Great Lakes Fishery Commission
Project Completion Report *

APPLICATION OF MODELS OF LAKE TROUT/SEA LAMPREY INTERACTION TO THE IMPLEMENTATION OF INTEGRATED PEST MANAGEMENT OF SEA LAMPREY IN LAKE ONTARIO

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ABSTRACT

This paper presents the results of an application of an Integrated Management of Sea Lamprey (IMSL) model to Lake Ontario. Several technical issues were resolved concerning the lethality of attack by sea lamprey. Consistent with findings in Lake Superior data, about 75% of Fall sea lamprey attacks were lethal, and we found no evidence for differential survival among various strains of lake trout in Lake Ontario. Application of IMSL to Lake Ontario over the period 1971 to 2003 indicates that fishing mortality and sea lamprey induced mortality have been major impediments to lake trout rehabilitation. Realistic fish management options, however, are likely to result in substantial gains in rehabilitation during the next few years. In contrast, there does not appear to be much scope for reduction in chemical control of sea lamprey. Model results suggest that as few as 50,000 to 60,000 parasitic phase sea lamprey in Lake Ontario may have hindered recovery of lake trout since 1979. Even minor fluctuations in abundance of parasitic phase lamprey causes substantial variation in mortality of lake trout at present abundance levels. The need for continued control of sea lamprey does not appear to diminish with lake trout recovery even under the most optimistic assumptions through the year 2003.

INTRODUCTION

Two issues have clouded application of analyses of lethality of sea lamprey attacks in Lake Superior (Pycha 1980) to the lower Great Lakes. First, Youngs (1980) found no relation between marking and lake trout mortality in Cayuga Lake. Second, the initial stocking of Seneca Lake strain of lake trout has survived very well in Lake Ontario, raising the possibility that the results from Lake Superior are limited to Lake Superior strains. These uncertainties with other problems have hindered the implementation of integrated management of sea lamprey in the Great Lakes.

Recent evaluation of the policy for Integrated Management of Sea Lamprey has focused on impediments to its implementation. The original adoption of the policy was a response to apparent problems in assessing effectiveness of the sea lamprey control program, of allocating control resources between lakes, and of rationalizing the budget process. According to Eshenroder (personal communication) the impediments to implementation are "insufficient incentive for lake committees to invest in the process, a lack of an acceptable method for relating lamprey activity to fishery losses, the absence of fishery goals for the Great Lakes, and some confusion as to what IPM [integrated pest management] is." Based on the results of work reported here and separate initiatives of the Lake Committees, I believe that lake trout management and sea lamprey control can now be addressed as a unified problem.

DEVELOPMENT OF IMSL

The research reported here is a product of a long-term series of collaborative research initiatives. The simulation model for integrated management of sea lamprey originated in two Adaptive Environmental Assessment and Management Workshops sponsored by the Great Lakes Fishery Commission (Koonce et al 1982; and Spangler and Jacobson 1985). Next was the adoption of uniform standards for reporting sea lamprey marking (Eshenroder and Koonce 1983). Ambiguity concerning the sea lamprey induced mortality in lake trout populations impeded application of these initiatives, and the Great Lakes Fishery Commission started a 2-year research project on the observability of the lethality of sea lamprey attacks. Using Lake Superior assessment data, Koonce and Pycha (MSa and MSb) were able to establish procedures for estimating lethality of attack and relative abundance of sea lamprey. Their work also extended the integrated pest management workshop model (Spangler and Jacobson 1985) by correcting some structural errors and updating the relation between the ratio lake trout to sea lamprey size and lethality of attack. Results of the Lake Superior applications indicated that the mean lethality of attack was 0.86 over the period 1966 to 1982. The generality of these results and a full scale application of the integrated management of sea lamprey model are the subjects of this report.

APPLICATION OF IMSL TO LAKE ONTARIO

HISTORICAL DATA

Lake Ontario entered the control program later than the upper Great Lakes. Treatments began in 1971 and both TFM usage and area treated declined to a rotation baseline by 1974 (Fig. 1). Salmonid stocking preceded chemical treatment in Lake Ontario (Fig. 2), but no systematic records of marking were available until 1978. Lake trout marking data for New York waters have shown no consistent pattern (Fig. 3), nor is there any consistent relation between marking statistics and more recent estimates of carcass density (Fig. 4). These results coupled with the doubts raised about the lethality of sea lamprey attacks on lake trout in Lake Ontario raise substantial concerns about the applicability of models developed for the upper Great Lakes.

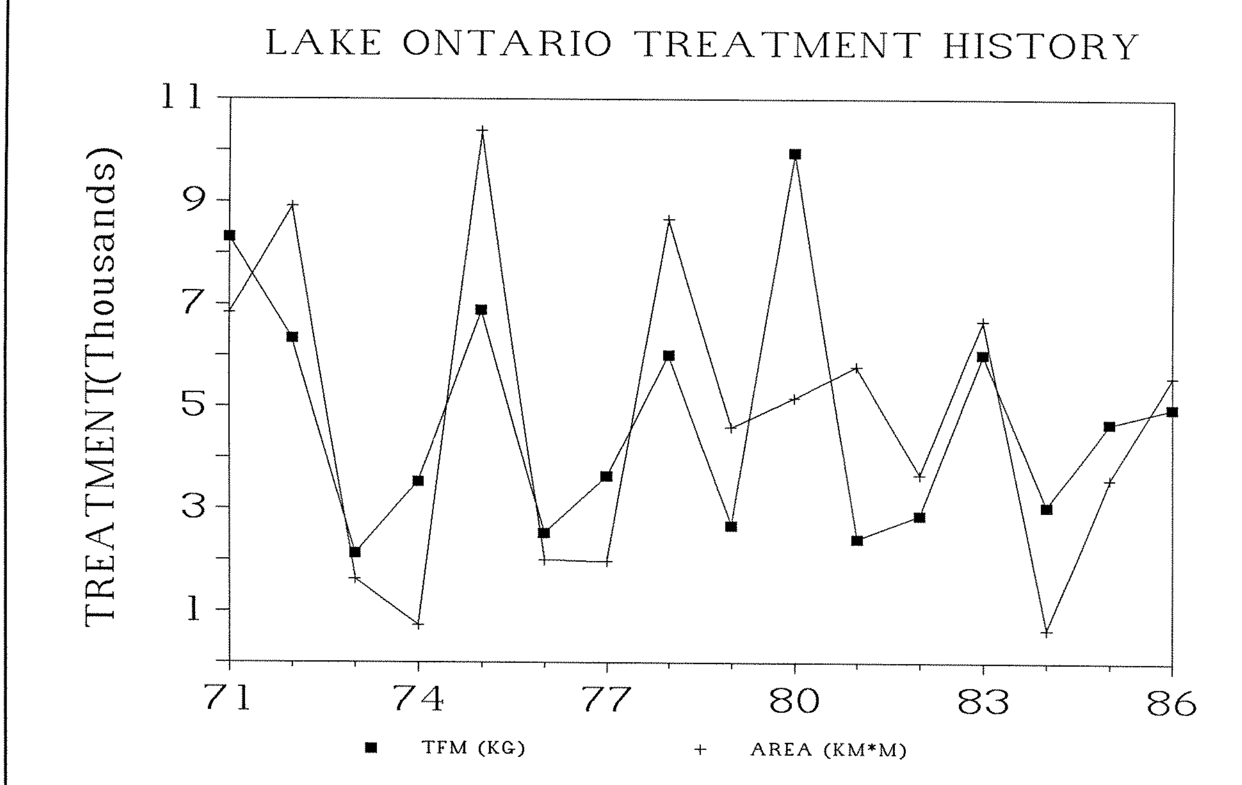

Fig. 1. Treatment history of the Lake Ontario basin. Both area treated and TFM usage are displayed.

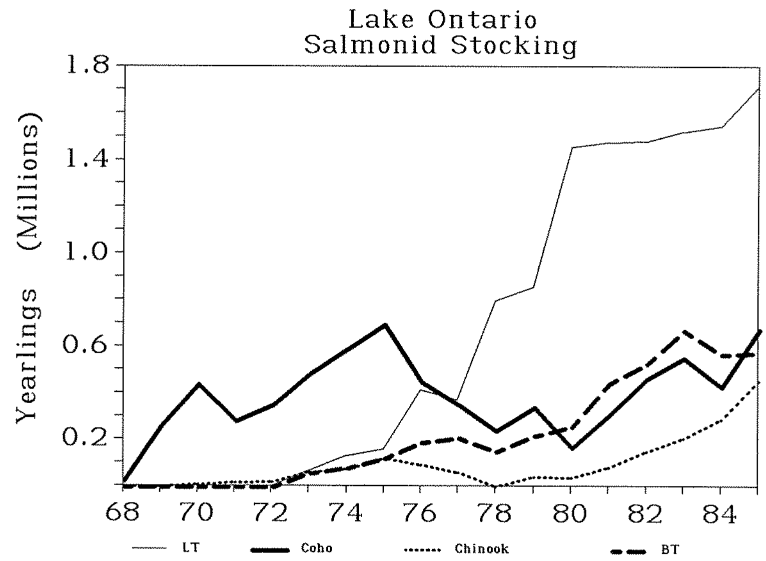

Fig. 2. Calculated salmonid stocking for the period 1968 to 1985. Stocking is expressed as yearling equivalents.

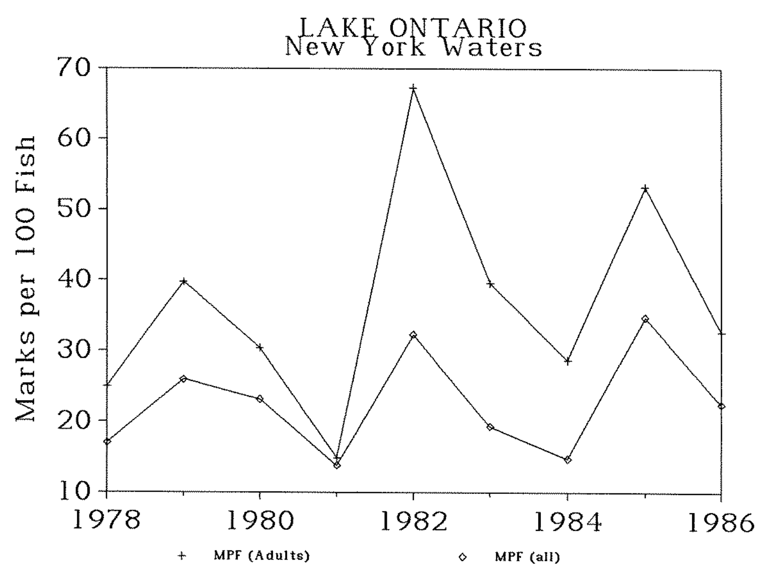

Fig 3. Summary of marking data for lake trout over the period 1978-86. Included are data for adult lake trout and pooled juvenile and adult groups.

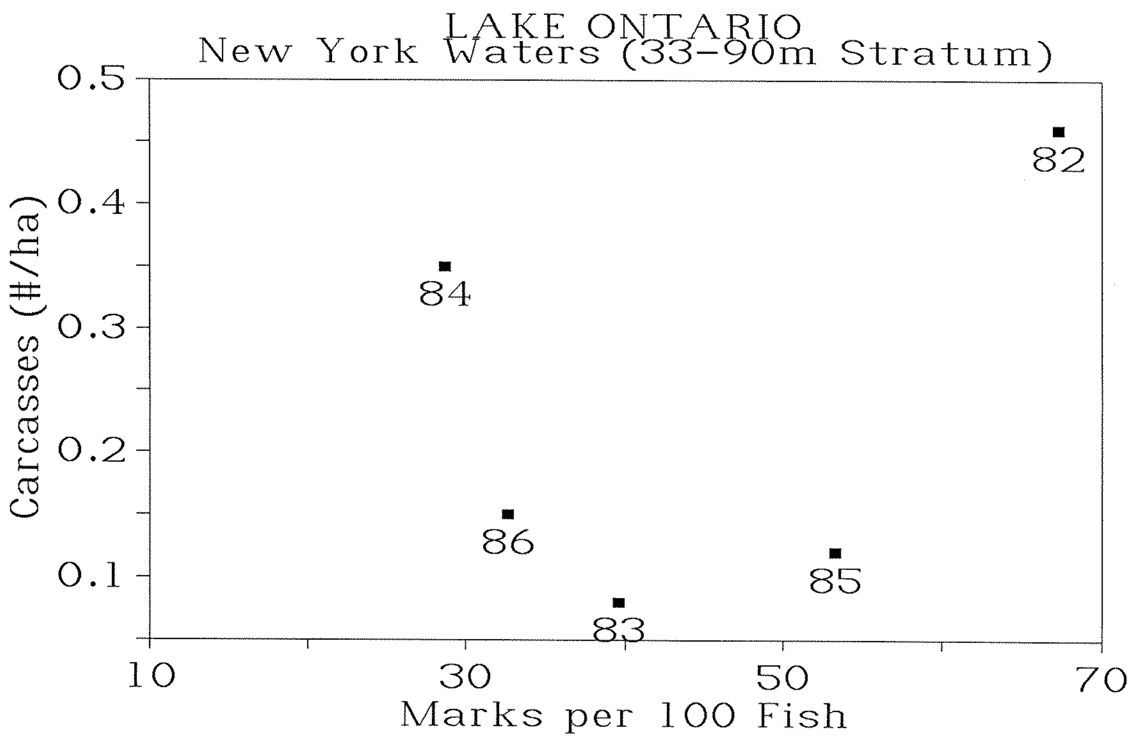

Fig. 4. Relation between estimated carcass density in the 33-90 m stratum of Lake Ontario (After Schneider, personal communication) and observed marking rates in New York waters.

As a result of two mini-workshops at Cape Vincent, New York, I now believe that the relation between sea lamprey attacks and fishery losses can be resolved and that findings for Lake Superior (Koonce 1986) are applicable to Lake Ontario. In the workshops, we examined the relation between marking and total mortality for two periods: 1982-85, considering various strains and year classes (Fig. 5); and 1978-79, considering various age groups of Lake Superior strain (Fig. 6). Clearly, these data are inconsistent with patterns observed for Lake Superior (Pycha 1980; and Koonce 1986).

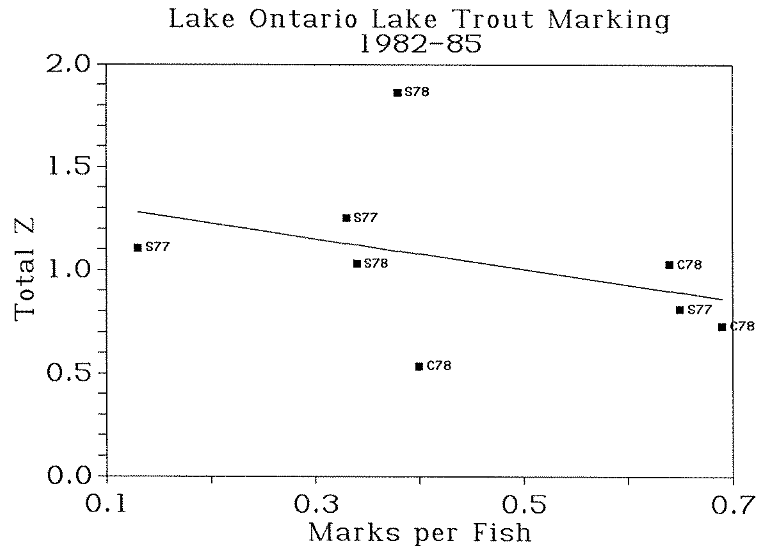

Fig. 5. Observed relation between total mortality and marking for various age groups of Lake Superior (S) and Clearwater Lake (C) strains of lake trout in the 1977 and 1978 year classes during 1982-85.

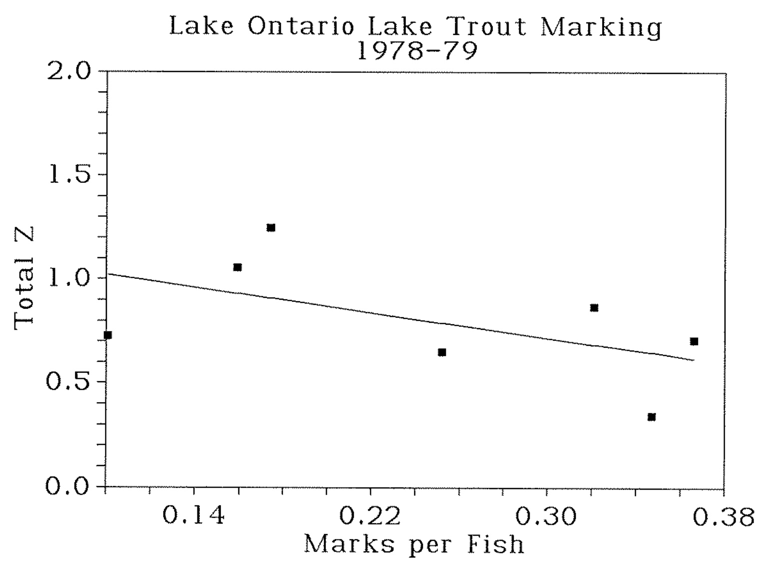

Fig. 6. Observed relation between total mortality and marking for Lake Superior strain lake trout of various ages in Lake Ontario during the period 1978-79.

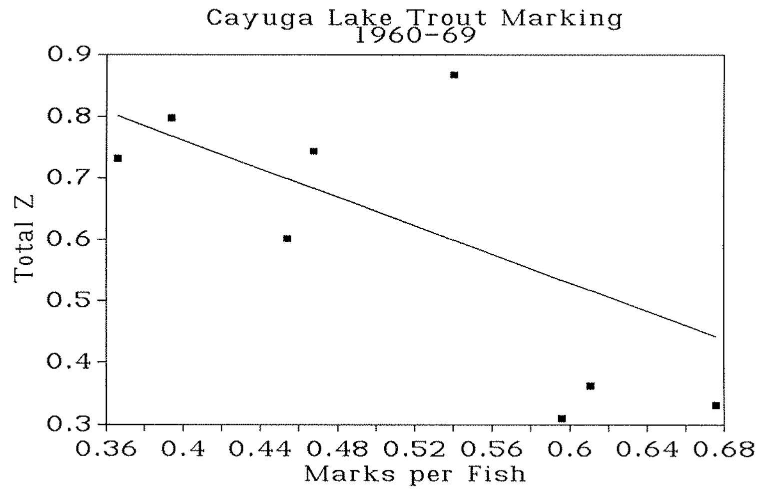

Fig. 7. Observed Relation between total mortality and marking for lake trout in Cayuga Lake from 1960 to 1969 (Data after Youngs 1972).

Similar deviations from expected pattern also appear in the Cayuga Lake data set (Fig. 7). Fig. 7 differs from Youngs' (1980) original analysis by associating marking statistics and estimated total mortality of the same year. Youngs (1972) weighted marking rates over a two year period to obtain annual marking statistics. He designed this procedure to attribute marking to a particular cohort of parasitic phase sea lamprey. Given the limited duration of a "fresh" lamprey wound and the accumulating evidence that most lamprey induced mortality occurs in the lake Fall, however, single year associations better measure attack characteristics.

Because fishing mortality appears to be the main source of variability of total mortality in Cayuga Lake (Fig. 8), we next examined its effects on observability of a relation between marking and total lake trout mortality. For Cayuga Lake, we assumed a constant lethality of attack and estimated fishing mortality from the residuals of the difference between observed total mortality and estimated lamprey induced mortality. The association between observed and estimated fishing was highly significant (Fig. 9). The absence of correspondence of ranges of values in fishing mortality is due to the method of estimating fishing mortality from tag returns. It is also interesting that the inverse procedure (predicting lamprey induced mortality from the residuals of the difference between total and fishing mortality) does not perform as well. This latter analysis, however, suffers from two problems. First, tagging data are used to estimate both total mortality and fishing mortality, and some level of correlation bias exists. Youngs (1972) discussed this problem, but could not resolve it. Second, fishing mortality appeared to vary more than lamprey abundance in Cayuga Lake. The fishing mortality thus has more contrast, implying that an analysis like Fig. 9 is more reliable.

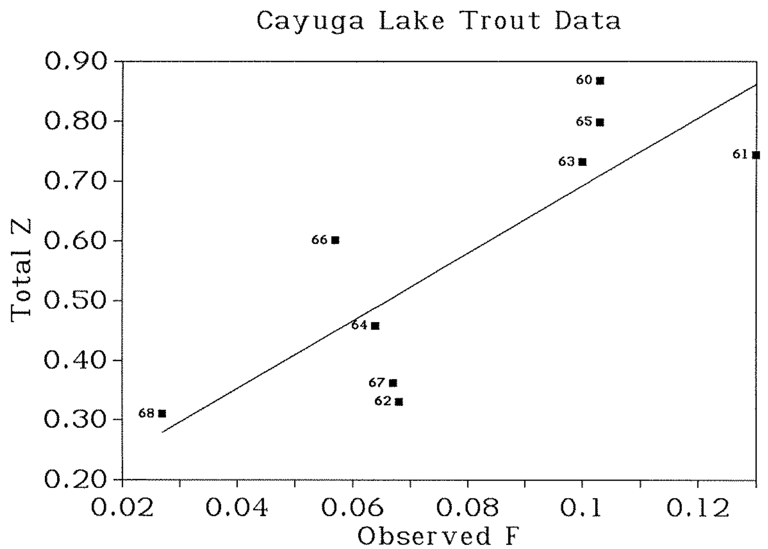

Fig. 8. Relation between fishing mortality of lake trout and total mortality in Cayuga Lake (after Youngs 1972).

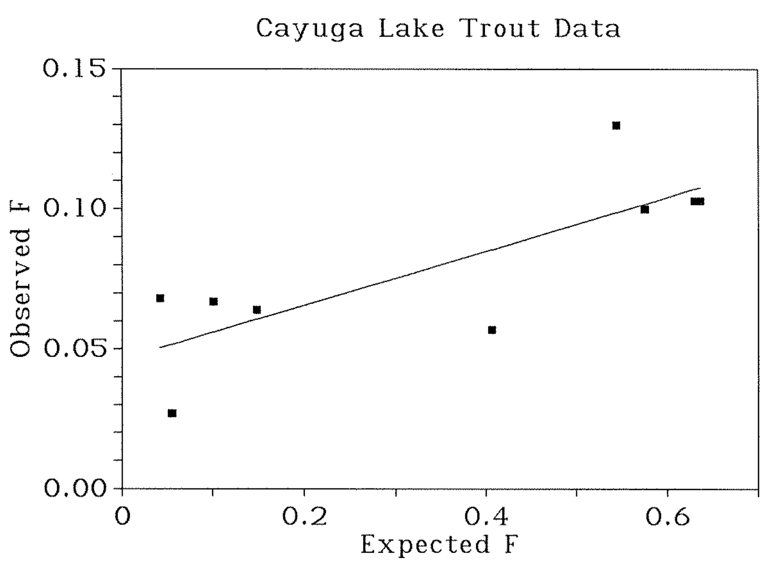

Fig. 9. Comparison of expected fishing mortality with fishing mortality observed for lake trout in Cayuga Lake by Youngs (1972). The expected fishing mortality is the difference between total mortality (Youngs 1972) and lamprey mortality calculated from the Fall marking data assuming that the lethality of attack was 0.3. The r value is 0.8, which is significant at the 0.01 level.

An interpretation of Fig. 9 is that fishing mortality transients obscure associations between marking and total mortality. This effect could explain the inconsistency between patterns in Figs. 5 to 7 and those reported by Pycha (1980). Preliminary Monte-Carlo simulations, in fact, show that random fluctuations in fishing effort coupled with relative constant sea lamprey abundance do yield results like those in Figs. 5 to 7. The lethality of attack assumed for these analyses, however, is much lower than that found in Lake Superior.

The experience with Seneca Lake strain of lake trout in Lake Ontario also implies that various strains of lake trout may vary in lamprey induced mortality. Therefore, an inconsistency remains for the probability of surviving a lamprey attack. Discussions during the mini-workshops also pointed to a resolution of this problem. Recent analysis of mortality of Seneca Lake strain (Schneider, personal communication) suggests that the variation between Superior and Seneca strains are due to attack, not lethality of attack, differences. Furthermore, analysis of wound staging data indicates a very high fraction of A1 marks in the survey data; implying that the survey samples are picking up a high frequency of on-going attacks. The effect of this inclusion would be to lower apparent lethality of attack. We still need to explore the implications of this finding, but again the generalizations from Lake Superior work (Koonce 1986) seem to hold for Lake Ontario.

The final inconsistency concerns the lack of a correlation between estimated carcass density and marking rates in New York Waters (Fig. 4). Depending upon lethality of attack, I expected to obtain such a relation (Fig. 10). This inconsistency, however, may stem from observational errors. Recent attempts to assess trends in density of lake trout carcasses (Schneider et al 1986) suggest that one depth stratum is not representative of carcass densities at all depth strata. Furthermore, marking statistics are highly dependent upon inclusion of large lake trout in the samples (cf. Fig. 1). Chance variation in sampling may thus add significant observational error to the marking data.

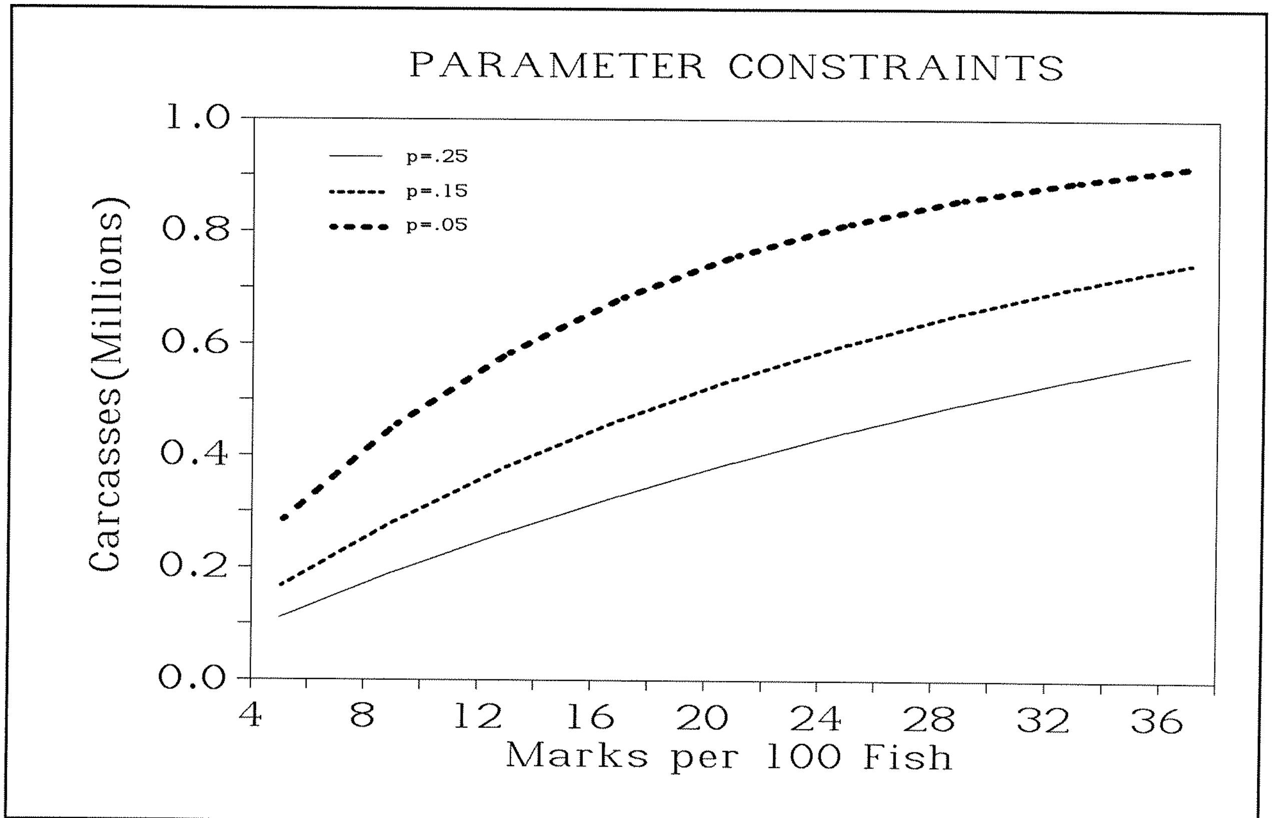

Fig. 10. Expected relation between carcass density and marking statistics for various probabilities of surviving a sea lamprey attack.

MODEL CALIBRATION

Following the mini-workshops at Cape Vincent and a working meeting on lamprey control data at Sault Ste. Marie, I could try to fit the IMSL model to available data from Lake Ontario. The starting point for model calibration was the IPM model (Spangler and Jacobson 1985) as modified for Lake Superior (Koonce 1986). I modified the model to include appropriate parameters describing the physical dimensions of Lake Ontario and its drainage basin (surface area, mean depth, volume, and length and width of ammocete habitat by three categories of stream flow). The model included actual stream treatment schedules (Fig. 1), stocking schedules for lake trout and both Coho and Chinook salmon (Fig. 2), and estimated historical fishing mortality. Surprisingly, little recalibration of the original parameter sets was required. Only lethality of attack (the probability of surviving an attack was finally assumed to have a maximum value of 0.25) and survival of stocked yearling trout (0.4) were varied to "fit" marking and carcass data. A product of the calibration is an estimate of the pattern of lake trout and salmon abundance for the period 1971 to 1986 (Fig. 11).

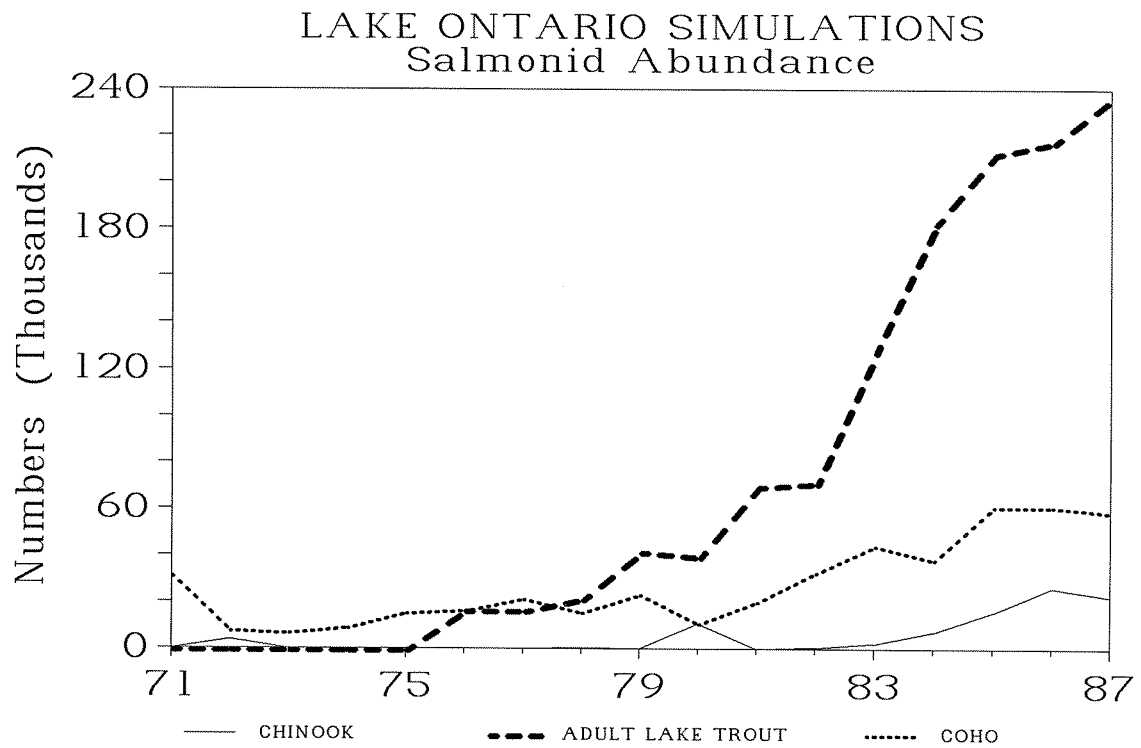

Fig. 11. Estimated patterns of adult lake trout, age 2+ Coho, and age 3+ Chinook salmon in Lake Ontario for the period 1971 to 1986.

Given the extreme variability in marking data, the model seems to represent lake trout marking adequately (Fig. 12), and the estimates of carcass density in Lake Ontario also seems to agree with the only lake wide estimates in 1985 and 1986 (Fig. 13). The pre-treatment abundance of sea lamprey is uncertain. The relative abundance pattern in Fig. 12 assumes peak abundance of about 300,000 parasitic phase sea lamprey, but simulations of no treatment and no rehabilitation scenarios indicate that this value could range from 200,000 to 500,000 or more depending upon the abundance of alternate prey. The model implies that currently abundance of spawning phase sea lamprey fluctuates between 50,000 and 60,000 (see also Fig. 17). Fig. 13 includes projections of carcass abundance under increased (High) or lower (Low) control starting in 1986.

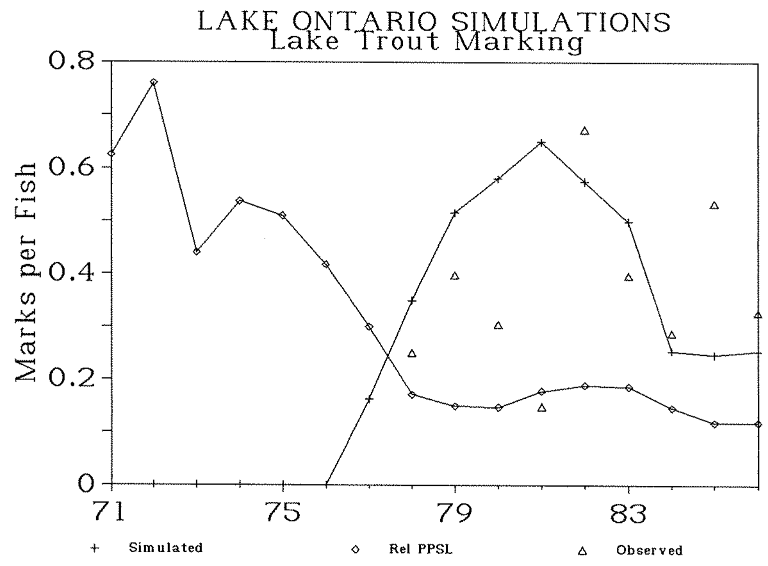

Fig. 12. Comparison of observed marking on adult lake trout and pattern predicted by IMSL. Relative abundance of parasitic phase sea lamprey is also included.

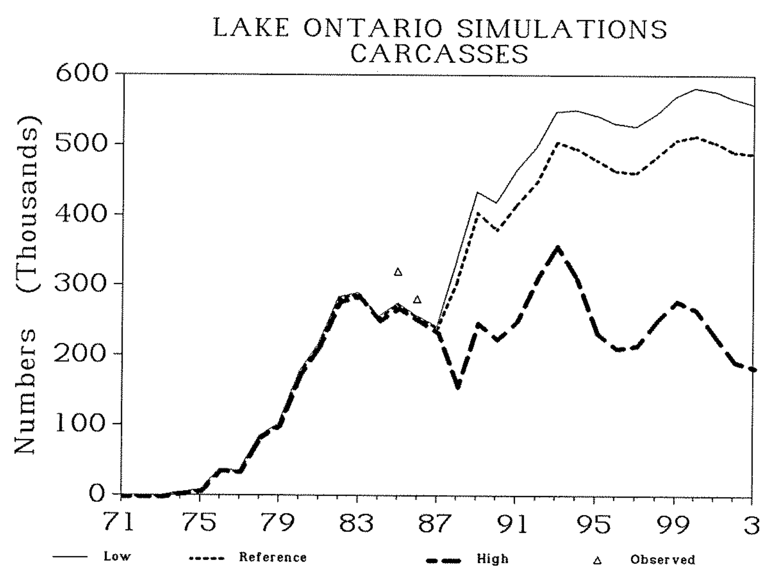

Fig. 13. Estimated carcass abundance for Lake Ontario from 1973 to 1987 with the predicted carcass abundance for three levels of future control budgets. Observed carcass abundance for 1985 and 1986 (Schneider et al 1986) are included.

FINDINGS

INTEGRATED MANAGEMENT OF SEA LAMPREY

To evaluate the implications of integrated management of sea lamprey to lake trout rehabilitation requires an examination of various fishery management options, stocking policies, and sea lamprey control options. As a reference for comparing various combinations of options, I have chosen the following standard:

- •Fishery management policy is the proposed slot limit policy for lake trout in New York waters of Lake Ontario. Fish less than 430 mm are generally unavailable to the fishery. All fish greater than 625 mm but less than 900 mm must be returned (0.15 probability of death assumed). The policy will be implemented in simulation year 1988. An annual quota is assumed to operate with harvest allowed only to a maximum total mortality of 0.4 per year on an instantaneous basis.
- •Stocking program starting in 1986 will consist of 2 million Superior strain lake trout and 500,000 Seneca strain annually. Salmon stocking will be at the rate of 678,000 for Coho and 454,000 for Chinook. All stocking assumed to be as yearling equivalents.
- •Sea lamprey control starting in 1987 will be limited to the effort required to hold spawning phase abundance in the current 50,000 to 60,000 range

All simulations cover the period 1971 to 2003. This range allows historical "validation" over the period 1971 to 1986 and projections of the consequences of various policy combinations through the next 15 years. The lake trout rehabilitation plan for Lake Ontario (Anon. 1983) provides a set of goals with which to compare these projections. The plan sets an interim objective: "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."

Fishery management options seem to have little influence on recovery of adult lake trout (Fig. 14). The three options considered are the Reference slot fishing option, a rigid quota of 80,000 lake trout lake-wide, and a No Regulation option. As long as the growth of the fishery remains modest, the goal of 0.5 to 1.0 million adults by the year 2000 is attainable even with a "No Regulation" policy. Basically, it is a continuation of the present bag limit policy. This policy, however, is clearly not sustainable. Adult abundance is declining in the year 2000.

In contrast, lake trout rehabilitation is much more sensitive to stocking and sea lamprey control options. Increasing or decreasing lake trout stocking by a factor of 2, for example, results in a more than 8 fold range of adult abundance by the year 2000 (Fig. 15). The magnitude of this result is somewhat induced by the start of the new stocking program in 1986, but it emphasizes the sensitivity of the rehabilitation to stocking. In the presence of 50 to 60 thousand parasitic phase sea lamprey, a 50% reduction in stocking will prevent attainment of the basic goal of 0.5 to 1.0 million adult lake trout by the year 2000.

A similar result is obtained for variation in sea lamprey control (Fig. 16). The control options reviewed concerned variation in the treatment threshold for detection of transforming ammocetes. The low control option is a 2 fold increase in the detection threshold relative to the "Reference" scenario, and the high control is a 20% decrease. Fig. 17 indicates the effects of these variations on abundance of spawning phase sea lamprey. Under all control options, the goal for adult lake trout is met by the year 2000, but also does not appear sustainable for the lower control option. For wild yearling production, however, only increased stocking (Fig. 18) or increased control (Fig. 19) will attain the goal of 100,000 wild yearling lake trout produced by the year 2000. In fact, at current levels of stocking and sea lamprey control, the simulation implies a steady production of less than 35,000 wild yearlings annually by the turn of the century.

Because of their dominant influence on rehabilitation, some combination of trade-off of stocking for sea lamprey control seems a possibility. Considering only extreme trade-offs, higher stocking coupled with lower control of sea lamprey yields adult abundance of about 2 million by 2000 (Fig. 20). The alternative of lower stocking with higher control does not perform even as well as the reference scenario, but it shows signs of continued recovery well beyond the year 2000. Wild yearling production (Fig. 21), however, reveals a different aspect of rehabilitation. The high stocking/low control option is better, but higher control continues to show more potential for sustaining the recovery process. Reliance on chemical treatment for sea lamprey control, therefore, appears to be a requirement for both phases (adult lake trout abundance and wild yearling production) of lake trout rehabilitation. This is especially true given the uncertainty about the limits of forage availability associated with high stocking rates.

These simulations indicate that fishing mortality and sea lamprey induced mortality have been major impediments to lake trout rehabilitation. Comparing harvest and carcass losses during the first 15 years of rehabilitation (Fig. 22), both fishing and sea lamprey mortality have been major factors slowing the pace of rehabilitation. These trends occur despite the reduction of spawning phase sea lamprey to a treatment oscillation abundance level of 50 to 60 thousand by 1979. As indicated by adult abundance, however, lake trout are now near an abundance level at which they can escape the effects of sea lamprey predation. Realistic fish management options (fishery regulation and stocking) are likely to result in substantial gains in rehabilitation during the next few years. In contrast, there does not appear to be much scope for reduction in chemical control of sea lamprey. Model results suggest that as few as 50,000 to 60,000 parasitic phase sea lamprey in Lake Ontario may be blocking recovery of lake trout, and even minor fluctuations in abundance of parasitic phase lamprey causes substantial variation in mortality of lake trout at present abundance levels. The need for continued control of sea lamprey does not appear to diminish with lake trout recovery even under the most optimistic assumptions through the next 15 years.

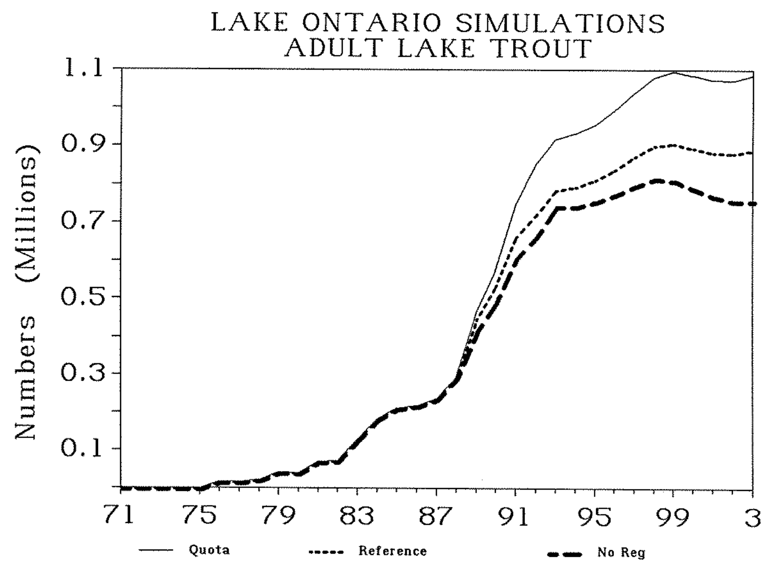

Fig. 14. IMSL simulations of the changes in abundance of adult lake trout due to various fishery management options, which could be implemented after 1988.

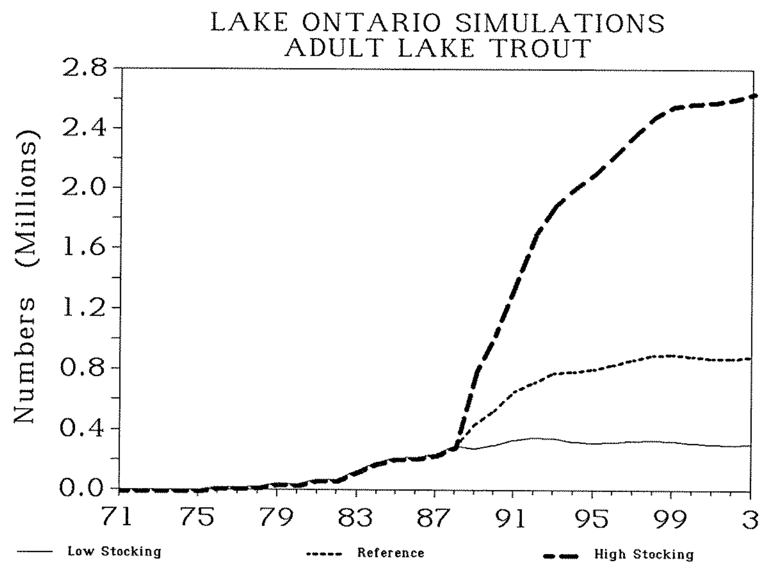

Fig. 15. IMSL simulations of the effects of stocking policy on abundance of adult lake trout starting in 1986.

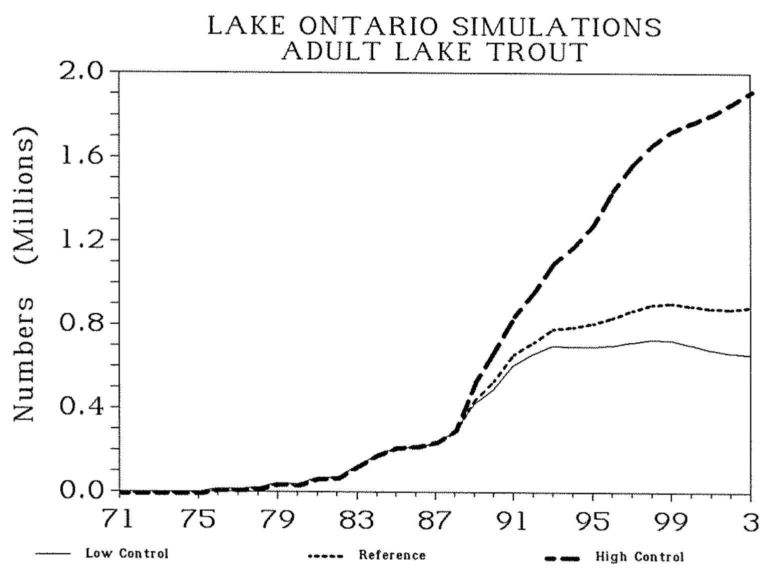

Fig. 16. IMSL simulations of the effects of varying sea lamprey control effort after 1988 in Lake Ontario on abundance of adult lake trout. Variation in control effort is due to changes in the threshold transformer density that triggers a chemical treatment for a stream.

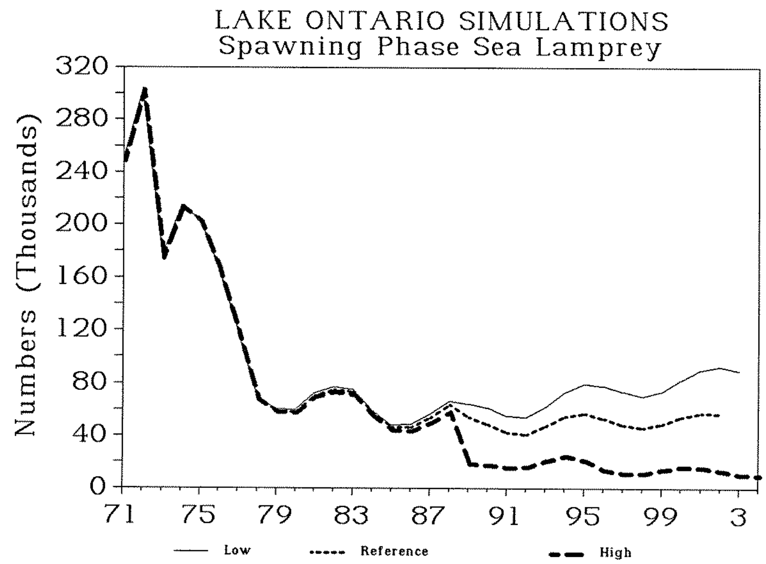

Fig. 17. IMSL simulations of the effects of varying sea lamprey control effort after 1988 in Lake Ontario on abundance of spawning phase sea lamprey.

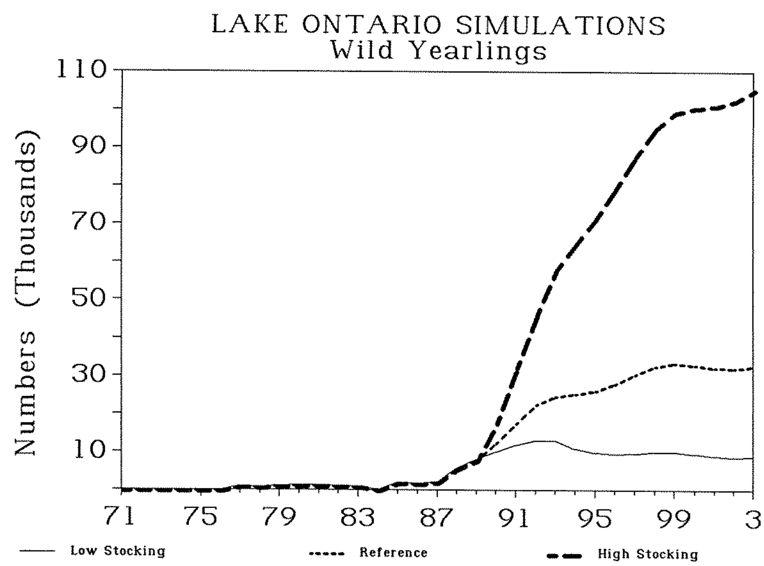

Fig. 18. IMSL simulations of the effects of various stocking levels on abundance of wild yearlings in Lake Ontario.

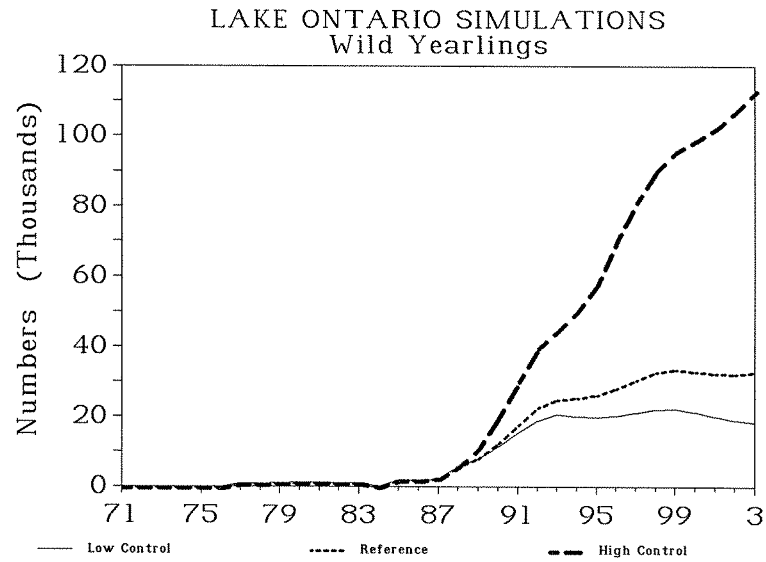

Fig. 19. IMSL simulations of the effects of varying sea lamprey control effort after 1988 on abundance of wild yearlings in Lake Ontario.

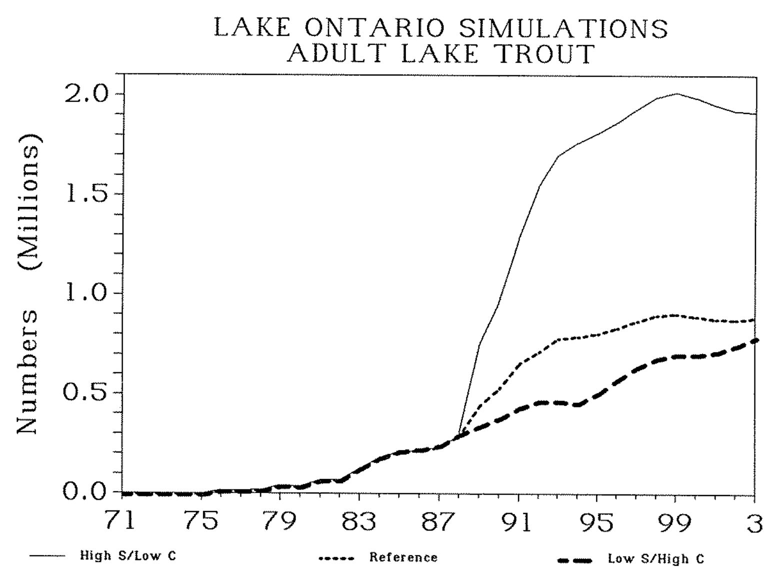

Fig. 20. IMSL simulations of the effects of varying sea lamprey control in combination with variation is stocking level on abundance of adult lake trout in Lake Ontario. Combinations of high stocking/low control and low stocking/high control are contrasted with the reference scenario.

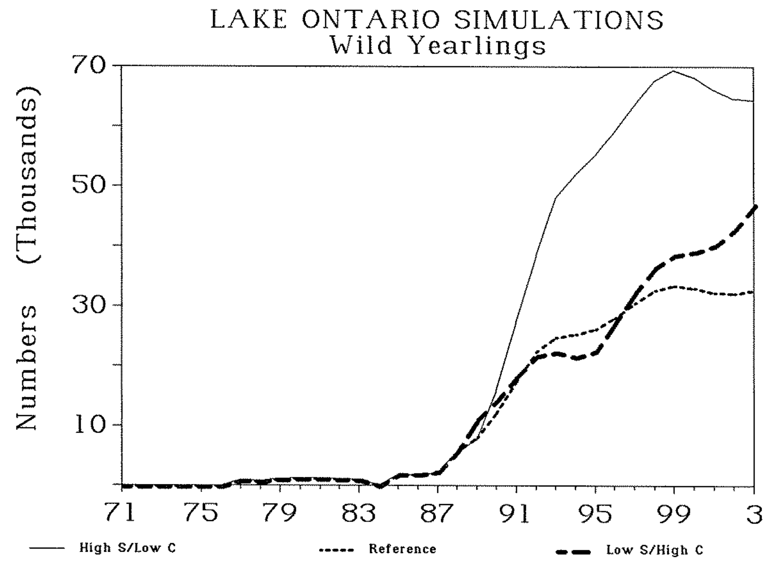

Fig. 21. IMSL simulations of the effects of combinations of stocking and sea lamprey control on abundance of wild yearlings in Lake Ontario.

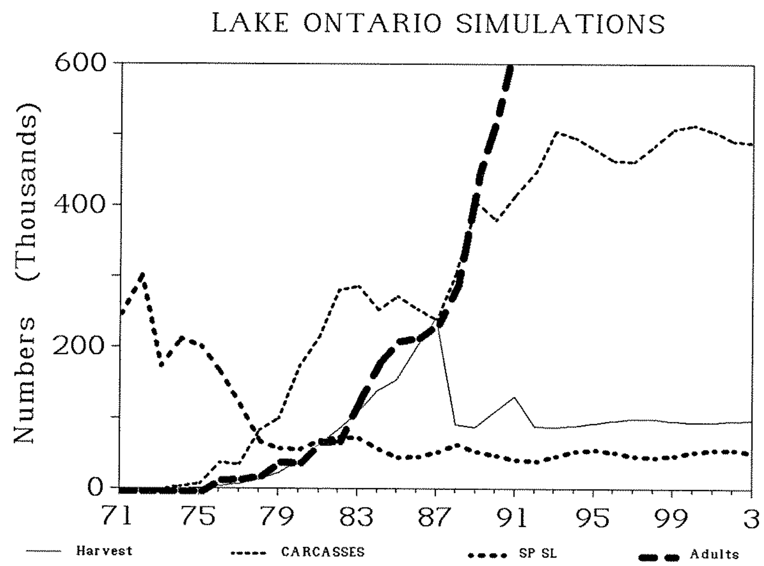

Fig. 22. IMSL simulations of harvest, carcass, spawning phase sea lamprey abundance and abundance of adult lake trout for the reference scenario.

FEASIBILITY OF ESTABLISHING ECONOMIC INJURY LEVELS

These results support the feasibility of the kind of trade-off analysis required to establish minimum levels of sea lamprey control implied by the notion of economic injury level.

As defined by Sawyer (in Spangler and Jacobson 1985), the economic injury level is "the lowest pest population that would inflict losses to the existing resource exceeding the cost of implementing a given set of pest control measures." To establish an economic injury level, therefore, will require evaluation of the losses of lake trout associated with various combinations of sea lamprey control and fishery management options. The following results of the Lake Ontario applications of the IMSL model illustrate the feasibility of the required trade-off analysis.

One benefit of sea lamprey control in the context of lake trout rehabilitation is the resulting harvest of lake trout. From the point of view of the Great Lakes Fishery Commission, the cost is mainly implementation of the control program. Fig. 23 illustrates the costs associated with three levels of sea lamprey control. These cost figures are crude attempts to equate all aspects of sea lamprey control (chemical treatment, assessment, barrier dam construction, research, and administrative costs) with quantity of TFM used. Taking an estimate of the budget for treatment of Lake Ontario in 1986 along with the quantity of TFM used, I obtained a conversion coefficient to determine both historical and future trends in costs. Of course, this crude assumption must be improved in future applications, but the general principles will apply. Harvests associated with these control levels are given in Fig. 24.

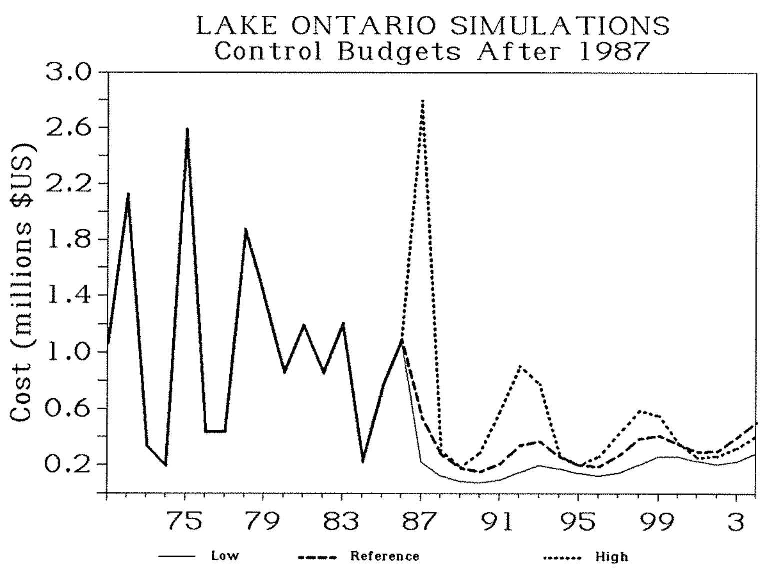

Fig. 23. Variation of control costs associated with changes in the treatment threshold for ammocete density. These are the IMSL simulated control costs for policies in Fig. 16.

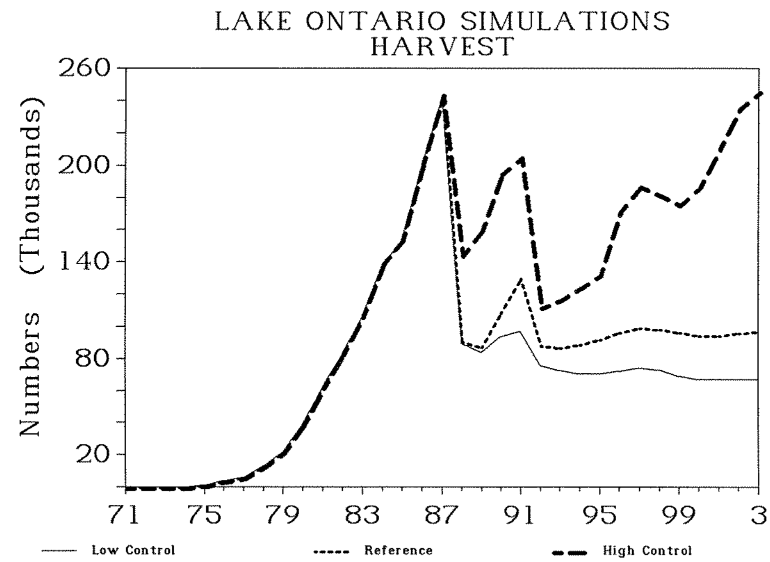

Fig. 24. Variation of lake trout harvest associated with changes in the treatment threshold for transformer density. These are the IMSL simulated control costs for policies in Fig. 16.

A peculiar feature of the control costs in Fig. 23 is the tendency to converge on a rather narrow range of treatment cycle costs. Short term savings due to lower control costs gradually erode, and both higher and lower control budgets converge on the same range of long term control costs. Actual control budgets are more complicated than I have portrayed, and there are many more options for mixes of control strategies that I have not considered. Nevertheless, I can approximate control costs over the period 1987 to 2003 by simply averaging annual costs for this period. Damage calculations are undoubtedly proportional to carcass abundance, but I found little empirical support of the changes if value of individual lake trout with increasing density. Recent attempts to estimate damage of St. Mary's River sea lamprey on lake trout and salmon in Northern Lake Huron have assumed a value of $12 per fish as an average value of lake trout for the entire Great Lakes Basin. Using these assumed values, the benefits of increased sea lamprey control in Lake Ontario are clearly greater than costs of control (Fig. 25). In fact, the difference between benefits and costs increase with control costs. The marginal gain (delta harvest/delta cost) peaks at intermediate control costs (Fig. 26). Until better data are available for value of lake trout at higher abundances, I hesitate to generalize these results. Nevertheless, it would appear that sea lamprey control in Lake Ontario is under-budgeted.

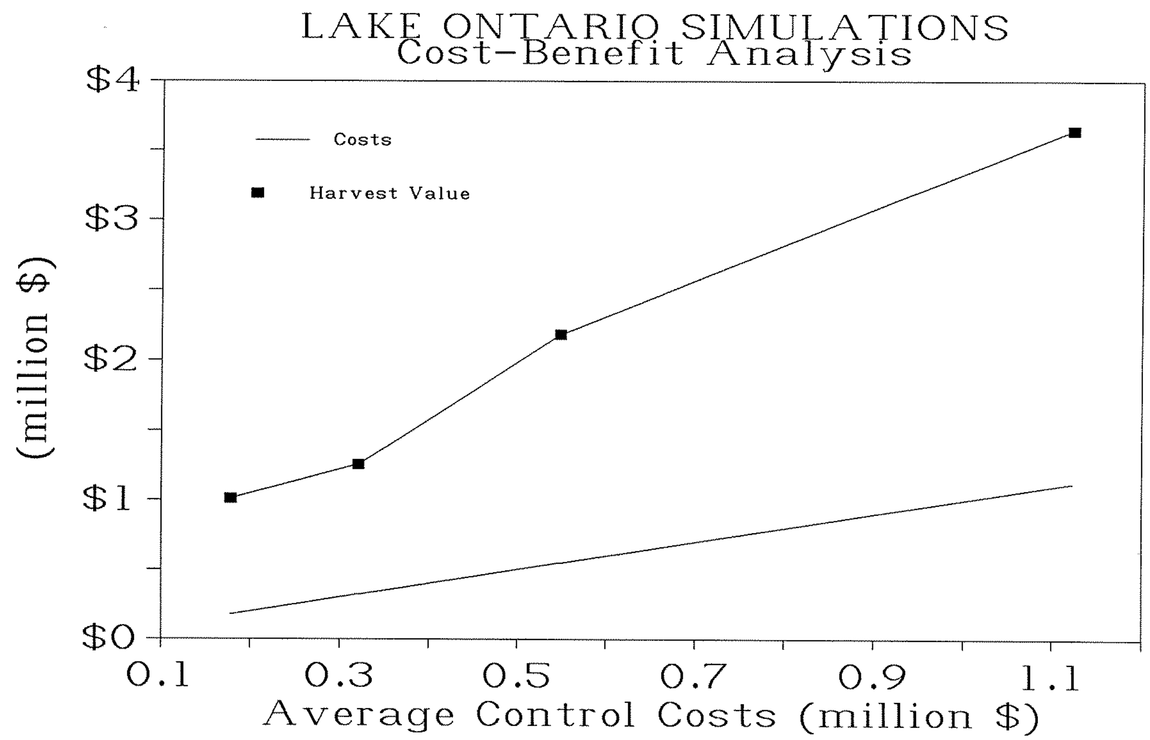

Fig. 25. Relation between average value of lake trout harvest and average costs for sea lamprey control over the period 1988 to 2003 for variations of sea lamprey control in the Reference simulations.

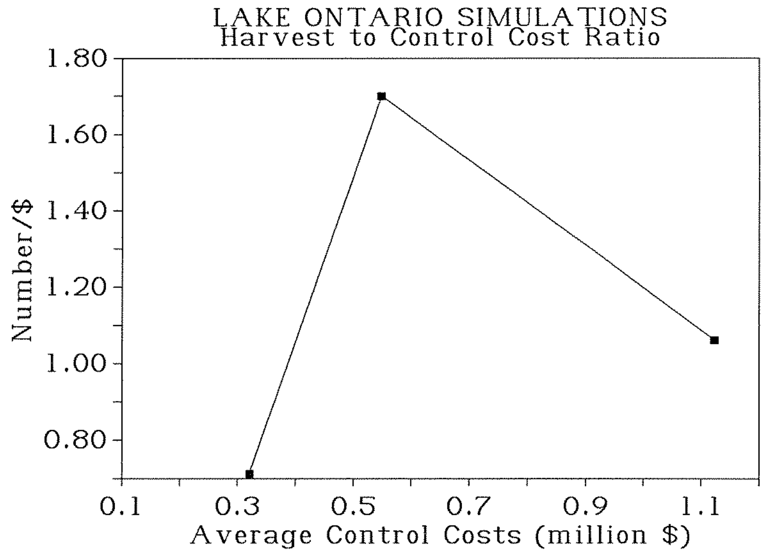

Fig. 26. Relation between control costs and average ratio of change in value of lake trout harvest to change in average costs for sea lamprey control over the period 1988 to 2003 for variations of sea lamprey control in the Reference simulations.

Just as Heimbuch and Youngs (1982) noted for efficiency of sea lamprey control, jurisdictional divisions will impede optimization of budgeting and allocation of control resources. Integrated management of sea lamprey will not be based on a single budget. Instead, the control resources are the exclusive domain of the Great Lakes Fishery Commission, provincial and state agencies are primarily responsible for fishery management, and the federal governments provide the majority of the resources for stocking programs. It seems, therefore, that consensus derivation necessary to implement integrated management of sea lamprey will require some type of computer aid to facilitate discussion.

CONCLUSIONS AND RECOMMENDATIONS

The main findings of this research are

- Sea lamprey and fishing have slowed lake trout recovery in Lake Ontario
- Substantial gains in rehabilitation are possible in the near future with reasonable fishery management policies (including fishery regulation and stocking)
- 50,000 to 60,000 parasitic phase sea lamprey remain a problem

- Continued sea lamprey control is needed in Lake Ontario to sustain rehabilitation gains

- Basic goals of rehabilitation of Lake Trout in Lake Ontario can be met by the year 2000.

Lake trout rehabilitation in the Great Lakes is a very slow process. Because of the success of the sea lamprey control program, public pressure is mounting to accelerate the recovery of lake trout and/or to improve salmonid enhancement efforts. Already, the Great Lakes Fishery Commission is being asked to expand control efforts without concomitant increases in resources for sea lamprey control. Issues of effectiveness and efficiency of use of these resources thus become more critical components of program management than in the past. Until now, there has been no effective way of establishing either target levels of sea lamprey abundance in the Great Lakes or evaluation of budgets required to achieve these targets. Despite relatively crude attempts to document costs of sea lamprey control and value of future lake trout harvest, this study shows that these program management activities are not only feasible, but are within the grasp of the Great Lakes Fishery Commission.

To pursue this opportunity, the Great Lakes Fishery Commission must begin to institutionalize the results of this project and its predecessors. First, the Commission must commit to an application of Integrated Management of Sea Lamprey. Although the approach has been endorsed in the past, progress will depend upon more specific decisions for its implementation. Two activities that would facilitate this step would be 1) To specify budgeting or allocation issues that the Commission wants to resolve; and 2) To set up a joint evaluation by Sea Lamprey Control Agents and Fishery Managers for an examination of these issues and their resolution. Second, the Commission with its cooperators must expedite the development of a decision support system, which will facilitate timely consideration of the trade-offs implicit in Integrated Pest Management.

In the work reported here, I have only illustrated the types of trade-off analysis possible. Within sea lamprey control alone, there are many possible mixes of control options yet to consider (e.g. barrier dams, sterile male programs, trapping, and various new and emerging technologies). Furthermore, data for all the other lakes must be assembled before basin wide budgeting and allocation issues are accessible. At a minimum, the Commission will need stream inventory systems for all of the Great Lakes as well as a common inventory of assessment data. An integrated database management system is thus a high priority. Even with the availability of data and models, the basic problem is so complex that the Commission may well need to consider development of a computer based package of trade-off analysis aids. This step will likely need to invoke some of the emerging Expert system technology. Finally, this system will only be as useful as the confidence its users have in its technical validity. Repeated testing and evaluation will be required throughout development and, therefore, should be part of the development process.

In summary, I make the following five recommendations for follow-up work:

- COMMITMENT TO APPLICATION
  - -Specification of budgeting and allocation issues of primary interest to the Great Lakes Fishery Commission
  - -Set up a joint committee of Sea Lamprey Control Agents and Fishery Managers to evaluate issues and their resolution
- DEVELOP A DECISION SUPPORT SYSTEM
  - -Need a database management system to integrate stream inventory and lake trout assessment data
  - -Need a computer based package of trade-off analysis aids
  - -Need ongoing evaluation and testing of the Decision Support System

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