. It required 6,200 kg of TFM.

In addition to treating the mainstream, the 15 tributaries to the St. Marys River would also require treatments in their lower reaches to toxify their estuaries. Otherwise, these estuaries would serve as refugia for ammocetes. The combined flow of the 15 tributaries is only 15 m^3/sec so the additional requirement for TFM is insignificant in comparison to that needed for the mainstream. Little Lake George may require treatment with bottom toxicants but more sampling is required to make a determination.

The Canadian control agent estimates that a complete TFM treatment as outlined here could be accomplished in one month with both agents fully engaged in the effort *Many* technical uncertainties remain unresolved, especially with supplying TFM to the application site. TFM is purchased and transported in six-gallon cans, and the 13,600 cans required for a treatment could not be handled and emptied in a 16 hour period. Consequently, a bulk delivery (railroad car) would be needed, and the logistics of this are unknown. Preliminary calculations suggest that if the TFM could be secured in bulk at the application site, existing pumping systems could be modified to meter the chemical. Thus, major purchases of hardware may not be required for a treatment.

We provide an indication of personnel costs for a treatment of the St. Marys River by prorating treatment schedule time onto total annual costs for both agents. Treatments are conducted approximately 6 months each year so if all available crews work for 1 month on the St. Marys River, this is equivalent to 2 months of the entire annual control budget. This approach covers overhead and administrative costs and is more realistic than a simple summary of personnel days for those directly involved in the operation. *In* FY 1987 control costs excluding lampricides amounted to $4.9 million. Thus, our estimate of personnel costs for a treatment of the St. Marys River is $810,000 (1/6 x $4.9 million).

Our very rough estimate of total treatment costs (lampricide plus personnel costs) amounts to $3.6 million (U.S.). The annual costs are particularly important for comparison with annual estimates of damage caused by sea lampreys from this river. Earlier in our model of ammocete dynamics we estimated the age at transformation to be 7.9 years. This age suggests treatments would be needed every 8-9 years. Thus, the annual costs of treatment would be about $450,000.

As regards effectiveness of treatment, our scenario assumes complete mortality on sea lampreys in the areas targeted for control (Zones 3, 4, 5, 6, upper parts of 7 and 12, 10, and 11). Zones 1 and 2 would be left untreated. Insomuch as these untreated zones contain 4% of the river's sea lamprey population, we presume that a treatment would be 96% efficient. Naturally, actual effectiveness would be lower, but this cannot be determined without flow studies.

NONTARGET EFFECTS OF TFM APPLICATION

A conventional treatment of the St. Marys River with TFM will cause mortalities to some of the river biota besides the sea lamprey. In this section we focus mainly on sensitive invertebrate and fish species likely to be affected by a treatment and predict the extent of any impact. The effects of lampricides on nontarget organisms are summarized by Gilderhus and Johnson (1980), Schuldt and Goold (1980), Dahl and McDonald (1980), and the Associate Committee on Scientific Criteria for Environmental Quality (1985). Fortunately, the biota of the river has been well studied in recent years in connection with investigations of pollution, dredging, and extended navigation (Schloesser and Hiltunen 1985, Duffy et al. 1986, Edwards et al. 1986). As a result of these studies more information is probably available on the fauna of the St. Marys River than on the fauna of any stream on the treatment schedule.

Our estimates of nontarget effects are based on the treatment scenario described earlier, which assumes optimal distribution of TFM applied at the power houses and compensating gates for 16 h at a concentration of 1.5 ppm. Actual distribution of the chemical bank and the true MLC remain to be determined from dye studies and field bioassays, respectively. Therefore, these preliminary findings are intended only to frame the problem until a more accurate assessment is made.

In general, nontarget effects are not expected to be severe in a TFM treatment of the St. Marys as compared to other fauna-rich streams with harder water. J. Seelye, USFWS, Millersburg, Michigan, (personal communication) found that in soft water, like the St. Marys River, the lethal concentration margin between sea lamprey and common nontarget organisms is greater than in harder water. Also, treating in August will lessen nontarget mortalities. During this month some sensitive fish species are much less abundant in areas where TFM concentrations would be significant and emergence of burrowing mayflies Hexagenia limbata is past.

Macrobenthos

Of the invertebrates the benthos is of greatest concern as **regards** nontarget effects because planktonic crustaceans appear to be very resistant to TFM at field concentrations (Gilderhus and Johnson 1980). Macrobenthos are emphasized here because they are important food for fish, and a number of species found in the St. Marys River are sensitive to TFM. A list of all invertebrate species (301 taxa) found in the river is given in Appendix V.

In soft substate areas of the river, chironomid larvae and oligochaetes are dominant with each group represented by 51 taxa. Chironomids are considered to be some of the most resistant invertebrates to TFM, but oligochaetes are sensitive. Other important soft substrate groups are Ephemeroptera, Amphipoda, and Mollusca. Ephemeroptera are of particular concern because of the burrowing mayfly Hexagenia limbata, which is seasonally important in fish diets and very sensitive to TFM. Substrates within the shipping channels contain a depauperate macrobenthos, apparently because of disturbances caused by ship passage. The macrobenthos of emergent wetland habitat is much more diverse with 171 taxa represented; taxonomic composition is similar to that of soft substrate areas except for additions of Hemiptera, Odonata, and Coleoptera, which all tend to be resistant to TFM. The rapids habitat is dominated by net spinning caddisflies (Hydropsyche bifida and Cheumatopsyche), mayflies (Stenonema and Leptophlebia), crayfish Orconectes propinquus), and Hydra. Of these, only Hydra is considered sensitive to TFM.

An understanding of the macrobenthic community of the St. Marys River and the potential effects of TFM application is clearer from estimates of production of key species in Lake Nicolet and the Neebish Island Rapids (Table 6). Nontarget effects in these two areas are expected to mirror treatment impacts in other sections of the river where TFM concentrations would be significant (1.5-0.5 ppm). Sensitive taxa in Lake Nicolet (Hexagenia, Spaeriidae, and Oligochaeta) represent 15% of the inshore and 22% of the offshore macrobenthic production. None of the taxa from the Neebish Island Rapids are considered sensitive to TFM except Hydra, which is usually considered as microbenthos. Hydra densities as high as 18,000 m^{-} were reported in the Neebish Island Rapids (Schirripa 1983), and although probably not important in fish food chains, Hydra would be greatly reduced by a treatment.

The above data suggest that a TFM treatment of the St. Marys River would not severely disrupt the macrobenthos. However, some sensitive taxa are much more important than others in fish diets, and recovery times among the taxa can vary tremendously. We believe that of the sensitive macrobenthos, only Hexagenia are of major concern because of their importance as fish prey and of their 2-year life cycle,

Table 6. **Estimated** benthic invertebrate production in the emergent littoral zone and the 3 meter depth contour of Lakes George and Nicolet and **in** the Neebish Island Rapids as $mg/m^2/yr$ (Edwards et al. 1986).

TAXON	LAKE NICOLET LITTORAL	LAKE NICOLET OFFSHORE	LAKE GEORGE LITTORAL	LAKE GEORGE OFFSHORE	NEBISH ISLAND RAPIDS
Ephemeroptera					
Ameletus sp.	10		166		
Caenls sp.	1,155	80	1,284	132	
Ephemera simulians	20	114	11	199	
Ephemerella sp.	3	69	43		
Hexagenia limbata	47	762	95	6,206	
Leptophlebia sp.	1	26	222	181	3,770
Stenonema tripunctatum					2,270
Trichoptera					
Ceraclea sp.	29	3			
Cheumatopsyche sp.					3.003
Grammotaulux sp.	201				
Phryganea sp.	38			263	
Phylocentropus sp.		14	12	64	
Polycentropus sp.	280	229	97	186	
Trianodes sp.	38	38	11	38	
Other Trichoptera	53	27	39	39	
Hemiptera					
Sigara cornuta	1,368	19	43		
Odonata					
Aeshna canadensis			4,761		
Arigomphus sp.			2,633		
Enallagma boreale	127		428		
Lestes disjunctus	134				
Libellula sp.			176		
Olptera					
Chironomidae					
Ablabesmyia sp.	90	1,069	412		
Cryptochironomus sp.	537	466	331	552	
Sarsia .	596	299	488	158	
Paratanytarsus sp.	1.200		305	35	
Polyoedilum sp.	1,520	2,205	839	1,191	
Procladius sp.	1,192	1,045	594	659	
Psectrocladius sp.	155	50	274	25	
Stictochironomus sp.	452	55	95	10	
Other Chironomidae	2,923	704	2,900	280	3,330
Simulidae					
Simullam sp.	6	a			112
Amphipoda					
Hyalella azteca	2,250	2,228	812	912	
armnaru~ fasciatus	354	85	111	129	
Isopoda					
Asellus inter-media	2,777	25	645	117	
Lirceus sp.	1.008	984	306	792	
Oecapoda					
Orconectes propinquus					11,200
Gastropoda	123	237	108	406	
Pelecypoda					
Spaeriidae	144	397	53	4,347	
Oligochaeta					
Stylaria fossularis	2.045				
Other Oligochaeta	1,464	2,003	291	1,468	
. Miscellaneous taxa	2,336	563	1,800	857	
Total	24.682	14.464	20.020	18.846	23,683

which makes the recovery issue more acute. For these reSOIlS we make detailed projections of Hexagenia mortality by zone for a TFM treatment of the St. Marys River.

Table 7. Estimates of numbers of age I Hexagenia nymphs by zone before and after a TFM treatment of the St. Marys River. (See Figure 1 for location of zones)

Zone	Total area ha	Preferred habitat ha	Number before treatment	Cone. TFM (mg/l)	Number after treatment	% mortality
1	8,726	2,880	2.87 x 109	0	2.87 x 109	0
2	2,096	1,496	0.22 x 109	0	0.22 x 10^9	0
3	637	125	0.04 x 109	1.5	0.02 x 10^9	58
4	4,387	3,989	4.31 x 109	1.2	2.84 x 109	34
5	1,057	930	1.21 x 109	1.0	0.98 x 109	19
6	1,342	856	1.19 x 109	1.0	0.96 x 10^9	19
7	12,248	11,808	12.85 x 109	0.7	12.21 x 109	5
a	6,823	6,645	6.25 x 10^9	0.5	6.25 x 10^9	0
9	20,927	20,927	9.63 x 10^9	0.5	9.63 x 10^9	0
10	537	0	0	1.5	0	0
11	905	905	0.004 2.46 xx 10^9	1.5	0.002 x 109	58
	7,920	6,336		0.8	2.24 x 10^9	9
13	2,911	?	2.44 x 10^9	0.5	2.44 x 10^9	0
14	4,478	?	?	0.5		0
Total	74,994	56,897	43.47 x 10^9		40.66 x 10^9	6.5

We estimate a total loss of 6.5% of the age I Hexagenia population in zones 1-13 of the river with a TFM treatment (Table 7). Mortality would be highest (19-25%) in the mainstream from the application point to Sugar Island (Zone 3) and in Lake Nicolet (Zone 4). To make these mortality estimates unpublished bioassay results from Hammond Bay Biological Station (Figure 8) were projected onto Hexagenia standing stock estimates developed from density data (Schloesser and Hiltunen 1986) and our habitat map (Appendix II). We assumed a ratio of 60:40 to convert total nymphs into age 0 and 1 cohorts. In an August treatment age II nymphs would have already emerged and only newly hatched nymphs, averaging less than 3 mm in length, and age I nymphs, ranging from 6-28 mm in length would be present (Schloesser and Hiltunen 1984). Newly hatched, small nymphs are more resistant to TFM than larger nymphs (Bills et al. 1985), and they would probably not be significantly impacted by a treatment. Therefore, only age I nymphs are included in the mortality analysis.

Overall, the impacts of a TFM treatment on Hexagenia in the St. Marys River is nominal (6.5% of the Age I nymphs) because, excluding Lake Nicolet, Hexagenia are most abundant in zones where TFM concentrations would probably be well below lethal levels. These areas of abundance are Lake George, which would only be impacted at its upper end, Lake Munuscong, and Potagannissing Bay. Imagos (winged adults) from these unaffected areas would be expected to contribute to the recovery of affected areas. Drift from the upper river (Zone 1 and 2) might also aid in the recovery process. Thus, it does not appear that a TFM treatment in August would cause serious or long lasting damage to the Hexagenia population of the St. Marys River. This opinion is tentative, however, and field bioassays should be conducted in August with resident Hexagenia before firmer conclusions are made.

Fish

The fish community consists of at least 74 species (Appendix VI) and is highly diverse, resembling that found in boreal lakes, though more diverse owing to its connections to oligotrophic fish communities of Lakes Superior and Huron (Duffey et al. 1986). The susceptibility to TFM of fish species found in the St. Marys River can be inferred from a combination of data derived from laboratory bioassays and field studies. Differences in exposure times, TFM concentrations, water quality, temperature, stress on organisms and stage of development make it difficult to compare results of individual bioassays with conditions present during a lampricide application to the St. Marys River. We can, however, predict which organisms would most likely be affected.

Bioassay information is available for about 40% of the species present in the St. Marys River, including most of the important sports fish (Applegate et al. 1961; Applegate and King 1962; Marking and Olson 1975; Marking et al. 1975; Bills and Marking 1976; Hammond Bay Biological Station, unpublished data). Susceptibility varies among major families of fishes. The centrarchids are the most resistant group and would probably not be directly affected by additions of lampricides. At the other extreme are species judged susceptible to the chemical, including some Catostomidae, Ictaluridae, and native lampreys. Salmonidae, Percidae, and Cyprinidae are of intermediate sensitivity.

Excessive mortality of nontarget fish was observed in about 40 of 1,300 (3%) stream treatments performed from 1958 to 1978 (Dahl and McDonald 1980). Usually, causes of such dramatic fish losses were identified and the recurrence of the situation avoided. White and longnose suckers, northern pike, brown trout, brook trout, rainbow trout, coho salmon, and walleye were included among the larger fish that were occasionally killed during treatments. Forage species included: longnose dace, blacknose dace, common shiners, spottail shiners, logperch, johnny darters, brook sticklebacks, troutperch, mudminnows, and sculpins. All the above species are present in the St. Marys River.

Mortality of a variety of species is common immediately downstream of chemical application sites. Because of the volume of chemical to be fed and the depth and velocity of the water in the St. Marys River, this area may extend farther downstream than in shallow rivers where a more rapid mix of chemical is attained. While morality of nontarget fish near a feeder site may include considerable numbers of fish, the effect is probably minimal to overall populations.

Fish in spawning condition are more vulnerable to the effects of TFM than are juveniles of the same species. Many of the major kills have been during spawning seasons, especially for white suckers, longnose suckers, northern pike, and brown trout. Most spawning in the St. Marys River is completed by late summer when treatment would occur.

From 1983 to 1985 fish were held in cages during treatment of 13 streams. Cages were not placed directly downstream of feeders but in areas where lampricide concentrations were more representative of the entire stream. Many of the species held in cages included those which were susceptible (white suckers, logperch) or those mentioned most often in treatment mortalities (common shiners, johnny darters, longnose dace, blacknose dace, brook stickleback, sculpins, logperch, and mudminnows). Mortality was quite low where concentrations were maintained at normal treatment levels (USFWS, Marquette Sea Lamprey Control Station, file data).

Among susceptible fishes in open water areas of the St. Marys River Considered for treatment are the white sucker, northern pike, and brown bullhead. Many troutperch have also been killed during spring and early summer lampricide applications in Great Lakes tributaries. This species is an important forage fish for Walleye, northern pike, and yellow perch. If treatment is outside of spawning seasons for these susceptible species, especially white suckers, some mortality will occur, but not On the scale that would prevent rapid recovery. In a well conducted treatment, yellow perch, walleye, and centrarchids should have no mortality.

Among the forage fish, which provide an important link between the resources of the benthic community and the larger fish, no information is available on the susceptibility of bluntnose minnow, emerald shiner, mimic shiner, spottail shiners, and ninespine stickleback to lampricides. No mortality resulted from caging brook sticklebacks and mottled sculpins during treatments. Among darters, johnny darters survived well (42 of 44 in 6 treatments), but some mortality was noted for logperch (20 of 26 survived in 5 treatments).

The lake herring and lake sturgeon are threatened species in Michigan (Liston et al. 1986) and the emerald shiner is rare in Lake Michigan and declining in Lake Superior. It is very important that these stocks of fish be safeguarded. Treatments are not normally conducted over these species, or over whitefish and rainbow smelt. It is advisable to determine susceptibility of such species through bioassays prior to treatment.

Larval lampreys are also abundant in open water substrates. The percentage of American brook lampreys exceeded those of sea lamprey larvae in surveys prior to 1976 in Lake Nicolet, but by 1978 accounted for only 35% of the collection (Braem et al. 1978). Percentages of Ichthyomyzon larvae have been quite low throughout the years. Ichthyomyzon ammocetes are probably those of silver lampreys as a few adults and recently metamorphosed individuals have been collected over the years.

The effects of TFM application upon native lampreys in this system should be similar to that of sea lampreys. In Lake Superior tributaries, American brook lampreys were not eliminated from most streams by TFM applications due to their establishment upstream of sea lamprey distributions (Schuldt and Goold 1980). American brook lampreys are present above the area considered for treatment and they could repopulate the river, but the less abundant silver lamprey could be eliminated by application of lampricides.

Wetlands in the St. Marys River serve as a nursery area for centrarchids, yellow perch, northern pike, bowfin, longnose gar, brown bullhead, cypr[illegible] and other species. Adult fishes move into these areas daily to forage and rest. The wetlands also are utilized as spawning habitat by some of the more important fish species of the St. Marys River such as northern pike, smallmouth bass, and yellow perch. Wetland fish species for which potential effects of TFM have not been previously discussed are gizzard shad, bowfin, and longnose gar, for which no information is available, and the bluegill which is very tolerant of TFM. Gizzard shad are unusual in that although 3,231 were collected in the St. Marys in 1982 and 1983 (Liston et al. 1986), no mature fish were taken. This suggests that young of the year migrated into the area rather than originated there. The importance of the bowfin and longnose gar is minimal due to their rough fish status and scarcity in the St. Marys River.

Beach shoreline habitat has been surveyed in the middle portion of the river from Lake Nicolet to Munuscong Lake (Liston et al. 1980, 1981). The fish community found in these beach zones is comprised of species found in wetlands as well as small demersal species common to open water areas. The most common species collected in beach zones were the troutperch, emerald shiner, spottail shiner, common shiner, and mimic shiner. Juvenile walleye are also common. Species for which additional information on TFM toxicity may be required are the redhorses. Three species were collected in the river in 1982 and 1983. The silver redhorse and shorthead redhorse are common, whereas golden redhorse are rare.

Salmon and trout that spawn in the St. Marys Rapids may not be a functional part of fish communities in other areas of the river. Most information available is from sport fishing harvests. Principal fish species caught in the rapids by anglers are whitefish, pink salmon, rainbow trout, lake trout, brown trout, and brook trout. Walleye and chinook salmon move into the rapids area during autumn. Koshinsky and Edwards (1983) included 38 species of fish that were collected from the rapids. Forage species which could be expected to be abundant are longnose dace and slimy sculpin. Treatments are regularly conducted over this type of fish community with the exception of whitefish and lake trout. In general, treatment strategy to preserve this community is to avoid treatment during spawning periods.

It is evident that the use of TFM to control sea lampreys in the St. Marys River will cause some mortalities among white suckers, northern pike, brown bullheads, trout-perch, and native lampreys. However, long term impacts of a treatment will probably be minimal because huge areas will not be affected and can serve as refugia and centers for recolonization.

Other Organisms

Twenty-eight species of plants occur in submersed wetlands, but three species dominate biomass: Chara globularis, Isoetes riparia, and Nitella flexilis. Widely scattered clusters of pondweed Potamogeton richardsonii are also abundant. The effects of TFM on macrophytes can be severe at high concentrations, but not at low concentrations used in lamprey control (Gilderhus and Johnson 1980). Maki and Johnson (1977) estimated that TFM inhibited growth of Elodea canadensis by 5-10% and Myriophyllum spicatum by 20% during the time of treatment.

The amphibian and reptile communities are rather depauperate and no studies specific to the river have been published. The range of 29 species encompasses the river and 17 are probable inhabitants of emergent wetlands along the river (Duffy et al. 1986).

Amphibians are the only vertebrates other than fish which appear to have been affected by lampricides. Chandler and Marking (1975) determined the toxicity of TFM to three species of frogs. The 96 h LC50 values for all three species indicated that all were more resistant to TFM than sea lampreys; however, some mortality of gray tree frogs could be expected since they are only marginally more resistant than sea lamprey ammocetes.

Mudpuppies are present in the St. Marys River since they have been found in the immediate vicinity of the river; however, no estimate of abundance is available. Mortality of this organism often results from treatment of tributaries of Lakes Superior and Michigan (Gilderhus and Johnson 1980).

Much information is available on birds and mammals found in the St. Marys River area. Many studies have been conducted on the effects of lampricides to meet requirements of the U.S. Environmental Protection Agency for pesticide registration. The evidence indicates that TFM does not cause harm to populations of birds or mammals.

CONCLUSIONS

Two key parameters with special relevance to policy development emerge from this study. The first is our estimate of 33,000 parasitic-phase sea lampreys being produced annually from the St. Marys River. The second is the estimate of 248,000 sea lampreys inhabiting northern Lake Huron. We cannot, accordingly, demonstrate that the St. Marys River is a major cause of the sea lamprey problem in northern Lake Huron. Consequently, it would be difficult to recommend expensive control measures in the river when there is no assurance that this diversion of control effort would have an appreciable effect on the standing stock of sea lampreys in northern Lake Huron.

Our data indicate that at present only a conventional TFM treatment would have the potential to control sea lampreys in the St. Marys River. However, the logistical feasibility and effectiveness of a conventional treatment remain to be determined. After all, the St. Marys River is 23 times larger than any river previously treated with lampricides. We have no evidence that sea lampreys in the St. Marys River form a discrete stock, which weighs against sterile males as an option. Existing bottom toxicants (Bayer 73) would probably cause too much environmental damage, because it is difficult to control concentration (Ho and Gloss 1987). Chemical costs alone for a bottom treatment of the infested areas would cost $4 to $8 million, an amount which exceeds the theoretical costs of a conventional treatment. In comparison to a conventional treatment increased trapping and/or sterile male release appear to be a bargain. These methods may reduce reproduction of sea lamprey in the river, but they should not be implemented until there is some prospect of evaluating their effect. If the population response to such measures is modest, it will be difficult at present to assess their value. When it becomes possible to accurately assess year class strength of larvae in the river, increased trapping and sterile male release can be attempted and a proper evaluation made. Therefore, by process of elimination we are left with conventional treatment as offering the best method of control. However, we computed annual damage caused by St. Marys River sea lampreys at $344,000 while annual treatment costs are $450,000. Consequently, the cost-benefit ratio for a conventional treatment appears to be marginal, and we have not included costs of nontarget effects and restricted power production because of the reduced flows needed for a conventional treatment.

The major unresolved issue that emerges from our study is an accounting for the extensive stock of parasitic-phase sea lamprey in northern Lake Huron. Our estimate of the damage caused by these sea lampreys was $2.6 million per year, and this figure may be conservative because we assumed no fish losses until sea lampreys reach a size achieved in late summer. We suspect substantial numbers of chubs would be destroyed by sea lampreys before late summer. However, even the $2.6 million damage figure, which amounts to 70% of the value of the affected fisheries, indicates an unacceptable level of control,

It is apparent that our damage estimate would be much improved if we had better information on the major species preyed upon by sea lamprey. In particular, marking data on chubs, whitefish, salmon, and burbot are needed. These species are normally assessed for other purposes, and the extra effort to obtain marking data would be nominal. Also, burbot are practically ignored in routine stock assessments in the Great Lakes, because of their lack of value. However, burbot are obviously important in the fish community, they may be important in sea lamprey prey selection, and, accordingly, they should be better studied.

Our major recommendation is concerned with identifying the source(s) of the sea lamprey in northern Lake Huron. Search effort should be substantially increased. Equally important, better assessment technology needs to be developed, especially gear for sampling transformers in lentic areas. Conventional practice does not require estimates of transformer production to justify chemical treatments in streams harboring sea lamprey larvae. But we believe that a treatment on the scale of the St. Marys River needs such justification. We do not, in fact, dismiss the St. Marys River as the major source. However, we could not prove that it was a major source and we cannot recommend a conventional treatment on an educated guess. Better survey gear and increased search effort may locate substantial numbers of transformers in the lower St. Marys River, which could well change our conclusions. If significant numbers of transformers are found in the river, it would be reasonable to proceed with dye studies and bioassays to firm the cost estimate of a conventional treatment. A decision on treatment could then be made.

ACKNOWLEDGEMENTS

Many persons other than the task force made substantial contributions to this report. We especially want to thank J. Heinrich, R. McDonald, and J. Moore for compiling and analyzing material on adult sea lamprey, J. Koonce for developing the damage estimate, R. Schuldt for writing the nontarget effects, and W. Westman for assessing the logistics of a conventional treatment. Their assistance is very much appreciated by the task force.

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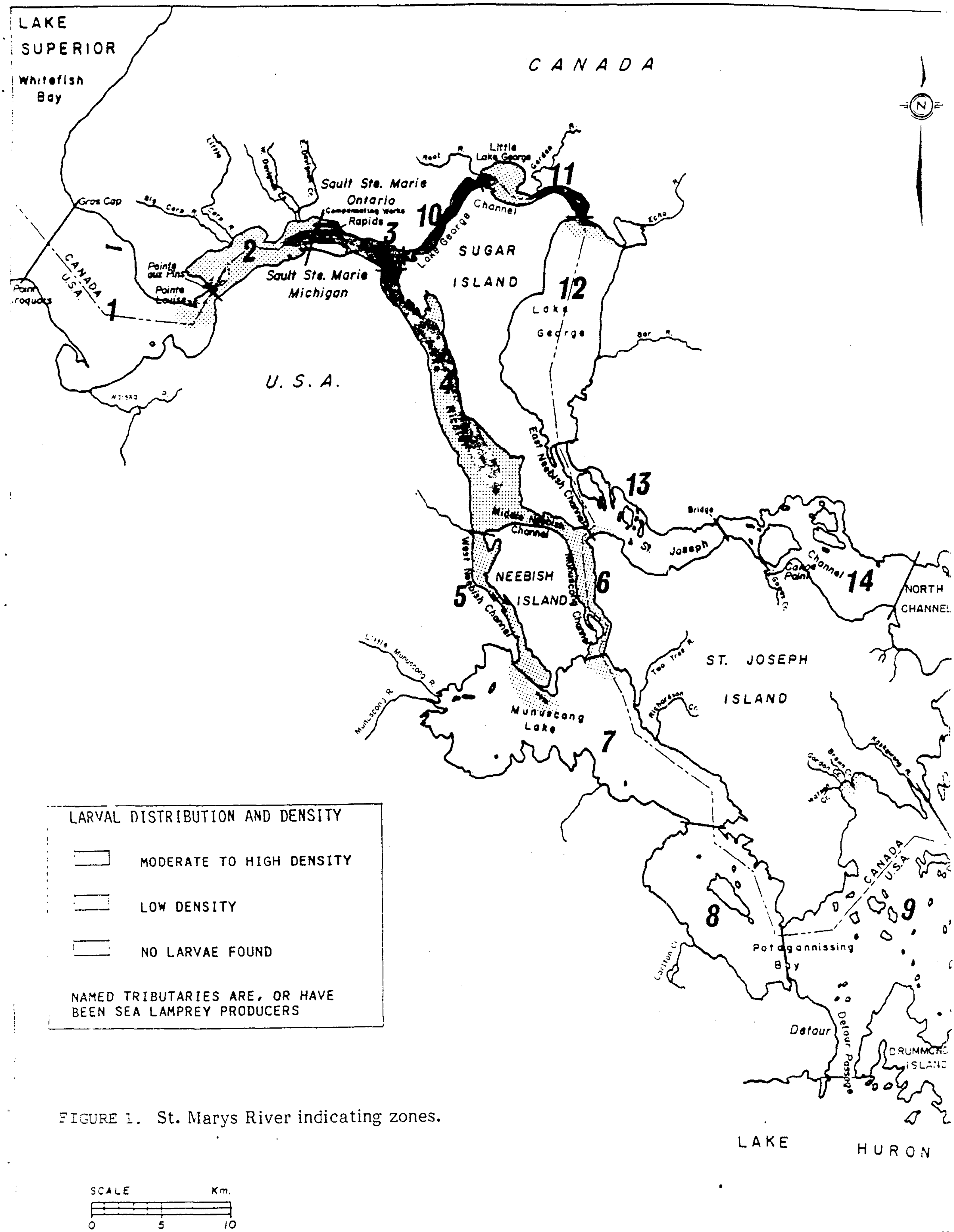


FIGURE 1. St. Marys River indicating zones.

Figure 2 Estimated Abundance of Spawning Sea Lampreys
St. Mary's River, 1964-1986

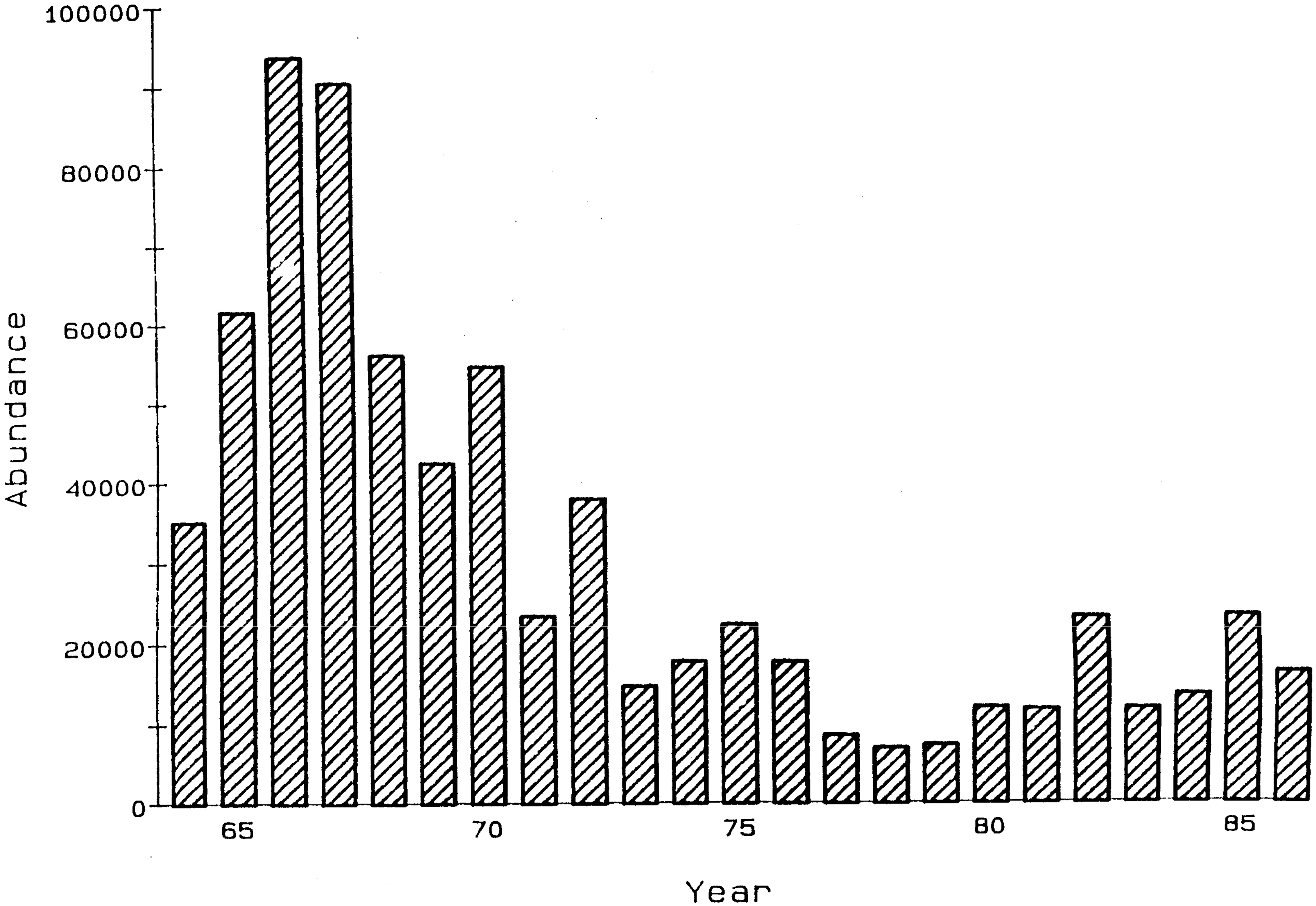


Figure 3. Ammocoete Length/Frequency Distribution - St. Mary's River

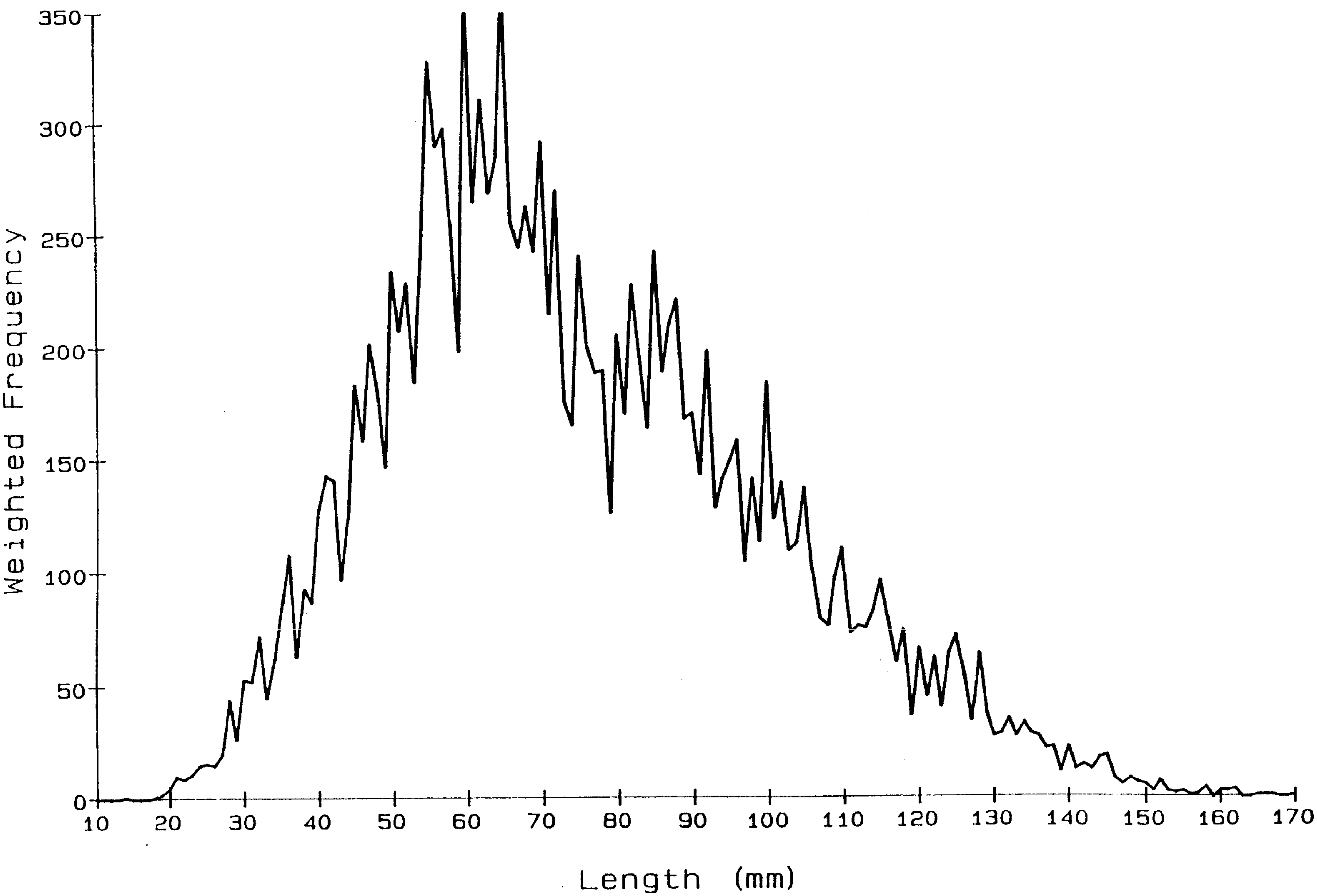
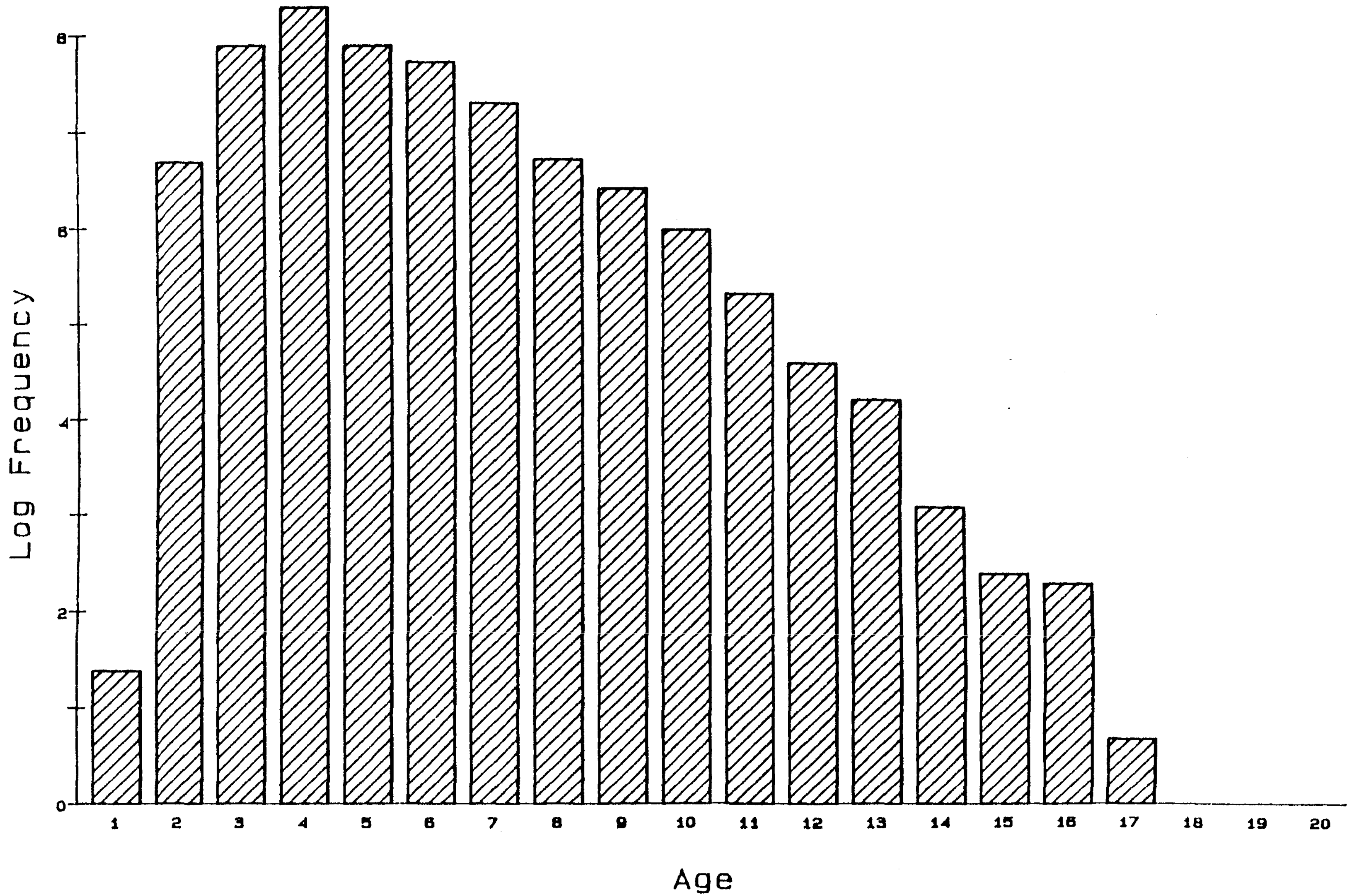


Figure 4. Theoretical age distribution of sea lamprey larvae in the St. Marys River, 1983-1986 not corrected for sampling vulnerability.



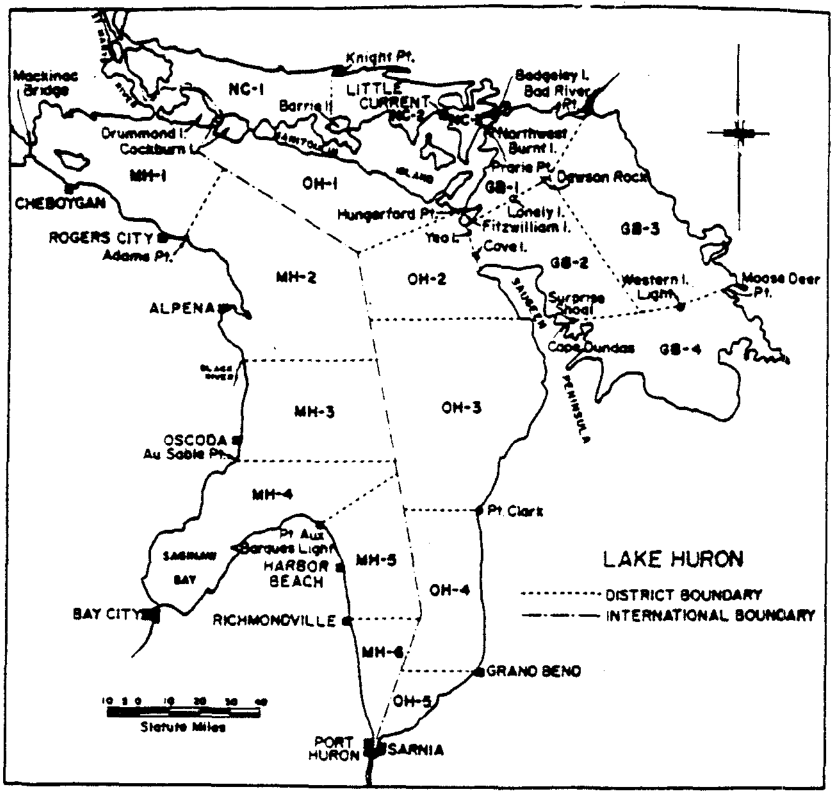


Figure 5. Statistical districts of Lake Huron (Hile 1962).

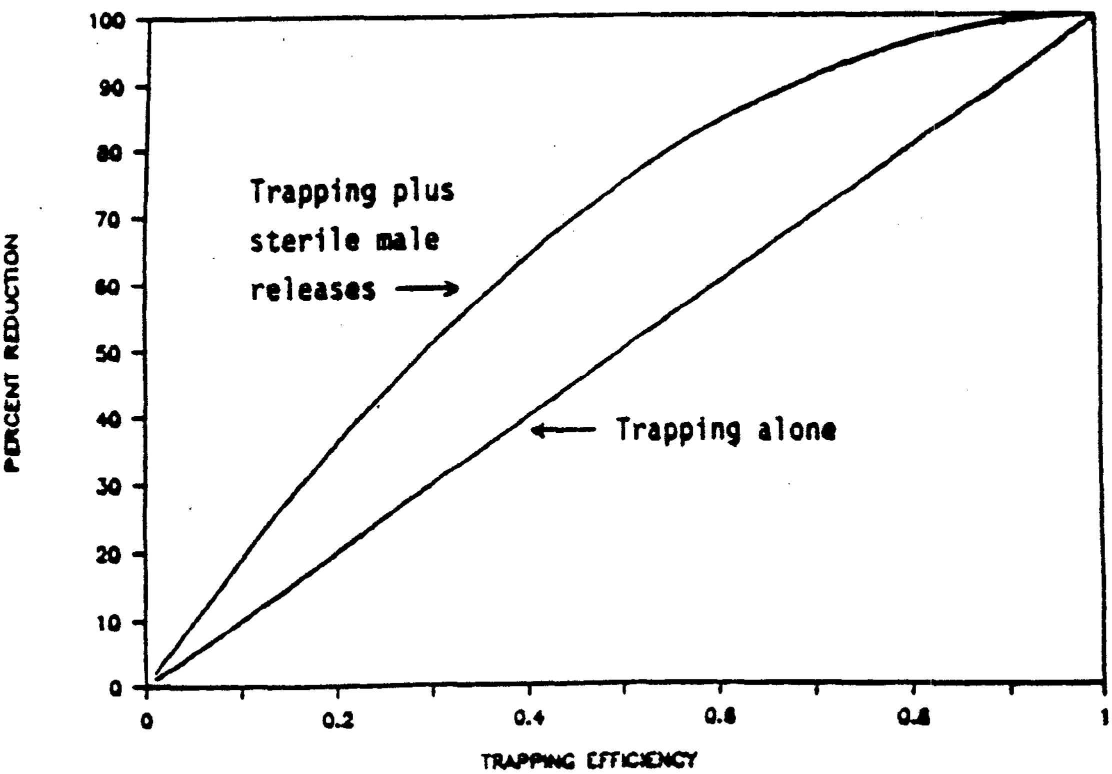
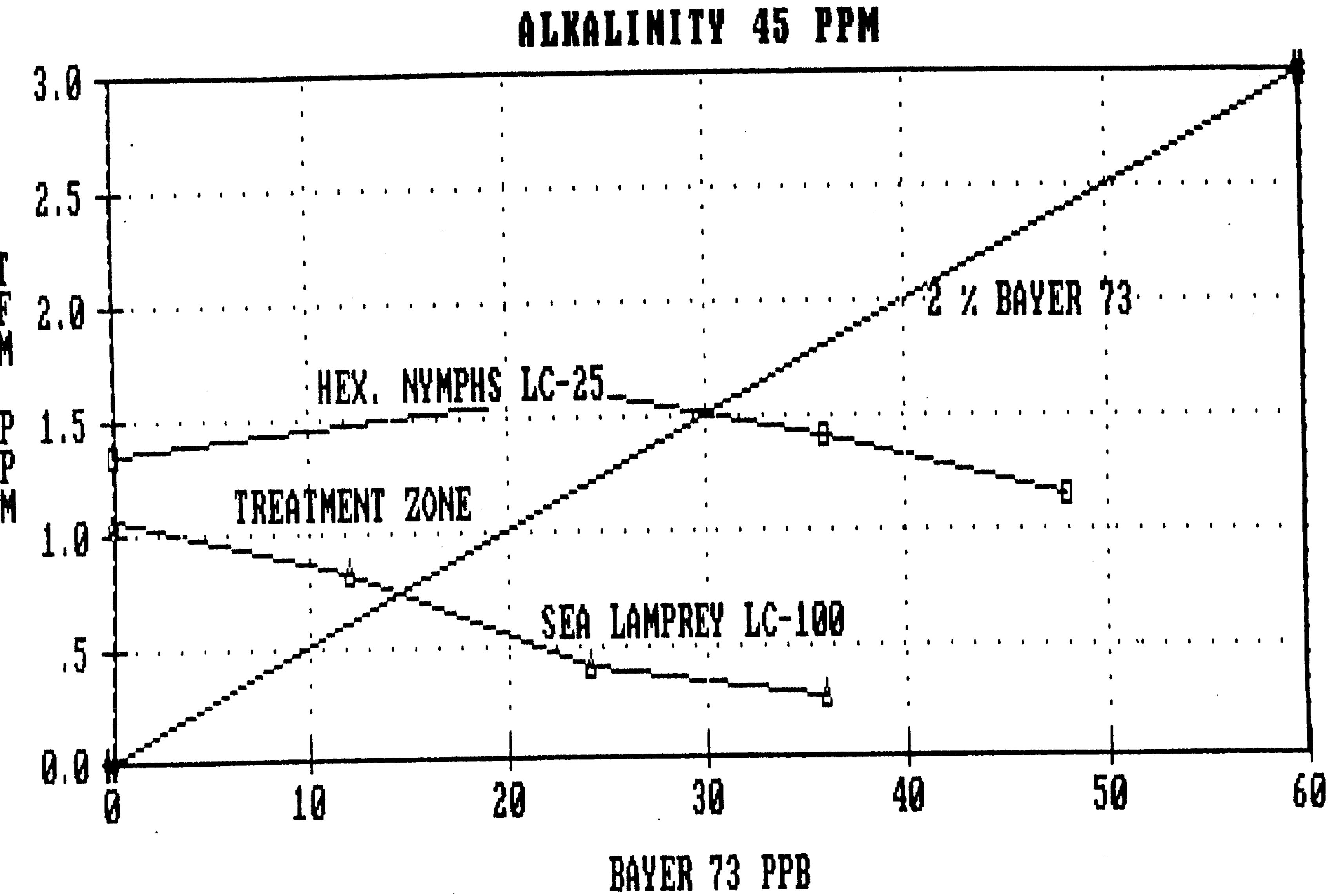


Figure 6 . Percent reduction in reproductive potential versus trapping efficiency for trapping alone and trapping in conjunction with the sterile-



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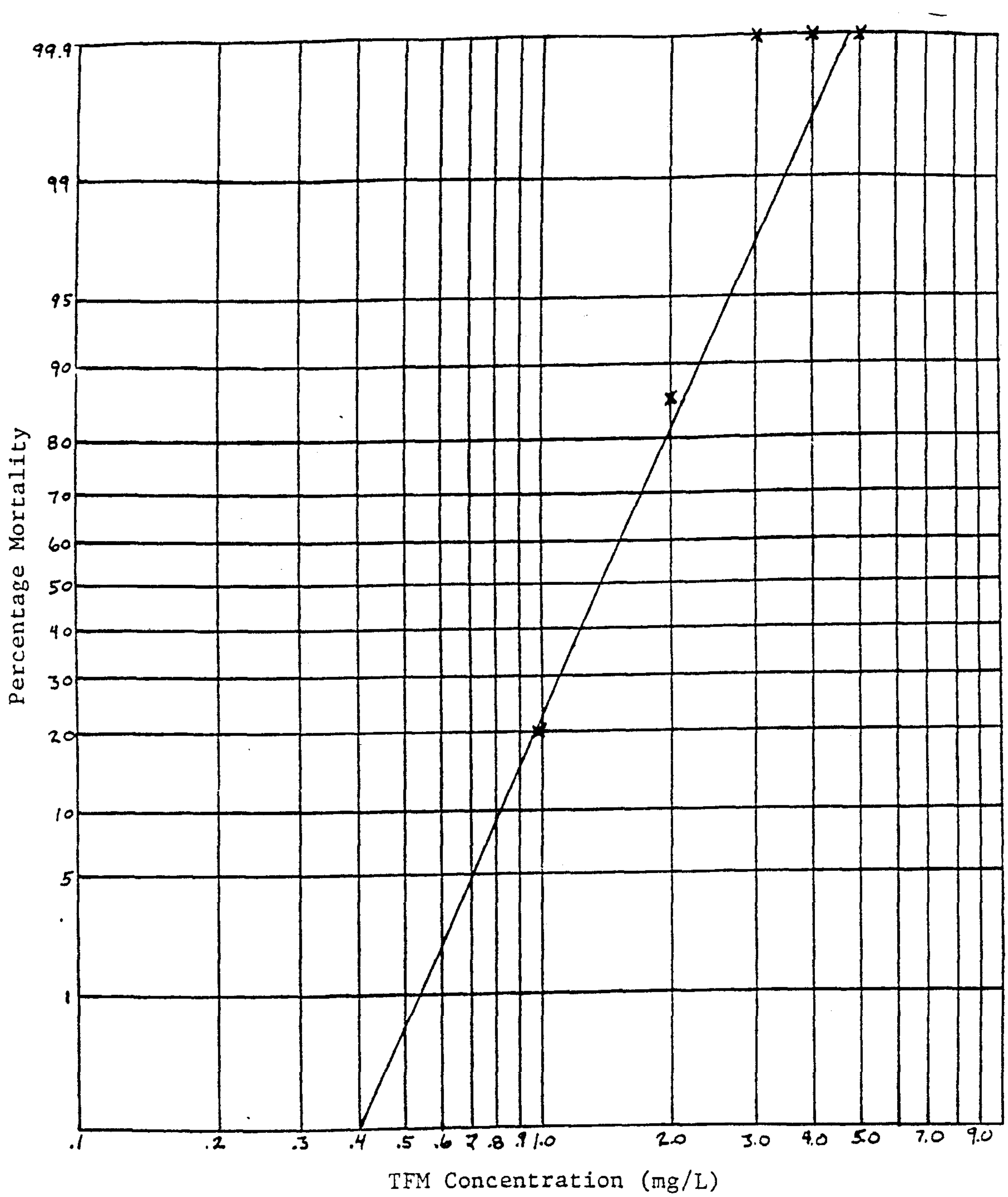


Figure 8. Toxicity curve for a 24-hour test of TFM on age II Hexagenia nymphs in water of 40 mg/L $CaCO_3$ (Hammond Bay Biological Station).

LIST OF APPENDICES

APPENDIX I

Spawning Sea Lamprey in St. Mary's River

(C.K. Minns and J.E. Moore)

We have, somewhat hesitantly, used the available index catches of adult sea lamprey to estimate spawner numbers from 1964 to 1986 (Table 1). The many assumptions are given with the table. The main assumptions are that:

(i) U.S. trap catch (1976-86) were an index of abundance and were affected by Canadian catches (1983-86); and

(ii) U.S. fall trawl catches (1963-1981) were either linear or log-linear with abundance.

Correction of recent U.S. trap catches accentuates the slight upward trend since 1976. The overall pattern suggests a decline from the highest levels in the mid 1960's to a low in the mid 1970's, followed by a moderate upswing in the 1980's (Fig. 1 (geometric mean of estimates 1964-76)).

The initial decline could be attributable to lake-wide lamprey control activities with the St. Mary's river, at that time, receiving excess spawners. With intense lamprey control and low fish stocks, transformer-spawner survival was poor through the early to mid-1970's. More recently with the strong recovery of fish stocks in Lake Huron (whitefish, chubs, etc.), transformer survival has likely improved. Thus it is possible that the transformer output of the St. Mary's River has not varied considerably since the 1960's but that their survival has.

Table 1 Estimated Population of Spawning Sea Lampreys in St. Mary's River, 1964-1986.

Trawling Year	Trawl Catch SL/100 hrs.	Spawning Year	Trap Catches		Population Estimate(s)	
			U.S.	Canada		
63	95	64	--	--	63419[a]	195[illegible]
64	242	65		--	161551	23554
65	495	66		--	330444	*26665*
66	466	67		--	311085	2640 5
67	207	68	--	--	138186	22913
68	130	69	--	--	86783	20919
69	198	70	--	--	132178	22727
70	49	71	--	--	32711	16726
71	108	72	--	--	72097	20122
72	24	73	--	--	16022	13653
73	32	74	--	--	21362	14896
74	46	75	--	--	30708	16456
75	32	76	--	--	21362	14894
76	12	77	1419	--	8679	
77	21	78	1148	--	7022	
78	18	79	1213	--	7419	
79	26	80	1995	--	12202	
80	5	81	1946	--	11903	
81	24	82	3848	--	23536	
82		83	1590	2409	12134	
83		84	1687	3624	13942	
84		85	3428	7763	23852	
85		86	1120	4790	16812	

-assumptions are attached.

Assumption: using Heinrich's tables 10 and 11, and Cuddy's figures for Canadian catches.

1. Trawling effort in 1963-1965 was the average of 1966-1981 ($n = 16$, $\overline{x} = 166.75$).

2. Multipliers from fall trawl to spring U.S. catch is:
   a> Σ(catches 77-82)/Σ(Trawl 76-81) = 109.1415
      assumes trawl catch is linear with abundance.
   b) Σ(catches 77-82)/Σ(log(Trawl)76-81) = 702.6254
      assumes trawl catch is log-linear with abundance.

3. U.S. Trap catches for 1983-86 must be corrected for interference by Canadian trap catches. I assumed that:

$$\text{Expected U.S. Catch} = \frac{\text{Actual U.S. Catch} \times \text{Population}}{(\text{Population} - \text{Canadian Catch})}$$

giving

Year	E(U.S. Catch)
1985	5082
1986	1566

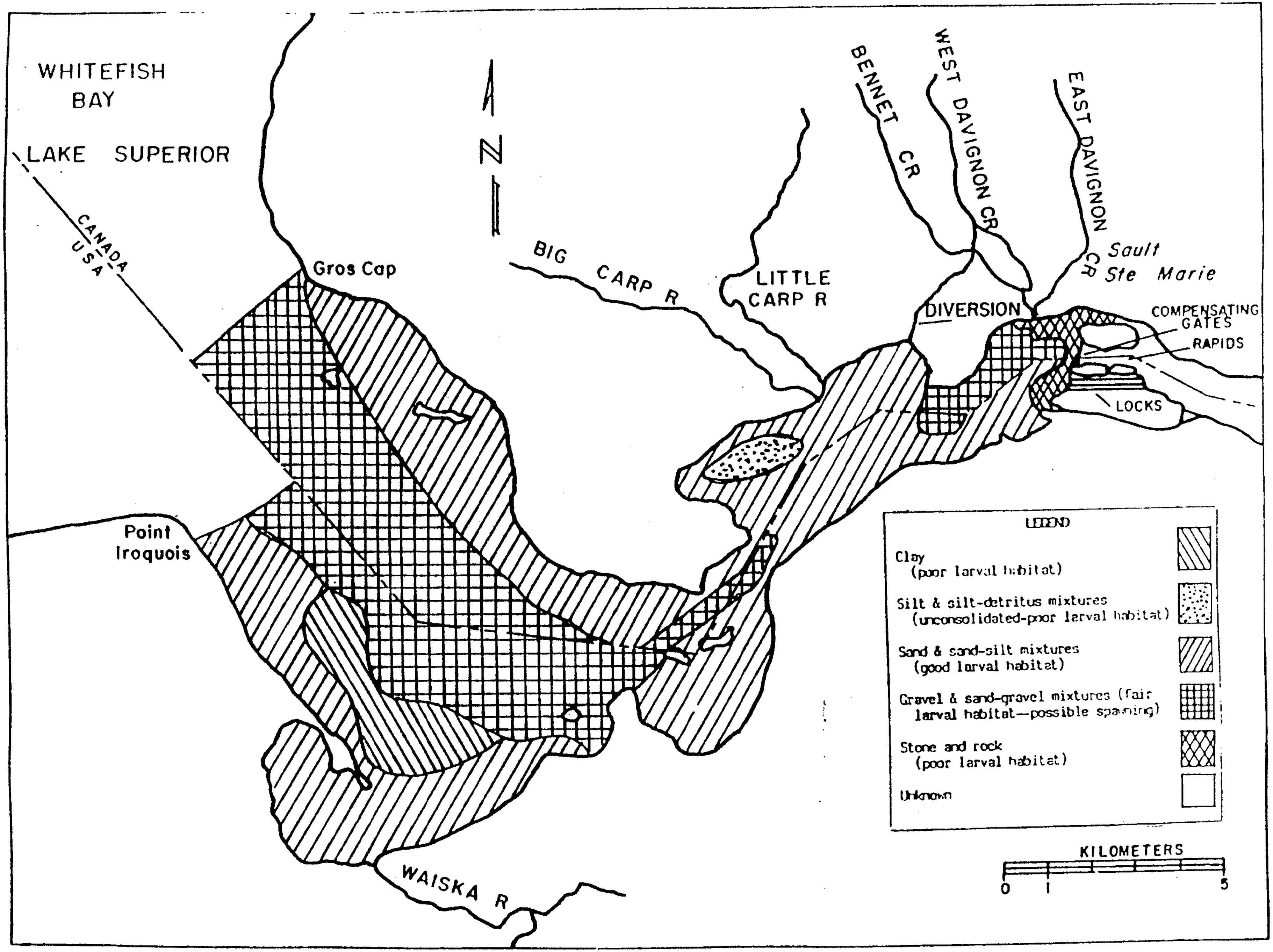
From these values, I calculated a U.S. Catch to Total Population multiplier by Σ(Populations 85-86)/Σ(E(U.S. Catch)85-86) = 6.1165.

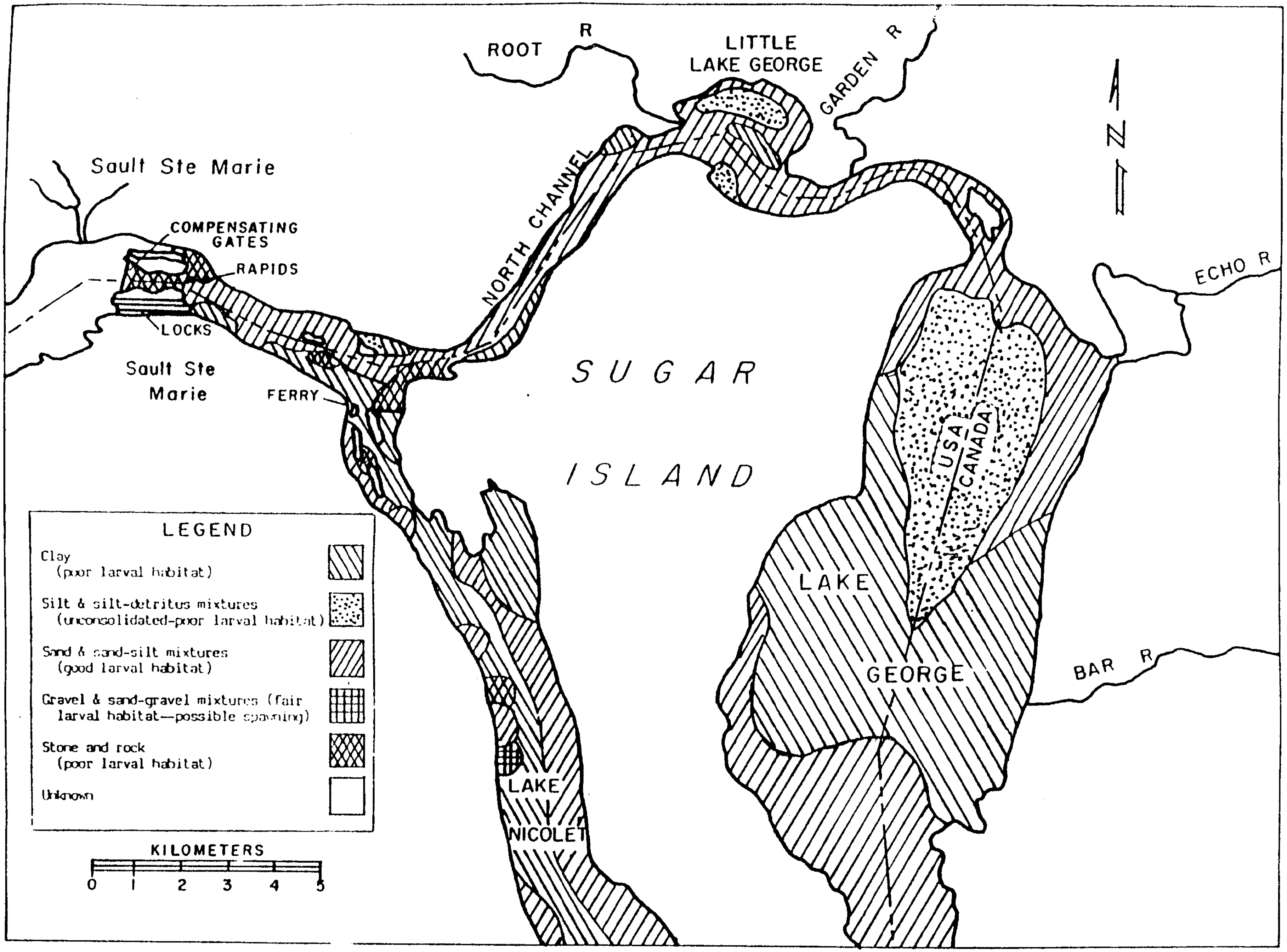
4. I applied the 6.1165 value to 83 and 84 U.S. Catches and corrected for Canadian catches.

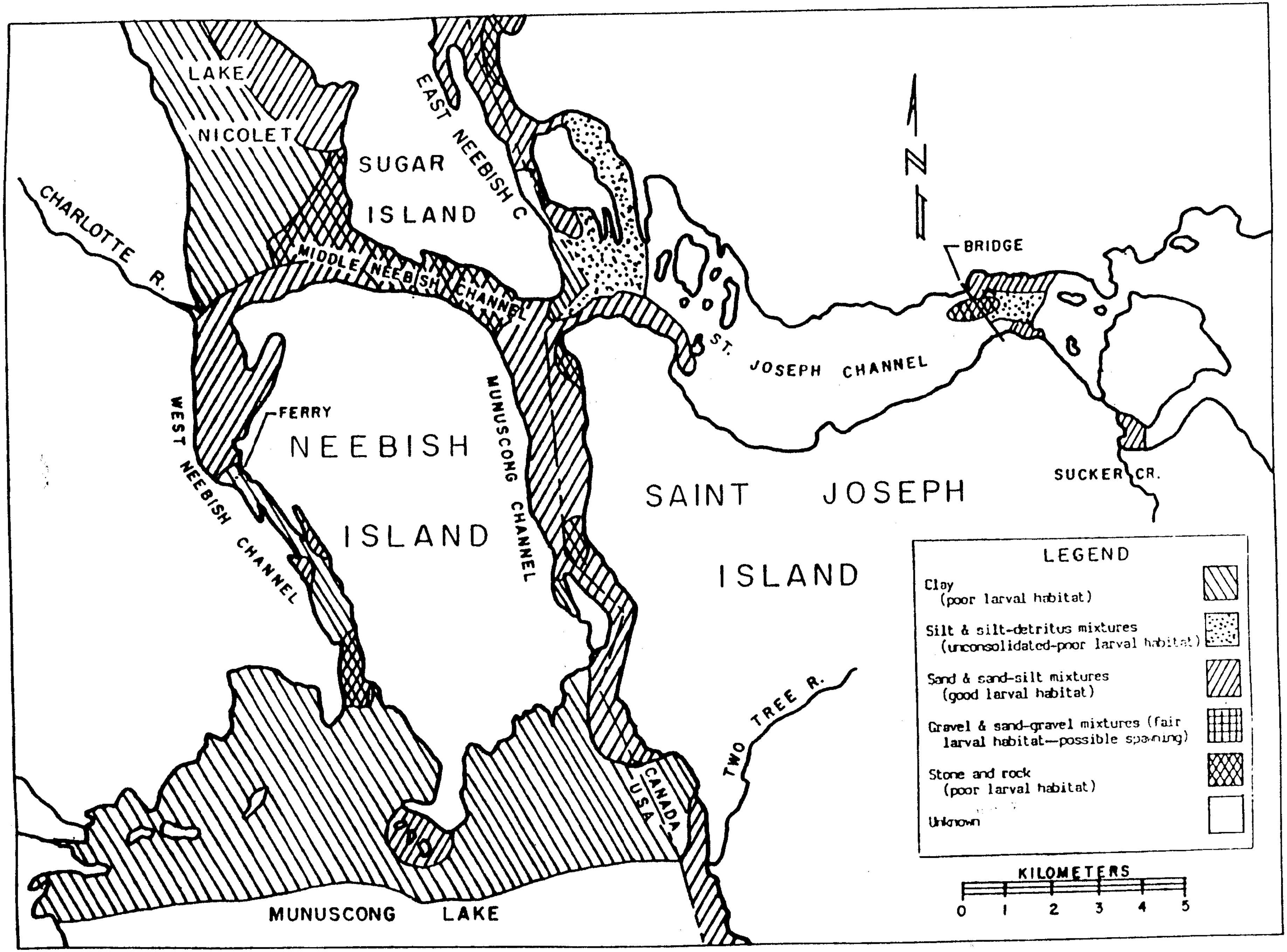
5. I applied the 6.1165 value to 77-82 U.S. Catches (75 and 76 values were discarded).

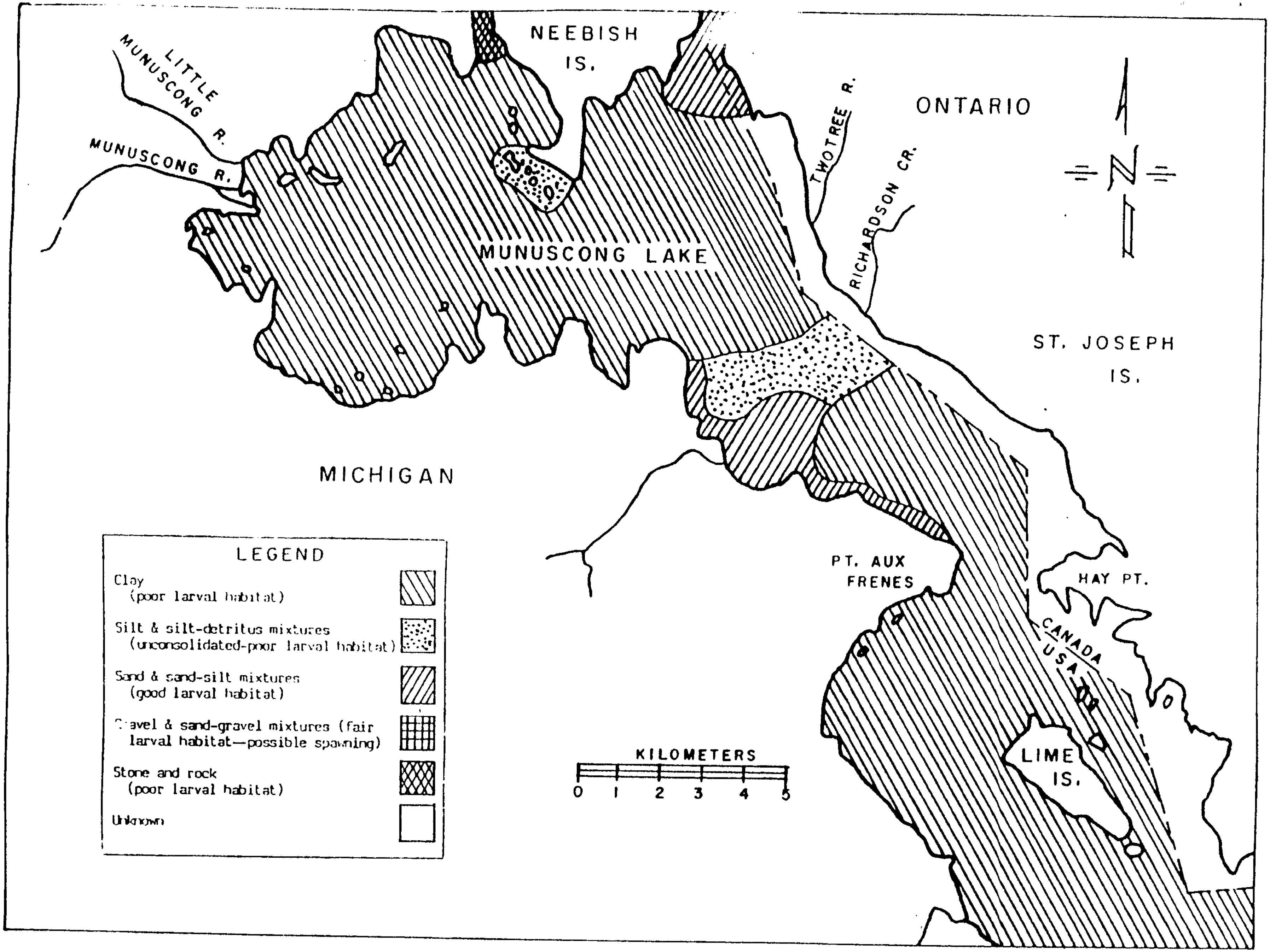
6. I applied the 6.1165 and the two trawl multipliers to estimate populations for 64-76.

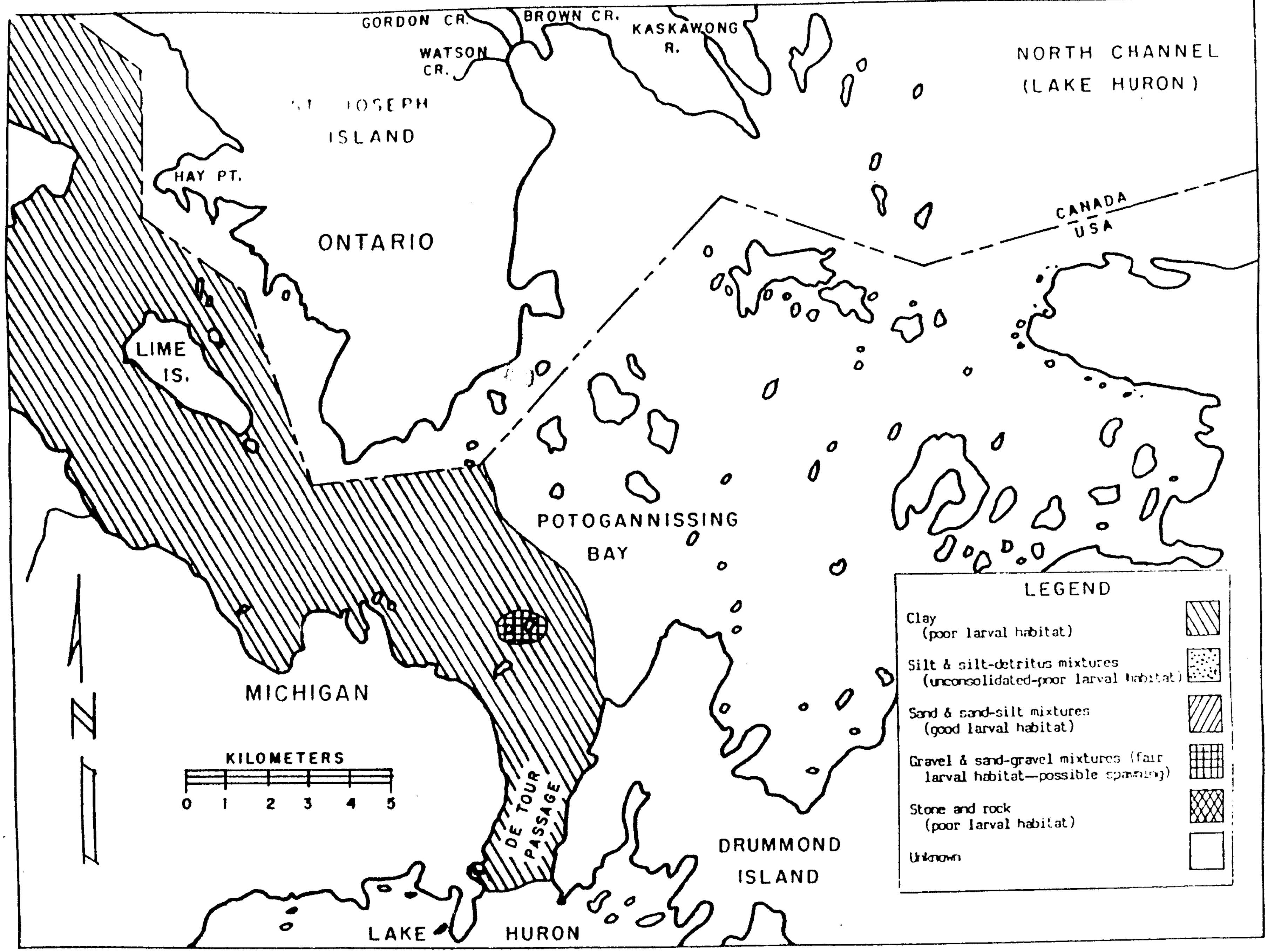
APPENDIX II


WHITEFISH BAY
LAKE SUPERIOR
CANADA
USA
N
Gros Cap
BIG CARP R
LITTLE CARP R
BENNET CR
WEST DAVIGNON CR
EAST DAVIGNON CR
Sault Ste Marie
DIVERSION
COMPENSATING GATES
RAPIDS
LOCKS
Point Iroquois
WAISKA R
LEGEND
Clay (poor larval habitat)
Silt & silt-detritus mixtures (unconsolidated-poor larval habitat)
Sand & sand-silt mixtures (good larval habitat)
Gravel & sand-gravel mixtures (fair larval habitat—possible spawning)
Stone and rock (poor larval habitat)
Unknown
KILOMETERS
0
1
5


ROOT R
LITTLE LAKE GEORGE
GARDEN R
N
Sault Ste Marie
COMPENSATING GATES
RAPIDS
LOCKS
NORTH CHANNEL
Sault Ste Marie
FERRY
SUGAR ISLAND
ECHO R
USA
CANADA
LAKE GEORGE
BAR R
LAKE NICOLET
LEGEND
Clay (poor larval habitat)
Silt & silt-detritus mixtures (unconsolidated-poor larval habitat)
Sand & sand-silt mixtures (good larval habitat)
Gravel & sand-gravel mixtures (fair larval habitat—possible spawning)
Stone and rock (poor larval habitat)
Unknown
KILOMETERS
0 1 2 3 4 5


LAKE
NICOLET
SUGAR
ISLAND
EAST NEEBISH C
CHARLOTTE R.
MIDDLE NEEBISH CHANNEL
ST. JOSEPH CHANNEL
BRIDGE
N
FERRY
NEEBISH
ISLAND
WEST NEEBISH CHANNEL
MUNUSCONG CHANNEL
SAINT JOSEPH
ISLAND
SUCKER CR.
TWO TREE R.
CANADA
USA
MUNUSCONG LAKE
LEGEND
Clay (poor larval habitat)
Silt & silt-detritus mixtures (unconsolidated-poor larval habitat)
Sand & sand-silt mixtures (good larval habitat)
Gravel & sand-gravel mixtures (fair larval habitat—possible spawning)
Stone and rock (poor larval habitat)
Unknown
KILOMETERS
0 1 2 3 4 5


NEEBISH IS.
LITTLE MUNUSCONG R.
MUNUSCONG R.
ONTARIO
TWOTREE R.
RICHARDSON CR.
MUNUSCONG LAKE
ST. JOSEPH IS.
MICHIGAN
PT. AUX FRENES
HAY PT.
CANADA
USA
LIME IS.
KILOMETERS
0 1 2 3 4 5
LEGEND
Clay (poor larval habitat)
Silt & silt-detritus mixtures (unconsolidated-poor larval habitat)
Sand & sand-silt mixtures (good larval habitat)
Gravel & sand-gravel mixtures (fair larval habitat—possible spawning)
Stone and rock (poor larval habitat)
Unknown



GORDON CR.
BROWN CR.
KASKAWONG R.
WATSON CR.
NORTH CHANNEL (LAKE HURON)
ST. JOSEPH ISLAND
HAY PT.
ONTARIO
CANADA
USA
LIME IS.
POTOGANNISSING BAY
LEGEND
Clay (poor larval habitat)
Silt & silt-detritus mixtures (unconsolidated-poor larval habitat)
Sand & sand-silt mixtures (good larval habitat)
Gravel & sand-gravel mixtures (fair larval habitat—possible spawning)
Stone and rock (poor larval habitat)
Unknown
N
MICHIGAN
KILOMETERS
0 1 2 3 4 5
DE TOUR PASSAGE
DRUMMOND ISLAND
LAKE HURON

APPENDIX III

A Simple Model of St. Marys River Sea Lamprey Population

(C.K. Minns and J.E. Moon?)

One of the central questions in the decisionas to whether the St. Marys River sealaqxeypqulation need ke controlled is "Does transformer production from St. Marys significantly influence the number of parasitic phase lampreys in Lake Huron?" w h e r e in this report, the number of parasitic-phase animals has been estimated to be 340,000. Below, a simple population model will be used to pr&ict transformer production starting from an adult population of 20,000 - approximately the level currently spawning in the St. Marys River.

Starting with 20,000 spawners, we need to determine the proportion of females and fecundity to predict egg production. Terry Morse (pers. comm) has developed a fecundity equation for St. Marys River lampreys:

$$\text{No. Eggs} = -89{,}428 + 367.4\ \text{Length (mm)}$$

Average female length varied between 462 and 487 mm from 1976 to 1985. Given there were 37 percgllt females spawning in 1985, egg production per spawner has ranged from 29,715 to 33,113.

The next stage in the population cycle is egg incubation through to fry emergence. In the GLFC-sponsored IPM modelling workshop, survival at this stage was estimated to be 3%. Given the above this would produce 17.8 to 19.9 million hatched ammocoetes from 20,000 spawners. If egg to hatch survival were 1%, the production of hatched ammocoetes would be 5.9 - 6.6 million (St. Marys is generally judged to be a harsher habitat for lampreys).

A Simple Model of St. Marys River Sea Lamprey Population

To then predict the subsequent ammocoete population and transformer product ion, we must know the annual survival rate, the threshold for transformation, and the transformation rate. Unfortunately very little is known about these rates.

We decided to axve&thecbemed ammocoete length-frequency distribution in the St. Marys River, into an age frequency by assuming a growth model for transformers. First the length ~ipc:for~variousz~in~river'~ pooled with weighing's based on the predicted ammocoete populations in the river zones (Morse and Cuddy, elsewhere in this report).

Growth is poorly known for ammocoetes but the data suggested ammocoetes grow to about 20 mm in the first year of life and the largest ammocoete seen was 169 mm. We decided to do a Bertalanffy grmthmdel:

$$L_t = L_\infty (1 - e^{-Gt})$$

Given estimates of L_1 and L_∞, G can be calculated. We used a range for L_1 (18, 20, 22mm) and L_∞ (180, 200, 220m) and used the model t0amvertlengthfrequen=ies to age frequencies, pooled into integer classes. Given the legth frequencies in St. Marys River (Figure 3) the age frequency for $L_\infty = 200$ and $L_1 = 20$ is shown in Figure 4.

The resulting age frequencies are assumed to be catch curves from a steady-state population where survival and transformation rates can keestirnated from the right-hard slope of the distribution (younger age classes are not fully recruited to the sampling gear). To separate survival and transformation, we assumed that survival

A Simple Model of St. Marys River Sea Lamprey Population

rates were constant and that transformation began at the age (TA) equivalent to a length of 116 mm. The model is as follows:

$$N_{t+1} = N_t e^{-(M + p.T)}$$

where: N_{t+1}, N_t = the number of ammocoetes in age classes t and t + 1.

M = instantaneous mortality rate

p = proportion of year class able to transform

= 0 for t< int (TA)

=1 fort> int (TA)

= (t + 1 - TA) fort= int (TA)

T = instantaneous transformation rate.

Given a cohort, the transformer production can be calculated:

$$N_T = \sum_{t=0}^{t=\infty} N_t \left(1 - e^{-(M + p.T)}\right) . \frac{p.T}{M + p.T}$$

We fitted the survival model to the age data generated using the growth model (Appedix Table 1). The estimates of T are very poor, in every case the p.T variable had to be forced to enter the multiple regression. A "test" of the fitted model was obtained by integrating the regression equations to predict transformer numbers. The expected was 104 the number in the original length frequency sample of 16,127. The best regression fit was obtained with L_∞ = 180 and L_1 = 22, and this equation also predicted the highest number of transformers, 58. The survival rate in that case is 66.3%/year and the transformation rate (length > 116m) is

5%/year$(1 - e^{-T})$. The low transformation rate is consistent with an anticipated great longevity of ammocoetes.

we then used the survival and transformation schedules with the hatched ammocoete numbers es-tinted for 20,000 spawners with two sizes of females and two egg-hatch survival rates, to predict transformer production by a cohort (Appendix Table 2). The best survival equation also predicted the highest numbers of transformers (25-85,000). Elsewhere in this report is reported that there were 104 transformers among 16,127 ammocoetes, and an estimated 6.8 million ammocoetes in the river, corresponding to 44,000 transformers. These results combined suggest that the spawning and the ammocoete data in the St. Marys River fit together quite well despite the many assumptions involved in the calculations.

Further we cannot assume that all transformers survive, indeed Bergstedt has suggested there has been a change in transformer survival. A 100 percent survival is unlikely even under idealconditions. We assumed that the mortality coefficient for parasitic phase was the same as the ammocoetes so that 20,000 spawners would potentially produce 17-56,000 spawners.

Despite the severe data limitations, a coherent sea lamprey population model emerges for the St. Marys River. The results suggest that St. Marys River accounts for 5-16 percent of the adult lampreys in Lake Huron. This is likely not sufficient to warrant TFM treatment at this stage, especially as trapping of adults could be greatly enhanced.

Doubtless, the growth, mortality and transformation models could be improved but clearly much hinges on the accuracy of the adult and ammocoete population estimates. If abundances are substantially greater, the St. Marys River could be a big producer. of course, the relative importance hinges on the estimate of the lake-wide adult akxmbce. Before a sound treatment decision can be made, the following measures will be needed to narrow the uncertainty on the population dynamics:

1. Increase the effort to measure the size of the spawning population and also to increase the number of spawners removed. Differential marking of animals trapped on the U.S. and Canadian sides should be done to facilitate assessment of a trap interference effect. St. Marys River.
2. Increase efforts to determine the lake-wide abundance of spawning sea lamprey. An enhanced predictive model based on stream characteristics and tied to trap catches and efficiencies would be preferable. Lake Huron.
3. Improve estimates of ammocoete abundance. St. Marys River.
4. Improve estimates of growth, mortality, and transformation rates. St. Marys River.

Table1 **Estimates** of **M and T** for the age **frequency distributions** given assumptions of L== **and L_1, and predictions of expected transformers in the frequency sample and age at transformation.**

Length (m)	Variable	Length at age 1 (mm) 18	20	22
180	1	4-	4-23	3-22
	2	0.	0.986	0.988
	3	0.3	0.4195	0.4106
	4	0.03	0.0222	0.0509
	5	44.75	33.22	57.95
	6	9.81	8.78	7.93
200	1	4-20	4-19	3-16
	2	0.980	0.976	0.982
	3	0.5333	0.5823	0.6430
	4	-0.0005	0.0061	0.0023
	5	—	7.16	1.55
	6	9.20	8.23	7.44
220	1	3-17	4-16	3-14
	2	0.960	0.952	0.966
	3	0.5014	0.6592	0.7533
	4	0.0507	0.0066	-0.0034
	5	39.81	7.19	—
	6	8.78	7.86	7.11

1 Age range included in regression.
2 Multiple correlation coefficient.
3 Instantaneous mortality rate.
4 Instantaneous transformation rate.
5 Integral prediction of **number** of **transformers** for regression **equation-expected** = 104.
6 Age at 116 mm - onset of transformation, yrs.

A Simple Model of St. Marys River Sea Lamrey Population

Table2 Projected cohort transformer production from 20,000 spawners under varying assumptions.

Female Length (mm)		=	462		487	
% Females		=	0.37		0.37	
Egg to hatch survival		=	0.01	0.03	0.01	0.03
Hatched ammocoetes (million)		=	5.943	17.829	6.623	19.868
Growth parameters			Projected Transformer Production by a Cd2ort			
L_1	L=					
18	180		22214	66641	24754	74262
20	180		7642	22926	8516	25548
22	180		25373	76119	28275	84824
20	200		521	1562	580	1740
22	200		184	552	205	615
18	220		6827	20482	7608	22825
20	220		334	1002	372	1117

MEMORANDUM April 21, 1987

TO: Randy Eshenroder
FROM: Joe Koonce
RE: Damage estimates for Sea Lamprey from the St. Mary's River

I have constructed the following procedure to estimate damage associated with suspected production of parasitic phase sea lamprey from the St. Mary's River. The estimation scheme is derived from the AEAM models of salmonid/lamprey interactions (Koonce et al. 1982 and Spangler and Jacobson 1985) and the more recent applications to Lake Ontario.

The AEAM models assumed that sea lamprey attacks followed a multiple species disc equation:

$$A_i = \frac{T \times S_i \times N_i}{1 + \sum_{i=1}^{n} \bar{h} \times S_i \times N_i}$$

where T is the time that a mark is in stages AI to AIII, S_i is the effective search rate, N_i is the abundance of the ith prey category, $\bar{h}$ is the mean duration of an attack, and A_i is the number of attacks per lamprey on prey i.

Effective search rates are functions of sea lamprey preference for size of host:

$$S_i = Q_i \times P_i \times V_i$$

where Q_i is the encounter rate of sea lamprey and prey i, V_i is the proportion of habitat overlap between sea lamprey and prey **i**, and P_i is the size based preference index for prey i.

As developed in the AEAM models, size preference is a sigmoidal function of the length of the prey, L_i:

$$P_i = \frac{L_i^5}{400^5 + L_i^5}$$

Damage and marking estimates require an estimate of lethality of attack. As summarized in Eshenroder and Koonce (1983), instantaneous mortality due to sea lamprey attack is

$$Z_i = p_i \times A_i$$

where p_i is the probability of surviving an attack.

Marking rates (marks per 100 fish) include marks due to survived attacks and marks due to ongoing attacks:

$$M_i = 100 \times A_i \times \left(p_i + \bar{h}/T \times (1 - p_i)\right)$$

CITATIONS

Eshenroder, R. L. and J. F. Koonce. 1983. Recommendations for standardizing the reporting of Sea Lamprey marking data. Spec. Publ. 83-l. Great Lakes Fishery Commission, Ann Arbor, Michigan. 39 **pp.**

Koonce, J. F. L. A. Greig, B. A. Henderson, D. B. Jester, C. K. Minns, and G. R. Spangler. 1982. A review of the adaptive management workshop addressing salmonid/lamprey management in the Great Lakes. Great Lakes Fish. Comm., Spec. Publ. 82-2. 57p.

Spangler, G. R. and L. D. Jacobson [eds.], 1985. A workshop concerning the application of integrated pest management (IPM) to sea lamprey control in the Great Lakes. Great Lakes Fish. Comm., Spec. Publ. 85-2. 97p.

Macroinvertebrates collected from the St. Marys River. (Duffy *et al*. 1986, Table 19).

Scientific name

- PORIFERA
  - *Eunapius fragilis*
  - *Spongilla lacustris*
- TARDIGRADA
- COELENTERATA
  - *Hydra americana*
- TURBELLARIA
  - *Dugesia* sp.
- NEMERTEA
- BRYOZOA
- OLIGOCHAETA
  - Branchiobdellidae
    - *Bdellodrilus* sp.
  - Glossoscolecidae
    - *Sparganophilus eiseni*
  - Haplotaxidae
    - *Haplotaxis gordioides*
  - Lumbriculidae
    - *Lumbriculus variegatus*
    - *Stylodrilus heringianus*
  - Naididae
    - *Amphichaeta* sp.
    - *Arctionais lomondi*
    - *Chaetogaster diastriphus*
    - *Chaetogaster limnae*
    - *Nais barbata*
    - *Nais communis*
    - *Nais simplex*
    - *Nais variabilis*
    - *Ophidonais serpentina*
    - *Paranais littoralis*
    - *Paranais simplex*
    - *Piquetiella michiganensis*
    - *Pristina foreli*
    - *Pristina longiseta longiseta*
    - *Specaria josinae*
    - *Stevensoniana trivandana*
    - *Stylaria fossularis*
    - *Uncinais uncinata*
    - *Vejdovskyella comata*
  - Tubificidae
    - *Aulodrilus americanus*
    - *Aulodrilus limnobius*
    - *Aulodrilus piqueti*
    - *Aulodrilus pleuriseta*
    - *Euilyodrilus vejdovskyi*
    - *Limnodrilus angustipenis*
    - *Limnodrilus cervix*
    - *Limnodrilus cladaredeanus*
    - *Limnodrilus hoffmeisteri*
    - *Limnodrilus profundicola*
    - *Limnodrilus spiralis*
    - *Limnodrilus udekemianus*
    - *Peloscolex ferox*
    - *Peloscolex freyi*
    - *Peloscolex multisetosis*
    - *Peloscolex superiorensis*
    - *Peloscolex variegatus*
    - *Potamothrix moldaviensis*
    - *Potamothrix vejdovskyi*
    - *Psammoryctides curvisetosus*
    - *Rhyacodrilus montana*
    - *Rhyacodrilus coccineus*
    - *Tubifex ignotus*
    - *Tubifex kessleri*
    - *Tubifex newaensis*
    - *Tubifex templetoni*
    - *Tubifex tubifex*
- HIRUDINEA
  - Erpobdellidae
    - *Dina lateralis*
    - *Erpobdella punctata*
    - *Mooreobdella microstoma*
    - *Nephelopsis obscura*
  - Glossiphoniidae
    - *Actinobdella* sp.
    - *Actinobdella inequiannulata*
    - *Batracobdella michiganensis*
    - *Glossophonia complanata*
    - *Helobdella elongata*
    - *Helobdella fusca*
    - *Helobdella michiganiensis*
    - *Helobdella stagnalis*
    - *Placobdella montifera*
  - Hirudinidae
    - *Haemopsis marmata*
    - *Macrobdella decora*
  - Pisacolidae
    - *Pisacola* sp.
- POLYCHAETA
  - *Manayunkia speciosa*
- ISOPODA
  - Asellidae
    - *Asellus intermedius*

(continued).

Asellus racovitzai racovitzai
Lirceus sp.
AMPHIPODA
Gammaridae
Allocrangonyx sp.
Crangonyx gracilis
Gammarus fasciatus
Talitridae
Hyalella azteca
Haustoriidae
Pontoporeia hoyi
DECAPODA
Astacidae
Orconectes propinquus
Orconectes virilis
ACARINA
Hydracarina
COLLEMBOLA
Isotomurus sp.
EPHEMEROPTERA
Baetidae
Baetis sp.
Callibaetis sp.
Cloen sp.
Baetiscidae
Baetisca sp.
Caenidae
Brachycercus sp.
Caenis sp.
Ephemeridae
Ephemerella sp.
Ephemera simulans
Hexagenia limbata
Heptageniidae
Stenacron sp.
Stenonema tripunctatum
Leptophlebidae
Leptophlebia sp.
Paraleptophlebia sp.
Metretopodidae
Siphloplecton sp.
Siphlonuridae
Ameletus sp.
Isonychia sp.
Parameletus sp.
ODONATA
Aeschnidae
Aeschna canadensis
Boyeria sp.
Coenagrionidae
Enallagma boreale
Enallagma hageni
Nehalennia irene
Cordulidae
Epicordulia
Somatochlora sp.
Gomphidae
Arigomphus sp.
Dromogomphus spinosus
Lestidae
Lestes disjunctus
Libellulidae
Libelulla sp.
Sympetrum rubicundilum
HEMIPTERA
Belostomatidae
Belostoma sp
Lethocerus sp.
Corixidae
Sigara alternata
Trichocorixa sp.
Gelastocoridae
Gelastocoris sp.
Gerridae
Gerris sp.
Hebridae
Hebrus sp.
Merragata sp.
Hydrometridae
Hydrometra sp.
Mesoveliidae
Mesovelia sp.
Nepidae
Ranatra sp.
Notonectidae
Buenoa sp.
Veliidae
Microvelia sp.
MEGALOPTERA
Sialis sp.
NEUROPTERA
Sisyra sp.
TRICHOPTERA
Helicopsychidae
Helicopsyche borealis
Hydropsychidae
Cheumatopsyche sp.
Hydropsyche sp.
Potamyia flava

Hydroptilidae
- Hydroptila sp.
- Ithytrichia sp.
- Ochrotrichia sp.
- Oxyethira sp.

Lepidostomatidae
- Lepidostoma sp.

Leptoceridae
- Ceraclea sp.
- Mystacides sp.
- Nectopsyche sp.
- Neuroclipsis sp.
- Nyctiophylax sp.
- Oecetis sp.
- Trianodes sp.
- Setodes sp.

Limnephilidae
- Grammotaulus sp.
- Limnephilus sp.
- Nemotaulus sp.
- Platycentropus sp.
- Pycnopsyche sp.

Molannidae
- Molanna sp.

Philopotamidae
- Wormaldia sp.

Phryganeidae
- Agrypnia sp.
- Banksiola sp.
- Fabria sp.
- Phryganea sp.
- Ptilostomis sp.

Polycentropidae
- Phylocentropus sp.
- Polycentropus sp.

Psychomyiidae
- Psychomia sp.

Rhyacophilidae
- Rhyacophila sp.

LEPIDOPTERA

Pyralidae
- Acentropus sp.
- Bellura sp.
- Nymphula sp.
- Paraponyx sp.

PLECOPTERA

Perlidae
- Isoperla sp

COLEOPTERA

Chrysomelidae
- Donacia sp.

Dytiscidae
- Deronectes depressus
- Hydrovatus sp.

Elmidae
- Dubiraphia sp.
- Microcylleopus sp.

Gyrinidae
- Gyrinus sp.
- Dineutus sp.

Haliplidae
- Brychius sp.
- Haliplus sp.
- Haliplus cribrarius

Hydrophilidae
- Helophorus sp.

Noteridae
- Hydrocanthus sp.
- Pronoterus sp.

Psephenidae
- Psephenus sp.

HYMENOPTERA

DIPTERA

Anthomyiidae

Ceratopogonidae
- Alludomyia needhami
- Bezzia varicolor
- Culicoides sp.
- Dasyhelia sp.
- Palpomyia prunescens
- Stilobezzia sp.

Chironomidae
- Ablabesmia sp.
- Chironomus sp.
- Cladotanytarsus sp.
- Clinotanypus sp.
- Coleotanypus sp.
- Conchapelopia sp.
- Constempellina sp.
- Corynoneura sp.
- Cricotopus sp.
- Cryptochironomus sp.
- Cryptocladopelma sp.
- Cryptotendipes sp.
- Demicryptochironomus sp.
- Diamesa sp.
- Dicrotendipes sp.
- Endochironomus sp.

Enfeldia sp.
Epoicocladius sp.
Eukerferrilia sp.
Glyptotendipes sp.
Heterotrissocladius sp.
Labrundinia sp.
Larsia sp.
Lauterborniella sp.
Metriocnemus sp.
Microspectra sp.
Microtendipes sp.
Monodiamesa sp.
Orthocladus sp.
Parachironomus sp.
Paracladopelma sp.
Paralauterborniella sp.
Parametriocnemus sp.
Paratanytarsus sp.
Phaenospectra sp.
Polypedilum sp.
Potthastia sp.
Procladius sp.
Psectrocladius sp.
Psectrotanypus sp.
Pseudochironomus sp.
Pseudosmittia sp.
Rheotanytarsus sp.
Stempellinia sp.
Stenochironomus sp.
Stictochironomus sp.
Tanytarsus sp.
Thienemanniella sp.
Tribelos sp.
Trissocladius sp.
Xenochironomus sp.

Culicidae
Aedes intrudens
Chaoborus sp.

Dixidae
Dixa sp.

Ephydridae

Empididae
Hemerodromia sp.

Sciomyzidae
Sepedon fuscipenis

Simulidae
Simulium sp.

Stratiomyiidae
Stratiomys sp.

Tabanidae
Chrysops sp.

Tipulidae
Antocha sp.
Erioptera sp.

GASTROPODA

Ancylidae
Ferrisia paralella

Hydrobiidae
Amnicola limnosa
Amnicola walkeri
Probythinella lacustris
Somatogyrus subglobosus

Lymnaeidae
Acella haldemani
Aplexa hypnorum
Bulimnea megasoma
Fossaria parva
Lymnaea palustris
Lymnaea stagnalis
Lymnaea stagnalis jugularis
Lymnaea stagnalis sanctae mariae
Pseudosuccinus columella
Stagnicola catascopium catascopium
Stagnicola elodes

Physidae
Physa gyrina gyrina
Physa heterostropha
Physa integra
Physa jennessi skinneri

Planorbidae
Helisoma anceps anceps
Helisoma campanulatum
Helisoma corpulentum vermilion
Helisoma trivolvis trivolvis
Helisoma trivolvis binneyi
Gyraulus deflectus
Gyraulus parvus
Promenetus exacuous exacuous
Planorbula armiger

Pleuroceridae
Goniobasis livescens
Pleurocera acuta

Truncatellidae
Pomatiopsis lapidaria

Valvatidae
Valvata sincera sincera
Valvata tricaranata

(completed).

Viviparidae	Sphaeriidae
Campeloma decisum	*Pisidium compressum*
PELECYPODA	*Pisidium fallax*
Unionidae	*Pisidium nitidum*
Alasmidonta calceolus	*Pisidium idahoensis*
Anodonta grandis grandis	*Pisidium variabile*
Anodontoides ferussacianus	*Pisidium* sp.
Elliptio complanata	*Sphaerium nitidum*
Lampsilis radiata siliquoidea	*Sphaerium occidentale*
Lasmigona compressa	*Sphaerium rhomboideum*
Lasmigona costata	*Sphaerium securis*
Ligumia recta latissima	*Sphaerium striatinum*
	Sphaerium sp.

APPENDIX VI

Fishes identified from the St. Marys River (Duffy et al. 1986), and months and temperatures at which these fish spawn in Upper Great Lakes waters (Auer 1982).

Scientific name	Common name	Spawning months	Spawning temperature
PETROMYZONTIDAE			
Petromyzon marinus	Sea lamprey	May-Jun	[illegible]
Lampetra appendix	American brook lamprey	Apr-Jun	[illegible]
ACIPENSERIDAE			
Acipenser fulvescens	Lake sturgeon	May-Jun	[illegible]
LEPISOSTEIDAE			
Lepisosteus osseus	Longnose gar	May-Jun	[illegible]
AMIIDAE			
Amia calva	Bowfin	Apr-May	[illegible]
CLUPEIDAE			
Alosa pseudoharengus	Alewife	Jul-Aug	[illegible]-27
Dorosoma cepedianum	Gizzard shad	Jun-Jul	10-24
SALMONIDAE			
Coregonus artedii	Lake herring	Nov-Dec	3-5
Coreongus clupeaformis	Lake whitefish	Nov-Dec	4-12
Prosopium cylindraceum	Round whitefish	Oct-Nov	0
Salmo gairdneri	Rainbow trout	Apr-Jun	10-15.5
Salmo trutta	Brown trout	Oct-Nov	6.7-8.9
Salmo salar	Atlantic salmon	Oct-Nov	-
Salvelinus fontinalis	Brook trout	Sep-Nov	9.4
Salvelinus namaycush	Lake trout	Aug-Dec	2.8-14.4
Salvelinus fontinalis x namaycush	Splake	-	-
Oncorhynchus gorbuscha	Pink salmon	Jul-Oct	11-13
Oncorhynchus kisutch	Coho salmon	Sep-Oct	-
Oncorhynchus tshawytscha	Chinook salmon	Sep-Oct	-
OSMERIDAE			
Osmerus mordax	Rainbow smelt	Apr-May	4-15
UMBRIDAE			
Umbra limi	Central mudminnow	Mar-Apr	12.8-15.6
ESOCIDAE			
Esox lucius	Northern pike	Mar-May	4-11
Esox masquinongy	Muskellunge	Apr-May	9-15
CYPRINIDAE			
Carassius auratus	Goldfish	May-Jun	16
Cousius plumbeus	Lake chub	May-Jun	10
Cyprinus carpio	Carp	May-Aug	15-25
Hybopsis storeriana	Silver chub	May-Jun	16-27
Nocomis micropogon	River chub	May-Jun	15-21
Notemigonus crysoleucas	Golden shiner	May-Aug	20-21
Notropis atherinoides	Emerald shiner	Apr-Aug	22
Notropis cornutus	Common shiner	May-Jun	15-25
Notropis heterodon	Blackchin shiner	-	-
Notropis heterolepis	Blacknose shiner	Jun-Jul	-
Notropis hudsonius	Spottail shiner	Jun-Jul	15-20
Notropis stramineus	Sand shiner	Jun-Jul	21-27
Notropis volucellus	Mimic shiner	-	-
Phoxinus eos	Northern redbelly dace	May-Aug	21-27

(continued)

Scientific name	Common name	Spawning months	Spawning temperature (°C)
CYPRINIDAE (continued)			
Pimephales notatus	Bluntnose minnow	May-Aug	19-21
Pimephales promelas	Fathead minnow		16-18
Rhinichthys atratulus	Blacknose dace	May-Jun	12-20
Rhinichthys cataractae	Longnose dace	Jun-Jul	14-19
Semotilus atromaculatus	Creek chub	Apr-Jun	13-18
CATOSTOMIDAE			
Catostomus catostomus	Longnose sucker	Apr-May	10-15
Catostomus commersoni	White sucker	Apr-May	7.2-10
Moxostoma anisuram	Silver redhorse		13-14
Moxostoma erythrurum	Golden redhorse	May	17-22
Moxostoma macrolepidotum	Shorthead redhorse	May	11-16
ICTALURIDAE			
Ictalurus nebulosus	Brown bullhead	Jun	18.5-25.8
Ictalurus punctatus	Channel catfish	Jun-Jul	21.1-29.5
ANGUILLIDAE			
Anguilla rostrata	American eel		
CYPRINODONTIDAE			
Fundulus diaphanus	Banded killifish	May-Aug	21-32.2
GADIDAE			
Lota lota	Burbot	Feb-Mar	0.4
GASTEROSTEIDAE			
Culea inconstans	Brook stickleback	May-Jul	8-19
Gasterosteus aculeatus	Threespine stickleback	Jun-Jul	14-22
Pungitius pungitius	Ninespine stickleback	Jun-Jul	11-12
PERCOPSIDAE			
Percopsis aniscanaycus	Trout-perch	Jun-Jul	4.4-20
PERCICHTHYIDAE			
Morone chrysops	White bass	Jun	11-15
CENTRARCHIDAE			
Ambloplites rupestris	Rock bass	May-Jul	15.6-21.1
Lepomis gibbosus	Pumpkin seed	May-Jul	17.5-29
Lepomis macrochirus	Bluegill	Jun-Aug	17.2-30.5
Micropterus dolanieui	Smallmouth bass	Apr-Jun	12.8-23.9
Micropterus salmoides	Largemouth bass	May-Jun	16-23.9
Pomoxis nigrcznaculatus	Black crappie	May-Jun	17.4-20
PERCIDAE			
Etheostana exile	Iowa darter	May-Jun	12-15
Etheostana -	Johnny darter	Apr-Jun	11.7-21.1
Perca flavescens	Yellow perch	May-Jun	5.6-18.5
Percina caprodes	Logperch	Jun-Jul	1o-15
Stizostedion canadense	Sauger	Apr-May	3.7-11.7
Stizostedion vitreum vitreum	Walleye	Apr-May	3.3-14.4
SCIAENIDAE			
Aplodinotus grunniens	Freshwater drum	May-Jun	18-25
COTTIDAE			
Cottus bairdi	Mottled sculpin	Mar-May	5.6-16.7
Cottus cognatus	Slimy sculpin	Apr-May	3-11.5
Cottus ricei	Spoonhead sculpin	May	4.5-10
Myoxocephalus quadricornis	Fourhorn sculpin	Nov-May	