A DECISION SUPPORT SYSTEM FOR THE INTEGRATED MANAGEMENT OF SEA LAMPREY

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Table *of* Contents

1 OVERVIEW OF IMSL DECISION SUPPORT SYSTEM

1.1 Introduction

The IMSL Decision Support System is the product of an on-going process to integrate sea lamprey control and fisheries management in the Great Lakes. Because this process is open, the IMSL Decision Support System itself can not be static. Rather it must also be open to change as the perception of problems in the integrated management of sea lamprey change. The documentation prepared here, therefore, is intended to supplement earlier reports and model documentation so that users may understand the structure of the IMSL Decision Support system and modify it as necessary. It is not an exhaustive summary of all aspects of models used. Key reports in the series of workshops and research initiatives sponsored by the Board of Technical Experts of the Great Lakes Fishery Commission that led to the decision support system are as follows:

(1) Koonce et al. 1982	Documentation of the simulation model produced by the Adaptive Environmental Assessment and Management "Salmonid/Lamprey" Workshop held in Sault Ste. Marie, Michigan in 1981.
(2) Spangler et al. 1985	Documentation of the simulation model produced by the Adaptive Environmental Assessment and Management "Integrated Pest Management" Workshop held in Sault Ste. Marie, Michigan in 1982.

(3) Koonce 1986	Detailed examination of the models from (1) and (2) to improve representation of lake trout and sea lamprey interactions and to reexamine the applicability of (1) and (2) to development of policy for trade-offs between sea lamprey control and lake trout management in Lake Superior.
(4) Koonce 1987	Development of an integrated management of sea lamprey simulation model for Lake Ontario. The simulation model was based on (2) as modified by the results of research in (3).
(5) Jones et al. 1987	Prototype expert system to aid selection of Lake Ontario streams for chemical treatment.

1.2 Contents of Documentation

This document is organized into four major sections and three appendices:

Section 1	An overview of the IMSL Decision Support System
Section 2	The documentation of the three components of the Decision Support System and discussion of database sources and organization
Section 3	A demonstration of the use of the Decision Support System concentrating on historical validation and typical analysis of trade-off options for future policies
Section 4	A software directory for the Decision Support System
Appendix A	A listing of the IMSL Simulation Model
Appendix B	A collection of variable definition tables for the IMSL Simulation Model

Appendix C The results of a model evaluation workshop held in Toronto, Ontario on July 12, 1988

1.3 Role of Decision support System in Integrated Management of Sea Lamprey

Integrated Management of Sea Lamprey has been part of the strategic planning of the Great Lakes Fishery Commission since 1982. Progress in implementing IMSL, however, has been slow. Ultimately, IMSL is a process that will provide information necessary to establish target levels of control of sea lamprey necessary for each of the Great Lakes, and thereby, provide a way of rationalizing budgets and allocation of control resources. IMSL, however, is fundamentally different from integrated pest management in agricultural systems. Integrated management of sea lamprey in the Great Lakes implies not only a mix of strategies to control sea lamprey abundance, but also trade-offs in fishery management. The institutional complexity of this coordination coupled with rather extensive data requirements to allow rational analysis of policy options, therefore, have been serious impediments to full implementation of IMSL.

The IMSL Decision Support System is an attempt to bridge gaps in quantitative information required to move forward with IMSL. In no sense is the decision support system a replacement for improved surveillance and monitoring. It has evolved through

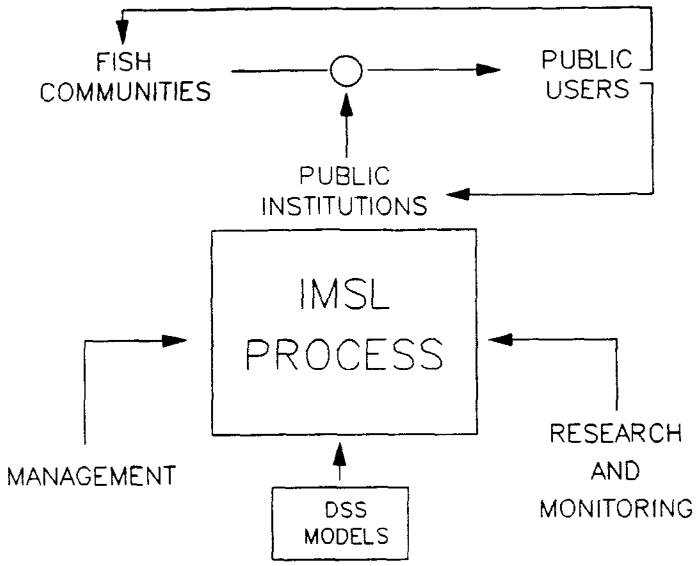

Fig. 1.3.1. Subsidiary role of the IMSL Decision Support System to the overall IMSL process.

a series of AEAM workshops devoted to salmonid/lamprey interactions (Koonce et al 1982 and Spangler and Jacobson 1985) and subsequent research (Koonce 1986 and Koonce 1987). Application of these evolving models to Lake Ontario (Koonce 1987) demonstrated potential application to the problem of specifying economic injury levels for sea lamprey control, and by implication, to setting target levels of control for sea lamprey. Target levels of control, however, are equally influenced by variation in sea lamprey control and by variation in fishery management. A formal decision support system is an advantage in such a situation because it provides a framework within which the consequences of alternative policy choices can be evaluated (Fig. 1.3.1). The role of the decision support system, therefore, is to promote quantification of sea lamprey control and to promote communication among the individuals and agencies ultimately involved in the rehabilitation of fisheries in the Great Lakes.

1.4 Structure of Decision Support System

The decision support system consists of three major components (Fig. 1.4.1). These components are

- **Database Management System**
- **Problem Specification System**
- **Simulation/Analysis System**

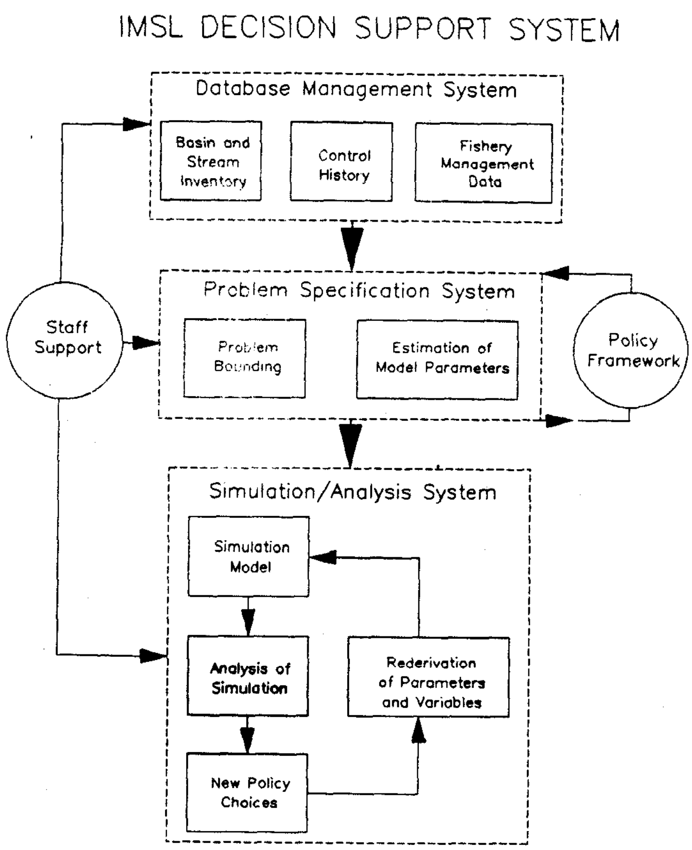

Fig. 1.4.1. Schematic diagram of the structure of the IMSL Decision Support System.

Each of the systems is discussed in more detail below. These components are designed around major software packages (dBase III Plus, Lotus 123, and Microsoft QuickBasic) and can be changed or upgraded with appropriate staff support. Because this system is designed for use in working meetings in which policy options are explored, it has graphics and analysis support sufficient to compare consequences. These features are illustrated in a demonstration section below (Section 3).

2 Documentation of Decision Support System

2.1 Database Sources and Organization

The database management system facilitates use of three types of data. It serves as an archive for a stream inventory database for the streams known to produce sea lamprey in Lake Ontario and for the control history data. Other data are derived from fishery management agencies and include observations on marking rates, mortality, carcass densities, growth rates, stocking rates, etc. These data are variously used to estimate parameters in models or to test model predictions. For Lake Ontario, all sea lamprey control data were provided by Jerry Weise (Lamprey Control Centre at Sault Ste. Marie, Ontario). Fishery data were provided by Bill Dentry (Ontario Ministry of Natural Resources) and-Cliff Schneider (New York Department of

Environmental Conservation).

2.2 Problem Specification system

The Problem Specification System is central to the communication process required for progress in IMSL. To initiate a set of analyses, users must discuss the range of issues and trade-offs they wish to explore. This problem bounding exercise is an important device to establish a common view of the problems in implementation of IMSL. Model parameters are then estimated and the Simulation/Analysis System is primed for use.

2.3 IMSL Simulation Model

The IMSL Simulation Model is an evolving instrument to integrate fishery management and sea lamprey control with biological regulation of fish communities in deepwater, oligotrophic portions of the Great Lakes. The model originated in an Integrated Pest Management workshop in 1982 (Spangler and Jacobson 1985) and was subsequently modified during applications to Lake Superior (Koonce 1986) and Lake Ontario (Koonce 1987). The current version, which is documented here, is fully implemented for Lake Ontario. It includes representation of salmonid/lake trout fish community, complete historical fishery management (stocking and exploitation), and sea lamprey control history. It provides many options for future management initiatives and includes a stream selection expert system (Jones, Koonce, and Wedeles, 1987) for chemical treatment Of sea lamprey ammocoetes.

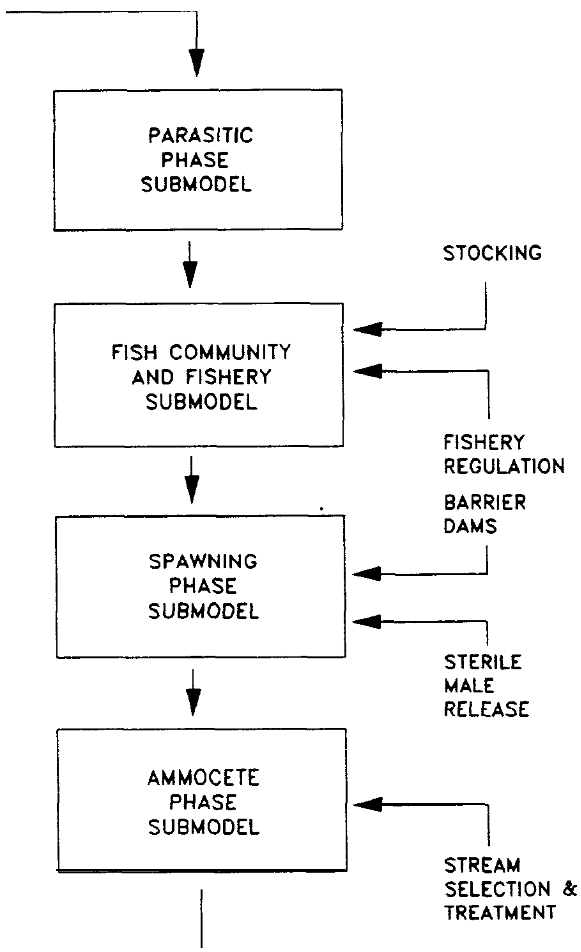

Fig. 2.3.1. Flow chart for IMSL Simulation showing logical connection of submodels and management actions.

The IMSL model consists of four submodels (Fig. 2.3.1). This is the same model structure as contained in the model produced by the IPM Workshop (Spangler and Jacobson, 1985). However, many of the assumptions, equations, and parameter values have been modified in application to Lake Ontario. Modifications in the Parasitic Phase Submodel relate to lethality of attack and resulting marking statistics. Description of the fish community and exploitation in the Fish Community and Fishery Submodel has expanded to include two exotic salmonid species as well as two strains of lake trout (Superior and Sceneca strains). Stocking policies may be established for all species. Fishing policy choices allowed are many: minimum size limits, slot limits, effort limits, and quotas. The Spawning Phase Submodel is nearly identical to the earlier version except for explicit representation of all lamprey producing streams. Barrier dams and sterile male programs remain as the primary lamprey control actions affected in the submodel. Finally, the ammocoete submodel is completely revised. Ammocoete densities are age-structured by individual producing streams. In the Lake Ontario drainage basin there are 49 such streams. Chemical treatments are determined by historical treatment schedules, and a stream selection expert system (Jones, Koonce, and Wedeles, 1987) provides a framework for future stream treatments under a variety of budgetary and tactical constraints. Specific details of model structure will be discussed below.

2.3.1 Parasitic Phase Submodel

Submodel Logic

As with the IPM Model (Spangler and Jacobson 1985), the purpose of the parasitic phase submodel is to predict attacks and marking rates of prey (Fig. 2.3.2) and to predict average size of parasitic phase sea lamprey. Following Murdoch (1973), attacks are assumed to obey a multi-species disc equation:

$$A_i = \frac{T \cdot e_i \cdot L}{1 + \sum_{i=1}^{n} \bar{h} \cdot e_i \cdot N_i}$$

where T is the time period during which all attacks occur, e_i is the effective search rate of an individual sea lamprey, L is the abundance of parasitic phase sea lamprey, $\bar{h}$ is the mean duration of an attack, and N_i is the abundance of the i-th prey group. The only departure from the IPM model assumptions concerning attacks is that effective search rate is also a function of the habitat overlap of sea lamprey and the prey species:

$$e_i = H_i \cdot P_i \cdot S_i \cdot R_i$$

where H_i is the habitat overlap {0,...,1}, and P_i, S_i, and R_i are, respectively, probability of attack, swimming speed, and radius of perception as defined for the IPM model.

Mortality Sources for Sea Lamprey Species

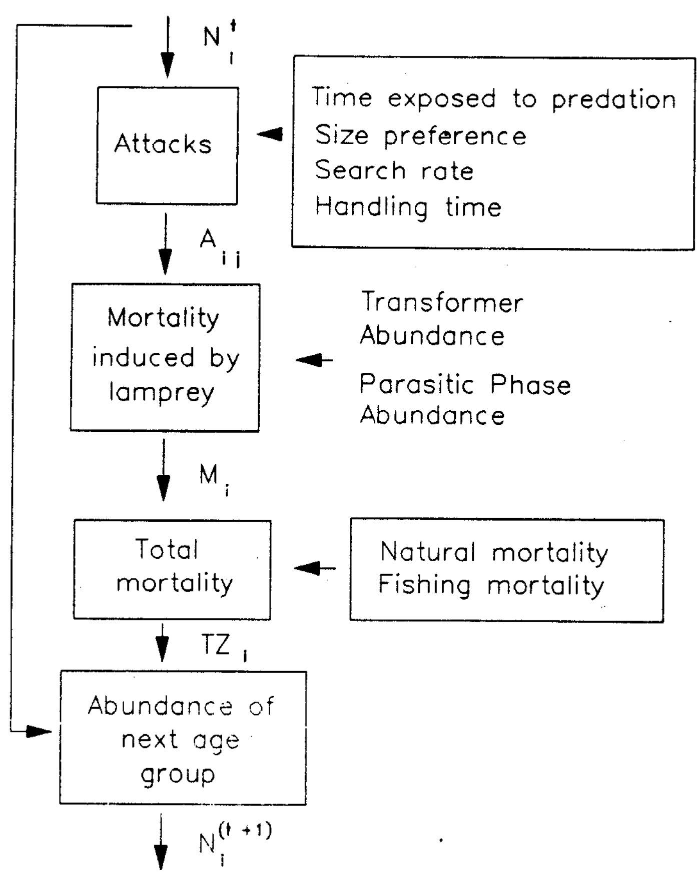

Fig. 2.3.2. Logical structure of sources of mortality affecting the dynamics of lake trout and other salmonid species subject to attack by sea lamprey.

Lethality of attack and marking rates, in contrast, are treated differently than in the IPM model. Lethality of attack is assumed to decrease with the ratio of prey to sea lamprey weight according to the formulation in Farmer (1980) until a fixed minimum value is obtained. The assumption in the IPM model was that prey more than 40 times the weight of a sea lamprey would survive an attack. Estimates for Lake Ontario suggest that the minimum probability of death due to sea lamprey attack is 0.75. Instantaneous mortality due to sea lamprey attacks is thus:

$$Z_L = (1 - Ps_i) \cdot A_i$$

where Ps_i is the probability of surviving an attack. The modification of marking statistics from the IPM model is to include ongoing attacks in the Al marking category. As demonstrated by Koonce and Pycha (Ms), the Al marking statistic that includes ongoing attacks is approximately:

$$M_{A1,i} = \frac{e_i \cdot L}{\sum_{i=1}^{n} e_i \cdot N_i} \cdot \left(Ps_i \cdot \frac{T_{A1} - \bar{h}}{\bar{h}} + 1 \right)$$

where $M_{A1,i}$ is the Al marks per fish for prey group i and T_{A1} is the healing time for an Al mark.

Important Assumptions and Limitations of the Submodel

Parameter estimation for this submodel is difficult. Except for lethality of attack and the habitat overlap parameter values are derived from the IPM model. Among habitat overlap, lethality of attack, and duration of attack, however, there is sufficient responsiveness to fit just about any marking pattern. The joint constraints of species specific marking rates and carcass density estimates for lake trout minimize this problem in Lake Ontario.

2.3.2 Fish Community and Fishery Submodel

Submodel Logic

This submodel accounts for the remaining mortality, reproduction, and stocking of salmonids and other sea lamprey prey (Fig. 2.3.2). Modification of the IPM model include: (1) modification of the lake trout growth equations (Koonce 1986), (2) addition of Chinook (Ages 1, 2, and 3) and Coho (Ages 1 and 2) salmon as prey groups, and (3) the addition of a wide range of fishery management options. Lake trout reproduction is a function of fecundity and young-of-the-year survival (Fig. 2.3.3) as described in the IMP model. Growth rate and fecundity parameters were fit to observations from Lake Ontario. Natural mortality and young-of-the-year mortality for lake trout were also provided by analysis of observations (Schneider and Dentry, personal communication). Historical stocking coupled with estimates of survival of planted fish (fingerlings, yearlings, etc.) were used to establish a schedule of stocking of yearling equivalents for these three salmonid species.

Determinants of Reproduction of Lake Trout

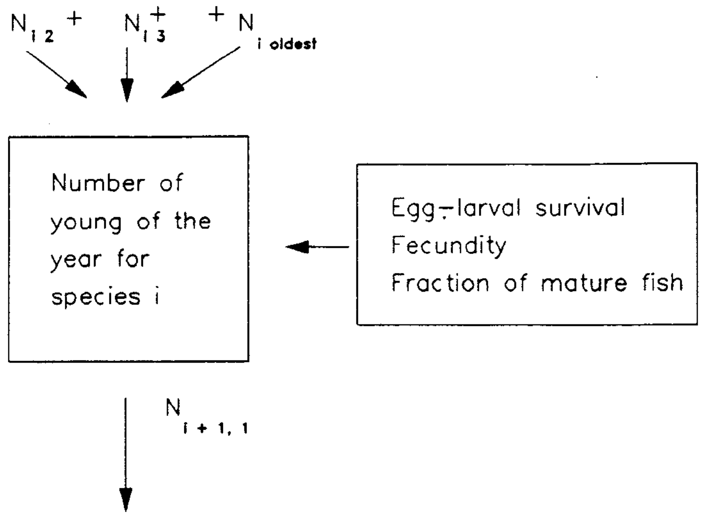

Fig. 2.3.3. Schematic representation of factors determining reproduction of lake trout.

The submodel provides three basic types of fishery management options: fixed effort (either regulated or growing), quota, and constant total mortality. Within these options, size regulations (slot limits, minimum size limits, etc.) are also possible to impose. Under all management options, catch and release mortality is assumed to be 15% of fishing mortality calculated from catchability and allowable effort. All management policies are implemented in the model by calculating effort allowed under the policy. For constant total mortality, fishing effort is allowed only when the sum of natural mortality and sea lamprey induced mortality are less than the target total mortality. In which case, the allowable effort is the difference between target mortality and the non-fishing mortality.

Important Assumptions and Limitations of the Submodel

This submodel has some important assumptions and a key weakness. Estimates of natural mortality and stocking mortality are quite difficult to obtain in most cases. Coded-wire tagging and other systematic observations, however, yield more confidence in estimating these mortality levels. Perhaps more importantly, the model does not provide a complete description of the fish community. There is, for example, no reliance of salmonid growth or standing stocks on the productivity or biomass of forage fish. This omission severely limits the model validity for very high density scenarios.

2.3.3 Spawning Phase Submodel

Submodel Logic

The spawning phase submodel is the least modified submodel from the IPM model. The major change is an explicit representation of spawning runs for individual streams (Fig. 2.3.4). As with the IPM model, spawners are partitioned by a specified weighting of stream flow and ammocoete density. The model accepts historical schedules of barrier construction, and future barriers may be planned on an individual stream basis. Traps may be incorporated into barrier design, but the submodel assumes that all lamprey entering the mouth of a stream either spawn in the stream or will be trapped at the barrier. Finally, the model provides for various options to implement a sterile male program. Important choices include: sources of spawning phase sea lamprey, cost of program, and the effects of sterile males on emergent larvae.

Reproductive Dynamics of Lamprey

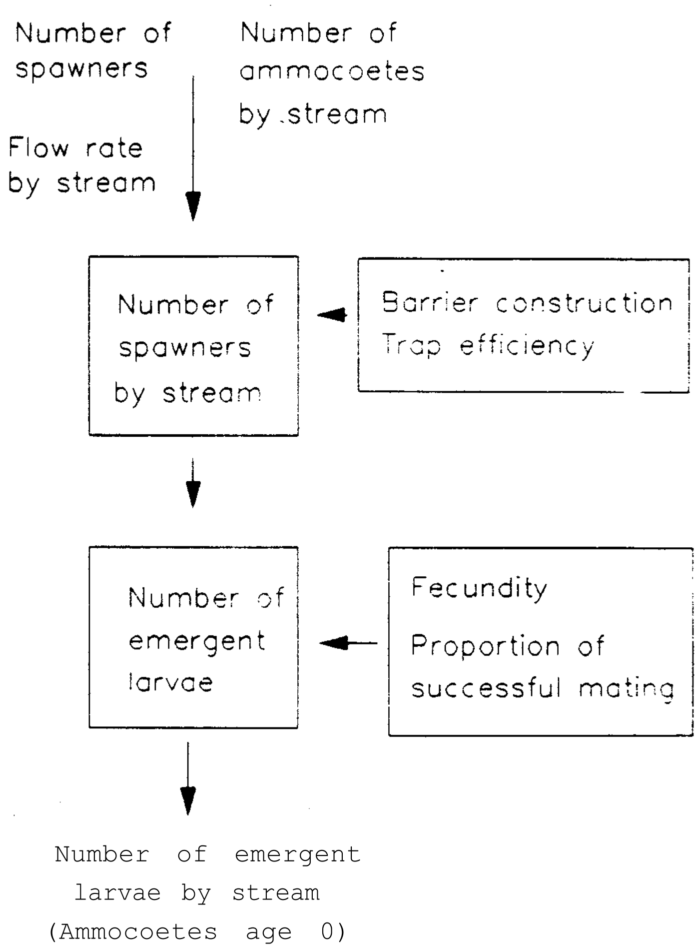

Fig. 2.3.4. Schematic representation of factors determining the distribution of spawning phase sea lamprey and the production of emergent larvae.

Important Assumptions and Limitations of the Submodel

Four primary assumptions are important to this submodel. First, the partitioning of spawning phase sea lamprey remains speculative. Although some combination of flow and ammocoete density is involved, little is known of the true partitioning rule. The assumption in the IPM model allows weighting by both factors. As in the baseline simulations of the IPM model, the assumption remains that spawners are partitioned equally according to the proportion of total stream flow and proportion of total ammocoete abundance obtained for a given stream. Second, the spawning phase allocation is limited to known producing streams. Third, the model assumes that all barriers are totally effective in eliminating upstream migration. Finally, fourth, the model assumptions about early larval mortality and reproductive success have not been well documented. The model continues to rely in large measure to the assumptions in the IPM model.

2.3.4 Ammocoete Submodel

Submodel Logic

The basic description of ammocoete dynamics in the IPM model has been incorporated into this submodel (Fig. 2.3.5). Six ammocoete age groups (Ages 0 to 5 and 6+) are represented in the model along with male and female transformers. Mortality sources for ammocoetes are transformation, natural mortality, and treatment mortality. Chemical treatment mortality, as in the IPM Model, is a function of stream flow (cf. Spangler and Jacobson 1985). Due to warmer temperatures in the streams of Lake Ontario, transformation is assumed to begin at age 3. Finally, ammocoete densities are modeled for each of the 49 known producing streams in the Lake Ontario drainage basin. Stream attributes are stored in a stream inventory database and include habitat area, flow, and chemical required for treatment (Table 2.3.1). The database also includes provision for a habitat suitability index. Current values of this index were derived from qualitative judgements of productive potential of each stream. The index varies between 0 and 1. Effective ammocoete habitat area is thus the product of the habitat suitability index and the estimated stream area.

The submodel provides two ways of selecting streams for treatment. The first uses historical (1971 to 1987) treatment schedules. These schedules explicitly reference the length of stream treated. Barrier construction is assumed to remove habitat above the dam and would thus be treated in the year of dam construction. The second method of stream selection involves the use of a stream selection expert system (Jones, Koonce, and

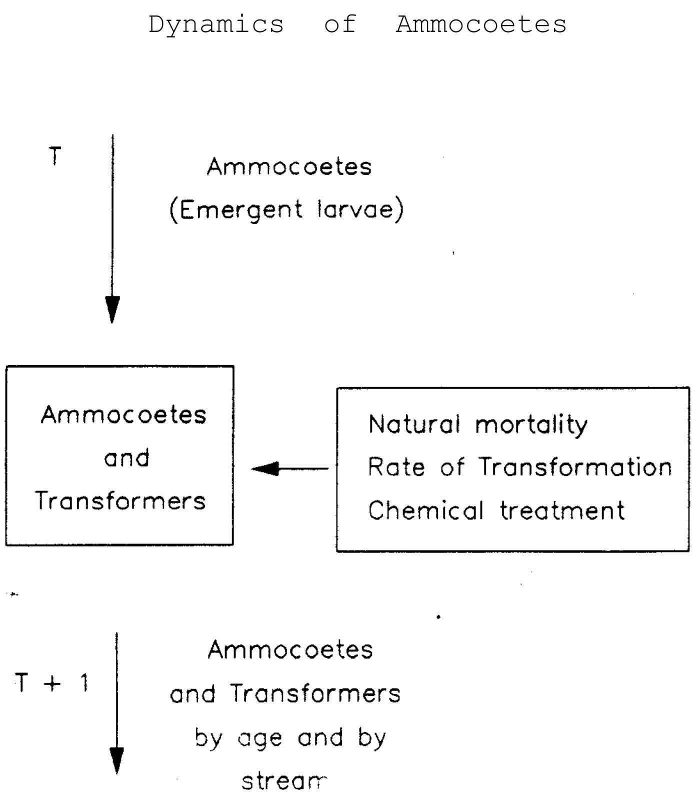

Fig. 2.3.5. Schematic representation of factors determining the dynamics of ammocoetes by age and stream.

Wedeles 1987). To use the expert system algorithm requires specification of a budget or target reduction constraint and the specification of a stream ranking algorithm (maximum benefit or maximum benefit/cost ratio).

Table 2.3.1. Stream attributes for streams known to produce sea lamprey in Lake Ontario.

STREAM	SEA LAMPREY CONTROL NUMBER	AREA (sq m)	FLOW (cms)	WIDTH (m)	LENGTH (km)	CHEMICAL REQUIRED (g/sq m)
ANCASTER	O-60	48300	0.34	3	16.1	3.50
BLACK CREEK	NY-O-66	27000	0.79	6	4.5	3.44
BLACK RIVER	NY-O-19	750000	48.14	50	15.0	5.20
BLIND	NY-O-49	19200	0.41	3	6.4	5.62
BLIND SODUS	NY-O-75	91800	0.14	6	15.3	1.60
BOWMANVILLE	O-131	127600	1.97	11	11.6	6.32
BRONTE	O-76	573000	3.07	15	38.2	2.18
BUTTERFLY	NY-O-59	33900	0.85	3	11.3	5.00
CARRUTHERS	O-120	61200	0.08	4	15.3	1.61
CATFISH	NY-O-60	250800	1.76	12	20.9	4.43
COBOURG	O-148	99400	1.42	7	14.2	5.67
CREDIT	O-92	880000	6.89	25	35.2	2.81
DEER	NY-O-52	193200	0.72	6	32.2	1.13
DUFFIN (Trib)	O-117	466200	1.30	14	33.3	2.37
FIRST	NY-O-84-1	9600	0.23	2	4.8	3.94
GAGE	O-145	58200	0.48	6	9.7	2.35
GRAFTON	O-154	24300	0.22	3	8.1	5.00
GRAHAM	O-133	180000	0.39	8	22.5	2.16
GRINDSTONE	NY-O-54	384300	1.44	9	42.7	0.77
HARMONY	O-125	93000	0.35	6	15.5	3.83
LAKEPORT	O-161	81500	0.46	5	16.3	2.47
LINDSEY	NY-O-48	150000	0.77	6	25.0	1.50
LITTLE SALMON	NY-O-58	2705500	2.67	35	77.3	0.52
LITTLE SANDY	NY-O-50	444000	1.07	15	29.6	0.63
LYNDE	O-121	205800	0.66	6	34.3	2.34
MAYHEW	O-230	16000	0.38	5	3.2	6.37

Table 2.3.1. (Continued)

STREAM	SEA LAMPREY CONTROL NUMBER	AREA (sq m)	FLOW (cms)	WIDTH (m)	LENGTH (km)	CHEMICAL REQUIRED (g/sq m)
NINEMILE	NY-0-71	181300	1.15	7	25.9	1.58
OAKVILLE	0-79	396000	2.42	6	66.0	2.12
OSHAWA	0-124	206000	1.37	10	20.6	2.81
PORT BRITAIN	0-141	41200	0.25	4	10.3	2.81
PROCTOR (Bulter)	0-166	28800	0.31	4	7.2	4.66
RED	NY-0-78	80000	1.18	8	10.0	4.13
RICE	NY-0-67	9600	0.85	3	3.2	19.75
ROUGE	0-110	299000	1.83	10	29.9	1.74
SAGE	NY-0-57	152400	0.47	6	25.4	0.99
SALEM	0-163	10800	0.21	4	2.7	8.68
SALMON	0-242	687000	4.29	30	22.9	1.21
SALMON	NY-0-53	6277500	28.77	75	83.7	0.63
SHELTER VALLEY	0-157	140700	0.71	7	20.1	2.91
SKINNER	NY-0-47	169400	0.97	7	24.2	1.98
SMITHFIELD	0-168	21200	0.37	4	5.3	5.59
SNAKE	NY-0-55	62000	0.26	4	15.5	1.30
SODUS	NY-0-84-2	20000	0.44	5	4.0	9.87
SOUTH SANDY	NY-0-45	357000	4.65	30	11.9	1.51
STERLING	NY-0-73	180000	2.23	10	18.0	4.35
STONY	NY-0-40	51200	0.37	8	6.4	2.54
THIRD	NY-0-84-3	6400	0.42	2	3.2	12.47
WILMOT	0-132	132000	0.82	6	22.0	3.91
WOLCOTT	NY-0-80	48500	1.26	5	9.7	6.99

Important Assumptions and Limitations of the Submodel

The ammocoete submodel has received the least testing of any of the submodels. The stream inventory database is only a first approximation with crude estimates of average stream width (Table 2.3.1) used to estimate area. The submodel assumes that Lake Ontario has no significant lentic ammocoete densities. More importantly, the streams included in the model omit the Niagara River and the entire Oswego drainage.

2.4 Economic Injury Analysis Model

This component of the IMSL Decision Support System is a simplified view of sea lamprey control. The model is developed in a spreadsheet and provides a steady-state analysis of the trade-offs in costs of sea lamprey control for harvests of lake trout. The cost accounting in the current version is not rigorous. Using 1987 as a baseline estimate of control costs, the model assumes that total control costs are proportional to amount of chemical applied during treatment. The proportionality coefficient is \$0.15/g of TFM in Canadian Dollars. The model assumes the following relation between treatment costs and steady-state abundance of spawning phase sea lamprey in Lake Ontario:

$$L = L_{\min} + e^{b_0 - b_1 \cdot C}$$

where $L_{\min}$ is the lowest level of lamprey abundance achievable under current control practices, C is the control cost, and b_0

and b_1 are constants. Estimates of all parameters are obtained from regressions of average abundance (over the preceeding 5 year period) of spawning phase sea lamprey after 20 years of treatment using the stream selection expert system. These parameters, therefore, are dependent upon the choice of algorithm for ranking streams prior to treatment.

Given a budget for sea lamprey treatment, the model then requires assumption of a harvest policy and a goal for steady-state abundance of lake trout. The model assumes that stocking will be used to offset losses to sea lamprey predation and fishing mortality. Harvest policies are restricted to levels of fixed total mortality:

$$F^* = Z_T - Z_L - Z_M$$

where Z_T is the target total instantaneous mortality, Z_L is the lamprey induced mortality, and Z_M is natural mortality. Harvest is not allowed if F^* is less than zero.

3 Demonstration of Decision Support System

3.1 Historical Validation

The main goal of calibration of the IMSL Simulation Model was to fit constraints on marking statistics and carcass density. As discussed in Koonce et al (Ms), the simulation predictions correspond well to observed patterns. Predicted marking statistics for the Al stage are good (Fig. 3.1.1), and the agreement between observed and predicted carcass density is also reasonable (Fig. 3.1.2).

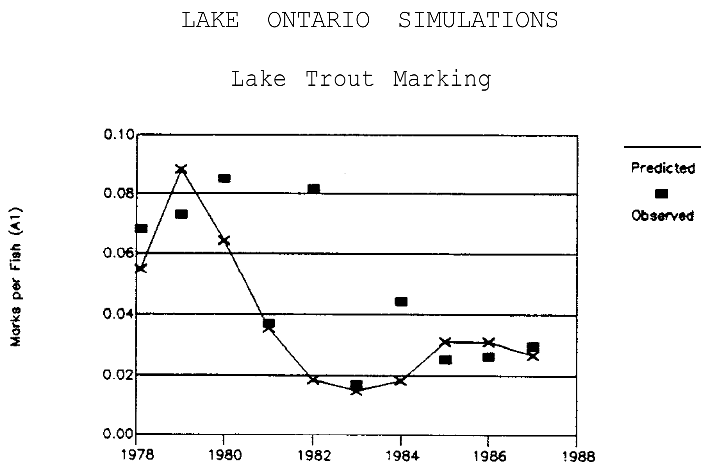

Fig. 3.1.1. Comparison between observed and predicted incidence of Stage Al marks for lake trout in Lake Ontario.

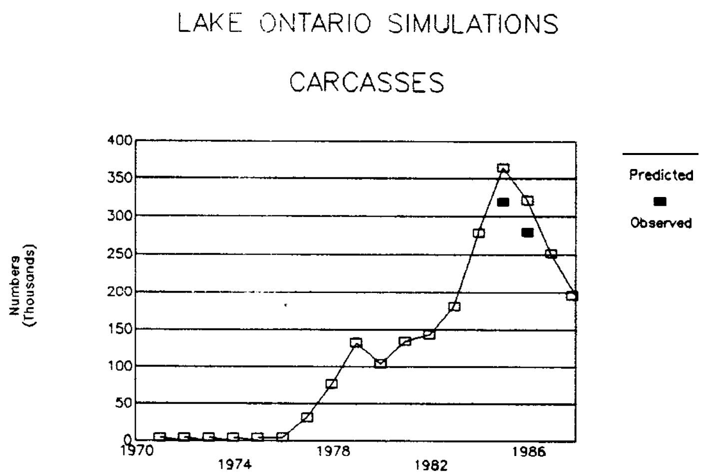

Fig. 3.1.2. Comparison between observed-and predicted carcass density on a lake wide basis in Lake Ontario.

3.2 Analysis of Future Trade-off Options

Scenario analysis provides some rich possibilities for exploring the consequences of various policy options. Fig.

3.2.1, for example, indicates the expected abundance patterns of lake trout subject to three different treatment levels (economic injury level, current level, or a 28% reduced level). Reducing control clearly increases the amplitude of population variation among sea lamprey.

LAKE ONTARIO SIMULATIONS

ADULT LAKE TROUT

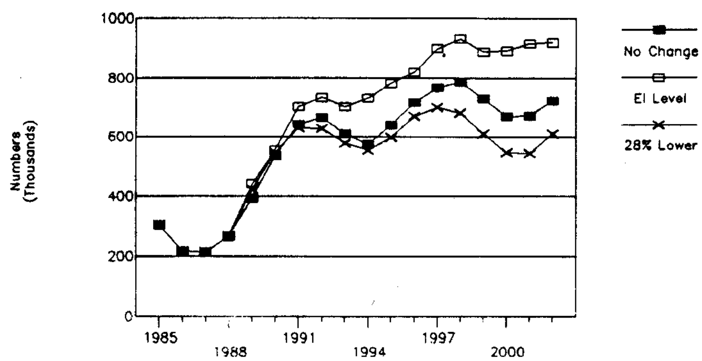

Fig. 3.2.1. Predicted variation in abundance of lake trout abundance for various budgets for sea lamprey control.

LAKE ONTARIO SIMULATIONS

Spawning Phase Sea Lamprey

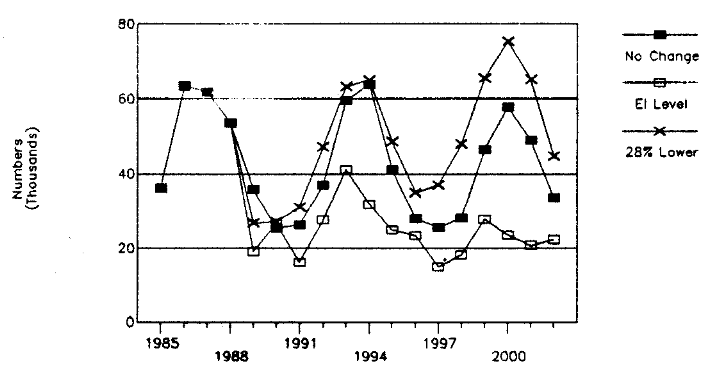

Fig. 3.2.2. Predicted variation in abundance of spawning phase sea lamprey for various budgets for sea lamprey control.

Using the steady-state, trade-off model, the IMSL Decision Support System also provides a basis for establishing economic injury level. At various steady-state levels of lake trout, there is a clear peak in the harvest/cost ratio at intermediate control costs (Fig. 3.2.3). These data imply that the economic injury level increases with decreasing steady-state levels of lake trout abundance (Fig. 3.2.4).

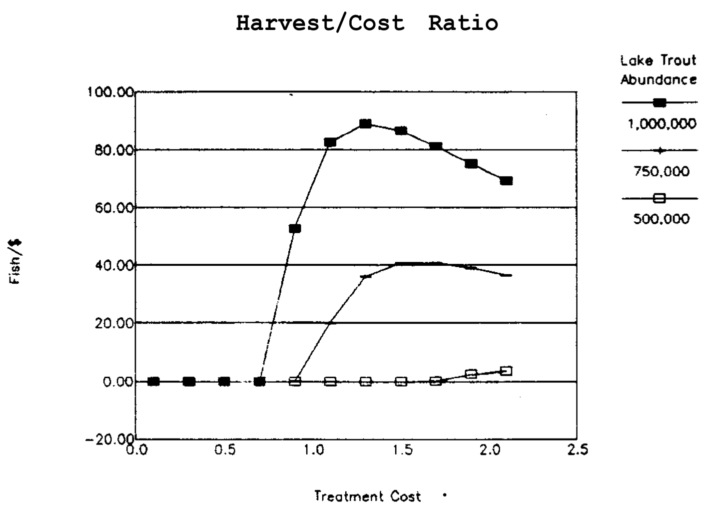

Fig. 3.2.3. Effects of steady-state abundance of lake trout on the harvest/cost ratio for Lake Ontario.

ECONOMIC INJURY LEVELS

Average Annual Control Costs

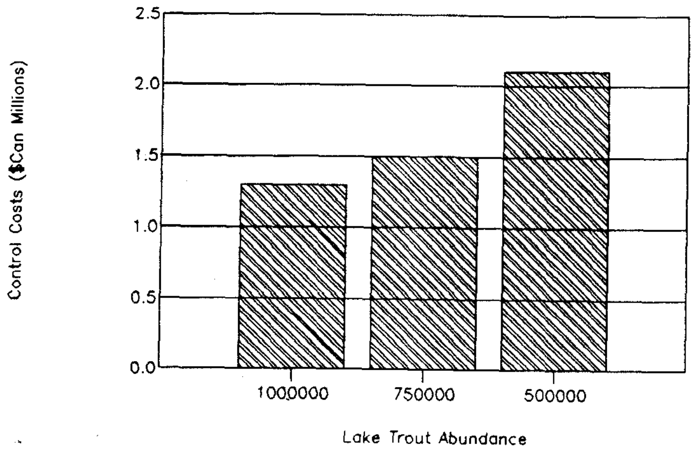

Fig. 3.2.4. Economic injury level for various steady-state levels of adult lake trout.

4 Software Directory for Decision Support System

The IMSL Decision Support System consists of 5 major components. These include databases, spreadsheet programs, and a simulation model programmed in BASIC.

Program	Description
TRTHIST.DBF	DBase III+ database for history of stream treatment
ANALWKS.WKS	Lotus 123 spreadsheet containing history of chemical treatment by stream and stream attributes. Barrier history is also summarized.
ONTDBS.WKS	Lotus 123 spreadsheet that creates setup files for the IMSL Simulation Model. Contains initial values for some parameters as well as historical stocking, barrier construction, and chemical treatment. By executing a Macro Command, this spreadsheet generates a series of print files that are required by the IMSL Simulation Model.
DSS_IMSL.BAS	A BASIC Program written for Microsoft QuickBASIC that contains the IMSL Simulation Model
TROFF.WKS	A Lotus 123 Spreadsheet model for steady-state analysis of trade-offs of chemical treatment for lake trout harvest.
DSSANAL.WKS	A Lotus 123 Spreadsheet template for analysis of output from the IMSL Simulation Model.

Literature Cited[1]

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1 Numbers before references refer to citations in Appendix B.

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Murdoch, W. W. 1973. The functional response of predators. J. Appl. Ecol. 10: 335-342.

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APPENDIX A.

Code for IMSL Simulation Model

```
'DSS_IMSL is the BASIC Version of the IMSL Model, but including the expert
'system stream selection module.
DECLARE SUB zstore ()
DECLARE SUB cand ()
'      Designation of Global Arrays
       DIM SHARED d(49), cmrq(49), ta(49), dens(49), eff(49), HP(49), rr(49)
       DIM SHARED streamflow(49), treat(49), habsi(49), tta(49)
       DIM SHARED z(20, 50)


'  ... parasitic phase declarations
       DIM pa(25), PB(25), PN(25), PQ(1), PT(1), spawn(1), py(25), PZ(25),
P1(1, 1), P2(25), P4(1), qc(25), qn(25), qw(25), q1(25)
'  ... Prey Species' Declarations
       DIM tn(1, 9), tw(1, 9), TL(1, 9), TD(1), TR(1), tm(1)
       DIM ts(1, 50), CB(49), CD(49), ck(49), TV(49), TE(49), fs(49), CM(49),
CT(49), tss(1)
       DIM coss(50), chss(50), SR(25), tkh(50)
'  ... Spawning phase declarations
       DIM FA(49, 2), ED(1), et(49), eu(49), fp(49), gn(49, 1), FM(49), EN(49),
hch(49, 30)

'  ... ammocete phase declarations
'
       DIM ad(7, 49), aa(49), AM(49)
       DIM AE(5), AF(5), AN(49), AMT(5)
       DIM transf(3)
 CLS
 zs = 0
 zt = 30
 NV = 20
 'read simulation control data from file
 OPEN "simcont.prn" FOR INPUT AS #1
 INPUT #1, zs, zt, firstyear, titrtst
 IF firstyear = 0 THEN
     firstyear = 71   'First year of simulation
     zs = 0
     zt = 30
     titrtst = 88  'First year of chemical treatment by model
 END IF
 CLOSE #1

 PRINT "Simulation Starts in "; firstyear + 1900
 PRINT USING "Simulation Interval: Years ## to ##"; zs, zt
 LOCATE 10, 10: PRINT "Simulating Year: "
```

```
 FOR time = zs TO zt
   LOCATE 10, 27
     PRINT time + firstyear + 1900
   ti = time
'      Initial Conditions
    IF time = 0 THEN

'Initialize Treatment Strategy Variables


'   ...  Chemical Treatment Stream Selection Parameters
'

      iamm = 1       '   Ammocete Density Flag
      iyr = 1        '   Time Flag
      ihp = 0        '   Historical Production Flag
      IRSK = 0       '   Risk Flag
      itime = 3      '   Minimum Treatment Time Interval
      imeth = 1      '   Treatment Method (1,2,3, or 4)
      bud = 700000! '   Annual Treatment Budget ($CAN)
      critdn = .05   '   Critical Ammocete Density for Treatment
      TARG = 600000!' Residual Target
      costtreat = .15  'Chemical Treatment cost (incl. Labor) $/kg

      istreamn = 49
' Initial Lake Values
115 sd = 365
150 SA = 1
     SV = 1
     sl = 981

     zz = 1E-10
     FOR i = 0 TO 25
       READ SR(i)
     NEXT i
155 DATA
1,1,1,1,1,1,1,1,1,1,.01,.1,.1,.1,.1,.1,.1,.1,.1,.1,.1,.05,.05,.05,.05,.05
160 QU = 0
     QV = 25
'  Parasitic Phase Initial Values



210 qm = 250000! / sl
     P9 = .2

220 PC = 2.36E-09
     PD = .31
     PE = 7.884
     PG = 7.500001E-06
     PI = 1
230 PK = 2
     PJ = 250 ^ PK
     PT(0) = .2
     PT(1) = .15
```

```
235 PU = .000022
     PV = -1.533
     PW = .00123
     PX = -1.15
240 P1(1, 1) = .75
     P1(1, 0) = .75
     P1(0, 1) = .75
     P1(0, 0) = .75
245 P4 = .41
     P7 = .625
     PA1H = 20 / sd
250 P8 = .3
     P0 = 1
     QA = .005
     QD = .006
     QE = .16
255 QH = .25
     QJ = .8
     QK = .16 ^ 4
     Q3 = .5
260 QP = 2.47E+07
     QQ = .397
     QR = .2
270 PF = 300
     qn = .85
     Q2 = .01
280 py = 10 / sd
     QMAX = .25
```

'Prey Species' Initial Conditions

```
     VY = .035
301 TC = 2393
     TD(0) = 2600
     TD(1) = 2600
     ta = .15
     IUK = 1
     T0 = .00005
     tq = .1374
     TT = .63
     TX = .1
     TZP = .4
     UA = 2.691
     UB = .0000033
     un = 7500000!
     U0 = .4
302 US = .436
     VF = 1650
     VG = 7150
     VH = .003
     VI = 1100!
     VJ = 20900!
     UU = 1000000!
305 VK = .0004
     VN = .25
     VP = 5
```

```
      VM = 2000!
      VQ = 1E+07
      VS = 2000!
      VT = 2500000!
      VU = 500!
      VV = 1000000!
      VW = 1000!
      VX = 3000!
      tss(1) = 500000!
      tss(0) = 2000000!
      UD = .0000625
307 UE = 1.625
      UF = 10000!
      TY = .45
      UT = 1000!
      ql(10) = 450
      qw(10) = 1
308 uml = 625
      umu = 625
      TSSC = .4
      TSSCO = .15
      TSSCH = .5
      umll = 430
320  DATA    .115,.362,.818,1.90,2.7,3.4  ,3.9  ,4.2  , 4.7 , 5.2
      FOR j = 0 TO 9
      READ tw(0, j)
      tw(1, j) = tw(0, j)
      qw(j) = tw(0, j)
      qw(j + 1 + 10) = tw(1, j)
      NEXT j
360 tm(0) = 0
      tm(1) = 11
361 TR(0) = 1
      TR(1) = 1
365 UJ = .115
370 UWKA3 = .1
      UWKB3 = -.00001
      URA3 = 2.2
      URB3 = -.000015
372 UWKA4 = 1.28
      UWKB4 = -.00005
      URA4 = .8
      URB4 = -.000015
380 TSCARL = .9
    TES = 1 'survival of Wild eggs
'   ... Spawning Phase Initial Conditions

'barrier history/future and stream database
      FOR k = 1 TO istreamn
       FA(k, 0) = -1
      NEXT k
      OPEN "barhist.prn" FOR INPUT AS #1
        WHILE NOT EOF(1)
```

```
      INPUT #1, k, FA(k, 0), FA(k, 1), FA(k, 2), et(k), eu(k)
    WEND
  CLOSE #1

  OPEN "stream.prn" FOR INPUT AS #1
    WHILE NOT EOF(1)
      INPUT #1, k, ta(k), streamflow(k), cmrq(k), habsi(k)
    WEND
  CLOSE #1
  OPEN "HCH.PRN" FOR INPUT AS #1
  WHILE NOT EOF(1)
   INPUT #1, k, iy, hch(k, iy)
  WEND
  CLOSE #1
'Barrier data
  ED(0) = 2240
  ED(1) = 18000
  medflow = 1.4     ' 50 CFS for large river classification
  EE = 4500
'Spawner Distribution
  FQ = .5
  GD = 25000
  GH = 500000!
'Sterile Male Parameters
  ER = 45000!
  EQ = .35
  EP = 0  'year sterile male program starts
  gs = 0
  GT = 0
'Spawning Phase Fecundity
  GZ = .03
  GX = 12107
  GY = 205.6

'
'  ...  ammocete phase data
'

   FOR i = 1 TO istreamn
  AM(i) = .1
   NEXT i
   FOR i = 0 TO 5
  READ AMT(i)
   NEXT i
   DATA 0,0,0,.5,2,5
   GP = 0
  medsfp = 0
  largesfp = 0
  medflowl = .28
  largeflow = 2.8
  FOR k = 1 TO istreamn
    GP = GP + streamflow(k)
  NEXT k
  sratio = .6
   AE(0) = -.006
   AF(0) = .28
```

```
      AE(1) = -.013
      AF(1) = .56
      FOR j = 2 TO 5
      AF(j) = .7
      AE(j) = 0!
      NEXT j
      AP = .1
      ay = .67
      ax = -.034
      A2 = .5
      CB = 1!
      CD = 1!
      ckslope = -.025
      ckint = .99
      ckmin = .9
      FOR k = 1 TO istreamn
      cka = ckint + ckslope * streamflow(k)
      ck(k) = cka * (CD ^ 3) * (CB ^ 4) / ((.015625 + CD ^ 3) * (.0625 + CB ^
4))
      IF ck(k) > 1! THEN ck(k) = 1!
      IF ck(k) < ckmin THEN ck(k) = ckmin
      NEXT k

700 REM SALMON INITIAL VALUES
710 CONM = .2
     CHNM = .2
     COFM = .1
     CHFM = .1

     FOR i = 21 TO 25
     READ qw(i)
     NEXT
750 DATA 2, 4.8, 2.8,7.5, 9.7

    'STOCKING and FISHING HISTORY/FUTURE
'read salmonid stocking history
 OPEN "salstok.prn" FOR INPUT AS #1
 INPUT #1, fpol, tipol, quota, tkmin
 WHILE NOT EOF(1)
     INPUT #1, k, ts(0, k), ts(1, k), coss(k), chss(k), tkh(k)
 WEND
 CLOSE #1
    'INITIAL VALUES OF STATE VARIABLES
 OPEN "icvar.prn" FOR INPUT AS #1
 INPUT #1, qm, transf(0), transf(1)
 qm = qm / sl
 transf(0) = transf(0) / sl
 transf(1) = transf(1) / sl
 FOR i = 0 TO 9
    INPUT #1, tn(0, i), tn(1, i)
    qn(i) = tn(0, i) / sl
    qn(i + 11) = tn(1, i) / sl
 NEXT i
 INPUT #1, un, co2, ch2, ch3p
 qn(10) = un / sl
 qn(22) = co2 / sl
```

```
qn(24) = ch2 / sl
qn(25) = ch3p / sl
CLOSE #1
'Stream Ammocete Densities
OPEN "ammden.prn" FOR INPUT AS #1
FOR k = 1 TO istreamn
  FOR j = 0 TO 7
    INPUT #1, ad(j, k)
  NEXT j
NEXT k
CLOSE #1
   END IF  'End of Initial Conditions

'Simulation Change Rules, Updates, and Variable Storage
'Initialize stream treatment array
     FOR k = 1 TO istreamn
      treat(k) = 0
     NEXT k

'Parasitic Phase
2000 spawn(0) = qm * ql
     spawn(1) = (1 - ql) * qm
     P9 = P9 * qn
     PL = (P9 * QP) ^ QQ
     QS = (transf(0) + transf(1) + transf(2) + transf(3)) * Q3
2005  SAHN = 0
     FOR i = QU TO QV
     PB(i) = 0
     qc(i) = 0
     pa(i) = 0
     ql(i) = (qw(i) / PC) ^ PD
     PM = ql(i) - PF
       IF PM <= 0 THEN
       PN(i) = 0
       ELSE
2020 PM = PM ^ PK
     PH = PG * ql(i)
      IF PH > QD THEN PH = QD
2025 PH = PH ^ 2 * 3.14
     PM = PI * PM / (PJ + PM)
     PN(i) = ql(i) * PE * PH * PM * SR(i)
     SAHN = SAHN + PN(i) * py * qn(i)
       END IF
2030  NEXT i
2035 PN(10) = PN(10) * Q2
2040 P9 = SAHN / (1 + SAHN)
     P9 = QR * P9 / (P9 + PQ)
2070 PSAVG = 0
     PSNUM = 0
     PSUMA = 0
2080  FOR i = QU TO QV
       IF PN(i) <> 0 THEN
2082 QG = P4 * PN(i) / (SAHN + 1)
     PR = P9 / (qw(i) + zz)
2090 QF = PR ^ 2
     QB = QMAX * (1 - P0 * QF / (QF + QA))
```

```
     pa(i) = 0
     PB(i) = 0
      IF qn(i) > 0 THEN
      PB(i) = QS * (1 - QB) * QG
      pa(i) = PB(i) / (1 - QB) * QB
      END IF
2095 qc(i) = pa(i)
     PSUMA = PSUMA + QG * qn(i)
2096  IF (i > 3) AND (i < 10) THEN
     PSAVG = PSAVG + QG
     PSNUM = PSNUM + 1
      END IF
     END IF
2098  NEXT i
2200 Q1 = P9 ^ 4
     QI = QJ * Q1 / (QK + Q1)
     ql = (transf(0) + transf(2)) / (transf(0) + transf(1) + transf(2) +
transf(3) + zz)
     qm = QS * QI


'Lake Trout and other Prey Species
3000 tw(0, 0) = UJ
     tw(1, 0) = UJ
     TB = 0
     TH = 0
     twyr = tn(0, 0) + tn(1, 0)
      FOR i = 0 TO IUK
        TV(i) = 0
        FOR j = 0 TO 9
          TV(i) = TV(i) + tw(i, j) * tn(i, j)
        NEXT j
        TB = TB + TV(i) / UT
      NEXT i
3001 TNH = 0
     TNKL = 0
     TKILLED = 0
3010  ts = coss(ti) + chss(ti)
     FOR i = 0 TO IUK
     tn(i, 0) = tn(i, 0) + ts(i, ti) * TSSC
      ts = ts + ts(i, ti)
     NEXT i
     TFNR = 1 - (ts(0, ti) + ts(1, ti)) * TSSC / (tn(0, 0) + tn(1, 0) + zz)
3015 qn(21) = coss(ti) / sl * TSSCO
     qn(23) = chss(ti) / sl * TSSCH
3020 TBB = TB
     IF TBB < 0 THEN TBB = 0 ELSE IF TBB > 10000! THEN TBB = 10000!
3025 tnv = 0
     TMAGE = 0
     tadult = 0
     TMTZ = 0
     tmpf = 0
     TAIMPF = 0
     tkq = tk
3030 FOR i = 0 TO IUK
```

```
     UZ = tm(i)
     TE(i) = 0
3032    FOR j = 0 TO 9
      ul = UZ + j
3034       uage = j MOD 10
      IF uage < 3 THEN
        tq = UWKA3 + UWKB3 * TBB
        TP = URA3 + URB3 * TBB
      END IF
3036      IF uage > 2 THEN
       tq = UWKA4 + UWKB4 * TBB
       TP = URA4 + URB4 * TBB
      END IF
3045      tk = tkh(ti)
      TL(i, j) = TL(i, j) * TSCARL + pa(ul)
      IF ti + firstyear >= tipol THEN
         IF fpol = 1 THEN 'quota policy
           tfb = 0
           FOR izz = 0 TO 1
      FOR jzz = 0 TO 9
        uzz = tm(izz) + jzz
        tfb = tfb + tn(izz, jzz) * (-((ql(uzz) > umll AND ql(uzz) <= uml) OR
(ql(uzz) > umu)))
      NEXT jzz
           NEXT izz
           IF tfb > quota THEN
       tk = -LOG(1 - quota / tfb)
           ELSE
       tk = 3
           END IF
           IF tk > 3 THEN tk = 3
           tkq = tk
           IF (((ql(ul) > umll) AND (ql(ul) <= uml)) OR (ql(ul) > umu)) THEN
tk = tkq ELSE tk = tkq * tkmin

         ELSEIF fpol = 2 THEN  'No Regulation Policy
           tk = tkh(time)
           IF (((ql(ul) > umll) AND (ql(ul) <= uml)) OR (ql(ul) > umu)) THEN
tk = tk ELSE tk = tkmin * tk
         ELSEIF fpol = 0 THEN  'Constant Z policy
           IF (((ql(ul) > umll) AND (ql(ul) <= uml)) OR (ql(ul) > umu)) THEN
tk = TZP - (ta + PB(ul)) ELSE tk = tkmin * (TZP - (ta + PB(ul)))
           IF tk <= 0 THEN tk = 0
         END IF
      END IF
      TZ = tk + ta + PB(ul)
      TSURV = EXP(-TZ)
      TH = TH + (1 - TSURV) * (((tk / TZ) * tn(i, j) * tw(i, j)) / UT)
      TLZ = PB(ul) + ta + tk
      TNH = tk / TZ * tn(i, j) * (1 - TSURV) + TNH
      TNKL = TNKL + PB(ul) / TZ * tn(i, j) * (1 - TSURV)
      tnv = tnv - tn(i, j) * (ql(ul) > umll)
3077      tkf = 1
      TF = TC * tw(i, j) - TD(i)
      IF TF < 0 THEN
        TF = 0
```

```
        tkf = 0
       END IF
3090      TMTZ = TMTZ + TLZ * tkf * tn(i, j)
      TMAGE = TMAGE + tkf * tn(i, j) * (j + 1)
      tadult = tadult + tkf * tn(i, j)
      tloa = (pa(ul) + PB(ul)) * py / sd
      TA1MPF = TA1MPF + tkf * tn(i, j) * (PA1H / P4 * pa(ul) + tloa)
      tmpf = tmpf + tkf * tn(i, j) * (pa(ul) + tloa)
            ' LPRINT USING "## ## ##.###^^^^ ##.###^^^^ ##.###^^^^ ##.###^^^^
##.###^^^^"; i, j, tn(i, j), pa(ul), tloa, tmpf, tadult;
            ' LPRINT tkf


3091      LOCATE 23, 40
          PRINT USING "F: ##.###"; tk;
      TKILLED = TKILLED + PB(ul) / TZ * tn(i, j) * (1 - TSURV) * tkf
3092      tn(i, j) = tn(i, j) * TSURV
3095      TE(i) = TE(i) + TF * (tn(i, j) / 2) * TO
      tw(i, j) = tw(i, j) * TP * TR(i) + tq
      NEXT j
       NEXT i
3097   UR = UA * U0 * un * EXP(-UB * un)
       un = un + UR
3098   qn(10) = un / sl
       un = un * EXP(-(PB(10) + US))
'Update Variables
3100   FOR i = 0 TO IUK
      UC = tn(i, 9) + tn(i, 8) + zz
      tw(i, 9) = (tw(i, 9) * tn(i, 9) + tw(i, 8) * tn(i, 8)) / UC
      tn(i, 9) = UC - zz
      ul = i * 11 + 9
      qn(ul) = tn(i, 9) / sl
      qw(ul) = tw(i, 9)
       NEXT i
3150   IF TH < VW GOTO 3170
3160   IF TH > VX GOTO 3180
3165   GOTO 3190
3170   VR = VS * TH
       GOTO 3195
3180   VR = VV
       GOTO 3195
3190   VR = VT - VU * TH
3195   VO = VQ - VP * TB
3196   IF TB > VM THEN VO = VL
3197   VA = ((VG * EXP(-VH * TH) + VF) * TH) - (VN * ts + VR + (VJ * EXP(-VK *
TB) + VI) * TH)
3200   FOR i = 0 TO IUK
       FOR j = 7 TO 0 STEP -1
         tn(i, j + 1) = tn(i, j)
         tw(i, j + 1) = tw(i, j)
         TL(i, j + 1) = TL(i, j)
         ul = tm(i) + j + 1
         qn(ul) = tn(i, j + 1) / sl
         qw(ul) = tw(i, j + 1)
         NEXT j
       NEXT i
```

```
      tn(0, 0) = TE(0) * TES
      tn(1, 0) = TE(1) * TES
      qn(0) = tn(0, 0) / sl
      qn(11) = tn(1, 0) / sl
      qw(0) = UWKA3 + UWKB3 * TBB
      qw(11) = qw(0)
3250  qn(22) = qn(21) * EXP(-PB(21) - CONM - COFM)
      FOR i = 25 TO 24 STEP -1
     qn(i) = qn(i - 1) * EXP(-PB(i) - CHNM - CHFM)
      NEXT i
3310 ttad = tadult + zz
     z(4, ti) = TB
     z(5, ti) = TH
     z(6, ti) = TMAGE / ttad + .5
     z(7, ti) = tmpf / ttad

     LOCATE 15, 1
     PRINT USING "MPF: #.###"; z(7, ti)
     LOCATE 16, 1
     PRINT USING "TADULT: ##.###^^^^"; tadult
     LOCATE 17, 1
     PRINT USING "Age 5 LT Size: ##.####  mpf: ##.###"; tw(0, 4), qc(4)
     z(8, ti) = qc(4)
     z(9, ti) = 1 - EXP(-TMTZ / ttad)
     z(10, ti) = TA1MPF / ttad
3320 z(17, ti) = tadult
     z(18, ti) = TNH
     z(19, ti) = TNKL
     z(20, ti) = qc(15)
3330 z(1, ti) = qn(15)
3340 z(2, ti) = (qn(24) + qn(25)) * sl
     z(3, ti) = (qc(24) * qn(24) + qc(25) * qn(25)) / (qn(24) + qn(25) + zz)
'Spawning Phase
      GV = 0
      FOR i = 0 TO 1
         spawn(i) = sl * spawn(i)
      NEXT i
      FOR k = 1 TO istreamn
     GV = GV + AN(k)
      NEXT k
      FOR k = 1 TO istreamn
     fp(k) = FQ * streamflow(k) / GP + (1 - FQ) * AN(k) / (GV + zz)
       IF streamflow(k) > medflowl THEN
          IF streamflow(k) > largeflow THEN
      largesfp = largesfp + fp(k)
          ELSE
      medsfp = medsfp + fp(k)
          END IF
       END IF
      NEXT k
      GE = (spawn(0) + spawn(1)) / (GD + spawn(0) + spawn(1))
      FOR k = 1 TO istreamn
     FOR j = 0 TO 1
        gn(k, j) = fp(k) * spawn(j)
     NEXT j
```

```
    fe = 0
    IF time = FA(k, 0) THEN
       fe = 1
       sttype = -(streamflow(k) > medflow)
       ec = ec + ED(sttype) * fe
       FM(k) = FM(k) + fe
    END IF
     NEXT k
     ef = 0
     GM = 0
     FOR k = 1 TO istreamn
     IF et(k) >= 1 THEN
        GI = eu(k) * FM(k)
        GM = GM + GI * gn(k, 0)
        ef = ef + FM(k) * EE
        FOR j = 0 TO 1
           gn(k, j) = gn(k, j) * (1 - GI)
        NEXT j
     END IF
     NEXT k

     FOR k = 1 TO istreamn
     fs(k) = 0
     NEXT k
     IF time >= EP THEN
     IF gs >= 1 AND gs <= 4 THEN
       IF GT = 0 THEN
         gu = GM
         es = ER
       ELSE
         gu = GT
         es = ER + GT * EQ
       END IF
       IF gs < 4 THEN
         'Stream Type allocation
         FOR k = 1 TO istreamn
           IF (streamflow(k) > largeflow AND gs = 2) THEN 'large streams
      fs(k) = fp(k) / largesfp * gu
           ELSEIF (streamflow(k) > medflowl AND streamflow(k) < largeflow AND
gs = 1) THEN 'Medium Streams
      fs(k) = fp(k) / medsfp * gu
           END IF
         NEXT k
       ELSE   'Adult Allocation Rule
         FOR k = 1 TO istreamn
           fs(k) = fp(k) * gu
         NEXT k
       END IF
     END IF
     END IF
     FOR k = 1 TO istreamn
    EN(k) = GZ * (GX + GY * PL) * gn(k, 1) * gn(k, 0) / (gn(k, 0) + fs(k) +
zz)
     NEXT k
     LOCATE 15, 50
```

```
     PRINT USING "PS: ##.##^^^^"; spawn(0) + spawn(1);
      z(11, time) = spawn(0) + spawn(1)
      z(12, time) = qn(4)


'C
'c ...  ammocete submodel
'C
'C-----------------------------------------------------
'c Update ammocete ages and densities prior to treatment
      FOR k = 1 TO istreamn
         aa(k) = 0!
         FOR j = 0 TO 5
            aa(k) = aa(k) + ad(j, k)
         NEXT j
'c Calculation of Natural Mortality and Update
         FOR j = 0 TO 5
        AS1 = AE(j) * aa(k) + AF(j)
        IF AS1 < 0! THEN AS1 = 0
        ad(j, k) = ad(j, k) * AS1
         NEXT j
         ad(5, k) = ad(5, k) + ad(4, k)
'c Update ages of ammocetes
         FOR j = 4 TO 1 STEP -1
      ad(j, k) = ad(j - 1, k)
         NEXT j
'c Calculate emergence of ammocete larvae
         ad(0, k) = EN(k) / (ta(k) + .000001)
'c Calculate transformer production
         GTX1 = 0
         FOR iil = 3 TO 5
        AS1 = 1! - AP * aa(k)
        IF AS1 < 0! THEN AS1 = 0!
        IF iil = 5 THEN
        IF AS1 < .1 THEN AS1 = .1
        END IF
        gtx2 = AM(k) * AS1 * ad(iil, k) * AMT(iil)
        IF ad(iil, k) > gtx2 THEN
          ad(iil, k) = ad(iil, k) - gtx2
        ELSE
          gtx2 = ad(iil, k)
          ad(iil, k) = 0!
        END IF
        GTX1 = GTX1 + gtx2
         NEXT iil
         ad(6, k) = GTX1
         propf = ay + ax * aa(k)
         IF propf > .9 THEN propf = .9
         ad(7, k) = propf * ad(6, k)
         IF ad(7, k) < 0! THEN ad(7, k) = 0
         ad(6, k) = ad(6, k) - ad(7, k)
      NEXT k
```

```
'Calculate ammocete densities and determine streams for treatment
      FOR k = 1 TO istreamn
     amgl25 = 0
     FOR j = 3 TO 5
         amgl25 = amgl25 + ad(j, k)
     NEXT j
     dens(k) = .5 * ad(2, k) + .75 * amgl25
      NEXT k
      iyear = time + firstyear
      IF iyear >= titrtst THEN
     CALL cand
     FOR k = 1 TO istreamn
       IF FA(k, 0) = time THEN treat(k) = 1
     NEXT k
     'insert steps for new dam construction

     'insert steps for sterile male program changes
      ELSE
     'Insert steps to derive treatment schedule from treatment history
     'Must calculate treat(k) etc

     FOR k = 1 TO istreamn

       IF (FA(k, 0) = time AND hch(k, time) = 0 AND time <> 0) THEN
STOP'temporary error check
       IF hch(k, time) > 0 THEN
      tta(k) = hch(k, time)
      d(k) = iyear + 1900
      treat(k) = 1
       END IF
       IF FA(k, 0) = time THEN
         treat(k) = 1
         IF tta(k) = 0 THEN tta(k) = ta(k)
         d(k) = iyear + 1900
       END IF
     NEXT k
      END IF
'c Calculation of Treatment Mortality
      cc = 0
      transf(0) = 0!
      transf(1) = 0!
      FOR k = 1 TO istreamn
         IF treat(k) > 0 THEN
           cc = cc + cmrq(k) * tta(k) * costtreat
           d(k) = iyear + 1900
           FOR j = 0 TO 7
       ad(j, k) = (1! - ck(k)) * ad(j, k) * ta(k) / tta(k)
           NEXT j
         END IF

         transf(0) = transf(0) + ad(6, k) * ta(k) / (sl + .000001)
         transf(1) = transf(1) + ad(7, k) * ta(k) / (sl + .000001)

         'If barrier construction occurred then reduce stream area
         'for future treatment.
```

```
      IF FA(k, 0) = time THEN
        ta(k) = ta(k) - FA(k, 2)
        IF ta(k) < 0 THEN ta(k) = 0
      END IF
   NEXT k

   IF time = 0 THEN
  'lprint "ANNUAL SUMMARY OF AMMOCETE DENSITIES"
  'lprint "BUDGET: "; bud; " METH: "; METH; " TARGET REDUCTION: "; TARG

   END IF
  IF time > 17 THEN
   'lprint "YEAR: "; iyear
   FOR k = 1 TO 49
   'lprint USING "##.##^^^^ "; ad(6, k) + ad(7, k);
   NEXT k
   'lprint
   'lprint "Streams Treated: ";
'   FOR k = 1 TO 49
'      IF treat(k) = 1 THEN lprint k;
'    NEXT k
   'lprint
  END IF


   BQ = transf(0) + transf(1)
   IF BQ > 5000000! THEN
    transf(0) = transf(0) * (5000000 / BQ)
    transf(1) = transf(1) * 5000000! / BQ
   END IF

   'Add lines for storage variables (e.g. control costs)
   nsttd = 0
   FOR k = 1 TO istreamn
  nsttd = nsttd + treat(k)
   NEXT k
   z(15, time) = twyr
   z(14, time) = (es + ef + ec + cc)
   z(16, time) = nsttd
   LOCATE 21, 50
   PRINT USING "cc: ###.##^^^^^"; cc
   LOCATE 22, 50
   PRINT USING "nsttd: ####"; nsttd
   z(13, time) = tnv

NEXT time

'Save Output
CALL zstore
END
```

```
SUB cand
'        Program to develop a candidate list based upon stream
'        selection criteria and then select streams for treatment
'        using cost/benefit, maximum benefit, or treatment level
'        technique.
'
     DIM idate(49), iswitch(49), bc(49), crit(49)
     DIM cps(49), cost(49), fkill(49)
'        character name$ * 30
'
     SHARED iamm, iyr, iseff, ihp, IRSK, itime, imeth, bud, critdn, TARG
     SHARED time, firstyear, costtreat, istreamn, ckslope, ckint, ckmin

     apop = 0
     icount = 0
     ICT = 0
     CD = 1
     CB = 1
     imax = 0
     xmost = 1E-09
     total = 0
'
'
     inow = time + firstyear + 1900
'
'
'  ..    Loop over streams
'
     tpop = TARG
'
 FOR i = 1 TO istreamn
     treat(i) = 0
     iswitch(i) = 0
     apop = dens(i) * ta(i) + apop
'  ...  FROM FLOW DATA AND APPLY REGRESSION GET fkill(I)

      cka = ckint + ckslope * streamflow(i)
      fkill(i) = cka * (CD ^ 3) * (CB ^ 4) / ((.015625 + CD ^ 3) * (.0625 + CB
^ 4))
      IF fkill(i) < ckmin THEN fkill(i) = ckmin
      fkill(i) = fkill(i) * dens(i) * ta(i)
'
'  ...    If time is a consideration then check if enough years have past
'
        idate(i) = INT(d(i))
        IF (iyr <> 0 AND (inow - idate(i) >= itime)) THEN

        iswitch(i) = 1
'
'  ...    If historical production is a consideration then check if it
'  ...    is important
'

      IF (ihp <> 0 AND HP(i) = 2) THEN

      iswitch(i) = 1
```

```
    ELSE
'
'  ...    If ammocete density is a consideration then check
'
          IF iamm <> 0 THEN

    IF dens(i) >= critdn THEN iswitch(i) = 1
          END IF
     END IF
          END IF
          bc(i) = fkill(i) / (cmrq(i) * ta(i))
'            CHECK TO SEE IF TREATMENT SHOULD BE AVOIDED DUE TO RISK
          IF (iswitch(i) <> 0) THEN
           IF IRSK <> 0 THEN
             IF rr(i) = 2 THEN SWITCH(i) = 0
           END IF
          END IF
'         COUNT NUMBER OF STREAMS FOR TREATMENT
    IF iswitch(i) = 1 THEN icount = icount + 1
NEXT i

'         Calculate target reduction of ammocetes
    tkill = apop - tpop
    IF tkill < 0 THEN tkill = 0
'
'  ...    If method is based on ammocete target use it as "budget", if not
'  ...    use money
'
    IF imeth = 1 THEN
      FOR j = 1 TO istreamn
        crit(j) = bc(j)
        cps(j) = cmrq(j) * costtreat * ta(j)
      NEXT j

    ELSEIF imeth = 2 THEN
      FOR j = 1 TO istreamn
        crit(j) = fkill(j)
        cps(j) = cmrq(j) * costtreat * ta(j)
      NEXT j

    ELSEIF (imeth = 3) THEN
      FOR j = 1 TO istreamn
        crit(j) = bc(j)
      NEXT j

    ELSEIF (imeth = 4) THEN
      FOR j = 1 TO istreamn
       crit(j) = fkill(j)
      NEXT j

    END IF
'
'  ...    Find the highest
'
  totcost = 0
  WHILE ICT <> icount
```

```
    FOR j = 1 TO istreamn
       IF ((iswitch(j) = 1) AND (crit(j) > xmost)) THEN
         xmost = crit(j)
         imax = j
       END IF
    NEXT j
'
' ...    treat(imax) = treat stream or not
'
    IF (imeth <= 2) THEN
      IF ((total + cps(imax)) <= bud) THEN
         total = total + cps(imax)
         treat(imax) = 1
      END IF
    END IF
    IF (imeth >= 3) THEN
      IF ((total + fkill(imax)) <= tkill) THEN
        total = total + fkill(imax)
        treat(imax) = 1
      END IF
    END IF

    xmost = 1E-09
    crit(imax) = xmost
    ICT = ICT + 1
    totcost = totcost + cps(imax)
    d(imax) = time + firstyear
 WEND
END SUB
 SUB zstore
 SHARED zs, zt, NV
     LOCATE 18, 1
     INPUT "SAVE Z DATA"; z$
     z$ = UCASE$(z$)
     IF LEFT$(z$, 1) = "Y" THEN
    INPUT "FILE NAME"; O$
    OPEN O$ FOR OUTPUT AS #1
    FOR j = zs TO zt
      FOR i = 1 TO NV
        PRINT #1, USING "##.##^^^^ "; z(i, j);
      NEXT i
      PRINT #1,
    NEXT j
     END IF
 END SUB
```

APPENDIX B.

Documentation for Variables of the IMSL Simulation Model

Table 1. Parasitic Phase Submodel

Legend:
* = values updated in the model (functional)
! = values read as data in the model
u = unitless

Variable	Description	Value	Units	Ref.
PA(i)	Number of wounds per prey type	*	number/prey	
PA1H	Healing time for Al wounds	*	Yr	
PB(i)	Lamprey induced instantaneous mortality	*	rate/year	
PC	Lake trout length/weight coefficient	2.36E-9	u	3
PD	Lake trout length/weight coefficient	0.31	u	3
PE	Predator swimming coefficient	7.884	km/yr/mm body length	3
PF	Length correlation factor for attack probability	300	mm	3
PG	Reactive distance coefficient	7.53-6	**km/mm**	3
PH	Reactive distance functional	*	m	
PI	Probability of attack coefficient	1	u	3
PJ	Probability of attack coefficient	250^2	u	3
PK	Probability of attack coefficient	2	u	3

Table 1 (continued)

Variable1	Description	Value	Units	Ref.
PL	Lamprey length	*	mm	
PM	Probability of attack/ Dummy variable	*	U	
PN(i)	Rate of effective search by prey type	*	km^2/yr	
PQ	Lamprey weight	*	kg	
PT(O)	Blood consumption coefficient	0.2	U	2
PT(1)	Blood consumption coefficient	0.15	U	2
PY(i)	Lethal attack handling time by prey type	*	Yr	
PZ(i)	Partial lethal attack handling time by prey type	*	yr	
P1(1,1)	% of lethal attacks by lake trout prey type	0.75	U	2
P1(0,1)	% of lethal attacks by lake trout prey type	0.75	U	2
P1(0,0)	% of lethal attacks by lake trout prey type	0.75	U	2
P2(i)	Mean handling time by prey type	*	yr	
P4	Lamprey feeding time	0.41	yr	2
P9	Lamprey weight	*	kg	
PO	Partial mortality coefficient	1	U	3

Table 1. (continued)

Variable	Description	Value	Units	Ref.
QA	Partial mortality coefficient	0.005	u	3
QB	Lethality of attack	*	u	
QC(i)	Marking rate	*	mark/fish	
QD	Max. reactive distance	0.006	km	3
QE	Max. lethal attack handling time	0.16	yr	3
QG	Attack rate	*	u	
QH	Healing time of A2 wounds	0.25	yr	3
QJ	Lamprey natural mortality coefficient	0.8	u	2
QK	Lamprey natural mortality coefficient	0.16[4]	u	3
QL(i)	Length of species i	*	mm	
QM	Density of spawning in t+1	2.5E5/SL	number/km^2	
QMAX	Max. probability of survival an attack	0.25	u	2
QN	Lamprey % weight loss prior to spawning	0.85	u	3
QN(i)	Density of prey i	*	number/km^2	
QP	Lamprey length/weight coefficient	2.47E7	u	3
QQ	Lamprey length/weight coefficient	0.397	u	3

Table 1. (continued)

Variable	Description	Value	Units	Ref.
QR	Lamprey weight at first feeding	0.2	kg	1
QS	Number of transformers entering the lake	*	number	
QU	Lower lamprey limit (index)	0	u	3
QV	Upper lamprey limit (index)	25	u	3
Q2	Preference of whitefish to lake trout by lamprey	0.01	u	3
Q3	Post transformation survival	0.5	u	2
SPAWN(i)	Spawning phase abundance	*	number	

Table 2. Pray Species Submodel

Legend:
* = values updated in the model (Functional)
! = values read as data in the model
U = unitless

Variable	Description	Value	Units	Ref.
IUK	Number of strains of lake trout .	!	U	
QL	Male fraction of transformers	*	U	
QL(i)	Length of alternate prey	*	mm	
QW(i)	Weight of alternate prey	!	kg	
TA	Natural mortality rate	0.15	U	2
TADULT	Total lake trout adults	*	number	
TAIMPF	Average Al mark per lake trout adult	*	U	
TB	Total biomass	*	kg	
TBB	Effective lake trout biomass	*	**kg**	
TC	Slope of egg production curve	2393	U	3
TD(O)	Intercept of egg production curve-normal	2600	U	2
TD(1)	Intercept of egg production curve-precocious	2600	U	2
TE(i)	Total number of egg lake trout of i	*	number	
TES	Survival fraction of wild egg	1	U	2
TFB	Total fishable stock	*	number	

Table 2. (continued)

Variable	Description	Value	Units	Ref.
TFNR	Total fraction of yearling due to natural reproduction	*	u	
TH	Harvest biomass	*	kg	
TIPOL	Year which fishing policy take place	*	yr	
TK	Instantaneous fishing mortality	*	u	
TKF	Sexually maturity flag	0 or 1	u	
TKH(k)	Historical lake trout fishing effort	!	1/yr	
TKILLED	Number of adults carcasses	*	number	
TKQ	Dummy variable for fishing mortality	*	1/yr	
TM(0)	Lake trout prey index for strain 0	1	u	
TM(1)	Lake trout prey index for strain 1	11	u	
TMAGE	Mean age of adult lake trout	*	yr	
TMPF	Mean marks per fish of adult lake trout	*	u	
TMTZ	Mean total mortality of adult lake trout	*	1/yr	
TN(i,j)	Number of lake trout by strain by age	*	number	
TNH	Total number of lake trout harvested	*	number	
TNKL	Number of lake trout carcasses	*	number	

Table 2. (continued)

Variable	Description	Value	Units	Ref.
TO	Egg survival	5E-[illegible]	u	1
TQ	Walford plot intercept	0.137	u	3
TR(0)	Growth rate coefficient by strain 0 (index)	1	u	
TR(1)	Growth rate coefficient by strain 1 (index)	1	u	
TSCARL	Discount rate for observable scars	0.9	u	3
TSS(0)	Annual stocking rate for strain 0	2E6	number/yr	
TSS(1)	Annual stocking rate for strain 1	5E5	number/yr	
TSSC	Annual survival fraction for stocked lake trout	0.4	u	2
TSSCH	Annual survival fraction for chinook salmon	0.5	u	2
TSSCO	Annual survival fraction of coho salmon	0.15	u	2
TSURV	Annual survival of adult lake trout	*	u	
TT	Stock survival	0.63	u	3
TV(i)	Biomass of lake trout by strain	*	M.T.	
TW(i,j)	Weight of lake trout by strain at age	*	kg	
TWYR	Total wild yearlings	*	number	
TZ	Total mortality for lake trout	*	1/yr	
UA	Stock recruitment parameter	2.69	u	3

Table 2. (continued)

Variable	Description	Value	Units	Ref.
UAGE	Dummy variable for late trout age	*	U	
UB	Stock recruitment parameter	3.3E-6	U	3
UD	Slope of growth curve	6.2535	U	3
UE	Intercept of growth curve	1.625	U	3
UF	Max. biomass of growth curve	1E4	M.T.	3
UJ	Initial weight at age 1 for lake trout	0.115	kg	2
UML	Lower-protected size limit per lake trout	625	mm	2
UMLL	Lower size limit of lake trout	!	mm	
UMU	Upper protected size limit per lake trout	!	mm	
UN	Initial value for number of alternate prey	7.536	number	3
UO	Proportion of population that spawns	0.4	U	3
URA3	Coefficient for Walford slope for lake trout <3 year	2.2	U	1-2
URB3	Coefficient for Walford slope for lake trout <3 year	-1.5E-5	U	1-2
URA4	Coefficient for Walford slope for lake trout <4 year	0.8	U	1-2

Table 2. (continued)

Variable	Description	Value	Units	Ref.
URB4	Coefficient for Walford slope for lake trout <4 year	-1.5E-5	u	1-2
US	Natural mortality rate for alternate prey	0.436	u	3
UT	Metric tonne	1000	scalar	
UU	Million dollar	1E6	scalar	
UWKA3	Coefficient for Walford intercept for lake trout <3 year	0.1	kg	1-2
UWKB3	Coefficient for Walford intercept for lake trout <3 year	-1E-5	kg/M.T.	1-2
UWKA4	Coefficient for Walford intercept for lake trout <4 year	1.26	kg	1-2
UWKB4	Coefficient for Walford intercept for lake trout <4 year	-5E-5	kg/M.T.	1-2
UZ	Dummy variable (index)	*	u	
UZZ	Dummy variable (index)	*	u	
U1	Counter	*	u	
VF	Min. of total benefit curve	1650	$/M.T.	3
VG	Parameter of benefit curve	7150	u	3
VH	Parameter of benefit curve	0.003	u	3
VI	Min. of total cost curve	1100	$/M.T.	3

Table 2. (continued)

Variable	Description	Value	Units	Ref.
VJ	Parameter of cost curve	20900	U	3
VK	Parameter of cost curve	0.0004	U	3
VM	Min. biomass before stock becomes endangered	2000	M.T.	3
VN	Stocking cost per fish	0.25	$/fish	3
VP	Slope of cost curve for endangered lake trout	5	U	3
VQ	Intercept of cost curve for endangered lake trout	1E7	U	3
VR	Fisheries management costs	*		
vs	Slope of 1st segment of management cost curve	2000	U	3
VT	Intercept of 2nd segment of management cost curve	2.536	U	3
vu	Slope of 2nd segment of management cost curve	500	U	3
vv	Constant for management cost curve	1E6	U	3
VW	Harvest for peak cost	1000	M.T.	3
vx	Harvest for constant cost	3000	M.T.	3
VY	Discount rate	0.035	U	3
ZZ	Divide by zero check	10E-6	U	

Table 3. Spawning Phase Submodel

Legend:

* = values updated in the model (Functional)
! = values read as data in the model
U = unitless

Variable	Description	Value	Units	Ref.
CMRQ(k)	TFM requirement by stream	!	gr/m^2	
ED(0)	Amortized construction cost per medium barrier by stream type	2240	**$/yr**	3
ED(1)	Amortized construction cost per large barrier by stream type	18000	**$/yr**	3
EE	Cost of trapping at a barrier site	4500	**$/yr**	3
EP	Input of year that sterile male program is started	0	U	
EQ	Cost per sterile male	0.35	$/lamprey	3
ER	Overhead cost of the sterile male program	45000	$/yr	3
ET(k)	Input of absence or presence of traps on medium rivers, large rivers, or the Nipigon River.	*	U	
EU(k)	Proportion of lamprey spawning run captured in traps by stream type	*	U	
FA(k,i)	Array by stream for barrier construction	!	U	

Table 3. (continued)

Variable	Description	Value	Units	Ref.
FQ	Proportion that weights the effect of stream discharge and ammocoete density on adult allocation into streams	0.5	U	3
GD	Adult density where 50% of spawning adults are allocated to stream habitat unoccupied by ammocoetes	25000	number	3
GH	Definition of high adult density	5E5	number	3
GS	Identification of sterile male allocation	!	U	
GT	Identification of source of males for sterile male program	!	U	
GX	Intercept coefficient of number of eggs vs. female lamprey length	12107	mm	3
GY	Slope coefficient of number of eggs vs female lamprey length	205.6	U	3
GZ	Proportion of eggs that results in emergent larvae	0.03	U	3

Table 3. (continued)

Variable	Description	Value	Units	Ref.
HABSI(k)	Habitat suitability index by stream	!	U	
HCH (k,iy)	History of chemical treatment by stream by year	!	U	
IY	Year of simulation	*	yr	
K	Index variable	*	U	
MEDFLOW	Flow demarcation for large streams	1.4	m^3/sec	2
STREAM-FLOW(k)	Flow rate by stream	!	m^3/sec	
TA(k)	Total areas of ammocoetes habitat by stream	*	m^2	

Table 4. Ammocoetes and Transformers Submodel

Legend:

* = values updated in the model (Functional)
! = values read as data in the model
u = unitless

Variable	Description	Value	Units	Ref.
AA(k)	Total ammocoete density,	*	number/m^2	
AD(j,k)	Ammocoete density	*	number/m^2	
AE(0)	Slope of survival line at age 0	-0.006	u	3
AE(1)	Slope of survival line at age 1	-0.013	u	3
AE(j)	Slope of survival line at age j	*	u	
AF(0)	Intercept of survival line at age 0	0.28	u	3
AF(1)	Intercept of survival line at age 1	0.56	u	3
AF(j)	Intercept of survival line at age j	*	u	
AM(i)	Proportion transforming in stream	0.1	u	3
AMG125	Density of ammocoetes > 125 mm	*	number/m^2	
AMT(i)	Ammocoete transformation rate coefficient by age	!	u	
AP	Density constant for transforming age IV ammocoetes	0.1	u	3
AS1	Annual survival rate for ammocoetes	*	u	

Table 4. (continued)

Variable	Description	Value	Units	Ref.
AX	Slope for density dependent proportion female transformer	-0.034	u	3
AY	Intercept for density dependent proportion female transformer	0.67	u	3
BQ	Total number of transformers	*	number	
BUD	Annual treatment budget	!	$	
CB	Coefficient for effectiveness of chemical treatment	1	u	3
CC	Chemical control cost	*	$	
CD	Chemical dosage (proportion of minimum lethal dose)	1	u	3
CHFM	Chinook salmon fishing mortality	0.1	1/yr	2
CHNM	Chinook salmon natural mortality	0.2	1/yr	2
CHSS(k)	Historical stocking of Chinook salmon	!	number	
CH2	Initial number of age 2 Chinook salmon	!	number	
CH3P	Initial number of age 3+ Chinook salmon	!	number	
CK(k)	Proportion killed by chemical	*	u	
CKA	Coefficient for effectiveness of chemical treatment	*	u	

Table 4. (continued)

Variable	Description	Value	Units	Ref.
CKINT	Coefficient for effectiveness of chemical treatment	0.99	u	2
CKMIN	Min. effectiveness chemical treatment	0.9	u	2
CKSLOPE	Coefficient for effectiveness of chemical treatment	-0.025	u	2
COFM	Coho salmon fishing mortality	0.1	1/yr	2
CONM	Coho salmon natural mortality	0.2	1/yr	2
COSS(k)	Historical stocking Coho salmon	!	number	
COST-TREAT	Cost of treatment	*	$	
co2	Initial number of age 2 Coho salmon	!	number	
D(k)	Year of last chemical treatment	*	yr	
DENS(k)	Density of ammocoetes > 125 mm	*	number/mm2	
FPOL	Fishing policy choice	!	u	
GP	Total stream flow	*	m^3/sec	
GTX1	Dummy variable	*	u	
GTX2	Dummy variable	*	u	
LARGE-FLOW	Demarcation of flow rate for spawning lamprey allocation in large streams	2.8	m^3/sec	2

Table 4. (continued)

Variable	Description	Value	Units	Ref.
LARGESFP	Sum of spawing lamprey fraction in large streams	*	u	
MEDFLOWL	Demarcation of flow rate for spawning lamprey allocation in medium streams	0.28	m^3/sec	2
MEDSFP	Sum of spawing lamprey fraction in medium streams	*	u	
METH	Method of ranking stream for chemical treatment	!	u	
PROPF	Proportion of female transformers	*	u	
QUOTA	Annual lake trout harvest quota	*	T.M.	
SL	Lamprey habitat area	981	km^2	2
TKMIN	Mortality fraction of catch and release lake trout	*	u	
TRANSF (i)	Transformers by sex	*	number	
TREAT(k)	Treatment status by stream by year	0 or 1	u	
TTA(k)	Total treatment area by stream	*	km^2	

Table 5. Stream Selection for Treatment Submodel

Legend:

* = values updated in the model (Functional)
! = values read as data in the model
u = unitless

Variable	Description	Value	Units	Ref.
APOP	Actual ammocoete population	*	number	
BC(j)	Benefit cost ratio by stream	*	u	
BUD	Annual treatment budget	!	$	
CPS(i)	Cost per treatment by stream	*	$	
CRIT(j)	Criteria used for treatment	*	variable	
CRITDN	Critical ammocoete density for treatment	!	number/m^2	
FKILL(i)	Fraction of ammocoetes killed by stream	*	u	
IAMM	Ammocoete density flag	*	u	
ICOUNT	Total number of stream to be treated	*	u	
ICT	Counter	*	u	
IDATE(i)	Date of last treatment by stream	*	yr	
IHP	Historical production flag	*	u	
IMAX	Dummy variable	*	u	
IMETH	Treatment method	1,2,3, or 4	u	

Table 5 (continued)

Variable	Description	Value	Units	Ref.
INOW	Current year	*	yr	
ISTREAM	Number of stream to be treated	49	number	2
ISWITCH (i)	Decision of treatment	0 or 1	u	
ITIME	Minimum treatment time interval	!	yr	
SD	Number of days per year	365	days	3
SL	Lamprey habitat area	981	km2	3
SR(i)	Habitat overlap by prey species	!	u	
TARG	Residual target	!	number	
TOTAL	Dummy variable	*	u	
TPOP	Targeted total ammocoete population	*	number	
XMOST	Dummy variable	1E-9	u	

APPENDIX C

Evaluation of Decision Support System

1 Evaluation Procedure

The IMSL Decision Support System is a complex tool. The models are not designed nor have they been sufficiently tested to automate sea lamprey control in Lake Ontario or any other lake to which they might be applied. The best use of the models is to explore possible consequences of various options to integrate fishery management with sea lamprey control. Used in this manner, the model becomes an objective framework within which to promote communication among agencies responsible for various aspects of system management. Evaluation of the decision support system, therefore, must also occur in the context of discussions of policy options to pursue the goals of integrated management of sea lamprey. To this end, the BOTE Sea Lamprey Task Group organized an evaluation workshop on July 12, 1988, in Toronto.

2 Evaluation Workshop

Purpose and Scope

The purpose of the workshop was to present the IMSL Decision Support System to a group of cooperators of the Great Lakes

Fishery Commission who might use it in future IMSL activities. This evaluation was required as part of the completion of the contract for the development of the decision support system.

Participants

Name	Affiliation
Bill Beamish	Univ. of Guelph
Larry Schleen	DFO, SSM
John Heinrich	USFWS, Marquette
Gary Klar	USFWS, Marquette
Aarne Lamsa	GLFC Secretariat
Jim Cady	GLFC Commissioner
John Kelso	DFO, SSM
Stan Dustin	DFO, SSM
Jerry Weise	DFO, SSM
Kim Houston	DFO, SSM .
Robert Young	DFO, SSM
Bill Taylor	Michigan State Univ.
Carlos Fetterolf	GLFC Secretariat
Randy Eshenroder	GLFC Secretariat
Ken Minns	DFO, Burlington
Gavin Christie	GLFC IMSL Specialist
Phil Cochran	St. Norbert College
Barb Staples	GLFC Secretariat
John Williamson	OMNR
Bill Dentry	OMNR
Joe Koonce	Case Western Res. Univ.

Agenda

Date	Time	Activity
12 July	9:00 am	Introduction and Overview of the IMSL Decision Support System for Lake Ontario
	10:00 am	Hands-on Demonstration
	12:00 pm	Lunch
	1:00 pm	Hands on Analysis of Trade-off Options in Integrated Management of Sea Lamprey

2:30 pm Analysis of Economic Injury Levels and Ways of Establishing Target Levels of Control for Sea Lamprey

4:00 pm Discussion and Evaluation of Decision Support System

5:00 pm Adjournment

3 Results of Evaluation Workshop

Evaluation Criteria

A complete evaluation of the IMSL Decision SUppOrt System can not be attempted without testing in discussions in which policy trade-offs are being considered. Participants in the workshop represented the range of individuals who would be active in such discussions, but the workshop itself was mainly oriented toward demonstration. Evaluation of the decision support system in this context, therefore, represents a judgement of the possible contributions it could make rather than do make. Accordingly, the workshop participants devised a set of criteria by which to judge the potential of the IMSL Decision Support System:

-Technical Credibility
-Responsiveness
-Ease of Use
-Adaptability
-Clarity
-Compatibility with Alternative Approaches
-Acceptability and Effectiveness

Underlying these criteria, however, is a more fundamental criterion that the decision support system should promote confidence building in Integrated Management of Sea Lamprey as a process.

Evaluation

The evaluation discussions were generally positive. The models seem technically credible and the trade-off analysis module seems to provide the kind of information necessary to establish target levels of control in the Great Lakes. The issue of documentation of the decision support system, however, arose repeatedly. The models are not easy to understand, and if use of the decision support system is to be internalized, there must be sufficient documentation to review critically the components of the decision support system. Furthermore, documentation will be required if others seek to modify or to expand the models. A recommendation of the evaluation, therefore, is to consider upgrading the documentation that would be delivered with the decision support system. The BOTE Sea Lamprey Task Group would be the appropriate group to facilitate this effort. The workshop also recommended that efforts begin to apply the decision support system to Lake Superior. This application will increase exposure to the decision support system and will also contribute to the planning of other IMSL activities, such as the sterile male program, that could benefit from quantification.

Another major item of discussion concerned the IMSL process itself and the role of the decision support system in confidence building. Two possible approaches to confidence building were discussed: 1) Better estimation of parameters in the model and more thorough testing of its structure: and 2) Use of the model in discussions about monitoring and surveillance that will lead to better quantification of key variables through enhanced survey work. The latter choice deemphasises the models and emphasizes the process of IMSL. The models thus are tentative statements of understanding of the interactions of sea lamprey control with fishery management. Their role is to provide a rationalization for coordination of IMSL and justification of the resources required to implement it.

SPECIAL PUBLICATION GREAT LAKES FISHERY COMMISSION

79-1 Illustrated field guide for the classification of sea lamprey attack marks on Great Lakes lake trout. 1979. E.L. King and T.A. Edsall. 41 p.

82-1 Recommendations for freshwater fisheries research and management from the Stock Concept Symposium (STOCS). 1982. A.H. Berst and G.R. Spangler. 24 p.

82-2 A review of the adaptive management workshop addressing salmonid/lamprey management in the Great Lakes. Edited by J.F. Koonce, L. Greig, B. Henderson, D. Jester, K. Minns, and G. Spangler. 40 p.

82-3 Identification of larval fishes of the Great Lakes basin with emphasis on the Lake Michigan drainage. 1982. Edited by N.A. Auer. 744 p.

83-1 Quota management of Lake Erie fisheries. 1983. Edited by J.F. Koonce, D. Jester, B. Henderson, R. Hatch, and M. Jones. 39 p.

83-2 A guide to integrated fish health management in the Great Lakes basin. 1983. Edited by F.P. Meyer, J.W. Warren, and T.G. Carey. 262 p.

84-1 Recommendations for standardizing the reporting of sea lamprey marking data. 1984. R.L. Eshenroder and J.F. Koonce. 21 p.

84-2 Working papers developed at the August 1983 conference on lake trout research. 1984. Edited by R.L. Eshenroder, T.P. Poe, and C.H. Olver.

84-3 Analysis of the response to the use of "Adaptive Environmental Assessment Methodology" by the Great Lakes Fishery Commission. 1984. C.K. Minns, J.M. Cooley, and J.E. Forney. 21 p.

85-1 Lake Erie fish community workshop (report of the April 4-5, 1979 meeting). 1985. Edited by J.R. Paine and R.B. Kenyon. 58 p.

85-2 A workshop concerning the application of integrated pest management (IPM) to sea lamprey control in the Great Lakes. 1985. Edited by G.R. Spangler and L.D. Jacobson. 97 p.

85-3 Presented papers from the Council of Lake Committees plenary session on Great Lakes predator-prey issues, March 20. 1985. 1985. Edited by R.L. Eshenroder. 134 p.

85-4 Great Lakes fish disease control policy and model program. 1985. Edited by J.G. Hnath. 24 p.

85-5 Great Lakes Law Enforcement/Fisheries Management Workshop (Report of the 21, 22 September 1983 meeting). 1985. Edited by W.L. Hartman and M.A. Ross. 26 p.

85-6 The lake trout rehabilitation model: program documentation. 1986. C.J. Walters, L.D. Jacobson, and G.R. Spangler. 32 p.

87-1 Guidelines for fish habitat management and planning in the Great Lakes (Report of the Habitat Planning and Management Task Force and Habitat Advisory Board of the Great Lakes Fishery Commission). 1987. 15 p.

87-2 Workshop to evaluate sea lamprey populations "WESLP" (Background papers and proceedings of the August 1985 workshop). 1987. Edited by B.G.H. Johnson.

87-3 Temperature relationships of Great Lakes fishes: A data compilation. 1987. D.A. Wismer and A.E. Christie. 195 p.

88-1 Committee of the Whole workshop on implementation of the Joint Strategic Plan for Management of Great Lakes Fisheries (reports and recommendations from the 18-20 February 1986 and May 1986 meetings). 1988. Edited by M.R. Dochoda. 170 p.

88-2 A proposal for a bioassay procedure to assess impact of habitat conditions on lake trout reproduction in the Great Lakes (report of the ad hoc Committee to Assess the Feasibility of Conducting Lake Trout Habitat Degradation Research in the Great Lakes). 1988. Edited by R.L. Eshenroder. 11 p.

88-3 Age structured stock assessment of Lake Erie walleye (Report of the July 22-24, 1986 Workshop). July 1988. R.B. Deriso, S.J. Nepszy, and M.R. Rawson. 12 p.

88-4 The International Great Lakes sport fishery of 1980. September 1988. D.R. Talhelm. 70 p.