A Joint Plan for the Rehabilitation of Lake Trout in Lake Ontario

By
The Lake Trout Subcommittee*
of the Lake Ontario Committee
-Great Lakes Fishery Commission-
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Lake Trout Rehabilitation Plan

Foreword

The Lake Ontario Committee commends the Lake Trout Subcommittee for developing a dynamic process with quantified objectives in their "A Joint Plan for Rehabilitation of Lake Trout in Lake Ontario". Clif Schneider, Dave Goldthwaite and Dianne Kolenosky, with support and assistance by many scientists, have utilized the available data gained through years of experience in the upper Great Lakes, personal experience on Lake Ontario, plus available information in the literature to complete this initial plan.

They have broken new ground in lake trout management that some others are already following. They recognize that the plan will be updated and some of the broad figures based on today's data will be refined on an annual basis as more information is obtained.

In this era of a community approach to fisheries management, one may ask the question "Why a separate plan for lake trout?". Water quality improvements, successes in sea lamprey control, and available lake trout for adequate stocking indicated it was timely to introduce the once native top predator fish into Lake Ontario. A plan was logical and necessary to outline how lake trout rehabilitation might best be achieved over the next two decades. However, this is not only a plan for lake trout management for it meshes with the lakewide management plans/programs for sea lamprey integrated management, forage species management and other salmonid programs.

The Subcommittee's accomplishments are: a complement to the agencies associated with the Lake Ontario Committee; a lasting example of the value of the Great Lakes Fishery Commission's support for sea lamprey control and lake trout restoration throughout the Great Lakes; and proof that international lakewide planning and programming can work as prescribed under the Strategic Great Lakes Fishery Management Plan - that has been accepted by all twelve Great Lakes fishery agencies.

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Executive Summary and Recommendations

The lake trout (Salvelinus namaycush) was one of the most important native species in Lake Ontario. Earliest reports indicated that lake trout were both abundant and widely distributed throughout the lake with some individuals reaching 23 kg (50 lbs.). Intensive exploitation began at the time the Atlantic salmon (Salmo salar) was declining (1830's). By 1860, prior to the time modern statistical surveys were inaugurated, the lake trout population of Lake Ontario was depleted. Exploitation continued and intensified during the early 1900's, resulting in further declines in commercial catches. The last native lake trout taken by commercial netters was in Lake Ontario's Eastern Basin during the 1950's.

Collapse of the lake trout population was the direct result of uncontrolled fishing effort and overharvest. Sea lamprey (Petromyzon marinus) had a serious negative impact on lake trout only after the fishery removed many of the large, older fish. Other factors, such as habitat degradation and competition from transplanted species were not considered important because the timing of these stresses came after lake trout were already seriously depleted from overfishing.

Canadian and American conservation agencies tried unsuccessfully to rehabilitate the population of lake trout in the Eastern Basin of Lake Ontario during the 1950's and early 1960's. Young trout survived well to age III, but few lived to maturity, because of the sea lamprey and uncontrolled commercial fishing.

Attempts to establish Pacific salmon (Oncorhynchus spp.) in Lake Ontario in the late 1960's and early 1970's also were unsuccessful, probably due to excessive sea lamprey predation. Those salmon that did survive were heavily scarred, averaging more than 10 marks per fish. Because the sea lamprey was implicated in the failure of both lake trout rehabilitation and salmon enhancement, the control of sea lamprey was considered to be essential.

In 1971, the Great Lakes Fishery Commission (GLFC) initiated sea lamprey control in Lake Ontario, which opened an entirely new phase in the management of the Lake Ontario fish community. The New York Department of Environmental Conservation (NYDEC), Ontario Ministry of Natural Resources (OMNR), United States Fish and Wildlife Service (USFWS) and Fisheries and Oceans Canada (DFO) carried out this second phase of lake trout rehabilitation. Highlights of these efforts included: a major reduction in sea lamprey abundance, the introduction during 1973-1982 of 7.5 million lake trout from several different genetic strains, greatly improved survival of adult fish, successful spawning and egg deposition, second generation culture of eggs collected from Lake Ontario spawners and the development of monitoring programs to assess rehabilitation progress.

Monitoring and assessment improved the effectiveness of rehabilitation efforts in Lake Ontario. Pioneering work with coded wire tags and juvenile trawl surveys are two recent examples. These methods of identifying individual groups and keeping track of their progress allowed efficient planning and implementation of stocking programs.

These assessment activities have identified a number of potential problems that may hinder or even preclude rehabilitation if they cannot be resolved: some genetic strains have survived poorly; sea lamprey wounding rates, although greatly reduced from pre-control periods, are still considered excessive; and a degraded environment both in terms of nutrient and toxic chemical loading could seriously inhibit successful reproduction. However, the potential for over-harvest from rapidly developing angling fisheries and incidental commercial catch is considered the greatest threat to rehabilitation.

To deal with these problems and to more effectively direct rehabilitation efforts, under the auspices of the GLFC, the Lake Ontario Committee (LOC) established a lake trout subcommittee with the charge to develop a joint inter-agency plan for the rehabilitation of the lake trout in Lake Ontario. This report represents the completion of that task.

This plan has a goal of rehabilitation, and specific, quantified objectives to be accomplished during the next 20 years. The approach, rationale, and activities required to attain the objectives are summarized in Section F.

The goal of this plan and the focus of our collective efforts is:

> *"To rehabilitate the lake trout population of Lake Ontario such that the adult spawning stock(s) encompasses several year classes, sustains itself at a relatively stable level by natural reproduction, and produces a useable annual surplus."*

To accomplish this goal, an interim objective was developed to demonstrate that rehabilitation is feasible.

> *"By the year 2000, develop a Lake Ontario lake trout stock consisting of 0.5 to 1.0 million adult fish with females that average 7.5 years of age and produce 100,000 yearlings annually."*

Four strategies were formulated to attain this objective. First, stocking is recognized as an essential activity throughout the period of rehabilitation. Historical data suggested that 2.5 million yearling lake trout would have to be planted each year to provide a level of recruitment comparable to that which maintained the native population during the period of exploitation. The selection of appropriate genetic stocks is another important component of the plan and will generally follow guidelines for fisheries rehabilitation programs established at the Stock Concept International Symposium: (1) several different genetic sources will be used initially to maximize genetic variation and, (2) a Lake Ontario stock will be constructed by mating together those lake trout from plantings that survive to maturity and return to spawning shoals. A Lake Ontario hatchery broodstock will ultimately be established.

Second, although lake trout have been stocked in the Great Lakes for over 25 years, little specific information is available on the best techniques to maximize recruitment of stocked fish. With the success of coded wire tags, it is now possible to identify cultural techniques and stocking methods associated with optimum survival and performance.

Third, to achieve the objective of 0.5 to 1.0 million adult lake trout, losses must be controlled. Total annual mortality should not exceed 35% to 40%. This requires effective sea lamprey control and vigorous regulation of fisheries. A catch quota is recommended.

Finally, continued improvements in water quality and further restrictions on the discharge of chemical wastes should result in improved habitat for reproduction. If the reproductive potential of lake trout is inhibited by degraded environment, then habitat improvement or alteration will be necessary.

Recommendations: These program recommendations improve some activities, redirect others, and require additional funding for a few.

(1) Increase stocking to 2.5 million yearlings annually.

(2) Conduct substrate surveys to identify the best spawning habitat and, if required, reassign stocking locations.

(3) Develop a Lake Ontario broodstock from surviving planted strains, and ultimately from their progeny produced in the lake itself.

(4) Improve sea lamprey control.

(5) Survey sport and commercial harvest and set quotas.

(6) Evaluate rearing and stocking practices and implement techniques that are shown to maximize survival of stocked fish.

(7) Develop and implement survey techniques for monitoring the early life history stages in natural habitats.

(8) Develop and implement spawning habitat evaluation and improvement.

These recommendations would be implemented in a sequence that first emphasized those activities (1-6) that lead to large numbers of spawners. As the population expands, then activities (7-8) that deal with reproductive success and habitat management would become more important.

A successful lake trout rehabilitation program for Lake Ontario may require 10-15 years to meet standing stock objectives alone. More time will be needed if harvest is allowed. Full rehabilitation will take many decades to complete. A well-conceived and adequately supported plan is essential to ensure that rehabilitation is not delayed further.

SECTION A - HISTORICAL DESCRIPTION OF THE NATIVE LAKE ONTARIO LAKE TROUT POPULATION AND PROBABLE CAUSES FOR ITS EXTINCTION

Canadians and Americans who settled the Lake Ontario watershed were blessed with a rich, productive and accessible fishery resource. Early accounts told of abundant and easily harvestable fish (Goode, 1884; Smith, 1892). Atlantic salmon, lake trout and whitefish (Coregonus sp.) were a major component of the diet of farming communities, and these fish also became important commercially. By the end of the 1800's the fish community had been altered dramatically with a major reduction in the abundance of large piscivores.

The Atlantic salmon was the first to suffer. By about 1830 the numbers of Atlantic salmon had declined sharply and the species was considered extinct by 1898 (Parsons, 1973). Intensive exploitation of lake trout and lake whitefish began around 1830. Before the end of the century the lake trout population, particularly on the American shore, was depleted - "the catch of trout and whitefish in American waters dropped off to insignificance as early as 1885" (Koelz, 1926).

Statistical surveys of fishing harvest began in 1867 in Canada and 1879 in the United States. The Canadian records show a decline from 1885 to 1900 (Section E; Table 2). American production was the highest the first year of the census and then quickly dropped to insignificance. Production on both shores during the 20th century began at extremely low levels, peaked during the 1920's and then declined throughout the 1930's and 1940's. The last of the lake trout native to Lake Ontario were taken by commercial netters seeking whitefish during the 1950's.

The Collapse of the Lake Trout - Who or What to Blame?

All the changes observed in the recent history of Lake Ontario's fish community can be attributed to man's influence (Christie, 1973). Major destabilizing factors that have been associated with successional changes of the fish community include: overharvesting, competitive displacement, cultural eutrophication, and habitat destruction and degradation.

1. Overharvesting

Of the four major destabilizing influences, overharvesting was the single most important factor responsible for the destruction of the Ontario stocks of lake trout (Christie, 1972). Although extinction finally came in the 1950's, some stocks may have been destroyed as early as the mid-1800's.

The first intensive, directed fishery for lake trout began in the 1830's after collapse of Atlantic salmon (Pritchard, 1931). This early fishery used seines to harvest nearshore spawning aggregations in the fall, a technique that was first instituted in Lake Ontario in 1807 (Koelz, 1926). Reports for these early fisheries indicated impressive harvests; in 1840 nearly 1.7 million kg (3.7 million lbs.) were marketed in Jefferson County (U.S. Census, 1840) and in 1860, 900,000 kg (2 million lbs.) were taken from Chaumont Bay alone (French, 1860). These early accounts included whitefish and lake herring (Coregonus artedii) along with lake trout, but they did not include the undoubtedly substantial harvest that was not marketed, i.e., that used as a food source by local residents.

Within the 30 year period from 1830 to 1860, many nearshore spawning lake trout stocks, particularly in U.S. waters, probably disappeared and by 1860, both lake trout and lake whitefish were rare in inshore waters (Koelz, 1926). The ensuing development of the lake herring and cisco fisheries was apparently keyed to the collapse of lake trout and lake whitefish,; "On account of the wasteful methods then in vogue, the supply of lake whitefish and lake trout declined to such an extent that it was soon profitable to fish for ciscoes" (Pritchard, 1931).

Gill nets first appeared in 1853 (Pritchard, 1931), probably because the seine became ineffective for harvest. With gill nets, fishing was then directed toward offshore stocks throughout the year rather then at near shore spawning populations in the fall.

Other reviews of successional changes in the fish community of Lake Ontario (Christie, 1972, 1973) focussed on events that occurred in Canadian waters beginning in the latter half of the 1800's, probably because modern statistical surveys were inaugurated in 1867 and because Canadian production was dominant (Christie, 1972, 1973) at that time. Although American production of lake trout dwindled by the late 1800's, Canadian catches remained relatively high. The imbalance noted in harvest between Canadian and American fisheries may have been due to the relative morphometry of the two shores and the impact of the earlier seine fishery. Most of the American shoreline is more steeply sloped with no offshore spawning shoals; consequently, the intensive seine fishery in this area may have completely destroyed many distinct nearshore spawning stocks.

In 1867, 175,000 kg (382,000 lbs.) of lake trout were taken from Canadian waters, but catches showed a general decline beginning in 1885 until the end of the century when only 27,000 kg (60,000 lbs.) were harvested (Baldwin, et al 1979). Production on both shores during the 20th Century began with depressed stocks that rebounded from 1910-1920 (Section E; Table 2). However, some of the observed increases in harvest noted during the 1920's could have been the result of increased effective fishing effort:

> "By 1910 the economic forces that stimulated fish production on the Canadian side of Lake Erie and in other Canadian waters at about the same time were felt on Lake Ontario, and fishing apparatus increased enormously, resulting in a more intensive and extensive exploitation of the fishery resources, particularly the salmonids" (Koelz, 1926).

After the relatively high production period of the 1920's, catches steadily dropped until extinction in the 1950's. The declines noted soon after peak production suggest overfishing brought about by increases in effective effort. Therefore, it is very likely that the forces that contributed to record production levels in the 1920's could have been the very same forces that eventually led to the lake trout's destruction.

2. Competitive Displacement

Changes in the species composition of the Lake Ontario fish community since the time of early settlement have been dramatic (Christie, 1973). Both indigenous and transplanted species were thought to have played a significant role in the collapse of some preferred cold water stocks.

Sea lampreys were probably not important in the decline in lake trout abundance observed in the 1800's, but they played a more important role after 1900 when lake trout abundance was reduced by overharvest (Christie, 1972). While the lake trout population contained many large, older individuals, the sea lamprey parasitized only the largest fish available (Christie, 1973). When intensive fishing removed the larger fish, the sea lamprey concentrated on smaller and sparcer individuals that were more likely to die from attacks (Christie, 1973). The additional mortality due to sea lampreys hastened the decline. In addition, sea lampreys may have become more abundant after the turn of the century. The dams and mills constructed in the 1800's began to deteriorate by 1900, opening streams to sea lamprey reproduction (Christie, 1973).

Alewife (Alosa pseudoharengus) and rainbow smelt (Osmerus mordax) are relatively recent invaders of Lake Ontario (1870 and 1929, respectively), and they now make up the major component of fish biomass. Alewives were used by native lake trout as a food item (Dymond, 1926). Rainbow smelt became established at the time when lake trout abundance was declining. Collectively, these two species probably had a minimal impact on the collapse of lake trout (Christie, 1973).

3. Cultural Eutrophication

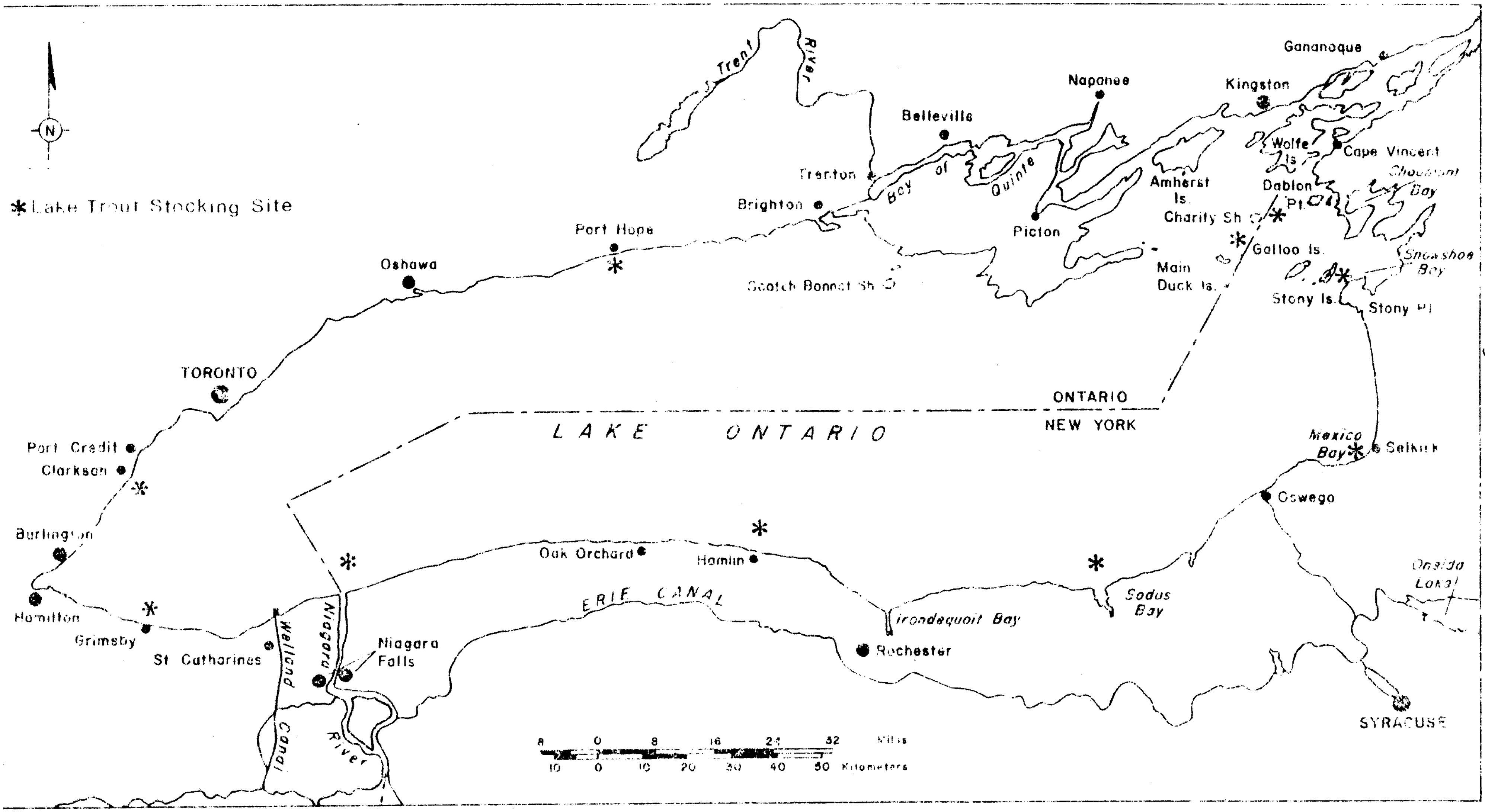
Enrichment of Lake Ontario by discharge of municipal and industrial organic wastes and from agricultural run-off probably did not contribute significantly to the failure of lake trout. Before 1900 there were some localized areas of excessive nutrient loading, but mostly, water quality remained unaffected by man (Beeton, 1965). Habitat alterations from excessive nutrient loading were first significant during the early 1950's (Christie, 1973), when lake trout stocks were near extinction. Although water quality conditons are now an important factor in a successful rehabilitation effort, they probably contributed little to the loss of lake trout.

4. Habitat Destruction and Degradation

One of the first alterations of the fish environment caused by man was due to clearing the land. Watershed destabilization resulted in increased run-off and extensive soil erosion, which in turn led to siltier and warmer streams (Christie, 1973). Dam construction on all tributaries was extensive as settlers looked for cheap and efficient sources of power for saw and grist mills (Christie, 1974); these dams also provided an effective method for harvesting fish. These developments had profound effects that were particularly significant for those anadromous species that used streams as spawning and nursery areas. The first and most conspicuous victim of man's activities was the Atlantic salmon. For lake trout, the impact of environmental deterioration was probably less severe than other cultural stresses, since with the exception of spawning, this species has principally offshore habits. One less obvious exception would be the destruction of possible spawning shoals in the Toronto area by "stone hookers," those early workers who removed large quantities of rock from the nearshore zone for use as construction material (Whillans, 1977).

Conclusion

Because of sparse and incomplete historical records it is extremely difficult to say with certainty what factor or factors caused the extinction of Lake Ontario's lake trout, but it appears that uncontrolled fishing was most responsible for the loss of the native population. Sea lamprey predation contributed to the collapse, but only after the fishery had seriously reduced the number of large, older lake trout. Other factors, such as habitat degradation, competition from transplants, and cultural eutrophication apparently contributed little to the decline and eventual extinction of Lake Ontario lake trout, but may affect rehabilitation efforts.



Map of Lake Ontario

SECTION B - STATUS OF LAKE TROUT REHABILITATION IN LAKE ONTARIO

Phase 1: 1953-1965

The same factors that apparently spelled the demise of lake trout native to Lake Ontario contributed to the failure of the first phase of rehabilitation, a cooperative experimental effort undertaken by the Province of Ontario and the State of New York between 1953 and 1964 to restore depleted spawning stocks in the Eastern Outlet Basin. Early stockings were small but by the early 1960's totalled more than 100,000 yearlings (LOFMC, 1962, 1965).

During phase 1, lake trout had a fast rate of growth and relatively good survival to age III. Survival beyond age III was poor (less than 30%) and few fish lived to maturity (Christie, 1971).1/ Sea lamprey predation was considered an important factor in lake trout mortality, based on an incidence of sea lamprey marks often exceeding 30% at age III and a correlation between mortality and sea lamprey density (Christie, 1974). Although sea lamprey induced mortality may have been substantial, biologists at the time were concerned that incidental harvest by the commercial lake whitefish fishery was excessive (LOFMC 1962). For example, observed recaptures for some plantings reached 25% and for the 1963 stocking, 12% were captured at age II, the year following stocking (LOFMC, 1965). Total recaptures could have been twice as great (Christie, pers. comm.). Some biologists felt reduction of the exploitation level was essential for success. Since neither resource agency was able to control these sources of mortality, the first phase of lake trout rehabilitation was abandoned in the mid-1960's.

Soon after the lake trout program was abandoned in Lake Ontario, the State of Michigan made the first planting of coho salmon (<u>Oncorhynchus kisutch</u>) in Lake Michigan. The success of the coho salmon program stirred interest, not only in the fishing public of Michigan, but with fishery biologists throughout the Great Lakes. Consequently, New York and Ontario began planting coho salmon in Lake Ontario in 1968 and 1969 respectively. By 1971 the two agencies had stocked nearly 1.5 million coho and chinook salmon (<u>Oncorhynchus tschawytscha</u>). During the same time, the Province of Ontario also introduced a half million splake (brook trout, <u>Salvelinus fontinalis</u>, x lake trout) and nearly four million kokanee fry (<u>Oncorhynchus nerka</u>) (Pearce, et al. 1980).

Survival for all of these plantings was poor and those fish that did survive had numerous sea lamprey scars. Coho and chinoook salmon returning to the Salmon River averaged 10 and 13 scars per fish respectively (Pearce et al. 1980) and more than 90% of the coho salmon sampled in the Credit River in 1970 bore fresh wounds (Christie and Kolenosky, 1980). During this period, harvest was minimal. Commercial fishing was prohibited in New York waters and limited in Canadian waters and the few fish failed to interest even the most determined angler. It was evident that sea lamprey predation had caused the poor return.

1/These survival estimates and those quoted in subsequent discussion were based on c/f from gill net captures and as such they are subject to a variety of potential biases, e.g. mesh selectivity, differential catchability between years and emigration out of the area under study.

Because sea lamprey were linked to the failures of both the early lake trout rehabilitation effort and the Pacific salmon introductions, the Lake Ontario Committee (LOC) of the Great Lakes Fishery Commission recommended that sea lamprey control be extended to Lake Ontario. The first chemical treatment of sea lamprey infested streams began in 1971 and marked the beginning of a second phase in the rehabilitation and management of fish stocks in Lake Ontario.

Phase 2: 1973-1982

Efforts to reestablish the lake trout in Lake Ontario began again in 1973 with a stocking of 66,000 yearlings near Stony Island. Since then, nearly 7.5 million lake trout have been stocked; 5.56, 1.6, and 0.26 million by the USFWS, OMNR, and NYDEC respectively. Beginning in 1979 the experimental capabilities of the rehabilitation effort were expanded with the pioneering work of the USFWS using coded wire tags in lake trout stocked in Lake Ontario. All three cooperating agencies have ongoing surveys of adult and juvenile fish.

Six different strains were introduced, with most fish marked so performance could be assessed. To date, the most notable feature of the second phase of lake trout rehabilitation has been the variation in performance of the different stockings. Several groups have done well; survival beyond age III has been excellent, many fish have matured, and spawning has been observed. Specific details are available in LOC reports, but major performance highlights are noted below.

Much of the variation in survival may be related to genetic origin. The strain of lake trout from Lake Superior survived best through age III+ (Elrod, et al. 1982). Recent recaptures of the Seneca Lake strain have been poor in juvenile trawl surveys, although adults from earlier stockings survived well and many reached maturity and spawned (Elrod, et al. 1982; Schneider, 1982). Some earlier stockings of the Clearwater Lake and Green Lake strains both survived well to age III+, but subsequent mortality was about 70% per annum (Schneider, 1982). More recent stockings of Clearwater Lake strain have survived poorly to age III+ (Elrod, et al. 1982). Provisional estimates of angling exploitation in 1979 were nearly identical (e.g. 14.5%) for both Clearwater Lake and Seneca Lake strains (age IV and older) near Stony-Galloo Islands in 1979. However, natural mortality, including losses from sea lampreys, was nearly twice as great for Clearwater as Seneca fish (Schneider, 1981). Index gill netting in Canadian waters has demonstrated good survival of Canadian stockings of Lake Superior and Lake Manitou strains. However, strain comparisons have been limited by available fin clips since Ontario has not been using coded wire tags.

Sea lamprey wounding on lake trout during the 1970's was markedly reduced from the pre-control period, but it was still greater than in Lakes Michigan and Superior, and high enough to suggest appreciable sea lamprey-induced mortality. The rate of fresh wounds on lake trout between 533 and 837 mm averaged 10.4% in Lake Ontario between 1976 to 1980 (Dustin, et al. 1981). For comparison, similar-sized lake trout in Lakes Michigan and Superior during this period averaged less than 4% with wounds (Wells, 1980a; Pycha, 1980a). Previously, when wounding exceeded 10% in the upper lakes, the annual rate of sea lamprey induced-mortality exceeded 30% (Pycha, 1980b; Wells, 1980b). This experience from the Upper Lakes indicates that lake trout mortality from sea lamprey predation in Lake Ontario is still substantial.

Several factors confuse this conclusion about the impact of sea lamprey predation. First, two separate plantings of Seneca Lake strain lake trout survived well as adults (65%) even when wounding was high, suggesting that Seneca Lake lake trout may be less vulnerable or more resistant to sea lamprey predation than other strains. Similar observations in Cayuga Lake indicated that sea lamprey predation was not a major component of adult mortality for Seneca Lake strain lake trout (Youngs, 1980). Secondly, Clearwater Lake is shallow (mean depth 12m) and progeny from this strain may not be physiologically suited for Lake Ontario where summer thermal conditions frequently force lake trout to depths of 35-45 m (115-145 ft.). There is strong evidence that incidental catch in the Canadian yellow perch (Perca flavescens) and lake whitefish fisheries contributes substantially to total mortality of both Canadian and U.S. plantings of lake trout in the Eastern Basin.

Growth of the lake trout from all strains planted in Lake Ontario is exceptional. At age III+ lake trout weighed 1.5 kg (3 lbs) and gained about 0.5 kg per year thereafter (Schneider, 1980). Not all strains have grown at the same rate. At age III+, the Seneca Lake and Clearwater Lake strains were 19% and 66% heavier respectively than Green Lake fish (Schneider, 1980). Clearwater Lake juveniles were larger than the Lake Superior strain and generally prefer warmer, shallower water compared with other strains, which may account for their faster growth (Elrod, et al. 1981).

Age at maturity is closely associated with growth rates; hence lake trout mature early in Lake Ontario. Males first mature at age III+ and nearly all are mature at IV+. Maturation of females occurs later than males; about 10%, 30% and 100% were mature at ages IV+, V+ and VI+ respectively (Schneider, 1980). Preliminary information suggests some variation in maturity schedules between strains, probably due to variation in growth rates. The relationship between fecundity and weight was linear with overall egg production averaged about 1500 eggs/kg of body weight for Clearwater Lake and Green Lake strains, but Seneca Lake strain females were more fecund averaging 1759 eggs/kg. (Schneider, 1980).

Contamination by persistant toxic chemicals is the major environmental problem of the Lake Ontario Basin (GLWQB, 1981). Initially it was believed that contaminants seriously affected reproductive capability of lake trout. Approximately 40% of the male lake trout collected in fall gill net surveys by NYDEC had abnormal testes development characterized by one or more constrictions. Histological examination indicated that lake trout with constricted testes showed delayed cycles of spermatogenesis where approximately 40% of the sperm did not achieve maturity in time for spawning (Ruby, 1980). Survival of lake trout eggs taken from Lake Ontario spawners from 1977-1979 and incubated in a laboratory averaged only 24.8% from egg take to 60 days after swim-up (Colquhoun, et.al. 1981). Lake trout eggs collected from relatively uncontaminated sources were used as controls and their survival averaged 46.9%. More recently, a laboratory study by NYDEC indicated no difference in early survival between Lake Ontario fry and controls (J. Skea, pers. comm.). Also, recent studies by DFO indicate that males with constricted testes produced viable young (V. Cairnes, pers. comm.).

In 1979 a cooperative Environment Canada-OMNR investigative team documented lake trout spawning on a shoal near Snowshoe Bay in the Eastern Outlet Basin (LOC, 1980). Although eggs were deposited at this site each year, advanced fry have yet to be collected. In the Fall of 1981, fertilized eggs were planted in wire mesh baskets on an artificially constructed shoal off Toronto. Live yolk-sac fry were found in some of the baskets when they were recovered in April by the Metropolitan Toronto and Region Conservation Authority. No naturally produced fingerlings or yearlings have been taken in summer trawling. (Elrod, et al. 1982 and Christie, pers. comm.)

SECTION C - GOAL & OBJECTIVES

REHABILITATION GOAL

The purpose of this plan is to document actions necessary to rehabilitate the lake trout population in Lake Ontario. The definition of a rehabilitated lake trout stock and the goal of this plan is:

> *"To rehabilitate the lake trout population of Lake Ontario such that the adult spawning stock(s) encompasses several year classes, sustains itself at a relatively stable level by natural reproduction and produces a useable annual surplus."*

OBJECTIVES:

Two sequential objectives were formulated that lead to the rehabilitation goal. Both were developed from an analysis of rather sparse historical accounts of native Lake Ontario lake trout, and there is some uncertainty regarding their development and application. At this time these objectives represent the best possible "target" for our rehabilitation efforts, but as progress is made toward full rehabilitation these objectives will undoubtedly be re-defined and modified to more accurately direct program activities.

I. *Interim Objective: By the year 2000, demonstrate that rehabilitation is feasible by developing a Lake Ontario lake trout stock consisting of 0.5 to 1.0 million adult fish with adult females that average 7.5 years of age and produce 100,000 yearlings annually.*

II. *Ultimate Objective: To develop a lake trout population in Lake Ontario of 0.5 to 1.0 million adults that produce 2 to 3 million yearlings annually and provide 450,000 kg (1 million lbs.) of usable surplus.*

Estimates of numbers of adults and the ultimate expected recruitment of 2 to 3 million naturally produced yearlings were derived from an analysis of growth and mortality factors required to produce 450,000 kg (1 million lbs.) of harvestable lake trout. The 100,000 yearling production for the interim objectives represents a level of natural reproduction that would demonstrate to program administrators the feasibility of rehabilitation; it has no biological basis.

In the application of these objectives, a very important factor to consider is the impact of density dependent population responses. Compared to what is presently observed, as the lake trout stock approaches the levels described in the objectives, growth rates will decline, age at maturity will increase, and fecundity will be reduced. For example, the 7.5 year average age for females in the interim objectives was obtained by adding a spawning frequency index of 2.0 years to a provisional estimate of the age at onset of maturity, 5.5 years. As the population expands, age at maturity will increase thus requiring an increase in the average age guideline. Not only will growth and maturity change, but density dependent responses in natural mortality may also occur. For lake trout stocks at moderate levels of biomass, natural mortality should approximate the average values noted for the species (25%), but at low biomass levels, natural mortality could be less, and conversely, at higher levels it could be greater (Christie, pers. comm.). In summary, the actual values outlined in the objectives could be considered as dynamic as the system they try to describe. Periodic assessment of objectives is a crucial element in the overall plan for rehabilitation.

STRATEGIES

To attain these objectives, four broad strategies were formulated:

A. Annually stock 2.5 million yearlings of Lake Ontario strains(s).2/
B. Maximize recruitment of stocked fish.
C. Maintain total annual mortality at 35 to 40%.
D. Maximize reproductive potential of lake trout.

2/Lake Ontario strain refers to the progeny of lake trout that have survived in Lake Ontario and spawned in the lake or have been taken and spawned artifically for hatchery rearing and restocking.

SECTION D - RATIONALE FOR OBJECTIVES

A critical component of this plan is the development of program objectives that provide clear, measurable criteria that can be used to assess the progress of rehabilitation. For the interim objective and several of the important subobjectives specified in the plan outline, estimates were developed for various population parameters for what is considered a rehabilitated lake trout population in Lake Ontario. These include estimates for mortality, age composition and spawning frequency, population size and recruitment. The following estimates represent current information developed by the Lake Trout Subcommittee of the LOC; as new information becomes available these estimates will be adjusted and modified to provide a more refined strategy for rehabilitation.

I. Mortality

Estimates of mortality have been an important and frequent component of Great Lakes assessment reports. If a minimal level of total mortality could be associated with stable, naturally-sustained lake trout populations then this rate of mortality might serve as a guideline in developing criteria for age structure. Furthermore, excessive total mortality might alert managers to problems due to fishing, sea lampreys, and other natural causes.

Healy's (1978) tabulation of 33 separate estimates of mortality of lake trout from the literature, and three estimates from other sources (Table 1) suggests that the conditional or annual rate of natural mortality was similar for unexploited and exploited populations. Mortality in unexploited populations ranged from 19% to 45% and averaged 29%. In exploited populations natural mortality ranged from 18% to 32% and averaged 24% if sea lamprey were absent. If sea lamprey were present, natural mortality ranged from 47% to 91% and averaged 59%.

As expected, fishing mortality was greater for those populations that did not coexist with the sea lamprey. In these cases, fishing mortality ranged from 2% to 44% and averaged 30%. For those populations with the sea lamprey, fishing mortality was much lower, ranging from 3.5% to 14% and averaging 10%.

In terms of total mortality, exploited populations ranged from 25% to 57% averaging 46%. For those populations with the sea lamprey present, total mortality was greater, ranging from 47% to 92% and averaging 65%.

Prior to the invasion of the sea lamprey into the Upper Lakes, mortality as estimated from commercial catch data was more or less comparable between the Great Lakes. In Lake Michigan before 1950, total mortality was estimated at 50% by Silliman (1969) with a computer simulation using commercial catch data. Likewise, Sakagawa and Pycha (1971), using a catch curve but with age composition data collected from Lake Superior in 1948, estimated total mortality at 50%; although the population may have been in decline at this time (Hile, et al. 1951).

In summary, the conclusions of Healy (1978) appear appropriate "... a generally low mortality rate, in the range of 20 to 30% or less appears typical of unexploited lake trout populations in the absence of sea lampreys. Under exploitation, at least some lake trout populations are able to withstand an

Table 1. Annual rates of mortality for various lake trout populations. [Primarily from Healey (1978) Table 2.]

Lake	Reference	Percent Mortality 3/ Total	Fishing	Natural
Low exploitation, no lamprey				
Great Bear	Miller & Kennedy, 1948	19	0	19
Great Bear	Falk, et al, 1973	17	?	?
Great Bear	Falk, et al, 1973	19	?	?
Great Bear	Falk, et al, 1973	23	?	?
Great Slave - West	Kennedy, 1954	23	0	23
Great Slave - East	Kennedy, 1954	30	0	30
Great Slave - East	Falk, et al, 1973	19	?	?
Great Slave - East	Falk, et al, 1973	21	?	?
Great Slave	Beverton & Holt, 1959	45	0	45
Red Rock	Martin, 1951	29	?	?
Louisa	Martin, 1951	54	?	?
LaRonge	Rawson, 1961	25	0	25
Kaminuriak	Bond, 1975	36	0	36
Hottah	Wong & Whillaus, 1973	32	0	32
Keller	Johnson, 1972	25	0	25
Mistassini	Dubois & Lagueus, 1968	23	?	?
Exploitation, no lamprey				
Manitou	Budd, et al, 1968	25	2	24
Opeongo	Martin & Fry, 1973	48	35	19
Opeongo	Martin & Fry, 1973	56	44	22
Opeongo	Martin & Fry, 1973	50	26	32
Swan	Patterson, 1968	49	33	24
Cold Stream Pond	DeRoche & Bond, 1955	57	40	28
Superior	Sakagawa & Phcha, 1971	50	42-44	22-23
Michigan	Silliman, 1969	50	39	18
South Bay, 1948	Fry, 1952	32	10	25
Exploitation, lamprey				
South Bay, 1948-54	Budd, et al, 1969	49	3.5	47
South Bay, 1948-54	Budd, et al, 1969	62	10	58
South Bay, 1948-54	Budd, et al, 1969	78	10	76
South Bay, 1948-54	Budd, et al, 1969	92	10	91
South Bay, 1949	Fry, 1952	68	14	65
Cayuga	Webster, et al, 1959	54	13	47
Cayuga	Youngs, 1980	44	8	39
Montreal River, 1951	Loftus, 1957	56	11	51
Montreal River, 1951	Loftus, 1957	62	11	57
Dog River	Loftus, 1957	59	9	55

3/To the careful reader who has inspected these figures and is troubled to discover that fishing and natural mortality when added together do not equal total mortality, please find consolation in the fact that they are not directly additive. The product of fishing and natural mortality (expressed as decimal equivalents) must be subtracted from the sum of fishing and natural mortalities in order to equal total mortality. For example: Dog River: 0.59 = 0.09 + 0.55 - (.09) (.55).

additional 30 to 40% fishing mortality for a total mortality rate of about 50% annually". Healy further concluded that populations with mortality in excess of 50% and those suffering heavy sea lamprey predation were in serious trouble and declining rapidly. Pycha (1980b) in a review of the recent efforts in rehabilitating the lake trout population in Lake Superior had a similar conclusion ". . . the evidence . . . strongly suggests that any management option that would increase (total mortality) above the level found in 1974-77 (total mortality = 50%) might prevent restoration of adequate spawning stocks."

From these analyses, annual mortality of 50% appears to be the maximum tolerable rate to maintain a stable lake trout population. However, rehabilitation implies expansion of numbers. To accomplish this a mortality guideline of less than 50% is required to permit population growth. An estimate based on information collected throughout the Great Lakes suggests that a total mortality target of 35-40% would be sufficient to permit population growth, while at the same time allowing for a small and carefully controlled harvest.

II. Age Composition and Spawning Frequency

For the purpose of rehabilitation there is a need to describe the age structure of the spawning population. Age composition of different lake trout populations varies markedly depending on genetic factors, growth, and intensity of exploitation; so it is important to establish a reasonable guideline for Lake Ontario lake trout. The average age of mature female lake trout was selected as a measure of age composition, i.e., larger average ages indicating populations with more age groups and older fish compared to population with younger average ages. Since no adequate age data exist for native Lake Ontario lake trout to estimate an average age guideline, descriptions for other lake trout populations were examined. Abrosov (1969) described a method for calculating an index of spawning frequency which was then used to help formulate an average age guideline for the interim objective.

Abrosov's method, developed for populations with moderate to intensive commercial fishing, utilizes two population parameters to make generalizations about the health of various stocks -- average age of the catch (commercial turnover) and the age of onset of sexual maturity. By subtracting the age of onset of maturity (z) from the average age of the catch (o), the result (t) is an algebraic expression of the extent to which the average age of the catch exceeds the age of onset of sexual maturity: $t = o - z$.

The values of t are generally species and gear specific, and empirically derived. Abrosov presented t-values for several species in various Russian fisheries, but none seemed applicable to our situation. However, we were able to examine published data for lake trout fisheries in North America and estimate t-values.

In Lake Superior, prior to the invasion of the sea lamprey and during a period of intensive fishing effort (1948), Sakagawa and Pycha (1972) reported the average age of the commercial catch for (11.4cm) gill nets and set lines as 8.7 and 10.1 years respectively. Although we did not have sufficient data to calculate the age at onset of maturity, Lawrie (1972) indicated that lake trout generally did not mature before ages 7 or 8 in the upper Great Lakes. From this information, it appears that the average age of the catch exceeded the age of onset of maturity (t) by a factor of 0.7 to 1.7 years for gill nets and 2.1 to 3.1 years for set lines. Hile et al (1951) indicated, however, that the lake trout population in 1948 was declining due to overfishing. Consequently, these t-values, particularly those for gill nets, may be too low.

In Lake Opeongo prior to 1948, the long-term average age of the anglers' catch was 7.8 years; at age VI, one-third of the lake trout were mature (Martin and Fry, 1973). Again, the calculated t-value likely falls between 1 to 2 years. From 1948 to 1961 the average age of the anglers' catch was similar to the previous period at 7.9 years, but by 1961 only one-tenth of the age VI fish were mature due to dietary changes (Martin and Fry, 1973). In this case, if the onset of sexual maturity occurred at age VII to VIII, then t-values would be 0.10 to 0.90 years.

In spite of the apparently low t-values for the relatively stable lake trout fishery in Lake Opeongo after 1948, these values may be actually too low. For example, in a similar circumstance in Cold Stream Pond, Maine, the average age of the anglers' catch was 5.7 years, and the average female matured at 6 years (DeRoche and Bond, 1955). Relative spawning frequency based on this data was t = -.03; however, DeRoche and Bond (1955) were concerned that the high rate of exploitation and the high incidence of immature fish in the catch (30%) would result in population instability. Subsequent to DeRoche and Bond's publication, the lake trout population in Cold Stream Pond did in fact go through a period of "instability." However, through the initiation of increased size limits, the population today is more stable and continues to maintain itself through natural recruitment (Bond, pers. comm.).

From the limited information on lake trout it appears that t's from 0 to 1 are too low to maintain a stable population. Lake trout have relatively low reproductive potential and may require more spawnings to achieve replacement (Christie, pers. comm.). Lake trout fecundity is lower per body weight than in other salmonids, and the first spawning of the female has eggs that are of poor quality (Kutkuhn, pers. comm.). Therefore, t-values greater than 1.0 seem justified.

For the lake trout population native to Lake Ontario, the calculated t may have exceeded 2.0 years. Dymond (1928) examined native lake trout taken from commercial gill netters off Port Credit, Ontario in 1927 and stated that the mean weight of lake trout taken was 3.9 kg and that " .... Lake Ontario lake trout do not begin to spawn until they reach (2.7 kg.)." By using the weight-length regression and the von Bertalanffy growth equation developed in a subsequent section, we estimated the mean age of the catch and age of onset of sexual maturity were 8.5 and 6.4 years respectively. Calculated t, in this important example, would then be 2.1 years based on the historic commercial gill net fishery, and if historical growth rates were available, the index of spawning frequency would most likely be even greater.

In support of the above conclusion, we examined the effect of different levels of mortality on the average age of a hypothetical adult population. If exploitation were limited to only mature fish we could use this approach to examine the relationship between total mortality and calculated t. In Figure 1 we have depicted a population based on constant recruitment of 1,000 mature fish at the age of onset of maturity (z). We calculated the survivors at z + 1, z + 2, etc. for three different rates of total mortality: 25%, 40%, and 65%. From our previous discussion we established that total mortality should not exceed 40%, and with this rate of mortality the average age of our hypothetical population would be 1.49 years greater than age of onset of maturity (z). With a 25% rate of total mortality, similar to that for an unexploited lake trout stock, the average age would exceed z by 2.97 years and for 65% by only 0.54 years (Figure 1). This suggests that if only mature fish (ages $>$ z) are harvested and total mortality is kept below 40%, t values will range from 1.49 to 2.97. These figures agree reasonably well with our previous conclusion based on actual data.

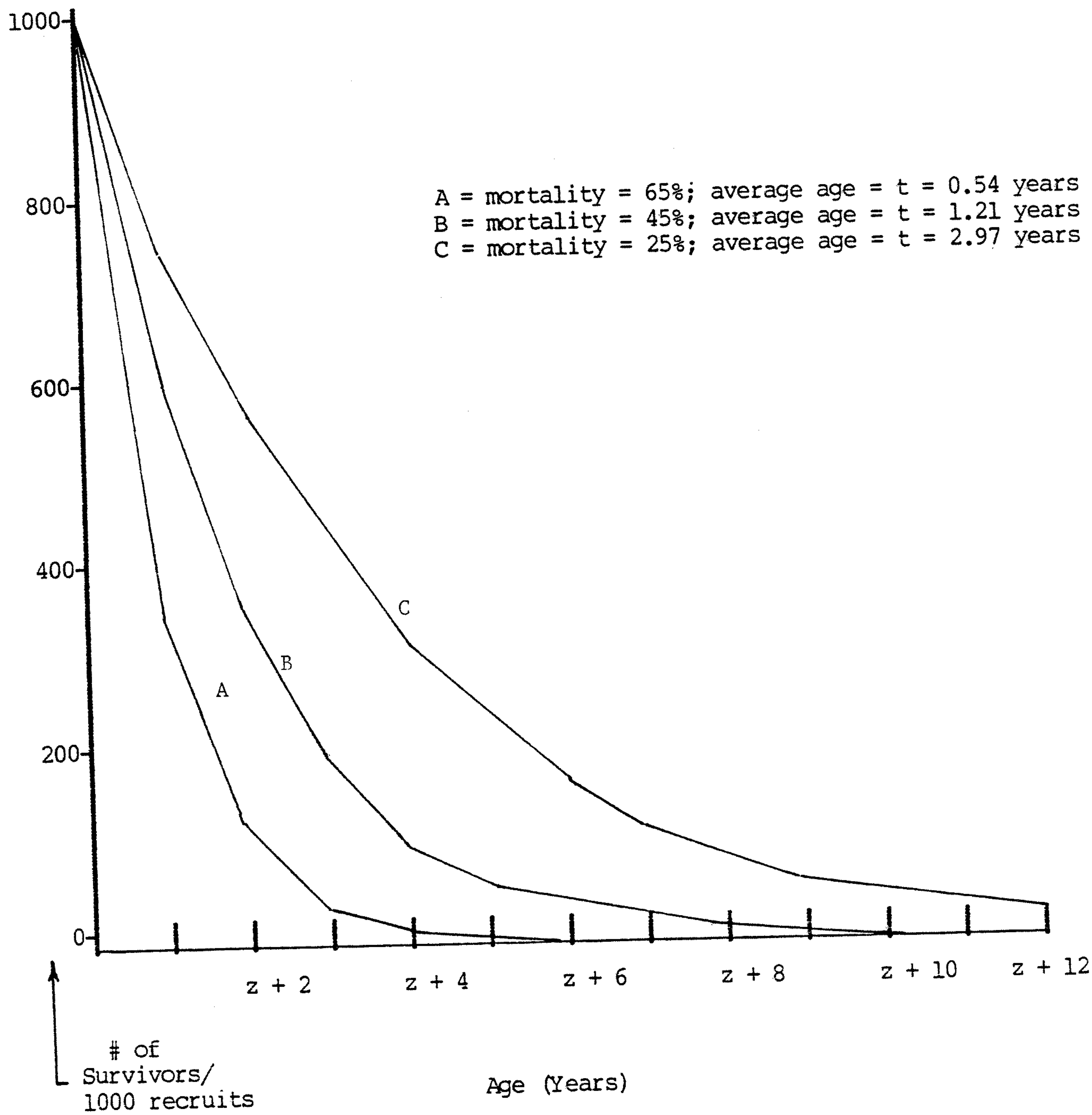
In summary, for Lake Ontario lake trout rehabilitation we recommend a trial value of t = 2.0 years. A preliminary maturity schedule developed for Seneca Lake strain lake trout from Lake Ontario indicates that the age of onset of maturity is 5.5 for females, thus a target average age for adult females would be 7.5 years. We expect that as rehabilitation progresses the age of onset of sexual maturity will increase because of genetic and growth variations of different stocks, as well as density dependent growth changes that are anticipated as population size expands. Consequently, to maintain a t value of 2.0 yrs., the average age of the catch guideline would have to adjusted upward in response to these changes in age of maturity. In practice, the spawning frequency and average age criteria will be used to assess the age composition of the adult population, and they may also be used to provide a basis for regulating fisheries.

III. Population Size and Recruitment

Other attempts to define lake trout rehabilitation in the Great Lakes emphasized the age structure of the mature part of the population. To better gauge the scope of rehabilitation, the size of the adult stock also needs to be quantified. In addition, the level of hatchery stocking required in the early stages of rehabilitation must be determined.

The Approach: To estimate standing crop and recruitment of the population native to Lake Ontario, we first established an average annual harvest from the historical catch records, assuming that year class strength and the rate of fishing were nearly constant over several years. Then we developed growth-at-age data, based on a few historical sources and recent surveys of hatchery lake trout. The growth of present stocks, however, is likely different from that of the native population. Next, we developed a possible range of instantaneous rates of total, natural, and fishing mortalities, based mostly on published accounts of other lake trout fisheries. Using these estimates and assumptions in a Ricker-type equilibrium yield model, we estimated the recruitment levels and standing crop required to produce the average annual harvest.

Figure 1. Expected numbers of survivors per 1,000 recruits of adult fish at the age of onset of maturity (z) for total mortality rates of 25, 45, and 65%. The average age of each hypothetical population is equivalent to Abrosov's t.



Historical Yield: The best estimates of the annual harvest of lake trout are from the catch records of the Canadian fisheries (Baldwin, et al., 1979, Table 2). Records for lake trout in the U.S. portion of Lake Ontario are less meaningful because that population was seriously depleted before the first record of harvest (Koelz, 1926). Peak production in the Canadian lake trout fishery occurred in 1925 when harvest exceeded 450,000 kg (1.0 million lbs.). The long-term (1867-1939) average production of lake trout in the Canadian fishery was about 160,000 kg (350,000 lbs.) or 0.16 kg/ha.

The Canadian average yield of 0.16 kg/ha for Lake Ontario is much lower than expected, based on a morphoedaphic index (MEI). This index of physical and chemical characteristics, when applied to Lake Ontario, suggested it was more productive than Lake Michigan i.e., MEI = 1.94 and 1.41 respectively (Ryder, 1965). Nevertheless, the long-term stable yield for Lake Michigan was 0.58 kg/ha, nearly four times greater than the average yield from Lake Ontario. Further, Lake Superior with an MEI of 0.39, averaged 0.24 kg/ha of lake trout. A recent report (OMNR, 1982) which attempted to partition yields estimated from the MEI into individual species yields recommended that 25% of the MEI yield be lake trout. If this percentage is applied to Lake Ontario, then an average lake trout yield of 0.47 kg/ha would be allowable.

The disparity between theoretical and observed yields may relate to the collapse of the American lake trout fishery prior to the maintenance of harvest records as well as the removal of lake trout biomass from the allowable harvest by the sea lamprey. Christie (1974) questioned the efficiency of a system dominated by alewife and smelt in vectoring nutrients when compared with the historical fish community of piscivores and ciscoes (Coregoninae). The structure of the present cold water community may limit the system's ability to meet theoretical yield targets.

For the purpose of this plan, an estimated annual average of 450,000 kg (1.0 million lbs.) or 0.24 kg/ha is considered a reasonable sustainable yield. It falls within the range between long-term average Canadian yield (0.16 kg/ha) and peak recorded production (0.46 kg/ha) and equals the average for Lake Superior.

Growth: Dymond (1928) presented growth data for lake trout native to Lake Ontario based on commercial netting in 1927. Of 134 lake trout, the largest weighed 14.8 kg (32.5 lbs.) and 10% of the sample exceeded 5.45 kg (12.0 lbs.). This size distribution was considered representative of Canadian commercial catches by Dymond. Dymond also presented data that we used to develop a weight-length regression. His data also indicated that 87% of the commercial catch was comprised of mature fish, those that exceeded 2.7 kg (6.0 lbs.).

To estimate length and weight-at-age we used several data sources. For age 1.5 we used the sizes of hatchery fish at planting. For fish between 2 and 8.5 years we used the 1972 year class of lake trout captured at Stony Island by NYDEC. For ages greater than 8.5 we extrapolated the above data, based on a von Bertalanffy growth equation.4/ These lengths-at-ages were then compared with a small sample of native lake trout collected in the early 1940's and aged by J.R. Greeley (NYDEC files). Weight-at-age was then calculated using the weight-length regression developed from Dymond (1928)5/ after total lengths were converted to fork lengths (Webster, et al 1959)6/.

4/ $l_t = 1064\ (1-e^{-0.1024(t+2.908)})$
5/ $W=0.00000233L$
6/ $TL=1.1+1.082FL$

Table 2. Commercial Production of Lake Trout from Lake Ontario From Baldwin et al. (1979).

Table 7.— Production (thousands of pounds) of LAKE TROUT in Lake Ontario.

Year	U. S. New York	Canada Ontario	Total	Year	U. S. New York	Canada Ontario	Total
1867	-	382	-	1922	34	722	756
1868	-	613	-	1923	36	755	791
1869	-	406	-	1924	45	939	984
1870	-	264	-	1925	70	1,062	1,132
1871	-	306	-	1926	61	784	845
1872	-	187	-	1927	42	713	755
1873	-	241	-	1928	43	806	849
1874	-	118	-	1929	62	556	618
1875	-	325	-	1930	24	364	388
1876	-	378	-	1931	14	388	402
1877	-	401	-	1932	18	302	320
1878	-	362	-	1933	12	353	365
1879	570	438	1,008	1934	14	256	270
1880	-	250	-	1935	7	245	252
1881	-	382	-	1936	8	227	235
1882	-	251	-	1937	13	205	218
1883	-	317	-	1938	17	276	293
1884	-	377	-	1939	16	269	285
1885	21	308	328	1940	14	187	201
1886	-	236	-	1941	3	126	128
1887	-	117	-	1942	1	90	91
1888	-	97	-	1943	3	76	80
1889	7	127	133	1944	4	74	78
1890	41	105	146	1945	1	105	106
1891	-	169	-	1946	1	102	104
1892	-	195	-	1947	1	64	65
1893	6	240	246	1948	*	42	43
1894	-	161	-	1949	*	22	22
1895	-	106	-	1950	-	15	15
1896	-	161	-	1951	2	40	42
1897	3	154	156	1952	2	32	34
1898	-	102	-	1953	3	14	17
1899	15	104	120	1954	1	7	8
1900	-	60	-	1955	*	4	4
1901	-	65	-	1956	*	2	2
1902	-	65	-	1957	*	1	1
1903	4	72	76	1958	1	1	2
1904	-	84	-	1959	*	1	1
1905	-	75	-	1960	4	1	6
1906	-	108	-	1961	5	3	8
1907	-	107	-	1962	1[1]	1	2
1908	14	177	191	1963	-	1	1
1909	-	640	-	1964	-	*	*
1910	-	413	-	1965	-	-	-
1911	-	385	-	1966	-	-	-
1912	-	631	-	1967	-	-	-
1913	31	573	604	1968	-	-	-
1914	29	633	662	1969	-	-	-
1915	31	555	587	1970	-	-	-
1916	14	540	554	1971	-	-	-
1917	24	469	492	1972	-	*	*
1918	24	387	411	1973	-	*	*
1919	26	554	580	1974	-	1	1
1920	28	462	490	1975	*	2	2
1921	25	559	584	1976	-[2]	2	2
				1977	-	1	1

[1]Fishery closed.

[2]The capture and sale of lake trout was banned 20 September 1976 when Mirex levels exceeded 0.5 ppm. Reopened 20 March 1977.

Rates of Fishing:7/ To arrive at probable rates of fishing mortality for the native population of lake trout in Lake Ontario we assumed that total mortality would not exceed 50% (Z=0.70), a rate established in a previous section as the maximum that could be tolerated by a self supporting lake trout population. Because of the endemic sea lamprey population we also assumed that natural mortality was probably greater than the average for other exploited stocks (see Mortality Discussion). For this analysis we considered a natural mortality rate of 30% (M = 0.35) as a reasonably conservative approximation for Lake Ontario. For younger age groups we assumed M = 0.50 based on survival estimated between ages II and III for Lake Michigan lake trout captured with trawls (Rybicki and Keller, 1978).

Given these limits of total and natural mortality, we developed a range of fishing mortalities from Z = F + M. For the situation where fishing mortality was greatest we estimate that F = 0.35, since we do not intend to exceed Z = 0.70 (F = Z-M). We also recognized that F could be somewhat less, resulting in reduced mortality. For this we assumed a total mortality comparable to our suggest guideline of 40% (Z =0.50). Therefore, the lower limit of fishing mortality was likely near F = 0.15.

Spawning Population Size and Recruitment: Based on estimates and assumptions for growth, mortality and annual production, we used a Ricker-type equilibrium yield model to calculate the number of mature fish and the level of recruitment (at age 1.5) associated with various population levels (Ricker, 1975). Because 87% of the fish examined by Dymond (1928) were mature (those that weighed over 2.72 kg), the full force of fishing mortality was assumed to begin at the age that coincides with this weight-at maturity, i.e., 6.5 to 7.5 years. To account for the harvest of immature lake trout, we assumed that the annual fishing mortality between ages 5.5 and 6.5 years was about 1/3 the rate of adults.

Two main scenarios were developed from the two rate of fishing estimates. In the first computation (Table 3) where fishing mortality was assumed to be intensive (F = 0.35), 2.0 million recruits were required to sustain a yield of 450,000 kg (1.0 million lbs.). The standing crop of mature lake trout in this instance would total 462,400 fish. In a second calculation (Table 4), based on less severe fishing mortality (F = 0.15), 3.0 million recruits would be required for the same annual yield but the adult population would be 927,400 trout.

Other combinations of natural and fishing mortality were also examined. In one assumption, we used rates of natural and fishing mortalities calculated for Lake Michigan by Silliman (1979), i.e., M = 0.20; F = 0.50. In this situation, losses due to fishing are clearly dominant and only 0.9 million recruits were required to maintain a yield of 450,000 kg (1.0 million lbs.). At the other extreme, a combination of fishing and natural mortality with severe predation by the sea lamprey (M = 0.60; F = 0.10) required 12.3 million recruits to produce the 450,000 kg (1.0 million lbs.) average annual yield. In summary, we estimate that average recruitment was from 0.9 to 12.3 million, with the more likely

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7/Conditional rates of mortality, expressed as a percentage, are the simplest and most common way of discussing mortality; however, instantaneous rates (decimal equivalents) are more convenient in population analysis. Unfortunately, the values for these two measures are not the same.

Table 3. Estimated equilibrium yield from 2.0 million age 1.5 lake trout recruits in Lake Ontario. Instantaneous rate of natural mortality M = 0.35 and instantaneous fishing mortality F = 0.35 at age 6.5 years and older. Rates of growth, mortality and recruitment are assumed constant within and between years.

Age Group	Total Length (mm)	Weight (kg)	G	M	F	GFM	Stock Weight (10^3kg)	Yield (10^3kg)	Number of Fish (10^3)
1.5	128	.018					36.0		2000.0
			2.433	.500	0	1.933		0	
2.5	299	.205					248.7		1213.2
			1.606	.500	0	1.106		0	
3.5	489	1.021					751.2		735.7
			.360	.350	0	.010		0	
4.5	546	1.463					758.5		518.5
			.291	.350	0	-.059		0	
5.5	597	1.958					715.4		365.4
			.242	.350	.100	-.208		64.8	
6.5	643	2.495					581.3		233.0
			.206	.350	.350	-.494		163.8	
7.5	685	3.067					354.8		115.7
			.176	.350	.350	-.524		98.9	
8.5	723	3.657					210.1		57.5
			.146	.350	.350	-.554		57.9	
9.5	756	4.230					120.7		28.5
			.131	.350	.350	-.569		33.1	
10.5	787	4.822					68.3		14.2
			.110	.350	.350	-.590		18.6	
11.5	814	5.383					37.9		7.0
			.099	.350	.350	-.601		10.3	
12.5	839	5.941					20.8		3.5
			.084	.350	.350	-.616		5.6	
13.5	861	6.464					11.2		1.7
			.075	.350	.350	-.625		3.0	
14.5	881	6.966					6.0		0.9
			.066	.350	.350	-.634		1.6	
15.5	899	7.441					3.2		0.4

Total Yield = 457,517 kg (1,006,537 lbs.)

Total Population = 5,295,200

Total Adults = 426,400

Table 4. Estimated equilibrium yield from 3.0 million age 1.5 lake trout recruits in Lake Ontario. Instantaneous rate of natural mortality M = 0.35 and instantaneous fishing mortality F = 0.15 at age 6.5 years and older. Rates of growth, mortality and recruitment are assumed constant within and between years.

Age Group	Total Length (mm)	Weight (kg)	G	M	F	GFM	Stock Weight (10^3kg)	Yield (10^3kg)	Number of Fish (10^3)
1.5	128	.018					54.0		3000.0
			2.433	.500	0	1.933		0	
2.5	299	.205					373.7		1819.5
			1.606	.500	0	1.606		0	
3.5	489	1.021					1,126.8		1103.6
			.360	.350	0	.010		0	
4.5	546	1.463					1,137.8		777.7
			.291	.350	0	-.059		0	
5.5	597	1.958					1,073.1		548.1
			.242	.350	.050	-.158		49.7	
6.5	643	2.495					916.6		367.4
			.206	.350	.150	-.294		120.0	
7.5	685	3.067					683.4		222.8
			.176	.350	.150	-.324		88.3	
8.5	723	3.657					494.2		135.1
			.146	.350	.150	-.354		63.1	
9.5	756	4.230					346.7		82.0
			.131	.350	.150	-.369		44.0	
10.5	787	4.822					239.7		49.7
			.110	.350	.150	-.390		30.2	
11.5	814	5.383					162.3		30.2
			.099	.350	.150	-.401		20.3	
12.5	839	5.941					108.7		18.3
			.084	.350	.150	-.416		13.5	
13.5	861	6.464					71.7		11.1
			.075	.350	.150	-.425		8.9	
14.5	881	6.966					46.9		6.7
			.066	.350	.150	-.434		5.8	
15.5	899	7.441					30.4		4.1

Total Yield = 443,814 (976,537 lbs.)

Total Population = 8,176,300
Total Adults = 927,400

range from 2.0 to 3.0 million age 1.5 recruits. For comparison, Sakagawa and Pycha (1971) estimated that 3.6 to 10.1 million age 1.5 recruits were required to maintain the 1.8 million kg (4.0 million lbs.) average annual production for the pre-sea lamprey lake trout fishery in Lake Superior.

To arrive at this equilibrium as quickly as possible, we recommend that 2.0 to 3.0 million yearling lake trout (apportioned equally between U.S. and Canada) be stocked in Lake Ontario annually. This level of stocking should provide a suitable size spawning population of 0.5 to 1.0 million adult lake trout by the year 2000.

SECTION E PLAN OUTLINE FOR REHABILITATING THE LAKE TROUT OF LAKE ONTARIO

To accomplish the interim objective of demonstrating that lake trout rehabilitation is feasible, a detailed step-down plan was developed (Phenicie and Lyons, 1973). This approach begins with a simply stated, single purpose primary objective. This objective is then broken down into its constituent parts identifying what obstacles have to be overcome. From this a series of second echelon items, or objectives, was identified. A conditional question was used for guidance throughout the process of formulating a hierarchy of rehabilitation objectives. Validity of these objectives was tested by asking "If and only if we accomplish the sub-objectives, will we then attain our primary objective?" This process provided a plan that clearly identified what we want to accomplish and it also demonstrated how we intend to attain it.

Four main strategies are considered necessary to accomplish our interim objective: to develop a Lake Ontario lake trout stock of 0.5 to 1.0 million adult fish with females that average 7.5 years of age that are capable of producing 100,000 recruits.

(1) Annually stock 2.5 million yearlings of Lake Ontario strain(s);
(2) Maximize the recruitment of stocked lake trout;
(3) Maintain total annual mortality between 35-40%, and
(4) Maximize reproductive potential of lake trout.

These four strategies are listed in the sequence in which they might logically occur. Briefly, the proposed rehabilitation scenario would begin with hatchery plantings of yearling fish similar in number to that which might have been produced by the native stock during the period of exploitation (1920's). Several different genetic strains would be used initially, but the redevelopment of a self-sustaining Lake Ontario stock(s) would be the major interest. This could be developed in two ways. First, eggs could be collected in Lake Ontario from those lake trout of whatever genetic strain survived to maturity and returned to spawning shoals; and (if that were unsuccessful), secondly, naturally produced young or surviving adult lake trout could be collected in the wild and brought into a "quarantine" hatchery for possible use as future broodstock. Through time, the ecological conditions in Lake Ontario would hopefully select the "fittest" genotype. Note: It will be most imperative to consider all possible disease implications in the development of a responsible program of utilization of wild stocks, especially so in setting up any "quarantine" hatchery. Any such program should follow the principles presented in the Great Lakes Fish Disease Control Program.

To make the best use of program resources, one of the earliest considerations should be maximizing recruitment of stocked lake trout. This will entail conducting short-term studies to establish the best size, age, location, and method of stocking. At the same time that hatchery resources are being allocated and procedures developed to maximize recruitment, it is necessary to begin minimizing lake trout mortality. Maintaining total mortality between 35 and 40% annually will provide for reasonable population expansion. Control of the sea lamprey population and restrictions on fishing losses should enable attainment of these mortality guidelines. Overexploitation from recreational and commercial fisheries represents the biggest potential threat to attaining mortality, age composition, and population size objectives. A form of quota management is proposed, which should provide the mechanism for good annual stock assessments and frequent review of fishing regulations and policies.

Finally, as the size of the spawning stock approaches 0.5 to 1.0 million individuals, recruits should be naturally produced. If not, efforts should be intensified to identify limiting factors in the early life history stages.

Within the next 20 years, program activities will likely shift. From 1980-1990, activities will focus on developing adequate hatchery resources, selecting genetic strains, optimizing recruitment and establishing policies to minimize losses. From 1990 to 2000 as lake trout accumulate, program emphasis should shift to those activities related to maximizing reproductive potential.

The detailed step-down rehabilitation plan is provided in the enclosed graphical and following tabled form:

PLAN OUTLINE FOR REHABILITATING THE LAKE TROUT OF LAKE ONTARIO

By the year 2000, demonstrate that rehabilitation is feasible by developing a Lake Ontario lake trout stock consisting of 0.5 - 1.0 million adult fish with females that average 7.5 years of age and produce 100,000 yearling recruits annually.

1.0 Annually introduce 2.5 million yearlings of Lake Ontario strain(s).

- 1.1 Rear, mark with coded wire tags, and stock 2.5 million yearlings (1.25 million/nation; Activity #6).
- 1.2 Develop a Lake Ontario broodstock.
  - 1.21 Initially maximize genetic diversity by using several different strains, and, if possible, choose preadapted varieties through environmental matching (Study #1).
  - 1.22 Evaluate the performance of the various genetic strains introduced into Lake Ontario and eliminate or de-emphasize unfit genotypes.
    - 1.221 Assess the comparative survival, behavior, distribution, contaminant update, growth and maturity of stocked fish.
      - 1.2211 Conduct juvenile trawl surveys (Activity #3).
      - 1.2212 Conduct gill net surveys for sub-adult and adult lake trout (Activity #4).
    - 1.222 Estimate the relative reproductive success of the various genetic strains.
      - 1.2221 Estimate relative abundance of spawners for each genetic strain.
        - 1.22211 Conduct gill net surveys of spawning shoals (Activity #1).
      - 1.2222 Examine the feasibility of determining the parental genetic strain of naturally produced young-of-year using electrophoretic and/or chromosome matching techniques.
        - 1.22221 Collect naturally produced young (Activity #2).
        - 1.22222 Conduct genetic analyses (Activity #5).

1.23 Emphasize the use of Lake Ontario broodstocks as they develop from initial plantings.

1.231 Collect eggs from adults spawning on Lake Ontario shoals (Activity #1).

1.232 Develop Lake Ontario hatchery broodstocks as required to supplement wild egg collec tions. (Adhere to established disease protection, utilize quarantine stations.)

1.2321 Collect mature adults from spawning shoals and maintain as a hatchery broodstock (Activity #1).

1.2322 Collect young, naturally produced lake trout from several Lake Ontario spawning shoals and raise for broodstock (Activity #2).

2.0 Maximize recruitment of stocked lake trout.

2.1 Provide a quality hatchery product.

2.11 Employ state-of-art fish cultural practices and provide best available hatchery conditions.

2.12 Determine the size and/or age at planting that will maximize recruitment (Study #2).

2.121 Stock various sizes/ages and for each, estimate the total hatchery production capability and costs.

2.122 Estimate relative survival for various sizes/ages using juvenile trawl survey collections (Activity #3).

2.2 Minimize post-planting mortality.

2.21 Determine the time, location, and method for stocking that maximizes survival of planted fish (Study #3).

2.211 Develop experimental design and stock lake trout.

2.212 Estimate relative survival for different treatments using juvenile trawl survey collections. (Activity #3).

3.0 Maintain total annual mortality between 35% to 40%.

3.1 Minimize losses from sea lamprey predation.

3.11 Reduce sea lamprey numbers and monitor results.

3.111 Continue lampricide treatment (Activity #7).

3.112 Use other methods of control where appropriate.

3.113 Provide direct estimates of sea lamprey abundance by collecting spawning adults with weirs or portable assessment traps (Activity #8).

3.12 Increase sea lamprey prey biomass.

3.121 Establish a large standing stock of very large lake trout (7-9 kg., 15-20 lbs.) capable of attracting and surviving sea lamprey attacks.

3.122 Develop a large standing stock of other salmonids.

3.13 Introduce genotypes potentially resistant to sea lamprey and monitor comparative stock mortality.

3.131 Conduct field studies to provide relative and/or absolute estimates of sea lamprey-induced mortality.

3.1311 Estimate sea lamprey mortality by subtracting fishing and natural mortality from total mortality.

3.13111 Conduct adult gill net surveys and tagging activities to estimate total mortality. (Activities #1 and #4).

3.13112 Estimate harvest of each strain (Activities #9 and #10).

3.1312 Estimate sea lamprey mortality by comparing total mortality with indices of lamprey density.

3.13121 Conduct gill net surveys to estimate mortality and wounding frequency (Activity #4).

3.1313 Estimate sea lamprey induced mortality from collections of dead lake trout in fall trawl surveys (Activity #14).

3.132 Where applicable, conduct laboratory studies to determine if any strains have differential survival to varying rates of blood loss (Study #4).

3.2 Limit exploitation.

3.21 Develop and up-date regulations so that harvest does not exceed established quotas and total mortality does not exceed 35% to 40%.

3.211 Establish an annual total allowable catch quota (TAC) commensurate with population size and mortality objectives. [NOTE: TAC = total allowable loss (TAL) - expected natural loss ENL]

3.2111 Estimate total allowable loss (TAL) by applying total mortality guideline to population size.

3.21111 Estimate the size of the fishable population at the beginning of each year.

3.211111 Apply age specific survival rates to number of lake trout stocked.

3.211112 Use mark and recapture methods to estimate population size (Study #5).

3.2112 Estimate (ENL) expected natural loss (including sea lamprey) by applying annual expectation of death from natural causes (v) to population size.

3.21121 Estimate the size of the fishable population (Section 3.21111).

3.21122 Use previous year's measure of total mortality (A) and exploitation (u) to estimate expected rate of natural loss ($v = A - u$).

3.212 Monitor the impact of fishing and determine if catch quotas are exceeded.

3.2121 Estimate total mortality ($A = 1 - s$) using gill net surveys and tagging studies (Activities #1 and #4; Study #5).

3.2122 Estimate exploitation (u = total catch divided by population size).

3.31221 Estimate total harvest.

3.212211 Conduct creel surveys (Activity #9).

3.312212 Conduct commercial catch surveys (Activity #10).

3.21222 Estimate size of fishable population (Section 3.21111).

3.22 Provide adequate enforcement of regulations (Activity #11).

3.23 Where appropriate and feasible, supplement fishing controls by creating refuges closed to fishing.

3.24 Provide other salmonid fishing opportunity (e.g. buffer species).

4.0 Maximize reproductive potential of lake trout.

4.1 Endorse, promote, and actively support pollution and contaminant abatement programs, and recommend modification where appropriate.

4.2 Maximize utilization of appropriate spawning sites.

4.21 Locate areas where substrate, thermal, and biological conditions appear suitable for spawning.

4.211 Develop standards to identify best available sites for spawning (Study #6).

4.212 Examine broad scale studies and historical evidence; evaluate and select most likely sites for reproductive success (Study #7).

4.22 Where siltation of good natural substrates may be a problem, examine the feasibility of improving natural substrates for spawning (Study #8).

4.23 Test effectiveness of an artifical spawning substrate at a location where thermal and biological conditions may be favorable for natural reproduction, but where suitable substrates may be limited (Study #9).

4.24 Stock yearling lake trout near or over the most suitable substrate available and determine if homing occurs (Activity #6).

4.25 Document the use of stocking sites by mature lake trout and modify site placement as required (Activity #1).

4.3 If reproductive success is limited, then identify that segment of the early life history stage where it may be inhibited.

4.31 Estimate contaminant levels in eggs and body tissue of adult lake trout.

4.311 Collect lake trout and egg samples (Activities #1 and #4).

4.312 Conduct contaminant analyses (Activity #12).

4.32 Conduct laboratory and/or in-situ studies of egg, larval, and fry survival under ambient conditions (Activity #13).

4.33 Conduct field assessment surveys to provide absolute or relative estimates of survival at key points in the early life history stages.

4.331 Develop sampling techniques and test/calibrate in a control lake(s) (Study #10).

4.332 Implement annual assessment surveys at selected sites in Lake Ontario (Activity #2).

SECTION F - PROSPECTUS FOR REHABILITATION

The prospect of attaining our goal of a self-supporting lake trout population will be determined largely by our committment to the goal of rehabilitation. To ensure an acceptable rate of progress, several strategies are considered essential and will have to be maintained. These include:

I. Choosing appropriate genetic strains and stocking at optimal rates.

II. Maximizing the recruitment of stocked lake trout.

III. Providing adequate survival of adults by restricting exploitation and suppressing sea lamprey.

IV. Maximizing reproductive potential of Lake Ontario by improving or enhancing lake trout habitat.

I. Choice of Genetic Strains and Stocking

Since native stocks of lake trout in Lake Ontario are extinct, the major focus of our rehabilitation effort will be the reconstruction of new Lake Ontario stock(s). Initially the choice of genotypes will follow two guidelines recommended from the Stock Concept International Symposium (STOCS; Krueger et el. 1981): (1) use environmental matching to choose pre-adapted genotypes from similar lake habitats and/or (2) maximize genetic variability by producing fish for stocking that represent as much of the genetic variation of the species as possible.

The choice of pre-adapted genotypes may not be feasible because we know little about the genetic variation of the native strain(s) compared with those presently available (Ihssen, per. comm.). Consequently, in order to maximize genetic variability the initial choice will come from what appears best from those strains that are currently available. Marking each group separately will allow comparison of strains, and those strains that do not perform well will be de-emphasized or eliminated; the criteria for performance will be survival and capacity to reproduce.

The other recommended strategy for choosing lake trout for stocking involves making collections from wild populations that represent the entire genetic diversity; thence making all possible crosses; and stocking the progeny. This idea of a "big genetic mix" may be practically accomplished with the development of a Lake Ontario strain. The offspring of those lake trout from the initial stockings that survive, mature and return to spawning sites will be considered a Lake Ontario strain(s). Eggs from surviving, stocked lake trout will be collected and reared in the hatchery much the same as the other groups. Initially these fish will most likely represent a number of different genotypes, but in time they should represent an environmentally selected Lake Ontario stock, preserving certain homing attributes such that various lake locations may well develop different strains.

Another approach to forming unique Lake Ontario strain(s) that has potential merit, but may be very difficult to accomplish, is to collect naturally produced lake trout from Lake Ontario and use them as a hatchery brood stock. This approach would have the added benefit of environmental selection on choice of spawning site by adults and the early life history stages, periods of intensive selection. However, disease considerations would have to be satisfied through the use of separate "quarantine" stations and strict disease protocol adherence if such a program were initiated. This cannot be overemphasized since current successes have been largely attributable to a well thought out disease program. (Great Lakes Fishery Commission, 1975).

Obviously the entire rehabilitation effort will have to be sustained for some time through hatchery introductions. Hatchery resources will have to be allocated and maintained to meet the stocking requirements of 2.5 million yearlings. Because of the very nature of the proposed multi-strain introductions, coded wire tagging techniques are considered essential in order to adequately assess the relative performance of various strains.

II <u>Maximize Recruitment</u>

Once sufficient hatchery resources are allocated for the production of artificial recruits, the next step will be to ensure that those resources are used most effectively. To maximize recruitment of hatchery lake trout, an optimum rearing density must be determined to balance numbers produced with survival in the wild. Presently, our experience indicates that optimal survival is best accomplished by stocking yearling fish; however, adjustments in rearing procedures could conceivably improve recruitment significantly.

Information from field surveys indicates that survival of different stockings can vary several-fold. Numerous factors could determine the success or failure of a stocking: size, time, location, and method of stocking; genetic origin; hatchery conditions and health history, and other factors are but examples. Obtaining more consistently successful performance of stocked lake trout will require an array of short-term studies designed to evaluate the effect of these factors on survival.

The Lake Ontario program provides a unique opportunity to examine these effects. First, coded wire tagging permits an almost limitless number of separate tagging combinations; consequently, experimental design is not constrained by just a few fins that have been traditionally used for marking. Secondly, a trawl survey of juveniles conducted by DEC, OMNR and FWS allows almost immediate performance evaluations. Differences in relative abundance of stocked fish have been determined as early as two months after planting (Elrod, et.al. 1982). The potential benefits of these activities should not only impact the Lake Ontario program, but they should be of value to all similar rehabilitation efforts throughout the Great Lakes and other waters.

III <u>Maintain Adequate Survival of Adults</u>

We expect that lake trout will be lost each year to one of three sources of mortality: fishing, sea lamprey predation, and other natural causes. To increase numbers, losses of stocked fish must be minimized. Death from natural causes is difficult to control; however, the sea lamprey population and fishing intensity can be manipulated. From an examination of the dynamics of exploited and unexploited lake trout populations, it was concluded that populations could not be sustained if mortality exceeded 50% annually (Section E). For rehabilitation with population expansion, mortality rates must be even lower, e.g. 35-40%.

This mortality rate range of 35-40% is also needed to meet age composition and spawning frequency guidelines (Abrosov's t; Section E).

A. Fishing

Management of Lake Ontario over the next 20 years will involve a restructuring of the fish community; agency goals are aimed at creating large standing crops of salmonids that will convert an abundant forage biomass of alewife, rainbow smelt and slimy sculpin (Cottus cognatus) into high quality fish products for public use. NYDEC has been actively promoting expansion of recreational fisheries, while severely restricting commercial harvest opportunities. For example, the state hopes to develop a 1.5 million angler trip fishery in Lake Ontario for a major new economic industry. Angling utilization by Canadians is not extensive, but incidental lake trout catch by Ontario's commercial fishery may represent a major mortality factor. Within this climate of intensive resource use and promotion, a major challenge for the cooperating agencies will be to separate the goals and objectives of lake trout rehabilitation from those of more intensively utilized fisheries, and provide adequate fishing controls so that lake trout losses do not exceed the guidelines.

Within the next 20 years the potentially most important single deterrent to lake trout rehabilitation will be whether premature removal can be controlled. Ironically, this is the same force that faced our parental agencies 100 years ago. History demonstrated that uncontrolled fishing led to the destruction of native stocks and contributed to the failure of the first rehabilitation effort. Not only is protection of lake trout critical to the success of rehabilitation, but even more importantly, it will demonstrate whether the resource can be managed in the future when a selfsustaining population is developed.

Since regulation of the developing fishery is critical to attainment of rehabilitation objectives, the approach toward fishing restriction must be active: a quota. Annual assessment of the expanding lake trout population will provide estimates of the total allowable catch (TAC) by the fishery without compromising rehabilitation guidelines and objectives. Planned creel and commercial surveys will monitor harvest, and if exploitation is excessive, end-of-season adjustments will be made in regulations to bring harvest rates in line with projected TAC's.

To a large degree, the success of Lake Ontario lake trout rehabilitation will depend on whether the public supports the program goals and objectives, particularly those related to harvest. Support, in turn, may well result from our effectiveness in communication with the fishing public. A well-designed public relations program is not only advisable, but probably critical for rehabilitation success. Since the lake trout is a long-lived top predator, it is an excellent integrator of the Lake Ontario environment. As such, its value as an environmental quality barometer for the many people drawing their drinking water from this lake increases its importance to the public in general as well as those who fish. Two recent developments have occurred that have the potential to improve public communication. One is the OMNR initiated "lake trout are fragile" theme, which should, if pursued actively, mold public attitudes toward rehabilitation. The second is the use of micro-computers and simulation modelling. This technique will demonstrate graphically the outcome of different harvest and management strategies. For selected small groups of interested people (such as advisory groups, anglers' organizations, legislators, and administrators) simulation modelling could be extremely effective in communicating the need for lake trout regulations, as well as stocking and other management activities.

B. Sea Lamprey Control

Without sea lamprey control, lake trout rehabilitation and salmonid fisheries development in Lake Ontario would likely be impossible to maintain. Past success of the sea lamprey control program throughout the Great Lakes is probably best demonstrated not by survey and assessment reports, but by the recent development of major new salmonid fisheries.

Although the GLFC is now actively promoting integrated pest control techniques, the principal means of suppressing the sea lamprey is the application of chemical lampricide to stream dwelling larvae. In Lake Ontario, chemical control was initiated in 1971 and resulted in major reductions in wounding levels of salmonids and coincident improvement in survival. Although these results were all positive, several factors suggested that effective control in Lake Ontario could still be improved. In the successful control of sea lamprey in the Upper Lakes, two important changes were noted in the sea lamprey population in response to major reduction in numbers: average size of spawning adults increased and sex ratio changed to favor production of females (Henirich et al., 1980). In Lake Ontario, the post-control adult sea lampreys grew faster but no female dominance appears to have followed.

Additionally, sea lamprey wounding rates and survival of lake trout also indicate that more effective sea lamprey control may be required. Wounding rates on lake trout from Lake Ontario during the 1970's were 2 to 3 times greater than comparable rates in Lakes Michigan and Superior. These high wounding levels suggest substantial sea lamprey-induced mortality. Survival of these lake trout was less than expected, again indicating the probability higher mortality from sea lamprey predation.

Three potential sources may have caused the apparent high sea lamprey abundance - the Black River, Oneida Lake, and Lake Erie systems. Black River was chemically treated for the first time in 1980, and based on the observations of the treatment crews, was probably a major source of sea lamprey. In 1981 a major reduction was noted in sea lamprey wounds and scarring frequencies on all salmonids (Jolliff, et.al. 1982). Lake trout wounding rates were reduced by more than half for some size groups. Unfortunately lake trout wounding rates measured in 1982 increased to the higher levels noted prior to 1981. The next step toward more effective control would be the experimental treatment of Oneida Lake. Plans are presently being formulated to assess the effectiveness of that procedure if and when it takes place. If the Oneida Lake treatment fails to provide the desired reduction in sea lamprey in Lake Ontario, then Lake Erie will be considered.

Two other potentially important developments may also have a dramatic impact on the future of sea lamprey control in Lake Ontario. If the Seneca Lake strain lake trout are even somewhat more resistant to sea lamprey predation, this could result in a lessening of dependence on chemical control. Another approach was suggested from the historic evidence (Christie and Kolenosky, 1980) and confirmed by modelling sea lamprey/lake trout dynamics (Lett, et.al. 1975). It consisted of developing a substantially large pool of older lake trout that would attract and absorb the major sea lamprey parasitic pressure and thus direct feeding sea lampreys toward that portion of the lake trout population that could survive attacks.

IV Maximize Reproductive Potential of Lake Ontario

In the review of the historic events that resulted in the demise of native lake trout stocks, environmental alteration and degradation was not considered a causal agent in their failure, principally because the lake trout population was declining prior to the period of most intensive eutrophication and contamination. At the time of the last days of the native lake trout, excessive nutrient loading was intensifying. In turn, increased eutrophication resulted in algal blooms, followed by increased turbidity, shading of rooted aquatic plants, dissolved oxygen deficiencies in bottom waters, reduction in sensitive fish populations and population explosions of pollution tolerant species (Bridger and Oster, 1981). Eutrophication stimulated the extensive growth of the filamentous alga Cladophora during the 1950's, which now occurs on nearly all of the wave-washed shoreline of Lake Ontario.

The most significant eutrophication related stress that may likely inhibit lake trout rehabilitation is the degradation of spawning substrates that are used for egg and larval development. It seems unlikely that eutrophication will have very much effect on the adult life stage since oxygen levels are more then adequate for lake trout survival. In the fall, dead algae deposited as a fine sediment may adversely affect lake trout egg and larvae survival on spawning shoals. Fortunately, recent trends in total phosphorous concentrations (a key indicator of eutrophication) in all areas of Lake Ontario have declined in response to phosphorous control programs implemented under the 1972 Canada-U.S. Water Quality Agreement. A major milestone was recently achieved in phosphorous control when nearly all municipal treatment facilities in the Lower Lakes Basin met the effluent limitation goal of 1.0 mg/L (GLWQB, 1981). A fundamental element of this rehabilitation strategy is to maintain and support the existing water quality improvement efforts, and if required, help accelerate those activities.

If research and management activities suggest that degraded spawning substrates hinder or prevent successful egg development and hatching, then habitat improvement or alteration activities will be considered. Observations from the Upper Lakes indicate that lake trout will readily use man-made reefs for spawning and that reproduction can be successful (Stauffer, 1981). Substrates badly sedimented with sand, silt and organic material in the intragravel spaces can reduce interstitial flow and oxygen supply, resulting in high mortatity of eggs and fry. Machines and techniques have been developed for improving spawning habitat for salmon (Mih and Bailey, 1981); and a similar technology may be effective in improving gravel shoals in Lake Ontario.

Although contaminants in Lake Ontario are a comparatively new cultural stress, today it is the most important lakewide environmental issue. The list of known contaminants is a long one which includes many heavy metals; pesticides such as dioxin, mirex, dieldrin/aldrin, DDT and its derivatives, and non-degradable organic compounds used in industry such as polychlorinated byphenyls (PCB's), chlorinated benzenes and polynuclear aromatic hydrocarbons.

Presently, the levels of contaminants in lake trout exceed most human consumption standards. Contaminant levels have been positively correlated with age and lipid content (i.e. older and fatty fish tend toward higher contaminant levels) and lake trout are the longest lived salmonid with the highest average percent lipid content (Armstrong and Sloan, 1980). Consequently, both DEC and OMNR have instituted health advisories warning the public that consumption of lake trout is considered hazardous to health and the commercial fishing for lake trout has been closed.

During the 1970's it was thought that contaminants had an adverse impact on the reproductive biology of lake trout (Ruby, 1980, Colquhoun, et. al., 1981). Abnormalities were noted in male gonads, and survival of larval lake trout was poor. Most recent laboratory studies suggest a much more positive prognosis; survival of eggs and fry is sufficiently good to consider using mature lake trout from Lake Ontario as broodstock.

Contaminant levels may have been most serious in the 1970's; recent data suggest a more rapid recovery than had been previously predicted. Suns, et al. (1981) have documented significant organochlorine residue reductions (DDT, PCB and Mirex) in young of the year spottail shiners (Notropis hudsonius) collected from the near-shore areas of Lake Ontario. This decline has also been reflected in many of the top predators. Dioxin (2,3,7,8-TCDD) in herring gull eggs from Scotch Bonnet Island showed a ten-fold decrease during the last decade (GLWQB, 1981). Christie (pers. comm.) has noted a substantial increase in comorants in eastern Lake Ontario over the past five years which may be related to these contaminent declines. These reductions were undoubtably in response to restrictions on usage and disposal of organochlorine compounds instituted throughout the Great Lakes Basin in the late 1960's and early 1970's. The prospect of further declines in toxic substances will depend largely on how vigorously regulatory agencies control the use and disposal of dangerous chemical wastes.

Conclusion

Overall, the prospects for demonstrating successful lake trout rehabilitation are positive and should increase further as this plan is implemented. Efforts directed toward curtailing water quality deterioration, suppressing sea lamprey numbers, and producing sufficient numbers of yearling lake trout for stocking are presently underway; these activities may have to be intensified. Egg collections from Lake Ontario lake trout and an active program for regulating harvest are two comparatively new rehabilitation strategies that should greatly improve the chances of restoring the lake trout. Better interagency coordination of on-going assessment activities is required to maximize the usefulness of data being collected. Some expansion of these activities will be needed in parts of the lake not receiving adequate monitoring. In addition, field techniques for monitoring the early life history stages and sport/commercial harvest surveys are required to render the assessment capability of cooperating agencies sufficient to monitor rehabilitation progress and identify problem areas if and when they develop. This planning process identifies what are presently considered the key elements required for successful rehabilitation of lake trout in Lake Ontario.

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GLOSSARY

Conditional Fishing Mortality Rate: The fraction of an initial stock that would be caught during the year if no other causes of mortality operated (Ricker, 1975).

Conditional Natural Mortality Rate: The fraction of an initial stock that would die from causes other than fishing during the year if there were no fishing mortality (Ricker, 1975).

Exploitation Rate: The probability that a fish would die from fishing during some specified period of time, usually a year, when all causes of death are working on the population.

Instantaneous Rate of Fishing Mortality (F): When fishing and natural mortality act concurrently, F is equal to the instantaneous total mortality rate (Z), multiplied by the ratio of fishing deaths to all deaths (Ricker, 1975).

Instantaneous Rate of Natural Mortality (M): When natural and fishing mortality operate concurrently it is equal to the instantaneous total mortality rate, multiplied by the ratio of natural deaths to all deaths (Ricker, 1975).

Instantaneous Rate of Total Mortality (Z): The natural logarithm (with sign changed) of the survival rate (Ricker, 1975).

Recruitment: The addition of new members, by growth or stocking, to the aggregate under consideration.

Stock: The part of a fish population which is under consideration from the point of view of actual or potential utilization (Ricker, 1975).

Strain: A distinct gene pool
Note: Lake Superior strain fish in Lake Michigan and Ontario are different stocks but may well be considered as the same strain.

Survival Rate(S): Number of fish alive after a specified time interval, divided by the initial number (Richer, 1975).

Total Mortality Rate(A): The number of fish which die during a specified time interval, divided by the initial number.

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