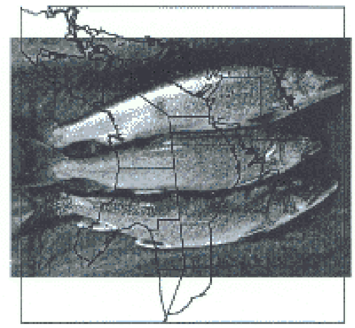
A LAKE TROUT REHABILITATION GUIDE FOR LAKE HURON



Great Lakes Fishery Commission

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August 1998

A. LAKE TROUT REHABILITATION GUIDE FOR LAKE HURON

edited by

Mark P. Ebener
Inter-Tribal Fisheries and Assessment Program
Chippewa/Ottawa Treaty Fishery Management Authority
179 W. 3 Mile Road
Sault Ste. Marie, MI 49783

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Great Lakes Fishery Commission
2100 Commonwealth Blvd., Suite 209
Ann Arbor, MI 481051563

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Mark P. Ebener, Editor
Intertribal Fisheries and Assessment Program
Chippewa/Ottawa Treaty Fishery Management Authority
179 W. 3 Mile Road
Sault Ste. Marie, MI 49783

ABSTRACT. The goal of lake trout *(Salvelinus namaycush)* rehabilitation in Lake Huron is to restore self-sustaining populations that are capable of yielding 1.4 to 1.8 million kg by the year 2020. Milestones and indicators for evaluating progress at achieving the rehabilitation goal should include: (1) the reproductive potential of hatchery-reared lake trout in high-priority zones and refuges, (2) the proportion of wild lake trout in spawning populations, and (3) the degree with which the fish community inhibits lake trout survival or reproduction. Stocking strategies, population regulation, community regulation, and strategic planning and stakeholder involvement are necessary to successfully rehabilitate lake trout. Classification of rehabilitation zones should reflect lake trout survival and the amount of spawning habitat, and rehabilitation efforts should be concentrated in areas with the largest amount of spawning habitat. Fishery regulations, such as depth restrictions and refuges, should be established to protect both juvenile and adult lake trout from exploitation. Unacceptably high sea lamprey mortality should be reduced. Stocking 2.5 yearling lake trout per ha of surface water habitat < 40 fathoms deep should occur in each rehabilitation zone and should be viewed as a cumulative process that considers historic spawning habitat, fishing mortality, sea lamprey (Petromyzon *marinus)* mortality, and rearing capacity of hatcheries. Stocking should consist of many different strains whose efficacy is first evaluated by multistrain-planting experiments. Supplemental-stocking strategies that use other lake trout life-history stages should be recognized as integral parts of the rehabilitation effort. Stocking and fishing rates should be adjusted to maintain at least 17 to 135 adult lake trout per 305 m of gillnet on historic spawning sites. Future research and assessment necessary to evaluate lake trout rehabilitation should focus on community interactions, measurement of progress toward rehabilitation objectives, evaluation of stocking strategies, population and community modeling, and critical life stages.

INTRODUCTION

In March 1983, the Lake Huron Committee (LHC) of the Great Lakes Fishery Commission established the Lake Huron Lake Trout Technical Committee and charged it with drafting a coordinated, lakewide lake trout *(Salvelinus namaycush)* rehabilitation plan. The technical committee drafted a provisional rehabilitation plan in 1985 and amended it in 1986. Shortly thereafter, the name of the committee was shortened to Lake Huron Technical Committee (LHTC), and it was charged with updating the amended plan. The LHTC submitted an updated rehabilitation plan to the LHC in 1992. Meanwhile, fish-community objectives for Lake Huron were being discussed, and agencies with membership in the LHC were developing lake trout rehabilitation plans for their individual jurisdictions. Accordingly, the 1992 plan was tabled by the LHC pending completion of the fish-community objectives exercise.

After publication of fish-community objectives (DesJardine et al. 1995), the LHTC was charged with modifying the 1992 plan. The LHC wanted a scientific guide useful for agencies involved in rehabilitation of Lake Huron lake trout populations. The LHC requested that the guide contain:

- Information on preferred strains for stocking
- Relevant findings from the International Conference on Restoration of Lake Trout in the Laurentian Great Lakes (RESTORE)
- Proposed refuges
- Requirements for early life-history research
- Criteria for establishing rehabilitation zones

Because each member agency on the LHC must consider various aspects of lake trout rehabilitation in conjunction with overall agency plans, creating a guide instead of a plan was deemed to be a more appropriate approach.

The LHTC has already written an assessment plan for evaluating certain stocking experiments in Lake Huron. The objectives, methods of sampling, agency responsibilities, and a schedule for each stocking experiment are described in an assessment plan (McClain et al. 1995).

Background

Before 1940, annual commercial harvests of lake trout from Lake Huron ranged from 1.8 to 2.7 million kg (1 kg = 2.205 lbs) (Baldwin et. al. 1979). After 1940, the harvest of lake trout declined dramatically-beginning first in the main basin of Lake Huron and later extending to Saginaw Bay and Georgian Bay (Berst and Spangler 1973; Eshenroder et al. 1995). Overfishing contributed to the decline of lake trout populations, but predation by sea lampreys *(Petromyzon marinus)* was the critical factor in the final decline of lake trout in Lake Huron (Berst and Spangler 1973; Coble et al. 1990; Eshenroder et al. 1992). Because of declining abundance, commercial harvests of lake trout were insignificant by 1946 in the main basin and by 1960 in Georgian Bay and the North Channel. Only two small remnant lake trout populations survived-one in Iroquois Bay off the North Channel and another in Parry Sound in Georgian Bay (Fig. 1). Lake trout populations declined in Parry Sound in the 1960s and 1970s, but the population has been recovering in recent years (Ontario Ministry of Natural Resources 1994, 1995). Lake trout reproduction in Iroquois Bay is inadequate to sustain the population.

Chemical control of sea lampreys (Smith and Tibbles 1980), combined with annual plantings of hatchery-reared lake trout and strict control or elimination of commercial lake trout fisheries, resulted in observable natural reproduction in Lake Huron beginning in the early 1980s (Nester and Poe 1984). Reproduction by hatchery-reared lake trout has produced measurable year-classes in Thunder Bay, Michigan (Johnson and VanAmberg 1995) and in South Bay, Manitoulin Island (Anderson and Collins 1995). Naturally produced age-0 lake trout have been caught on Six Fathom Bank (Fig. 1) every year since 1992, but naturally produced age-l and older lake trout have not been found. Naturally produced lake trout are not abundant enough, except in Parry Sound, to sustain themselves at current rates of mortality in Lake Huron (Johnson et al. 1995).

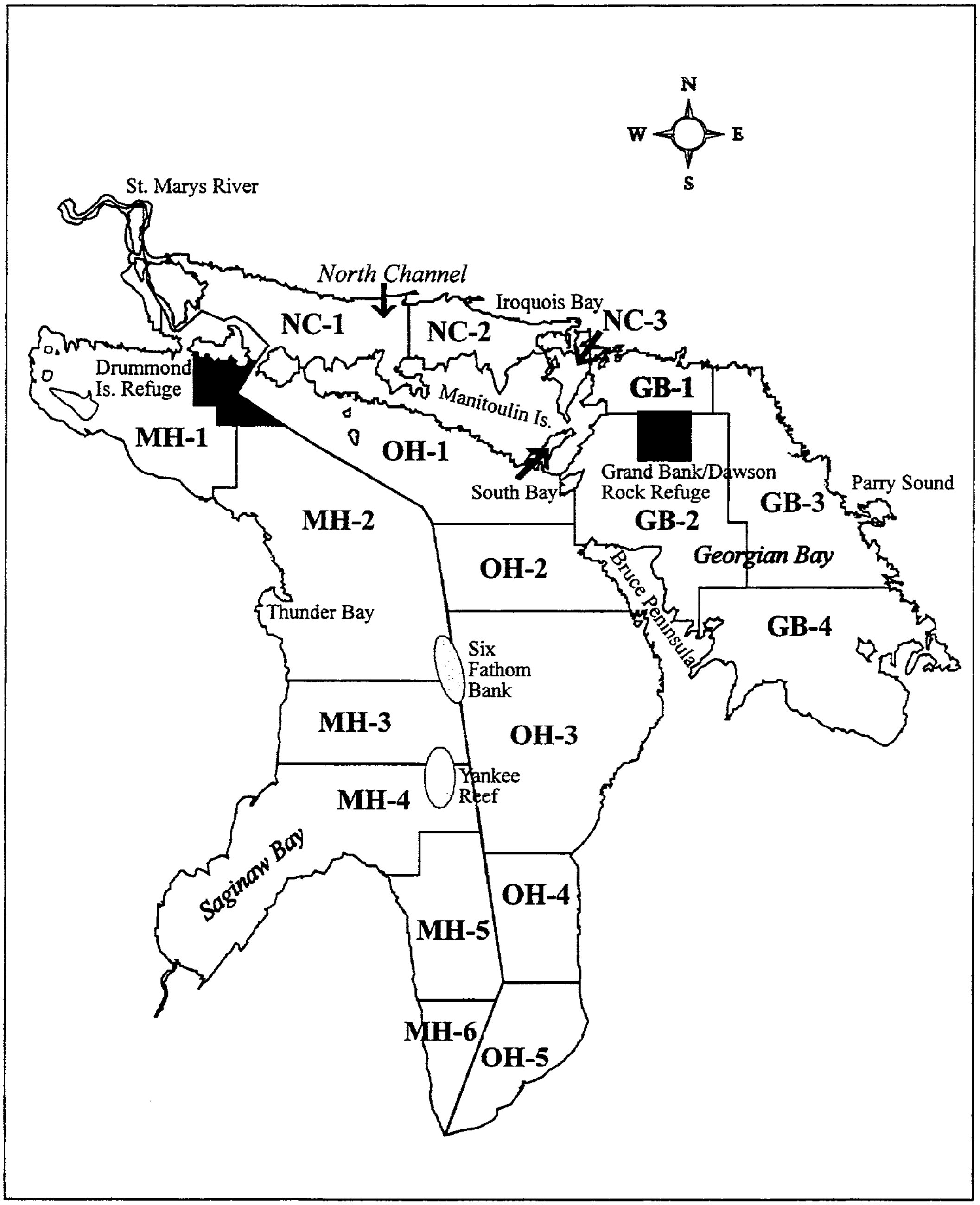

Fig. 1. Map of Lake Huron showing statistical districts and locations referenced in this report.

Although lake trout are reproducing in Lake Huron, populations remain much less abundant than they were historically in most areas, and they are supported almost solely by hatchery-reared fish (Johnson et al. 1995). The lake trout restoration effort in Lake Huron is being impeded by:

- Fishing harvests
- Sea lamprey predation
- Insufficient hatchery rearing space
- Deferment of rehabilitation effort in areas where suitable spawning habitat is most plentiful within the main basin

Lake trout sport and commercial catches from 1986 to 1992 were only 20% of the rehabilitation harvest goal and 10% of the historic harvest during 1912-40. Although control of sea lampreys continues at the present time, sea lampreys are more abundant in Lake Huron than any other Great Lake because of an uncontrolled larval population in the St. Marys River (Morse et al. 1995).

MILESTONES AND INDICATORS

The process of rehabilitating lake trout populations to self-sustaining status is viewed as having a beginning, middle, and end. The beginning of the process involves planting hatchery-reared fish. The middle of the process involves the control of sea lampreys and fishing mortality and rehabilitation or protection of habitats critical to lake trout survival and reproduction (Francis et al. 1979). Habitat includes the abundance and composition of species that interact with lake trout as well as the substrate they use for reproduction. The end of rehabilitation in Lake Huron will occur when self-sustaining lake trout populations are capable of yielding 1.4 to 1.8 million kg targeted for the year 2020 (DesJardine et al. 1995). Lake trout rehabilitation in Lake Huron is currently much closer to its beginning than to its end.

Milestones and indicators are needed to measure progress in rehabilitating lake trout in Lake Huron.

- Milestones are points along a trajectory that can be used to assess progress in relation to a final goal

- Indicators are measurable quantities (for example, catch per effort (CPE), average age, mortality rate, sex ratios, and sea lamprey marking (Marshall et al. 1987)) that determine whether a milestone can be or is being reached

The following milestones and indicators are recommended as guides for evaluating progress in achieving rehabilitated lake trout populations in Lake Huron.

Milestone 1

Seven to 12 years after stocking begins, the reproductive potential of hatchery-reared lake trout in high-priority zones and refuges should be sufficient to produce measurable quantities of lake trout offspring caught in standard assessments.

Indicators for Milestone 1

- The average age of hatchery-reared, mature lake trout is one year older than the average age of first maturity

- The average catch of adult lake trout on the spawning grounds should range from 17 to 135 fish per 305 m (1 m = 3.281 ft) of gillnet

- The average catch of juvenile wild lake trout made in annual surveys should be one or two fish per 305 m of gillnet.

Milestone 2

Within 14 to 24 years after stocking begins, wild lake trout should make up sustainable levels of the spawning population.

Indicators for Milestone 2

- The average age of wild, mature lake trout should be 9.5 years in the northern and offshore areas of the main basin and 8.5 years in Georgian Bay and in the southern waters of the main basin

- The average catch of wild adult lake trout on the spawning grounds should range from 17 to 135 fish per 305 m of gillnet

- The average catch of juvenile wild lake trout made during annual surveys should be one or two fish per 305 m of gillnet

Milestone 3

The community associated with lake trout does not inhibit lake trout survival or reproduction.

Indicator for Milestone 3

The egg-to-yearling survival of lake trout ranges from 0.001 to 0.004 and resembles that found in inland lake trout lakes.

The milestones and indicators were created based on several prerequisites:

- Stocking and control of mortality must be sufficient to establish a population that can become self-sustaining

- Stocking by itself is not necessarily an effective rehabilitation effort

- The number of lake trout stocked must be consistent from year to year and must be large enough to produce a minimum number of adults in assessment catches (Selgeby et al. 1995)

- The abundance of adult lake trout must translate into naturally produced yearling lake trout that grow and subsequently contribute to the spawning stock

- Habitat conditions and fish communities in Lake Huron should allow for the normal range of survival from the egg to yearling stage (Matuszek et al. 1990; Evans and Willox 1991; Evans et al. 1991; Jones et al. 1995)

- Lake trout will help shape the fish community through predation, but the food being consumed should not inhibit the ability of lake trout to reproduce (Fisher et al. 1996)

The milestones and indicators were created with the understanding that growth and maturation rates increase from northern to southern areas of the main basin and that growth is faster in Georgian Bay than in the main basin (Eshenroder et al. 1995; Johnson et al. 1995).

INSIGHTS FROM RESTORE

The 48 papers associated with RESTORE (Selgeby 1995) offer insights that can be applied to the lake trout rehabilitation process in Lake Huron. These papers consistently reaffirm many of the same basic ideas about lake trout rehabilitation that have become established in the Great Lakes basin-but with much better documentation. Recommendations from RESTORE for management of lake trout in the Great Lakes can be sorted into four categories:

- Stocking strategies

- Population regulation

- Community regulation

- Strategic planning and stakeholder involvement

Stocking Strategies

Almost every synthesis paper has urged the stocking of a wider diversity of lake trout more representative of that known to occur among North American populations (Burnham-Curtis et al. 1995). This recommendation relates not only to shallow-water forms but, more importantly, to the use of deep-water forms extant in Lake Superior. Lake Huron was known to have supported specialized, deep-water forms of lake trout, the deepest of which became extinct in the 1930s (Berst and Spangler 1973; Eshenroder et al. 1995; Krueger and Ihssen 1995).

Reliance on a single strategy of stocking yearling-sized lake trout was also questioned. Yearlings were seen to have potential only at inshore areas where rocky outcrops are prevalent and at certain offshore sites where distance and depth discourage emigration. Stocking early-life stages of lake trout, capable of imprinting, was recommended for intermediate sites, which are separated from the mainland but within the littoral zone. Construction of spawning habitat in areas where it is scarce was suggested by Marsden et al. (1995). In Lake Huron, this strategy may be useful only from MH-4 to MH-6 and from OH-4 to OH-5 because the rest of the lake has suitable spawning habitat. Several papers from RESTORE suggested stocking native adult lake trout from Lake Superior in areas that are devoid of adults (Burnham-Curtis et al. 1995; Marsden et al. 1995).

Population Regulation

Developing abundant spawning populations in areas where spawning habitat is plentiful remains a key recommendation. Three obstacles appear significant in preventing achievement of lake trout rehabilitation in Lake Huron.

- The ratio of the number of sea lampreys to the number of lake trout is far too high in the northern waters of the main basin and in the North Channel

- The preponderance of the spawning habitat is in zones managed for commercial fishing at the expense of lake trout rehabilitation (Eshenroder et al. 1995)

- The effort to build spawning populations in Michigan's waters was diminished by the lack of a. comparable effort in Ontario waters of the main basin up to 1992 (Eshenroder et al. 1995)

Community Regulation

Two ideas emerged concerning community effects:

- Lake trout do best in simple communities (Jones et al. 1995)

- Lake trout at high levels of abundance are capable of shaping a community to its benefit - that is, making it more simple

The alewife *(Alosa pseudoharengus)* was seen to be especially problematic. Unlike the native planktivores, alewives move to shoal water for spawning in the spring when lake trout fry are emerging and vulnerable to predation (Krueger et al. 1995). Alewives eaten by lake trout and other salmonines are suspected of causing a thiamine deficiency in female fish that results in high mortality of newly hatched fry (Fitzsimons 1995; Fisher et al. 1996). Besides the alewife, other non-indigenous species may inhibit reestablishment of self-sustaining lake trout populations (Evans and Olver 1995).

Strategic Planning and Stakeholder Involvement

Lake trout rehabilitation is an ecosystem-level process, and the associated goals and objectives should be incorporated into all relevant plans (such as, environmental objectives that support fish-community objectives and Lakewide Management Plans (LAMPs) that deal with ecosystem impacts). This approach will broaden the base of support for lake trout rehabilitation and create opportunities for collaborative efforts. Likewise, the rationale for rehabilitation needs to be more widely communicated to involve a wider base of stakeholders. An almost complete reliance on the harvesters of fish to provide stakeholder input was viewed as being undesirable.

REHABILITATION STRATEGIES

Rehabilitation Zones

Classification of rehabilitation zones should reflect lake trout survival and the amount of spawning habitat. Estimates of survival of lake trout should be based on a five-year average for an area and should be > 60% (I 40% annual mortality) in zones where rehabilitation is actively being pursued by an agency. Because survival varies with age, survival will be under 60% for some ages and above 60% for others, Therefore, it is more appropriate that spawning stock produced per recruit should be at least as high as would be achieved if survival were ≥ 60% for all lake trout over age 4. As of 1995, survival is ≥ 60% only in MH-4 and MB-5. Sea lampreys are too abundant in most parts of Lake Huron, except Georgian Bay, for lake trout rehabilitation to proceed. Most of the historically used spawning habitat in the main basin of Lake Huron is located in northern Michigan waters-along Manitoulin Island and the Bruce Peninsula and on Six Fathom Bank and Yankee Reef (Eshenroder et al. 1995). Lake trout rehabilitation efforts should be concentrated in areas with the largest amount of spawning habitat to increase the prospects for rehabilitation (Fig. 2). Statistical district MH-1 contains most of the spawning habitat in Michigan waters and holds an even larger share of the nearshore habitat (Eshenroder et al. 1995), but nearly all of MH-1 is a deferred rehabilitation zone. An area is designated as deferred because of excessive fishing and/or sea lamprey mortality, poor habitat, and little or no historic harvest. A deferred zone can be given a higher rehabilitation priority if survival can be increased or if rehabilitation of habitat occurs.

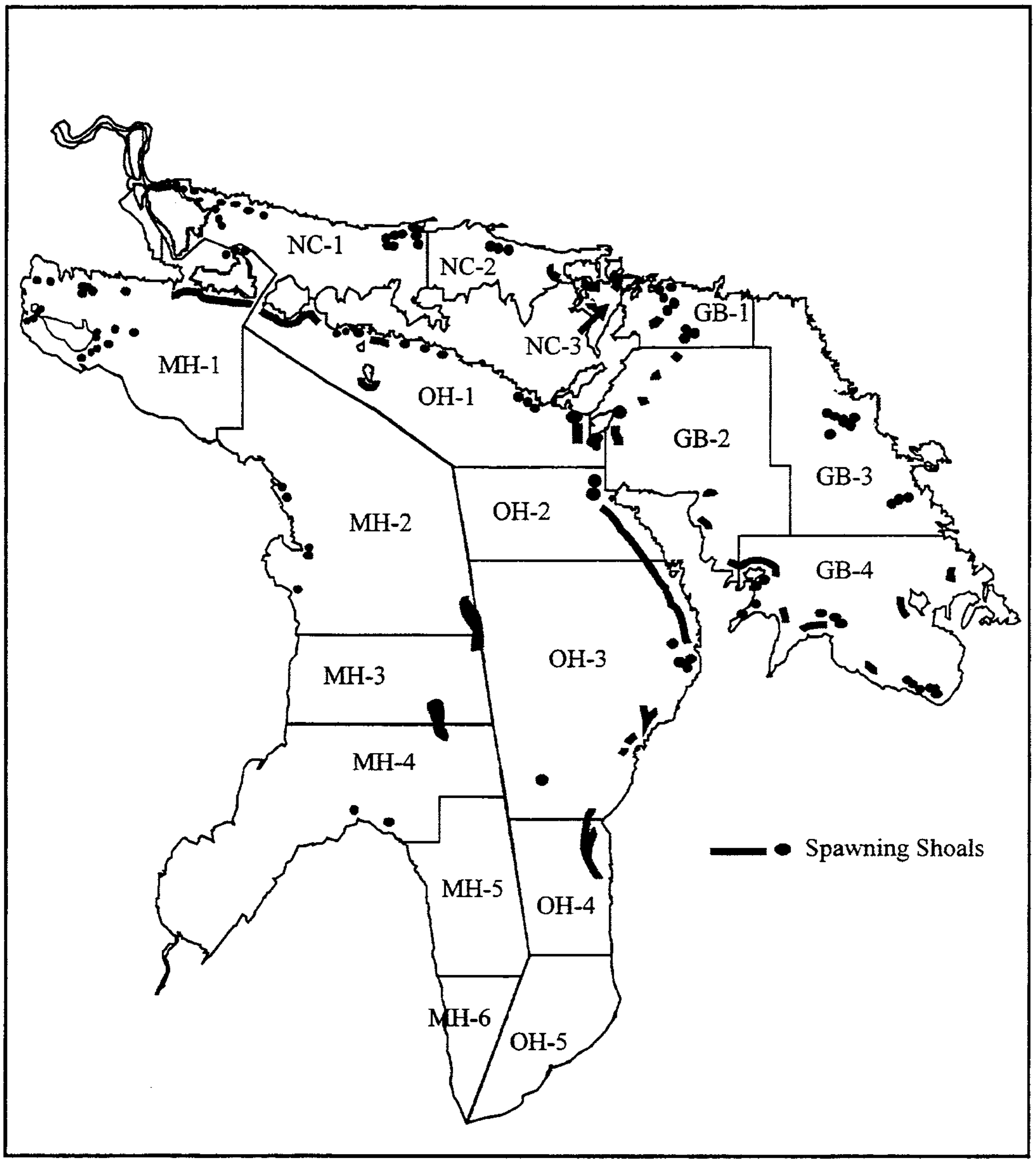

Fig. 2. Location of historic lake trout spawning shoals in statistical districts of Lake Huron based on Smith (1968) and Eshenroder et al. (1995).

Agencies should report annually mortality, stocking, and sea lamprey marking in addition to other lake trout data on a statistical district basis (Fig. 1), as described in Smith et al. (1961), even though current agency management zones may not completely align with these districts. The original statistical-district boundaries (Smith et al. 1961) have been modified to follow statistical grid lines (Appendix A) to ease reporting of data, and these modified statistical district boundaries are slightly different from the zones established in the 1986 and 1992 versions of the rehabilitation plan (Appendix B).

Fishery Regulation

In zones where rehabilitation will be pursued, small-mesh gillnet fisheries targeting bloaters *(Coregonus hoyi)* should be directed to waters deeper than 40 fathoms (1 fathom = 6 ft or 1.83 m). The incidental catch of mainly juvenile lake trout in bloater fisheries was < 1 fish per 305 m of gillnet from waters > 40 fathoms deep and 14 lake trout per 305 m of gillnet from waters < 40 fathoms deep in MH-1 and MH-2 1992-95 (Fig. 3). Bloater catches averaged 33 kg per 305 m of gillnet in waters > 40 fathoms deep, as compared with 23 kg per 305 m of gillnet in waters < 40 fathoms deep in MH-1 and MH-2 1992-95 (Inter-Tribal Fisheries and Assessment Program, 179 W. 3 Mile Road, Sault Ste. Marie, Ml, 49783, unpubl. data).

Refuges that provide lake trout protection from fishery exploitation are a useful tool for rehabilitation in Lake Huron. Grand Bank/Dawson Rock is an existing refuge in northwestern Georgian Bay (Ontario Ministry of Natural Resources 1996) as is the south shore of Drummond Island (Fig. 1). Lake trout in Wisconsin waters of Lake Superior are provided year-round protection from sport and commercial fishing by the 70,000 ha Gull Island Shoal Refuge (Swanson and Swedberg 1980; Schram et al. 1995). This refuge has aided the recovery of wild lake trout by protecting them from fishing. Both Schram et al. (1995) and Bronte et al. (1995) recommended that Gull Island Shoal Refuge be maintained to provide protection for adult lake trout.

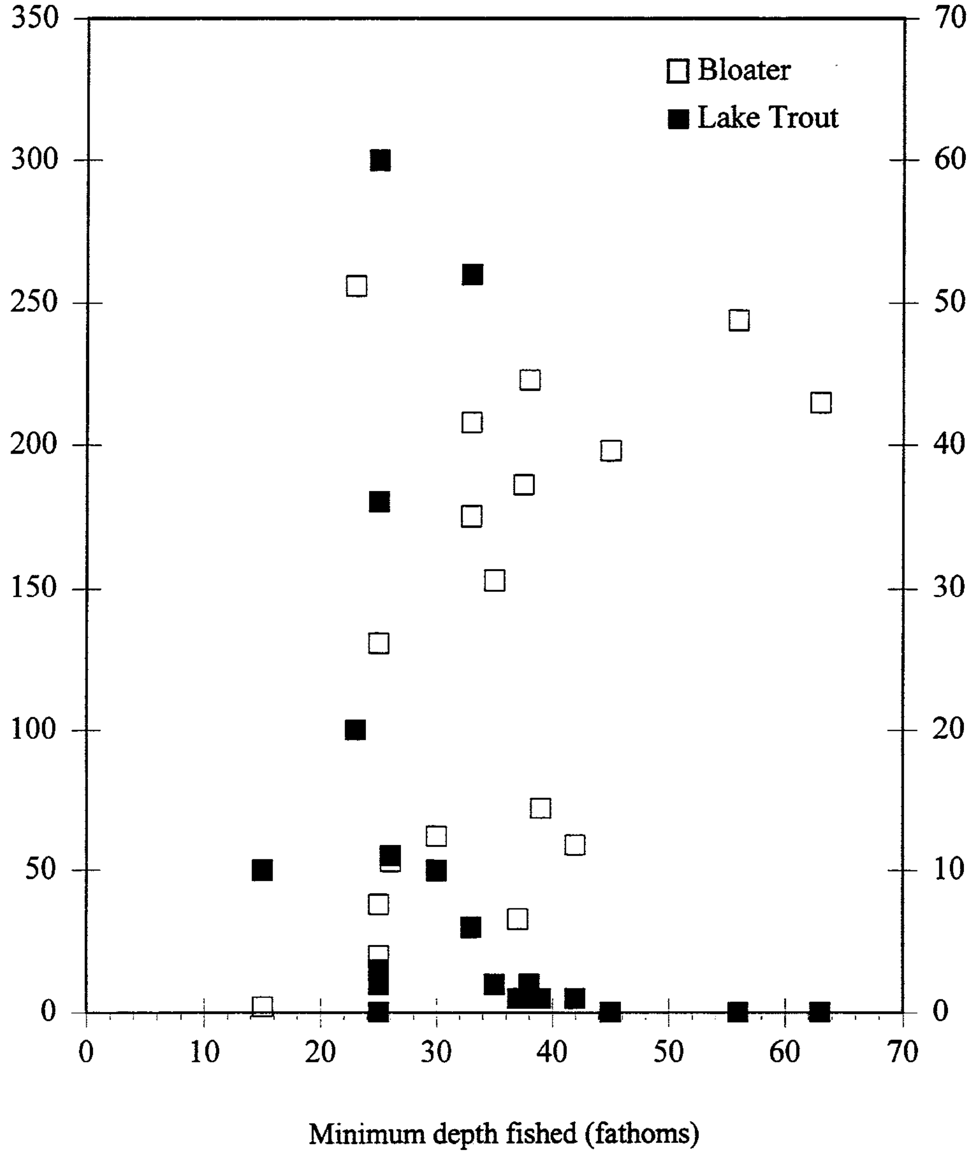

Fig. 3. The CPE of bloaters and lake trout caught in commercial gillnet fisheries targeting bloaters at various depths in statistical districts MH-1 and MH-2 during 1992-95.

Based on gillnet assessments, adult lake trout are currently most abundant at three sites in U.S. waters:

- Six Fathom Bank
- MH-4 near Port Austin
- Drummond Island Refuge

Adult abundance in the Drummond Island Refuge averaged 15 fish per 305 m of gillnet in 199 1-95 and generally increased in 199 l-95. In addition, mean size of the largest-sized lake trout increased each year (Inter-Tribal Fisheries and Assessment Program, 179 W. 3 Mile Road, Sault Ste. Marie, MI, 49783, unpubl. data):

- 748 mm in 1991
- 763 mm in 1992
- 828 mm in 1994
- 848 mm in 1995

The Drummond Island Refuge does appear to be protecting adult lake trout despite the presence of an uncontrolled sea lamprey population in the area and despite substantial commercial fishing in surrounding waters (Sitar 1996). Establishment of a refuge in waters surrounding Six Fathom Bank (Fig. 4) should be pursued to protect adult lake trout. Effective April 1997, the state of Michigan has designated that portion of Six Fathom Bank in Michigan waters as a refuge where taking, keeping, and sport fishing for lake trout are prohibited. Ontario has placed a minimum depth restriction of 40 fathoms on commercial fishing in waters around the refuge but has not restricted sport fishing in the same area. An increasing number of age-0 naturally produced lake trout has been caught on Six Fathom Bank every year since 1992, and this area presently provides the best prospects for rehabilitation in the main basin of Lake Huron. Lake trout marked with coded wire tags and stocked on Six Fathom Bank in 1985-92 were recaptured at areas throughout the main basin in 1988-95 (Fig. 5). A total of 56% of the recaptures was caught on three reefs that make up part of Six Fathom Bank. Of these recaptures, most were caught during fall spawning surveys. Protection of adult lake trout on Six Fathom Bank is essential for promoting lake trout rehabilitation throughout the main basin.

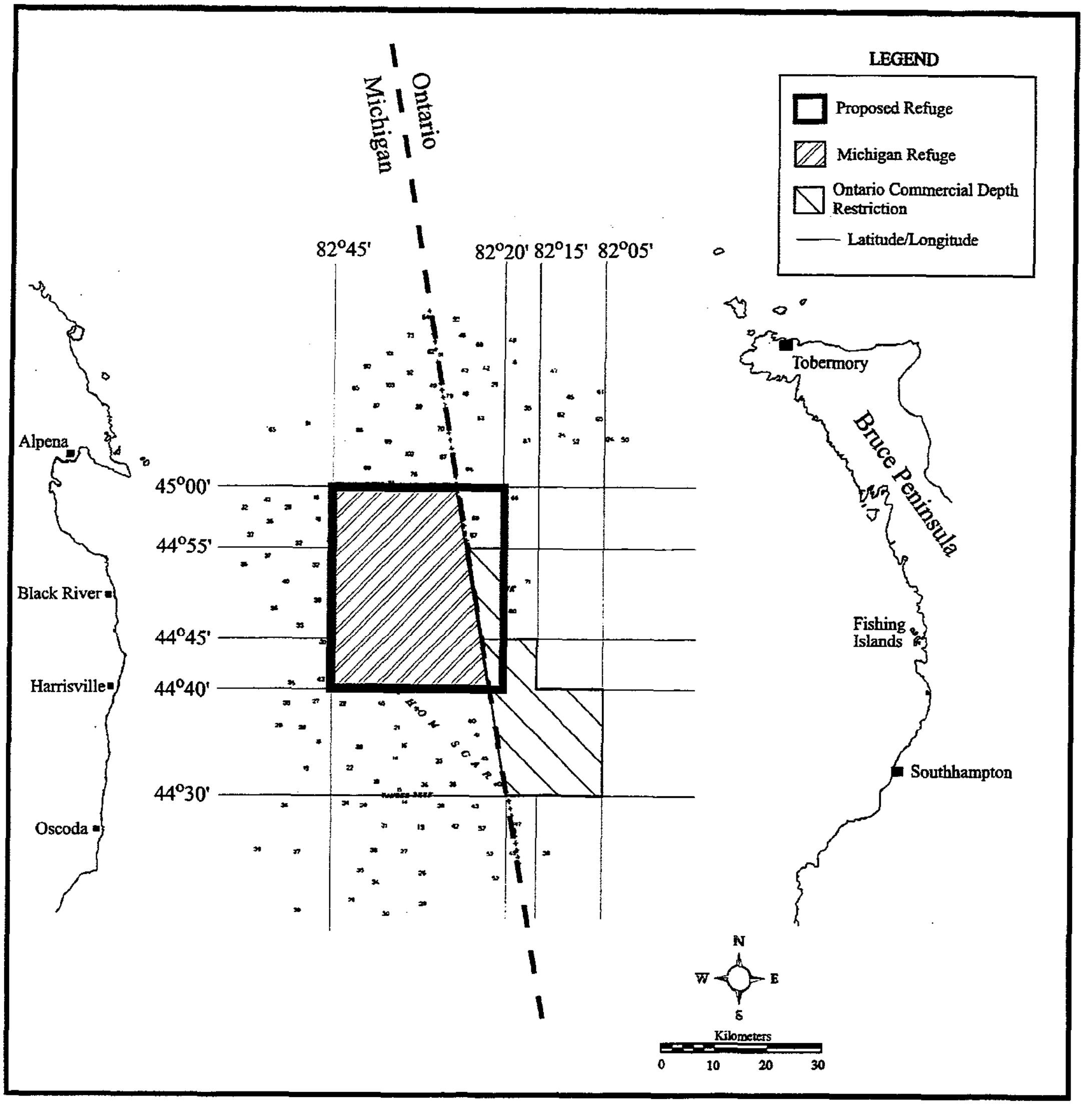

Fig. 4. Boundary for the refuge around Six Fathom Bank in central Lake Huron.

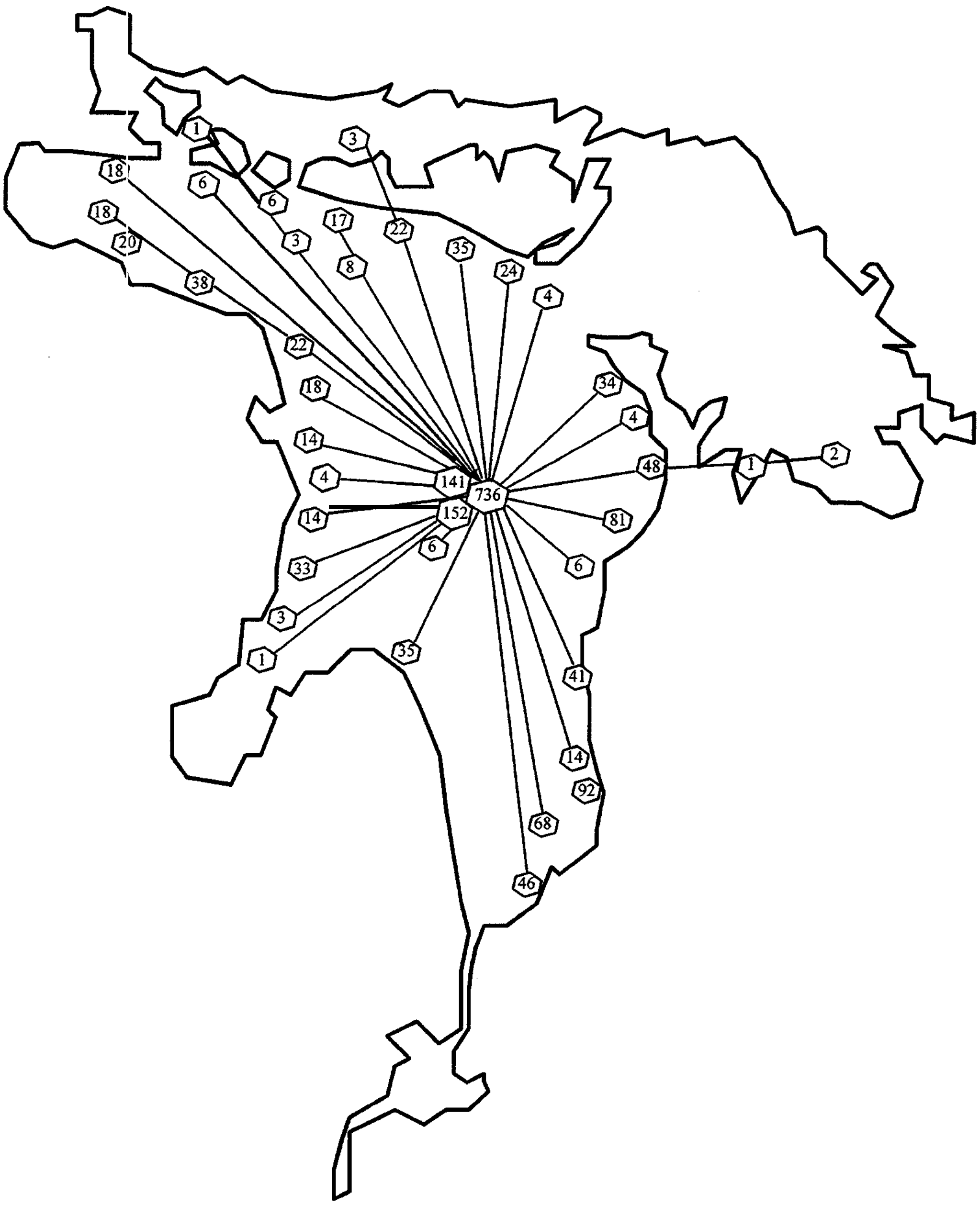

Fig. 5. Number and location of coded-wire-tagged lake trout stocked on Six Fathom Bank in 1985-92 and caught by sport and commercial fisheries and agency assessments throughout Lake Huron in 1988-95.

stocking

Since 1969, 46.5 million lake trout of various strains and life stages have been stocked into Lake Huron. Most areas of the lake have been stocked at least once, but stocked fish have reproduced only in several areas and in limited amounts (Nester and Poe 1984; Anderson and Collins 1995; Johnson and VanAmberg 1995). Stocking sites chosen in the 1986 and 1992 rehabilitation plans were based on historic yields, mortality rates, proximity to fisheries, and political/social considerations. It is recommended that future stocking be based on the following two criteria in order of priority:

- Location and amount of historic spawning sites (Smith 1968; Goodyear et al. 198 1; Eshenroder et al. 1995)

- Sea lamprey and fishing mortality (Johnson et al. 1995; Sitar 1996)

Agencies should stock 2.5 yearling lake trout per ha (1 ha = 2.47 acres) of water < 40 fathoms deep in each rehabilitation zone that contains substantial amounts of historic spawning habitat (Fig. 2). This stocking density is recommended because it was believed to have produced the high densities of adult lake trout that effected recovery in large areas of Lake Superior (Lake Superior Lake Trout Technical Committee 1986; Hansen et al. 1995). Lake Huron contains roughly 3.6 million ha of habitat < 40 fathoms deep: 1.4 million ha in U.S. waters and 2.2 million ha in Canadian waters (Table 1; Appendix C). The amount of habitat < 40 fathoms deep in U.S. statistical grids is provided in Appendix D. Stocking areas with historically important spawning habitat will require 8.0 million yearlings annually (Table 1; Fig. 6A). Stocking 8.0 million lake trout as well as another 7 to 12 million top predators could cause a shortage of prey (Jones et al. 1993). If the total number of all predators is considered in a lakewide context, then there may not be a need to stock 8.0 million lake trout. These stocking levels apply to lake trout that average 18 to 47 g-the standard for stocking in both U.S. and Canadian waters since the 1970s. The LHTC is currently comparing post-stocking survival of 38- to 45-g hatchery-reared lake trout with survival of the standard-size fish (McClain et al. 1995). The 38- to 45-g lake trout are expected to survive better than the standard-size fish. Future stocking densities will have to be reduced if the 38- to 45-g fish become the new standard for stocking Lake Huron.

Table 1. Area < 40 fathoms deep (in thousands) in each statistical district and the corresponding number of yearling lake trout recommended for stocking for each of three criteria at a stocking rate of 2.5 yearling per ha, compared to the numbers stocked in 1996.

Statistical district	Area < 40 fa deep (acres)	(ha)	Criteria: Spawning habitat	Lamprey mortality	Fishing mortality	1996 stocking numbers: Yearlings	Fingerlings	Fry
MH-1	668	270	668	0	0	301	0	0
MH-2	563	228	563	563	563	694	0	0
MH-3	926	375	926	926	926	262	0	0
MH-4	807	327	807	807	807	394	0	0
MH-5	806	124	0	0	0	146	0	0
MH-6	164	66	0	0	0	0	0	0
OH-1	550	222	549	0	0	0	0	0
OH-2	206	83	206	206	206	0	0	0
OH-3	742	300	741	741	0	188	0	0
OH-4	327	132	326	326	326	188	0	0
OH-5	486	197	0	0	0	0	0	0
NC-1	568	230	568	0	568	0	0	0
NC-2	299	121	299	0	299	220	0	0
NC-3	71	29	71	71	71	131	0	0
GB-1	233	94	232	232	232	0	0	0
GB-2	662	268	662	662	662	200	200	1,000
GB-3	634	256	634	634	0	20	200	0
GB-4	743	301	743	743	0	620	0	0
Total	8,955	3,624	7,996	5,911	4,661	3,363	400	1,000

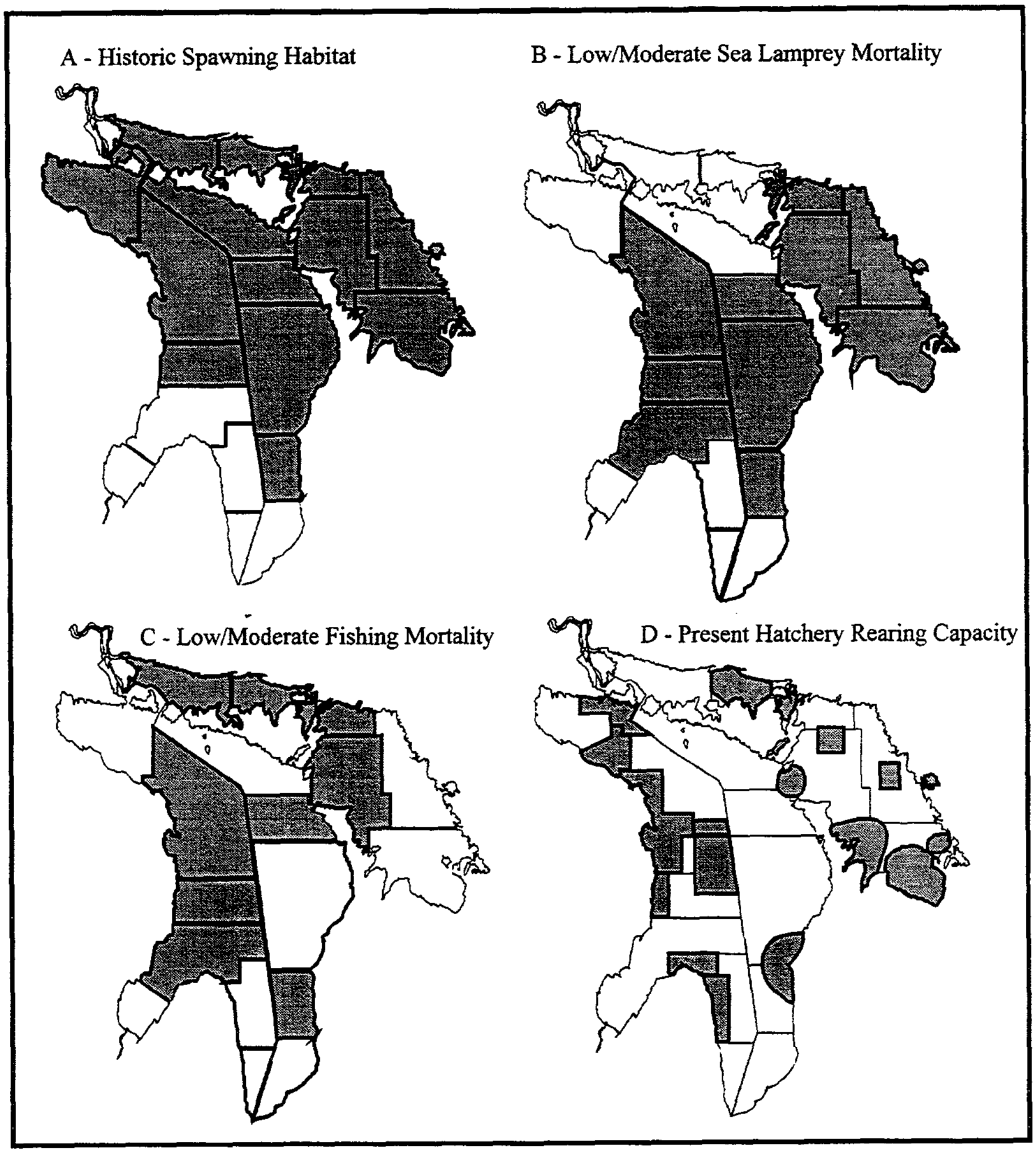

Fig. 6. Statistical districts (shaded) recommended for stocking with lake trout based on (A) the amount of historic spawning habitat, (B) sea lamprey mortality, (C) fishing mortality, and (D) present capacity of hatcheries.

Except for Saginaw Bay and the southern waters of the main basin, most statistical districts of Lake Huron possess substantial habitat for lake trout reproduction (Table 1). Nester and Poe (1987) classified:

- Nine historic spawning grounds north of Saginaw Bay in Michigan waters as suitable for lake trout

- Three spawning grounds off Port Austin (Fig. 1) as much less suitable

Edsall et al. (1992) surveyed the historic spawning grounds on the Six Fathom Bank/ Yankee Reef complex and found the lake bottom there was suitable for lake trout spawning and fry production. Stocking yearling lake trout has produced abundant populations of adult lake trout in MH-3 to MH-5, but no natural reproduction beyond the fry stage has been detected in these areas (Nester and Poe 1987; Johnson et al. 1995; Foster and Kennedy 1995). Spawning habitat may limit reproduction in lower Lake Huron.

Efforts should be made to stock lake trout on Yankee Reef. This area has substantial amounts of spawning habitat (Edsall et al. 1992) and was an important spawning area in central Lake Huron (Eshenroder et al. 1995). Only two plants of fall fingerling lake trout were made on Yankee Reef in the 1990s. Yet Yankee Reef offers the same prospects for rehabilitating lake trout in Lake Huron as does the Six Fathom Bank.

Unacceptably high fishing and/or sea lamprey mortality (Figs. 6(B) and 6(C)) should be reduced to allow rehabilitation to occur. Sea lamprey mortality of lake trout is highest in MH-1, northwestern OH-l, NC- 1, and NC-2 and declines in more southern and eastern waters of Lake Huron (Johnson et al. 1995). Sea lamprey mortality of lake trout was estimated to range from 17% on age-3 lake trout to 74% on age 8 and older fish in both MH-1 and northwestern OH-l during 1991-93 (Sitar 1996). Fishing mortality is considered to be excessive in MH-1, northwestern OH-l, OH-3, GB-3, and part of GB-4. Fishing mortality of ages 4 to 9 lake trout averaged 22% annually in MH-1 and northwestern OH-l during 1991-93 (Table 2). Sea lampreys accounted for about 54% of all lake trout deaths in MH-1 and northwestern OH- 1 during 199 l-93, whereas commercial and sport fisheries accounted for 33% of all deaths during the same time period. If zones are deferred because of high mortality rates, and all areas with low to moderate mortality rates are stocked at 2.5 fish per ha of water < 40 fathoms deep, then 4.7 to 5.9 million yearling lake trout will be required to fully stock Lake Huron (Table 1).

Table 2. Percent average total annual, recreational (rec.), commercial (corn.), and sea lamprey-induced mortality on lake trout estimated from statistical catch-at-age models for the northern (MH-1 and OH-l), central (MH-2 and OH-l), and southern (MH-3 to MH-6 and OH-3 to OH-5) areas of Lake Huron in 1991-93 (data from Sitar (1996)).

	Northern				Central				Southern		
Age	Total	Rec.	Corn.	Lamprey	Total	Rec.	Corn.	Lamprey	Total	Fishing[1]	Lamprey
1	49	0	0	0	49	0	0	0	49	0	0
2	27	0	0	0	27	0	0	0	47	0	0
3	33	0	4	17	27	0	1	12	28	3	12
4	43	0	24	15	29	1	6	14	30	7	13
5	56	0	31	29	34	2	8	12	34	8	19
6	68	0	27	51	37	2	7	25	35	8	23
7	62	0	19	48	36	2	4	25	36	8	25
8	77	0	16	69	36	2	4	26	37	8	26
9	77	0	14	70	37	2	3	27	38	8	27
10	75	0	7	70	36	2	2	27	38	8	27
11	77	0	7	72	36	2	2	27	39	8	27
12	78	0	7	74	36	2	2	26	39	8	28
13	78	0	7	74	36	2	2	27	39	8	27
14	78	0	7	74	36	2	2	26	39	8	27
15	78	0	7	74	36	2	2	26	38	8	28
16	78	0	7	74	36	2	2	26	39	8	27
17	78	0	7	74	36	2	2	26	39	8	28
18	78	0	7	74	36	2	2	26	39	8	28
19	78	0	7	74	36	2	2	26	39	8	28
20	78	0	7	74	36	2	2	26	39	8	28

[1] Represents both recreational and commercial fishing mortality (Sitar 1996).

Finally, if the current capacity of fish hatcheries is not sufficient to produce 4.7 to 8.0 million yearling lake trout required for stocking Lake Huron, then stocking should be concentrated in a limited number of areas (Fig. 6(D)). These areas account for most of the best historic spawning habitat in the lake (Fig. 2). Secondly, stocking these areas would maintain the current schedule for Lake Huron. Although the current stocking schedule is not what is fully required for rehabilitation of lake trout in Lake Huron, stocking a consistent number of fish in sufficient quantity in areas of suitable habitat is needed to develop populations capable of spawning. Stocking lake trout at only a limited number of sites will require hatcheries to produce 3.4 million yearlings annually (Table 1).

Stocking hatchery-reared lake trout in rehabilitation areas should be viewed as a cumulative process.

- Yearling lake trout should be stocked at recommended densities in areas with historically important spawning habitat (Fig. 6(A))

- Stocking should be reduced or eliminated in an area if survival of lake trout is consistently less than 60% due to either sea lamprey or fishing mortality (Figs. 6(B) and 6(C)); management actions to control fishing mortality or prospects for improved sea lamprey control should be considered when deciding whether or not to stock an area

- Stocking should be reduced further or concentrated in specific areas (Fig. 6(D)) depending upon the rearing capacity of the hatcheries

Fig. 6(D) represents the worst-case scenario for stocking lake trout in Lake Huron.

At some point, stocking of lake trout should be reduced or cease in response to increasing populations of stocked adults and wild fish. Stocking of hatchery-reared lake trout has stopped in many areas of Lake Superior because managers believe wild stocks are abundant enough to sustain present populations (Schreiner 1995; Lake Superior Committee 1996). Discontinuation of lake trout stocking in Lake Superior is based on four criteria: agency commitment to rehabilitation, harvest control, wild-fish abundance, and stocked-fish survival (Hansen 1996). The criteria for reducing stocking do not address harvest control or agency commitment but are based on abundance and survival. Stocking rates should be reduced if all of the following criteria are met:

- Survival of hatchery-reared lake trout declines

- Wild lake trout make up 25% of the mature portion of the population

- Abundance of wild fish is stable or increasing over the most recent three- to five-year time period

Stocking of hatchery-reared lake trout should cease when wild lake trout make up 50% of the mature portion of the population.

This recommendation to reduce stocking reflects evidence that the value of stocked lake trout to the population in a lake declines once reproduction is well under way. Predation of recently stocked lake trout by previously stocked and wild lake trout was responsible for declines in survival of hatchery-reared lake trout in Lake Superior (Hansen et. al. 1994a, 1996) and Lake Ontario (Elrod et al. 1993). Based on experiences in Ontario inland lakes and modeling of lake trout stocks, Evans and Willox (1991) suggested that stocking hatchery-reared lake trout in lakes with wild stocks be discontinued, especially with non-native hatchery lake trout. Evans and Willox found that abundance of wild stocks was suppressed by stocking on top of wild populations.

Preferred Strains

The Marquette strain, splake (male brook trout x female lake trout hybrid), and backcross (splake x lake trout) were the primary forms of lake trout used in the early years of the rehabilitation effort on Lake Huron (Berst and Spangler 1973; Eshenroder et al. 1995). Stocking efforts using $\mathbf{F_4}$ and $\mathbf{F_5}$ splake began in 1969 in Canadian waters (Berst and Spangler 1973) and in 1970-72 in U.S. waters (Eshenroder et al. 1995). Since splake grew faster and matured earlier than pure lake trout, they were stocked in hopes that they would spawn before reaching sizes where they would be vulnerable to sea lamprey predation. After 1978, backcross were employed in the rehabilitation effort in Canada (Johnson et al. 1995) in an attempt to put more lake trout genes into the populations. Marquette-strain lake trout that originated in Lake Superior were the only strain of lake trout stocked in U.S. waters of Lake Huron from 1973 to 1985. Lake Manitou-strain lake trout were stocked in Canadian waters after 1981. Splake and backcross have failed to reproduce in Lake Huron, and Marquette and Lake Manitou strains of lake trout have produced some positive, but very limited, rehabilitation results.

Historically, as many as 12 subpopulations or strains of lake trout may have inhabited Lake Huron-each reflecting various degrees of adaptation to their local environment (Eshenroder et al. 1995). Of these 12 strains, only two remain. One strain is found in Parry Sound, Georgian Bay, and the other is found in Iroquois Bay off the North Channel. Efforts are being made to preserve and protect these two remnant stocks.

The efficacy of each strain of lake trout stocked into Lake Huron should first be evaluated by multistrain planting experiments in areas with different selection pressures. Growth, survival, contribution to the spawning stock, and contribution to wild progeny (Grewe et al. 1994) should be contrasted among areas of Lake Huron with different mortality rates, growth, spawning substrate, and fish communities (Burr&am-Curtis et al. 1995). For example, a strain of lake trout may survive well in areas of low sea lamprey abundance but may not survive well in areas of high sea lamprey abundance. Also, the same strain may survive well but contribute nothing to naturally produced offspring.

Each strain of lake trout should be evaluated in areas with low/high sea lamprey abundance, low/high fishing mortality, good/poor spawning habitat, and simple/complex fish community.

It is recommended that stocking of hatchery-reared lake trout in Lake Huron be made up of many different strains, as follows:

- Seneca-strain lake trout is preferred over other strains until sea lamprey control is improved in areas of high sea lamprey abundance

- At lower levels of sea lamprey abundance, preferred strains are Parry Sound, Iroquois Bay, Slate Island, Michipicoten Island, Lake Manitou, Marquette, and Lewis Lake

- Feral stocks from Lake Huron

- A deep-water form of lake trout from Lake Superior

The Seneca strain of lake trout has proven to be a success story in terms of its ability to survive and reach sexual maturity in Lake Huron. These fish originated from Seneca Lake, New York, and were first stocked in 1985 as fall fingerlings in the Drummond Island Refuge and on Six Fathom Bank. Lake trout in Seneca Lake have co-existed with sea lampreys possibly as early as 1820 and have demonstrated resistance to them. Since their introduction in Lake Huron in 1985, Seneca-strain lake trout made up the majority of spawners found in the Drummond Island Refuge and on Six Fathom Bank during 1991-95 even though equal numbers of each strain were stocked (Fig. 7). In the Drummond Island Refuge, Seneca-strain lake trout made up nearly 100% of spawning-sized lake trout captured during 1991-95. On the Six Fathom Bank, over half of the spawning-sized lake trout captured are of the Seneca strain.

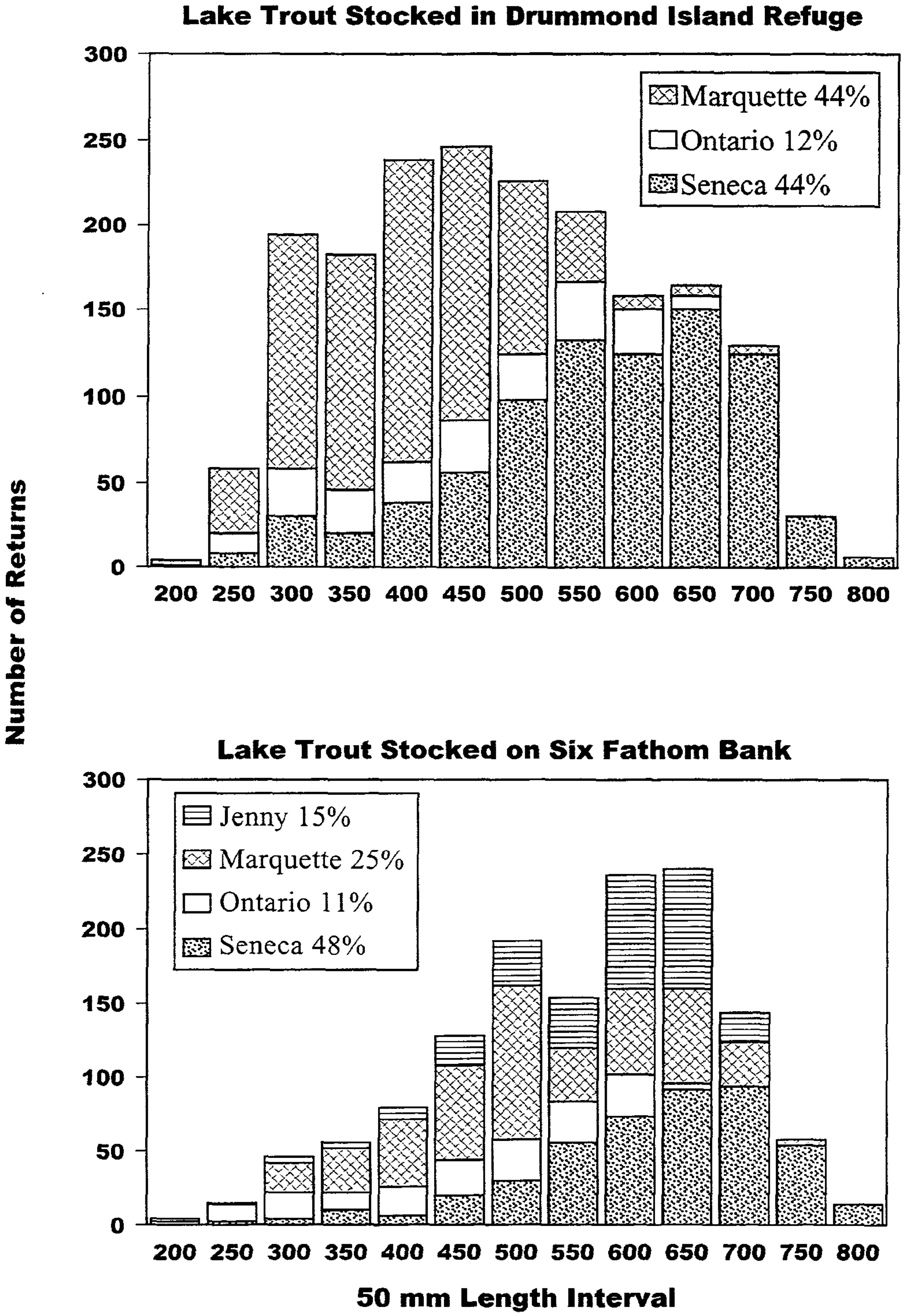

Fig. 7. Number of coded-wire tag returns for various strains of lake trout stocked in equal numbers in the Drummond Island Refuge and on Six Fathom Bank in 1985-94 and subsequently recaptured in 1991-95. The overall percent return by strain is in the box.

The Seneca strain of lake trout, especially at small sizes, appears to be more resistant to both sea lamprey predation and commercial and sport fisheries than other strains stocked in Lake Huron. No Seneca-strain lake trout < 532 mm in length captured during 1991-95 in Lake Huron bore sea lamprey marks. By way of comparison, sea lamprey marking rates on other strains at comparable sizes had sea lamprey marking rates that were up to ten times greater (Fig. 8). In northern Lake Huron, Seneca-strain lake trout are subjected to intense sea lamprey predation rates, yet this strain still grows to reproductive size. Age-10 Seneca-strain lake trout were captured on spawning grounds in the Drummond Island Refuge in 1995. Most other strains of lake trout that live in MH-1 do not survive past age 6.

The Marquette and Lake Manitou strains of lake trout continue to be preferred for the rehabilitation process because both are known to have produced measurable year-classes of progeny in Lake Huron (Johnson and VanAmberg 1995; Anderson and Collins 1995). The Lake Manitou strain of lake trout originated from an inland lake on Manitoulin Island, Ontario (Fig. 1) and is believed to have successfully reproduced in South Bay, Manitoulin Island (Anderson and Collins 1995). Marquette-strain lake trout annually produce measurable year-classes of progeny in the Thunder Bay area near Alpena, Michigan (Johnson and VanAmberg 1995).

The Slate Island and Michipicoten Island strains of lake trout originated from wild Lake Superior stocks. These two strains are currently being used in rehabilitation efforts in Canadian waters of Lake Huron. Growth and maturation rates of the Slate and Michipicoten Island strains appear to be slower than for the Lake Manitou strain. These two strains seem better suited to areas of Lake Huron where sea lamprey and fishing mortality are low due to characteristic slow growth. Stocking additional Lake Superior strains will increase the genetic diversity of Lake Huron lake trout stocks, as suggested by various authors at RESTORE.

The Lewis Lake strain of lake trout is recommended for restoration efforts in Lake Huron because it may contain original Great Lakes genetic material. In 1889, Lewis Lake in Yellowstone National Park was stocked with progeny reared from eggs collected from lake trout captured in northern Lake Michigan. Lake trout reproduction was so successful in Lewis Lake that fish from there were used to stock other high mountain lakes in the park. A Lewis Lake brood stock was subsequently developed at the Saratoga National Fish Hatchery in the mid-1980s. Introduction of Lewis Lake-strain lake trout to the rehabilitation effort in Lake Huron could prove helpful because these fish may retain some genetic characteristics of the original northern Lake Michigan population.

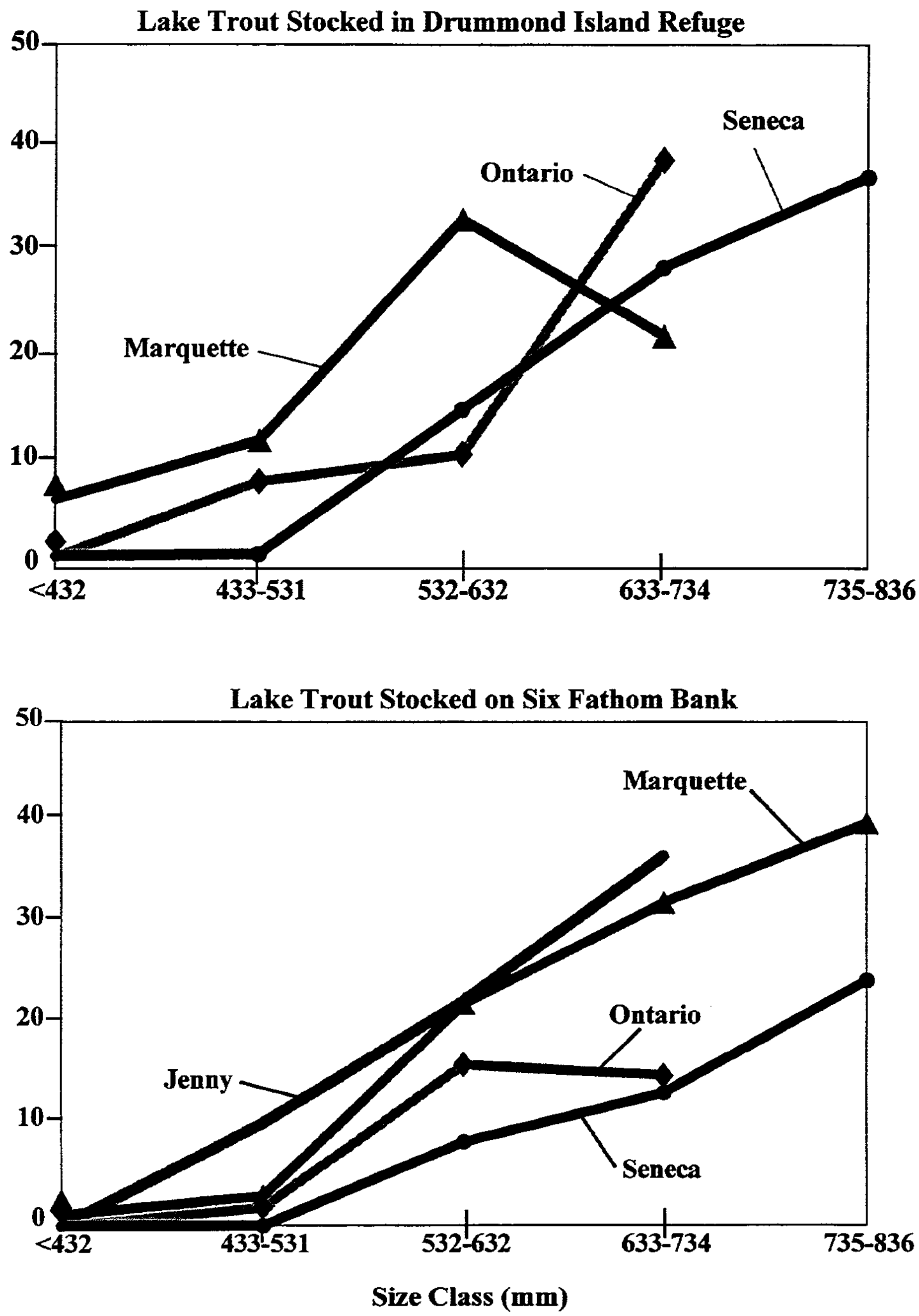

Fig 8. Number of sea lamprey marks per 100 lake trout of various strains stocked in the Drummond Island Refuge and on Six Fathom Bank from 1985 to 1994 and recaptured from 1991 to 1995.

Of the two remnant strains of Lake Huron lake trout, the Parry Sound brood stock began providing eggs in 1995, and an Iroquois Bay brood stock is being developed. Parry Sound represents the most successful lake trout rehabilitation effort in Lake Huron (Ontario Ministry of Natural Resources 1994, 1995). Success in this area is likely due to the continued existence of some wild lake trout. Although the population in Parry Sound is not fully rehabilitated, wild lake trout abundance continues to increase slowly. Stocking of Parry Sound-strain lake trout will be expanded to other areas of eastern Georgian Bay. Small numbers of Iroquois Bay-strain lake trout have been stocked in Iroquois Bay and in North Channel areas from a limited source of eggs. Additional North Channel and northern Georgian Bay sites will be stocked with Iroquois Bay-strain fish after hatchery production from this brood stock reaches full capacity. Parry Sound and Iroquois Bay strains of lake trout should be given first priority in multistrain stocking experiments because they are native Lake Huron genotypes.

A Lake Huron strain of lake trout should be started from feral adults in the lake. Adult lake trout from the Drummond Island Refuge and Six Fathom Bank have gone through intense sea lamprey and fishing pressures in Lake Huron and show the ability to survive in a hostile environment. Lake trout from these areas could prove invaluable to rehabilitation efforts in Lake Huron. An isolation facility for fertilized eggs from feral Lake Huron adults is needed. Management agencies with jurisdiction on Lake Huron should attempt to build or renovate an existing hatchery facility that could serve as an isolation facility for feral Lake Huron brood stocks.

Finally, a Lake Superior deep-water strain of lake trout should be planted in Lake Huron. Berst and Spangler (1973), Eshenroder et al. (1995), and Krueger and Ihssen (1995) all reported that a deep-water form of lake trout was historically present in Lake Huron. In Lake Superior, deep-water strains of lake trout have increased dramatically despite no human efforts to foster these populations (Peck and Schorfhaar 1994; Hansen et al. 1995). Stocking a deep-water form of lake trout into Lake Huron would further increase genetic diversity of the stocks (Burnham-Curtis et al. 1995), and till a vacant niche for a deep-water predator on burbot *(Lota lota),* bloaters, and sculpins *(Cottidae* spp.),

Early Life-History Stage Stocking

The single strategy of stocking yearling and fingerling lake trout to reestablish breeding populations has produced only limited results in Lake Huron after 28 years. Abundant, reproducing populations of lake trout exist only in Lake Superior (Hansen et al. 1994b; Hansen et. al. 1995), and it appears that both hatchery-reared and wild lake trout have contributed to natural reproduction in that lake (Peck 1984, 1986; Krueger et al. 1986; Hansen et al. 1995; Schram et al. 1995). In most of the Great Lakes, stocking of hatchery-reared lake trout has failed to result in natural reproduction even though adult fish became abundant. Even with recovery of populations in Lake Superior, some historically important shoals are not used by spawning adult lake trout (Peck 1979). Exclusive reliance on a single stocking strategy is unlikely to result in levels of restoration hoped for by agencies (DesJardine et al. 1995). To increase the prospect that goals will be achieved, supplemental-stocking strategies that use other lake trout life-history stages should be recognized as integral parts of a well-rounded effort.

Stocking of fertilized lake trout eggs or fry on historic but presently unused spawning grounds should be employed in Lake Huron. Wagner's (1992) planting of eyed eggs yielded swim-up fry on a historic spawning reef on the southwest shore of Drummond Island. Wagner recommended stocking green fertilized eggs instead of eyed eggs in all future endeavors. Swanson (1982) successfully stocked green eggs incubated in artificial-turf incubators anchored on spawning shoals in Lake Superior. The artificial-turf incubators have also been deployed in Lake Michigan (Holey 1993), and Wagner (1992) recommended their use to increase the survival of planted eggs from that spawned naturally. Stocking lake trout fry on historic spawning sites may also prove useful in rehabilitation efforts because the cost of stocking fry will be less than costs using artificial incubators. Most of the historic spawning grounds in MH-1 and several sites in MB-2 are currently unused by lake trout. In Canadian waters, a fry stocking experiment is currently under way in the Bruce Peninsula Archipelago (McClain et al. 1995).

The number of eggs required for early life-history plants depends on the life stage being stocked and the stocking technique. A target spawning population of 2,000 to 3,000 individuals made up of six year-classes should serve as the basis for estimating the number of eggs or fry to stock. This concentration of spawners is based empirically on numbers of wild spawners reported for Gull Island Shoal, Lake Superior, during the late 1960s-a period of rapid lake trout recovery (Swanson and Swedburg 1980; Schram et al. 1995). The minimum number of green eggs required would range from 1.3 to 2.0 million if artificial incubators were used as the stocking technique. Stocking this number of eggs assumes a survival rate of 0.002 from egg to age-6 spawner. If seeding directly over spawning reefs is employed, a minimum density of 500 eggs per m^{-2} of substrate should be targeted-the number estimated to overcome both egg and fry predation in the Great Lakes (Jones et al. 1995).

Spawning-Stock Abundance

A minimum number of lake trout spawners is needed for reproduction to occur in the Great Lakes. The catch rate of female lake trout spawners caught in Gull Island Refuge in Lake Superior increased from 8 fish per 305 m of gillnet in 1964 to 77 fish per 305 m of gillnet in 199 1. A significant, positive linear relation was found between abundance of wild females on spawning shoals in the refuge and density of age-0 lake trout on adjacent nursery grounds (Schram et al. 1995). The CPE values of 17 to 135 adult lake trout per 305 m of gillnet have resulted in recruitment of substantial numbers of age 1 or older wild lake trout in the Great Lakes (Selgeby et al. 1995). Catch rates of 3 to 5 spawners per 305 m of net resulted in no reproduction (Selgeby et al. 1995). Historic spawning sites in Lake Huron rehabilitation zones should be assessed to estimate density of spawning lake trout, and stocking and fishing rates should be adjusted to maintain at least 17 to 135 adult fish per 305 m of gillnet lifted.

RESEARCH AND ASSESSMENT NEEDS

Successful rehabilitation programs evolve. They commence initially on the basis of available knowledge and concepts and necessarily involve some assumptions. They are later modified through trial and error, application of emerging science, and testing of assumptions. The developmental process proceeds more rapidly if experimentation is built into the rehabilitation program. Many of the recommendations found in the guide have resulted from experiments conducted during the last 40 years in the Great Lakes (Selgeby 1995). Papers in RESTORE answered questions such as:

- Minimum number of adults needed for reproduction
- Maximum allowable mortality rates
- Optimal stocking sites
- Effects on restoration of fish communities associated with lake trout

Many more questions, however, need to be answered concerning lake trout rehabilitation in Lake Huron. Five categories of research and assessment necessary to evaluate lake trout rehabilitation have been created and are listed in order of priority:

- Community interactions
- Measuring progress toward rehabilitation objectives
- Evaluating stocking strategies
- Population and community modeling
- Critical life stages

Community Interactions

Community relationships relate largely but not exclusively to feeding and the food web. What organisms serve as food for lake trout? To what extent are lake trout the prey of other fish at some stage in their lives? With what species do lake trout compete for food? Information is needed on:

- Which species occur in association with lake trout and in what relative abundance
- Biomass of major forage fishes
- Diet of lake trout and their potential competitors
- Sea lamprey mortality of lake trout throughout the lake
- Distribution of sea lamprey attacks among the various host species and how this distribution changes with changes in host abundance
- What predators may be limiting survival of lake trout fry

Measuring Progress Toward Rehabilitation Objectives

Progress must be assessed at the population level or by rehabilitation zone if distribution of the population is unknown. Needed measures include:

- Movement studies to identify home range
- Population abundance and age structure
- Harvests by various means of fishing
- Rates of growth and survival
- Time to maturity and egg production
- The proportion of naturally produced fish in the population
- Sea lamprey wounding rates
- The fraction of the population being harvested
- Densities of adult lake trout on historic spawning shoals

Evaluating Stocking Strategies

Employing the same stocking practices across the lake affords few opportunities to evaluate success because variation is the key to uncovering relationships potentially important to the stocking outcome. It is proposed, therefore, that the following variables be manipulated experimentally:

- Depth at planting site
- Planting density
- Size and age at stocking
- Lake trout genotype

Population and Community Modeling

Mathematical modeling is a tool used by fisheries biologists to simulate fish populations. The components of a model may include approximations of natural, fishing and sea lamprey-induced mortality, the age structure of the population, and the level of natural recruitment. Modeling affords a means for synthesizing these aspects of population biology and their efforts on community ecology.

The Sustainability of Intensively Managed Populations in Lake Ecosystems (SIMPLE) (Jones et al. 1993) model has been used extensively in Lakes Ontario and Michigan to address prey supply. Application of SIMPLE and other models to Lake Huron will help to improve the understanding of lake trout populations and their management. In particular, it will be useful to evaluate a mix of harvest controls, stocking levels, and sea lamprey-control measures as they relate to rehabilitation goals (Sitar 1996). The integrated management of sea lampreys program and SIMPLE are modeling approaches that will help provide insights into these interactions. The development of models, however, must be undertaken with specific goals in mind and with the understanding that their usefulness will depend on constant revision, such as with the Lake Trout Management Protocol (Bryan Henderson, Ontario Ministry of Natural Resources, 300 Water Street, Peterborough, Ontario, K9J 3C7, pers. commun.) developed in Ontario.

EXAMINING CRITICAL LIFE-HISTORY STAGES

Some aspects of life history are in the measures of performance discussed earlier. The critical stages referred to here are largely those concerned with reproduction and juvenile life. New research has found that consumption of alewives severely reduces survival of lake trout fry in the Great Lakes by reducing vitamin levels in adult females (Fisher et al. 1996). Investigations into juvenile life history should focus on:

- Presence or absence of early mortality syndrome in lake trout from various parts of the lake
- Where spawning occurs in relation to where lake trout historically spawned
- Physical nature and condition of spawning sites
- Density of eggs deposited, egg viability, and survival to hatch
- Early life history from spawned egg through age 1
- Growth and diet of juvenile fish

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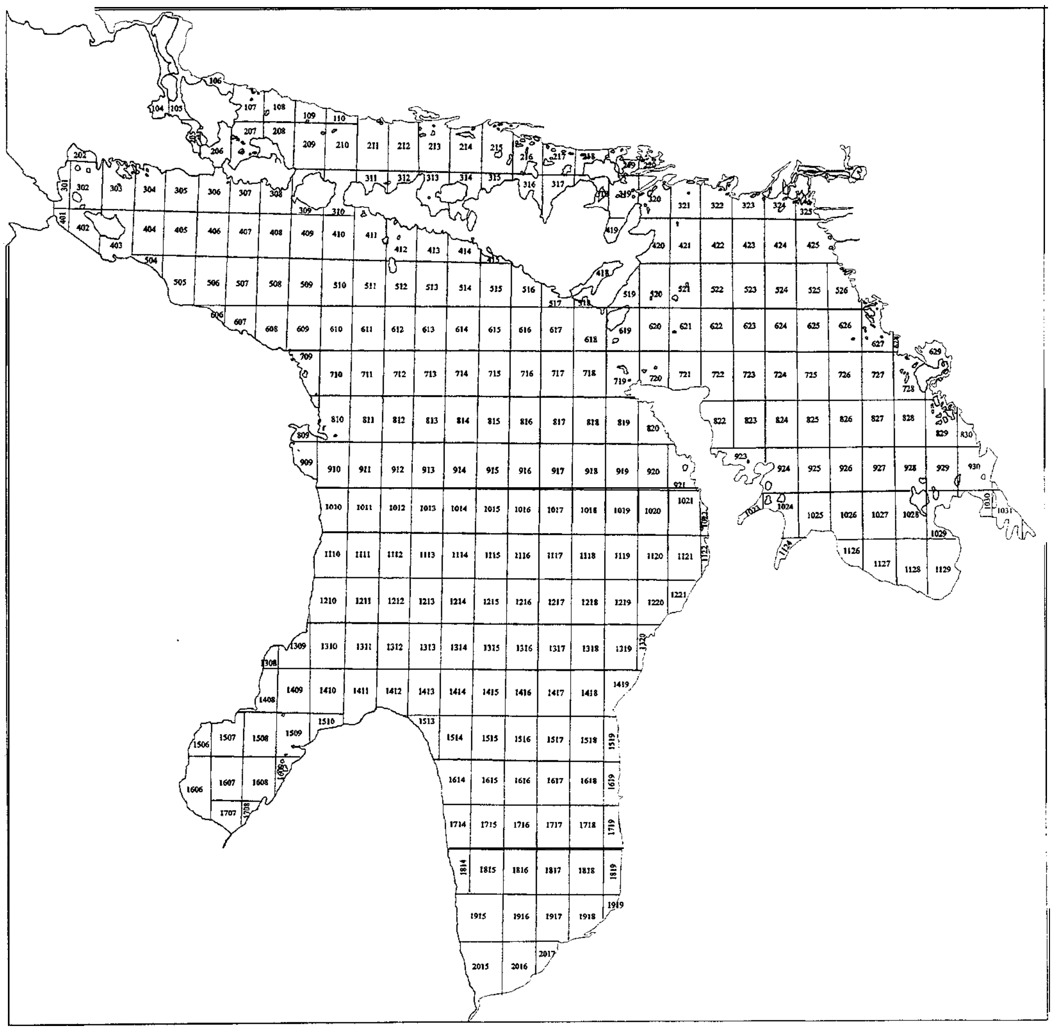
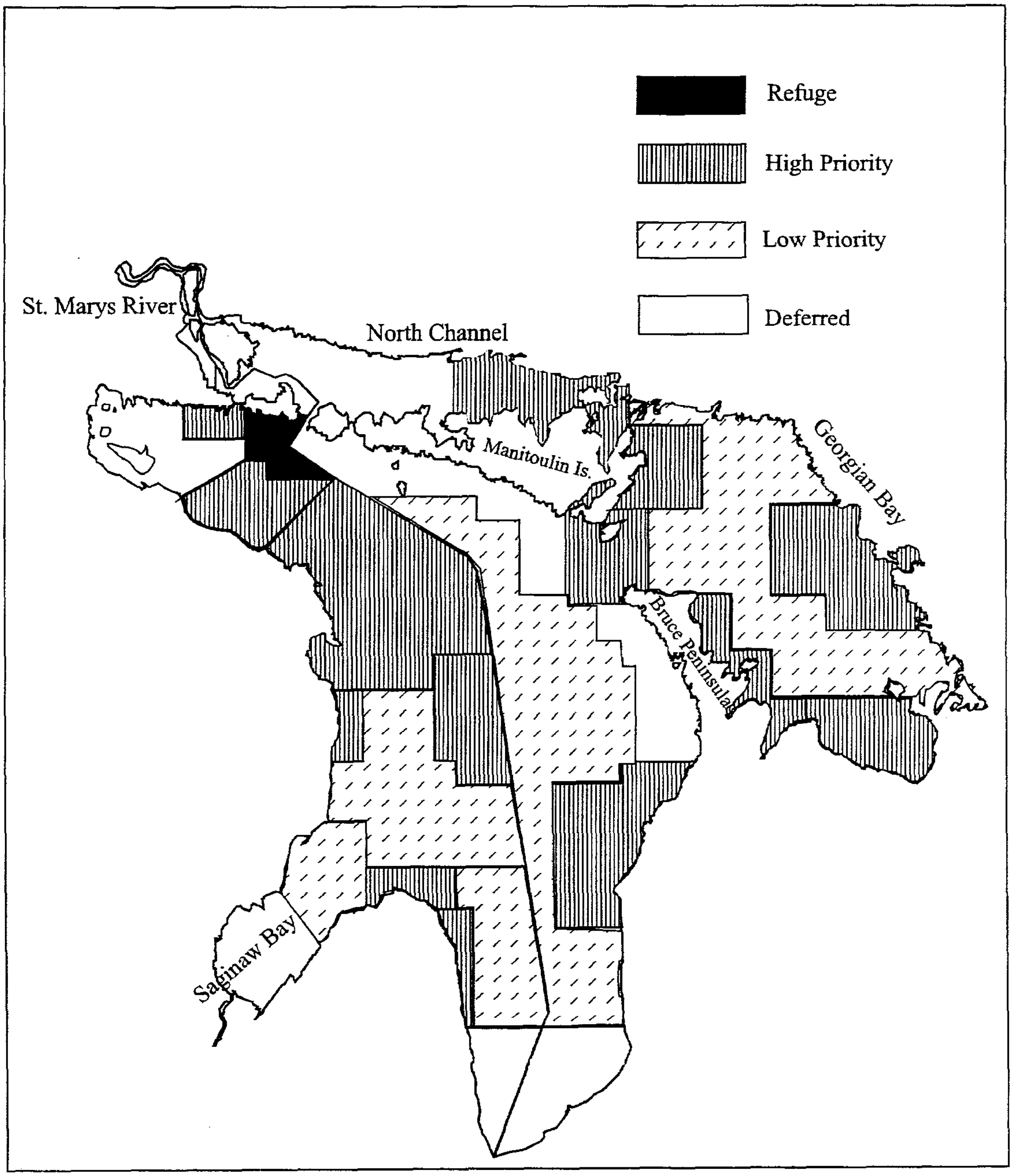
APPENDIX A
Ten-Minute Statistical Grids in Lake Huron



APPENDIX B
Rehabilitation Zones

Rehabilitation zones in the 1986 and 1992 versions of the lake trout rehabilitation plan.



APPENDIX C
Stocking Criteria

Amount of habitat < 40 fathoms deep, amount of historically used spawning habitat, levels of sea lamprey and fishing mortality, and stocking schedule for lake trout by statistical district.

Statistical district	Area < 40 fathoms deep (x 1,000) (acres)	(ha)	Historic spawning habitat	Recent sea lamprey mortality	Recent fishing mortality	Stocking schedule based on hatchery rearing capacity
MH-1	668	270	High	High	High	Annually
MH-2	563	228	Moderate	Moderate	Low	Annually
MH-3	926	375	Moderate	Moderate	Low	Annually
MH-4	807	327	Moderate	Moderate	Low	Annually
MH-5	306	124	None	Moderate	Low	Annually
MH-6	164	66	None	unknown	Low	-
OH-1	550	222	High	High	High	Annually
OH-2	206	83	High	Moderate	Moderate	-
OH-3	742	300	High	Moderate	High	Annually for three years
OH-4	327	132	Moderate	Moderate	Moderate	Annually for three years
OH-5	486	197	None	Moderate	Moderate	-
NC-1	568	230	High	High	Low	-
NC-2	299	121	Moderate	High	Low	Annually
NC-3	71	29	High	Low	Low	Yearlings (yls), annually; fingerlings (ff) and fry, every two years
GB-1	233	94	High	Low	Moderate	-
GB-2	662	268	High	Low	Moderate	Yls, annually; ff & fry, every two years
GB-3	634	256	Moderate	Low	High	Yls, annually; ff, every two years
GB-4	743	301	High	Low	High	Annually
Total	8,955	3,624				

APPENDIX D
Area < 40 Fathoms Deep

Area < 40 fathoms deep in U.S. statistical districts and grids of Lake Huron.

Statistical district	Grid	Acres	km²	Proportion of area in U.S.	Proportion of area in Canada	Acres in U.S.	Acres in Canada
MH-1	202	8,896	36	1.00	0.00	8,896	0
	301	20,756	84	1.00	0.00	20,756	0
	302	53,374	216	1.00	0.00	53,374	0
	303	56,339	228	1.00	0.00	56,339	0
	304	46,455	188	1.00	0.00	46,455	0
	305	39,533	160	1.00	0.00	39,533	0
	306	36,571	148	1.00	0.00	36,571	0
	307	30,640	124	1.00	0.00	30,640	0
	308	30,640	124	0.67	0.33	20,529	10,111
	309	19,768	80	0.05	0.95	988	18,780
	401	11,861	48	1.00	0.00	11,861	0
	402	33,606	136	1.00	0.00	33,606	0
	403	47,443	192	1.00	0.00	47,443	0
	404	51,397	208	1.00	0.00	51,397	0
	405	37,559	152	1.00	0.00	37,559	0
	406	5,930	24	1.00	0.00	5,930	0
	407	0	0	1.00	0.00	0	0
	408	5,930	24	0.87	0.13	5,159	771
	504	12,849	52	1.00	0.00	12,849	0
	505	52,385	212	1.00	0.00	52,385	0
	506	43,490	176	1.00	0.00	43,490	0
	507	15,814	64	1.00	0.00	15,814	0
	508	988	4	1.00	0.00	988	0
	606	6,919	28	1.00	0.00	6,919	0
	607	28,664	116	1.00	0.00	28,664	0
Subtotal		697,807	2,824			668,145	29,662

Statistical district	Grid	Acres	km²	Proportion of area in U.S.	Proportion of area in Canada	Acres in U.S.	Acres in Canada
MH-2	409	0	0	0.50	0.50	0	0
	509	0	0	1.00	0.00	0	0
	510	988	4	0.90	0.10	889	99
	511	4,942	20	0.50	0.50	2,471	2,471
	512	35,582	144	0.30	0.70	10,675	24,907
	608	39,536	160	1.00	0.00	39,536	0
	609	37,559	152	1.00	0.00	37,559	0
	610	7,907	32	1.00	0.00	7,907	0
	611	0	0	1.00	0.00	0	0
	612	0	0	0.98	0.02	0	0
	613	0	0	0.70	0.30	0	0
	614	0	0	0.25	0.75	0	0
	709	24,710	100	1.00	0.00	24,710	0
	710	41,513	168	1.00	0.00	41,513	0
	711	0	0	1.00	0.00	0	0
	712	0	0	1.00	0.00	0	0
	713	0	0	1.00	0.00	0	0
	714	0	0	0.95	0.05	0	0
	809	15,814	64	1.00	0.00	15,814	0
	810	61,281	248	1.00	0.00	61,281	0
	811	47,443	192	1.00	0.00	47,443	0
	812	16,803	68	1.00	0.00	16,803	0
	813	988	4	1.00	0.00	988	0
	814	0	0	1.00	0.00	0	0
	815	0	0	0.25	0.75	0	0
	909	19,768	80	1.00	0.00	19,768	0
	910	60,292	244	1.00	0.00	60,292	0
	911	53,376	216	1.00	0.00	53,376	0
	912	62,269	252	1.00	0.00	62,269	0
	913	34,594	140	1.00	0.00	34,594	0
	914	21,745	88	1.00	0.00	21,745	0
	915	5,930	24	0.50	0.50	2,965	2,965
Subtotal		593,040				562,598	30,442

APPENDIX D, continued

Statistical district	Grid	Acres	km²	Proportion of area in U.S.	Proportion of area in Canada	Acres in U.S.	Acres in Canada
MH-3	1010	48,432	196	1.00	0.00	48,432	0
	1011	52,385	212	1.00	0.00	52,385	0
	1012	53,374	216	1.00	0.00	53,374	0
	1013	44,478	180	1.00	0.00	44,478	0
	1014	61,281	248	1.00	0.00	61,281	0
	1015	38,548	156	0.60	0.40	23,129	15,419
	1110	53,374	216	1.00	0.00	53,374	0
	1111	53,374	216	1.00	0.00	53,374	0
	1112	60,292	244	1.00	0.00	60,292	0
	1113	47,443	192	1.00	0.00	47,443	0
	1114	46,455	188	1.00	0.00	46,455	0
	1115	36,571	148	0.75	0.25	27,428	9,143
	1210	71,659	290	1.00	0.00	71,659	0
	1211	59,304	240	1.00	0.00	59,304	0
	1212	69,188	280	1.00	0.00	69,188	0
	1213	59,304	240	1.00	0.00	59,304	0
	1214	68,200	276	1.00	0.00	68,200	0
	1215	28,664	116	0.95	0.05	27,231	1,433
Subtotal		952,326				926,331	25,995

APPENDIX D, continued

Statistical district	Grid	Acres	km²	Proportion of area in U.S.	Proportion of area in Canada	Acres in U.S.	Acres in Canada
MH-4	1308	14,826	60	1.00	0.00	14,826	0
	1309	43,490	176	1.00	0.00	43,490	0
	1310	62,269	252	1.00	0.00	62,269	0
	1311	53,374	216	1.00	0.00	53,374	0
	1312	62,269	252	1.00	0.00	62,269	0
	1313	53,374	216	1.00	0.00	53,374	0
	1314	62,269	252	1.00	0.00	62,269	0
	1315	36,571	148	1.00	0.00	36,571	0
	1408	43,455	176	1.00	0.00	43,455	0
	1409	52,385	212	1.00	0.00	52,385	0
	1410	62,269	252	1.00	0.00	62,269	0
	1411	49,420	200	1.00	0.00	49,420	0
	1412	44,478	180	1.00	0.00	44,478	0
	1413	5 1,397	208	1.00	0.00	51,397	0
	1414	62,269	252	1.00	0.00	62,269	0
	1415	53,374	216	1.00	0.00	53,374	0
	1506	17,791	72	1.00	0.00	17,791	0
	1507	53,374	216	1.00	0.00	53,374	0
	1508	62,269	252	1.00	0.00	62,269	0
	1509	41,513	168	1.00	0.00	41,513	0
	1510	13,838	56	1.00	0.00	13,838	0
	1606	38,548	156	1.00	0.00	38,548	0
	1607	62,269	252	1.00	0.00	62,269	0
	1608	54,362	220	1.00	0.00	54,362	0
	1609	0	0	1.00	0.00	0	0
	1707	21,745	88	1.00	0.00	21,745	0
	1708	5,930	24	1.00	0.00	5,930	0
Subtotal		1,179,128	4,772			1,179,128	0

APPENDIX D, continued

Statistical district	Grid	Acres	km²	Proportion of area in U.S.	Proportion of area in Canada	Acres in U.S.	Acres in Canada
MH-5	1513	8,896	36	1.00	0.00	8,896	0
	1514	61,281	248	1.00	0.00	61,281	0
	1515	53,374	216	1.00	0.00	53,374	0
	1516	-	-	-	1.00	-	0
	1614	42,501	172	1.00	0.00	42,501	0
	1615	53,374	216	1.00	0.00	53,374	0
	1616	-	-	0.90	0.10	-	0
	1714	33,606	136	1.00	0.00	33,606	0
	1715	53,374	216	1.00	0.00	53,374	0
	1716	-	-	0.90	0.10	-	0
Subtotal		306,406	1,240			306,406	0
MH-6	1814	16,803	68	1.00	0.00	16,803	0
	1815	59,304	240	1.00	0.00	59,304	0
	1816		-	0.50	0.50	-	0
	1915	61,281	248	1.00	0.00	61,281	0
	1916		-	0.25	0.75	-	0
	2015	44,478	180	0.60	0.40	26,687	17,791
Subtotal		181,866				164,075	17,791