A REVIEW OF THE ADAPTIVE MANAGEMENT WORKSHOP ADDRESSING SALMONID/LAMPREY MANAGEMENT IN THE GREAT LAKES

(Convened by the Great Lakes Fishery Commission at Sault Ste. Marie, Michigan, September 30-October 6, 1981)

by

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SPECIAL PUBLICATION 82-2

Great Lakes Fishery Commission

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November 1982

The Great Lakes Fishery Commission, established by the 1955 Convention on Great Lakes Fisheries between Canada and the United States, was organized in April 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has three major responsibilities: to develop and coordinate fishery research programs, to advise governments on measures to improve the fisheries; and to develop measures and implement programs to manage sea lamprey. The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties.

PROBLEM DEFINITION

The Great Lakes Fishery Commission has two areas of responsibility including control of the Sea Lamprey and fostering interagency cooperation in various fisheries matters. One aspect of this latter responsibility has been a sustained effort to facilitate communication between fisheries managers and scientists. Given the complex fisheries problems in the Great Lakes, the Board of Technical Experts of the GLFC approved a plan to apply the techniques of Adaptive Management to some of these problems.

Adaptive Management is a communication and problem solving procedure developed by C. S. Holling (1978) and his associates at the Institute for Animal Resource Ecology, University of British Columbia. Basically, the procedure consists of a highly structured series of meetings and workshops that seek to produce a computerized simulation model of a resource system. The purposes of the modeling exercise are to promote communication among policy makers, managers, and technical experts, to explore policy options, and to identify information gaps for future work.

To bring this technique to the Great Lakes Region, the GLFC held a training workshop at the University of British Columbia. Based on the favorable response of a group of potential clients and scientists, it was decided that the workshop format should be used to address a current Great Lakes fisheries problem. Because of the substantial investment in control of Sea Lamprey, a general problem in the interactions of salmonids and lamprey seemed appropriate. This first workshop, therefore, had a dual purpose. First, it was to be a demonstration of the potential usefulness of the techniques of Adaptive Management, and second, it was a clarification of the problems and policy options surrounding sea lamprey control and Lake Trout Rehabilitation. Specifically, members of the Council of Lake Committees and some Commissioners of the Great Lakes Fishery Commission suggested that the workshop address an evaluation of the effectiveness and economy of alternative policies to manage offshore fish communities in the Great Lakes.

BOUNDING THE PROBLEM

In an earlier scoping meeting, the client group and workshop staff had established the general problem for the workshop. However, the workshop participants had to interpret this charge. With an explicit goal of creating a simulation model, the participants first decided upon the kinds of actions they would like to take to manage offshore fish communities and what characteristics of the resource system they would want as indicators of the effectiveness of various actions. The actions involved with management fell into three categories: sea lamprey control, fishery regulation, and stocking (Table 1). Indicators of response to these management actions fall into three slightly different groups: economic, fishery, and lamprey abundance (Table 2). In addition to these, several actions and indicators related to water quality were suggested, but were not included in the model due to lack of time.

The problem was further constrained by establishing time and space boundaries. The participants did not need indicators at less than annual periods and felt that at least two generations (~ 30 years) were required to see the effects of rehabilitation of species like

Table 1. Management actions identified at the salmonid/lamprey workshop.

Category	Action
Sea Lamprey Control	- Funding level of control program
	- Regulation of Mix of Treatment Methods
	- Regulation of frequency of treatment
	- Regulation of the location of treatment
Fishery Regulation	- Establish catch quota and allocate to angling and commercial fisheries
	- Size regulations
	- Regulation of by-catch in other fisheries
	- Season closure limits of effort
	- Establishment of refugia
	- Taxation and subsidies to various modes of fishing
	- Regulations on amount and selectivity of gear
Stocking	- Regulation of number stocked by species and age
	- Regulation of stocking location
	- Regulation of origin of stocked fish

Table 2. Indicators of Response of the Salmonid/Lamprey Community Identified by Workshop Participants

Category	Indicator
Economic	- New return to commercial fishery
	- Contribution to the Regional Economy
	- Total Management Costs
	- Cost to benefit ratio
Fishery	- Effort by anglers
	- Effort in various commercial fisheries
	- Catch per unit effort in various fisheries
	- Abundance of spawners in various species
	- Biomass of various species
	- Size at age for various species
	- Alewife die-off
Lamprey Abundance	- Wounding rates of main species
	- Lamprey adult abundance
	- Age composition
	- Number of spawners
	- Number of ammocoetes

Lake Trout. In addition, the group decided to limit the spatial boundaries to a single large lake.

Within these contraints,. five submodels seemed to partition the workload evenly among the participants. These submodels were:

1. Fishery Dynamics and Economics
2. Lamprey
3. Lake Trout
4. Whitefish/Pacific Salmon
5. Prey or forage species for trout and salmon

Linkages between these submodels were explicity identified in a looking outward matrix (Fig. 1). The diagonal elements contain the main actions and indicators to be produced in each submodel, and the other elements indicate type of information to be exchanged.

MODEL STRUCTURE

The model followed a strict calculation sequence (Fig. 2) utilizing annual time steps for a maximum period of 35 years. The model was written in Applesoft BASIC on an Apple II-Plus microcomputer using the Microsimcon ultility developed at the University of British Columbia. Indicator variables are listed in Table 3.

DESCRIPTION OF SUBMODELS

Fishery Submodel

The fishery submodel describes dynamics of fishing effort and calculates the economic consequences of fishing and management. The dynamics of fishing effort are driven by economic return in commercial fishing and catch rate in sport fisheries.

Sport fishing effort is calculated from combined lake trout and salmon catch rate as

$$\text{Effort} = \frac{\alpha C^2}{(\beta + \gamma) * (K + C^2)}$$

where C is catch rate as fish/angler day, Y is population of the area from which people travel predominantly to the lake in question, multiplied by angler days per year per capita

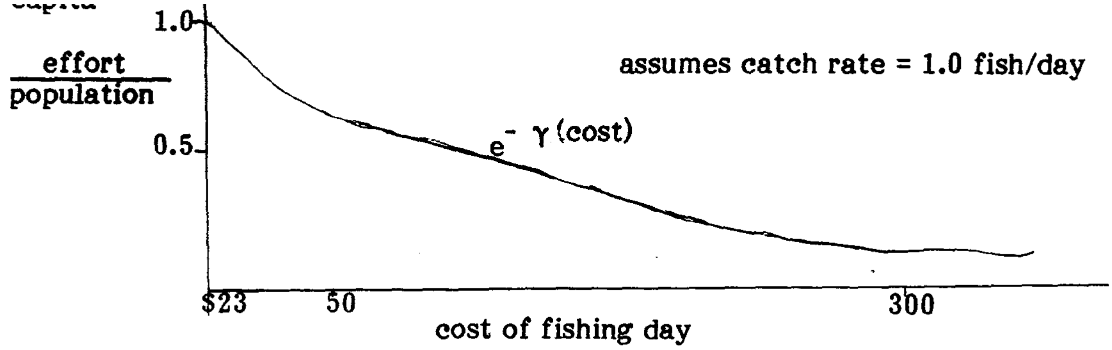


Figure 1. Linkages among submodels

	LAMPREY	LAKE TROUT	WHITEFISH & SALMONIDS	PREY	FISHERY
LAMPREY	downstream trans. sex ratio size wounding rate *	death by age	mortality rate by species	mortality rate by species 7.1 kg	cost of control
LAKE TROUT	age and size (N)	stocking population stats. *	X	instantaneous mortality rate	harvest by gear MT management cost - stocking vulnerable biomass
WHITEFISH	age and size (N)	X	stocking pop. stats *	instantaneous mortality rate	harvest by species costs - stocking costs vulnerable biomass
PREY	abundance, age	total biomass by species (YOY) age metric tonnes 0.1 kg	metric tonnes biomass small and large	alewife } combined smelt } herring & cisco sculpins alewife die-off *	harvest by gear MT cost stocking vulnerable biomass
FISHERY	X	effort-gill 1000 km/night trap-100 set nights angler-days	effort (same units) angler-days	effort (same units) trawls-hrs dipnet-days pound-100 set nights	management cost.$ landed value.$ economic impact

Fig. 2. Calculation Sequence of the Salmonid/Lamprey Workshop Model

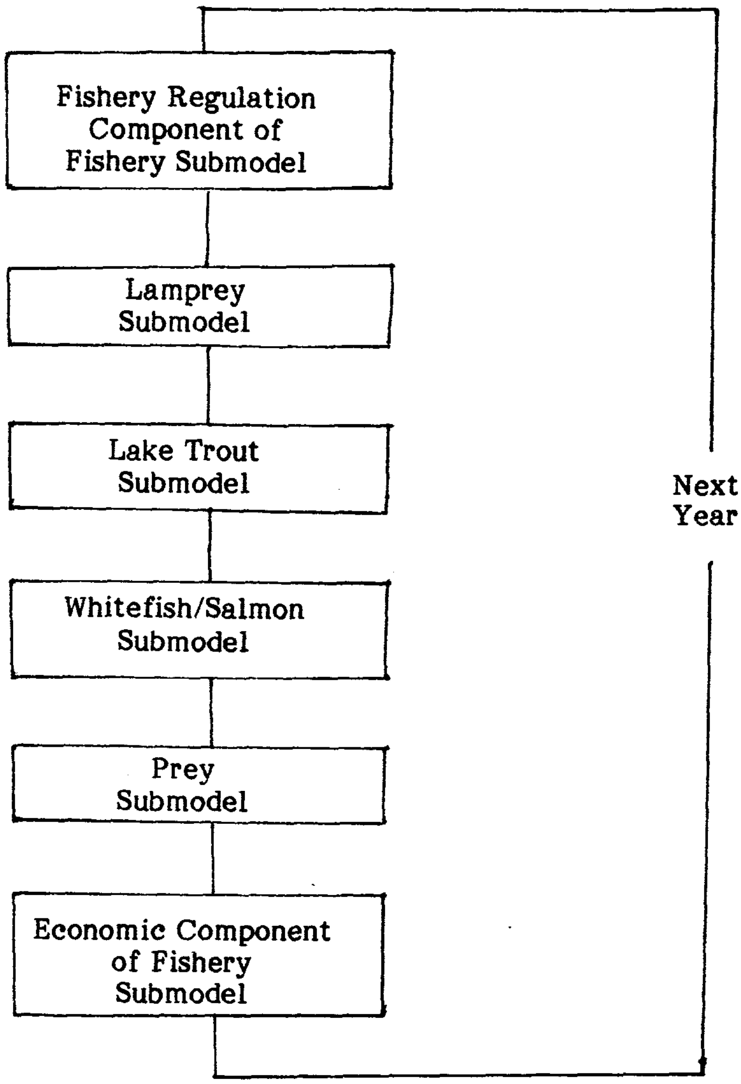
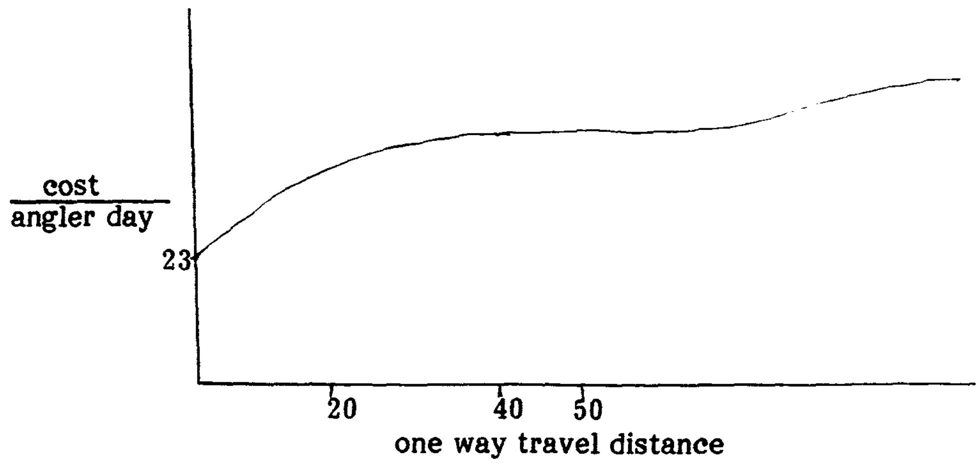
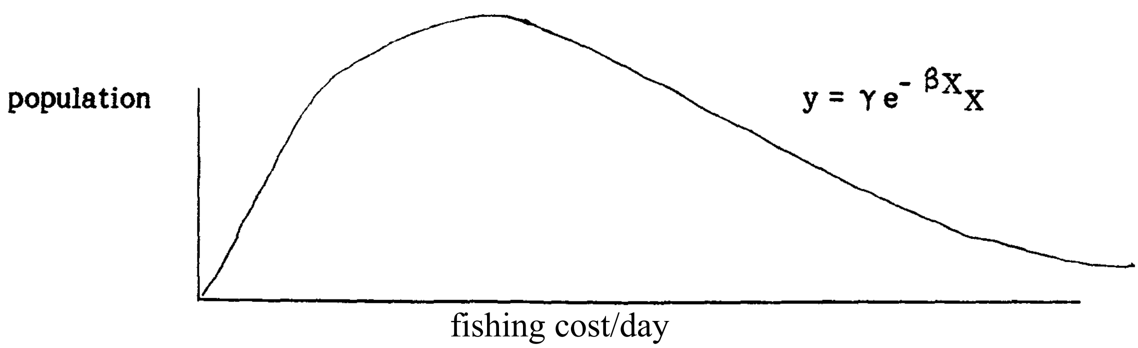


Table 3. Indicator variables stored in the Simulation Model

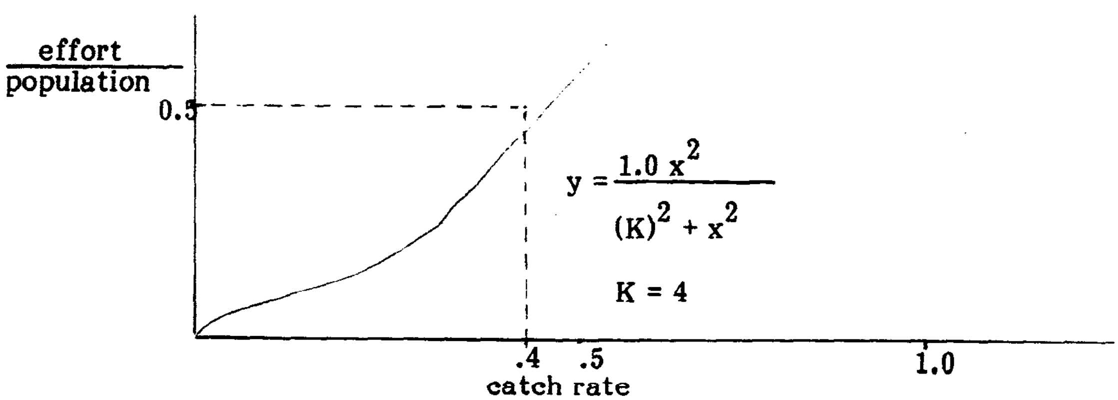
Variable Number	Description
1	Total Number of Mature Female Lake Trout
2	Total Harvest (MT) of Lake Trout
3	% Natural Lake Trout Yearlings
4	Total Lake Trout Biomass (MT)
5	Management Costs (millions of $)
6	Contribution to Regional Economy ($)
7	Angling Effort (10^3 angling days)
8	Salmon Harvest (MT)
9	Whitefish Harvest (MT)
10	Whitefish Biomass (MT)
11	Lamprey Attack Rate on Lake Trout (#/yr/ind)
12	Lamprey Attack Rate on Whitefish (#/yr/ind)
13	Number of Yearling Lake Trout
14	Net Return in Commercial Fishery ($)
15	Salmon Escapement (MT)
16	Alewife Biomass (MT)
17	Adult Cisco Biomass (MT)
18	Gillnet Effort (km)
19	Alewife Die-off (MT)
20	Number of Trapnet Lifts





is chosen to make the area under the curve equal the population in areas from which people are attracted to the fishery.

At a fixed cost of $23

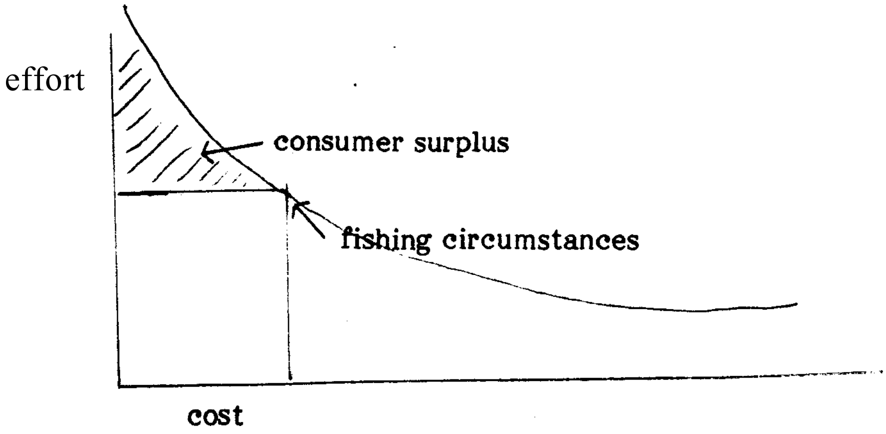


Integration of these relationships leads to

$$\text{Effort} = \frac{\alpha C^2}{(\beta + \gamma)(K + C^2)}$$

where C is catch rate and the parameters are indicated in the graphs above.

Value of the sport fishery is calculated as consumer surplus from

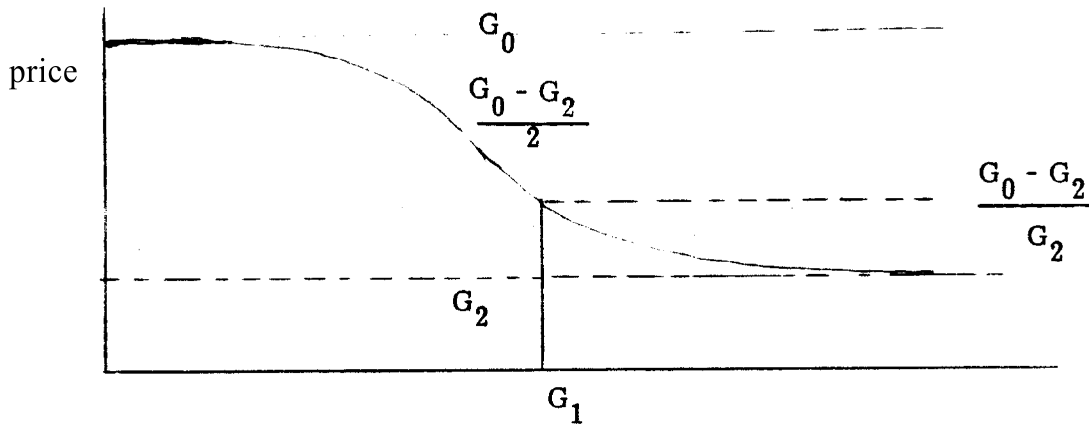


which in this formulation turns out to equal

$$\delta * \text{Effort}$$

with $\delta = .75$

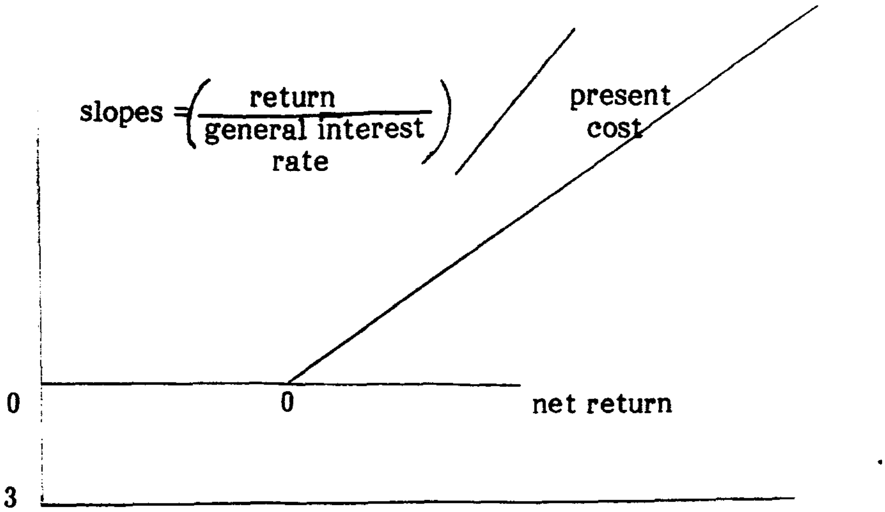
Commercial fishing effort is calculated based on the notion that effort will expand to use available revenue. To do this, the dockside value of fish is calculated from



These calculations are done through arrays indexed by

1. alewife young
2. alewife adults
3. small chubs
4. large chubs
5. sculpin
6. whitefish
7. lake trout

Return to each type of gear is calculated as the the sum of price times catch over all species less the cost of the fishing effort. General increase or decrease in fishing cost then follows:



The change in effort for any particular gear type is then made proportional to net return to that particular gear type. If return is negative this reduces effort and if it is positive it produces an increase. The sum of these changes is equal to the net general investment.

Variables used in the fishery submodel are listed in Table 4.

Lamprey Submodel

The lamprey submodel determines attack rates and mortalities of various prey species given the abundance of prey and adult lamprey. Control measures are assumed to yield a constant number of transformers each year. The basic predation model used for this submodel was the multiple-species disk equation after Holling:

$$LA(i) = LC(i) * L/[\,1 + \sum_{j=1}^{6} LC(j) * Ml * LF(2, J) * LF(1, J)]$$

where LA(i) is the attack rate per year per individual of species i, L is the adult lamprex abundance, M1 * LF(2, J) is the handling time per attack, with Ml assumed to be 3.8x10 yrs/mm and LF(2, J) average individual length of prey species j. LF(1, J) is the abundance of prey species j, and LC(i) is the effective search rate of lamprey for species i (or j) Effective search rate is a function of prey size:

$$LC(i) = K * LF(2, i) * LR(i),$$

where K is a scaling constant representing the fraction of the lake volume searched by an individual lamprey adult per year and LR(i) is a species preference index.

The instantaneous mortality due to lamprey attack is a probabilistic function:

$$LC(i) = (1 - J1) * LZ * LA(i),$$

Table 4. Fishery Submodel Variables

Variable	Description
EA	Discounted value of net benefits from year 6 to T1 in dollars (U.S.)
EC	Regional economic multiplier for commercial landed value
EL	Regulated upper limit of fishing effort indexed over gear types
EM	Minimum effort allowed by gear type - used for test fishing
EP	Dockside prices for commercial fish indexed over species
ER	Net contribution to the regional economy in U.S. dollars
ES	Regional economic multiplier for angler-days
FD	Management costs in millions of U.S. dollars
FE	Fishing effort indexed over gear types
FI	Net total contribution to regional economy
FL	Total commercial landed value
FR	Net return by gear types in dollars
FT	Cost of fishing by gear type in dollars
FZ	Cost of assessment work
GA	Scales population-distance from fishery distribution to size of regional population
GB	Inverse of mean cost/angler day for population of fishermen
GC	Management cost multiplier of commercial landed value
GF	Cost of fishing by gear type in dollars per effort unit
GG	Rate of decay of angling effort with increasing costs per angling day
GH	Total harvest of each species by all commercial gear types indexed by species
GI	Commercial fishing depreciation rate
GK	Square of catch rate at which angling effort is one-half of its saturation level
GS	Management cost multiplier of sport fishing effort
Gb	Maximum price paid for fish in short supply indexed by species
G1	Harvest per year at which price is halfway between Gb and G2 indexed by species
G2	Minimum price paid for fish during glut supply indexed by species
G6	General rate of return on investment in the economy
LD	Administrative overhead management cost in millions of dollars

where LZ is the fraction of a year in which lamprey are actively feeding (assumed to be 0.33 in these analyses), and J1 is the probability of survival. This probability is a function of the ratio of prey to lamprey size:

$$\text{if } LF(2, i)/M3 \geq M5 \quad J1 = 1$$

$$\text{if } LF(2, i)/M3 < M5 \quad J1 = M4 * LF(2, i)/M3$$

where M5 is a threshold ratio of prey/lamprey size (.292 in the model) and M4 is 3.8×10^{-5} mm^{-1}.

Variables used in the lamprey submodel are listed in Table 5.

Lamprey prey categories included in the model and their preferences were

Index	Prey Category	LR(i)
1	Lake Trout	1.0
2	Whitefish	0.2
3	Age 2 Coho	0.4
4	Age 2 Chinook	0.4
5	Age 3 Chinook	0.4
6	Adult Cisco	0.05

Lake Trout Submodel

The lake trout submodel is an age-structured model that describes growth as well as abundance changes. The model provides for 10 age classes:

$$TA(i,t+1) = TA(i-1,t) * \exp[-Z(i-1,t)], \quad i = 2 \text{ to } 9,$$
$$TA(10,t+1) = TA(9,t) * \exp[-Z(9,t)] + TA(10,t) * \exp[-Z(10,t)],$$

where TA(i,t) is the abundance of age group i at time t and Z(i,t) is the instantaneous total mortality of age group i at time t. Recruitment as yearlings is a function of fecundity and survival of the first year of life:

$$TY = \sum_{i=1}^{10} TM(i)*TA(i,t)*(U5*TW(i)-UG)*(UR(i)+UP*(1-UR(i)))$$

where TY is the number of eggs deposited, TW(i) is the average weight of a fish of age i in year t,1-UR(i) is the fraction of age i fish that were stocked, UP is the fraction of stocked fish that reproduce, U5 and U6 are fecundity coefficients (estimated to be 1.779 eggs/g and 0.5496 eggs, respectively). The fraction of mature females in an age group, TM(i), was also a function of body size:

$$TM(i) = U3*TW(i)-U4,$$

Table 5. Lamprey Identification

Variable	Identification
J	Index
J5	Survival Probability
K	Proportion of lake volume searched annually
KK	Summation term
LA(i),i=1,6	Lamprey attack rate
LC(i),i=l,6	Effective Search Rate/and Instananeous mortality coefficient
LF(l,i)i=1,6	Abundance of each prey category
LF(2,i)i=1,6	Average length of prey in each category
LP	Instantaneous mortality of adult ciscos
LR(i),i=l,6	Probability of attack for each prey category
LT	Instantaneous mortality of lake trout
LW	Instantaneous mortality of whitefish
LX	Summation term
LY	Summation term
LZ	Proportion of year for active lamprey feeding
M1	Slope of handling time vs. size of prey 3.8×15^{-5} yrs/mm
M2	Probability of attack within reactive distance 1.0 unitless
M3	Survival ratio threshold for prey/lamprey 356 unitless
M4	Survival slope coefficient for small prey .292 unitless
M5	Threshold size ratio for prey survival 3.42 unitless

where U3 and U4 are maturity coefficients (0.00054 g^{-1} and 0.80428 respectively). If TM(i) was less than zero then the age group contributed no mature females. Total yearlings in the next year were the sum of stocked yearlings and the survival (assumed to be 0.001) of the deposited eggs.

The instantaneous mortality coefficient for each age group was dependent upon an assumed natural mortality of 0.26 yr , mortality due to lamprey attack, and fishing mortality. Fishing mortality was computed over six different fishery/gear types. Associated with each fishery type was a catchability coefficient and a "knife-edge" vulnerability dependent upon body size (i.e. if a fish is greater than a certain size then it is fully vulnerable to the fishery and not vulnerable if it is less than or equal to the cutoff size). Catchability coefficients and knife-edge vulnerability weights for each fishery were

Fishery	Critical Body Wt. (g)	Catchability Coefficient Value	Units
Angling	1000	0.0001	10^3 angler day
Trawling	1000	0	hrs
Small mesh chub gill nets	500	0	km
Large mesh trout gill nets	1500	1.65×10^{-5}	km
Large mesh whitefish gill nets	1500	3.3×10^{-5}	km
Trapnets	1000	1.26×10^{-5}	100 lifts

Effort for each gear type is provided by the Fishery/Economic submodel. Harvest by gear type is computed from the ratio of fishing mortality by gear to total mortality:

$$T6(j) = \sum_{i=}^{10} (T9(j)/TZ\ )*(1-\exp(-TZ(i)))*TA(i,t)*TW(i)/U1,$$

where T6(i) is the biomass caught in gear j, T9(j) is the fishing mortality of age group i in gear j, TZ(i) is the total instantaneous mortality of age i, U1 is a conversion of grams to metric tons. All other variables are defined above.

Growth rate of lake trout in the submodel is determined by the average weight change of each age group:

$$TW(i,t+1) = TW(i,t) + TX(i) *TT,$$

where TW(i,t) is the mean weight of fish in age group i at time t, TX(i) is the maximum weight increment for the age group at maximum consumption, and TT is the proportion of maximum consumption for year t. This proportion depends upon prey abundance as follows:

$$TT = \left(\sum_{j=1}^{5} P(j)*T1(j) \right) / \left(TD + \sum_{j} P(j)*T1(j) \right),$$

where TD (assumed to be 50,000 MT in these simulations) is the prey biomass at which consumption is ½ of the maximum rate, P(j) is the abundance of prey species j, and T1(j) is a preference index for each prey species (all assumed to have a value of 1.0). Instantaneous mortality rate of each prey due to lake trout predation is thus:

$$TV(j) = T1(j)*TS*TB/[TD + \sum_j P(j)*T1(j)],$$

where TB is total lake trout biomass.

Variables used in the lake trout submodel are listed in Table 6.

Whitefish - Salmon Submodel

Whitefish

State Variables

WN	# Age classes considered
WA	# in each age class, 1 WN
WL	Total length mm by age class
WB	Weight kg by age class
WH	Harvest MT for 7 forms of fishing effort
WB	Biomass kg of fish age 1 and older
A	Area of Lake Michigan km^2
V	Volume of Lake Michigan km^3

Functional Relationship

Natural Mortality rate age 1 or older

This rate was determined by a linear function of population biomass:

WW = X3 + X4 * WB, where

X3 = 0.4, X4 = 1E - 3/A

Mark Ebener had a summary of estimates from his thesis on Green Bay Whitefish and the, literature.

Extreme values of 0.4 and 0.67 for exploited and unexploited populations respectively, were used from Healey's work. A value of 0.4 was set as the minimum and 0.67 was set as the value for an estimated unexploited biomass in Lake Michigan of 236 kg/km^2.

In the discussions, some consideration was given to the idea that immatures, males and females might have different mortality rates. There was limited discussion of the possibility that the rate might increase with age. For the scenarios run on October 6, 1981, X4 was arbitrarily set to zero.

Table 6. Lake Trout Variables .

Variable	Identification
T	Number of mature females
TA(i);i-1 to 10	Total number of trout in each age class
TB	Total lake trout biomass (MT)
TC	Summation term
TD	Biomass of prey at half maximum feeding rate (MT)
TF	Number of stocked yearlings
TG	Growth weight increment (g)
TH(j);j=1,6	Total lake trout harvest in each gear (MT)
TK	Amount of each prey type eaten (MT)
TL(i);i=1,10	Catchability coefficient of 6 gears
TS	Maximum consumption rate
TT	Consumption summation term
TU(k),k=1,5	Mortality rate of each prey type
TV(j);j=1,6	Knife-edge vulnerable weight for each gear type (gms)
TW(i);i=1,10	Average weight (gm) of trout in each age group
TX(i);i=1,10	Maximum weight increment (gm) of trout in each age group
TY	Total yearlings
T1(k);k=1,5	Prey preference of trout for each prey type
T2	Counter
T3	Counter
T4	Counter
T5	Total instantaneous fishing mortality
T6(j);j=1,6	Biomass of trout harvested by each gear
T9(j);j=1,6	Instantaneous fishing mortality rate by gear
TB	Survival rate from egg to yearling
UD	Summation term
UH	Total Biomass of Trout harvested
UP	Proportion of stocked Trout that spawn
UR(i);i=1,10	Proportion of naturally recruited fish of age i
U1	Conversion of g to MT
u3	Slope for maturation curve
u4	Intercept for maturation curve
U5	Slope for fecundity curve
U6	Intercept for fecundity curve
u7	Catch per effort of lake trout
U8	Conversion factor for weight to length
VA	Average age of spawning female

Exploitation

Catchability coefficients were estimated on the assumptions:

i) Fishable biomass	3E3 MT
ii) Trapnets caught	0.1 MT/lift
iii) Gillnets (large mesh) caught	0.06 MT/Km set

Therefore, Trapnet q = 3.3 E - 5 (XE)
Gillnet q = 2.0 E - 5 (Xl)

These estimates came from Borgeson (250 lbs/lift and 40 lbs/1000 ft). These figures are probably too high for the whole of Lake Michigan, since they are estimates for catches in Green Bay and northern Lake Michigan where whitefish are concentrated.

Size selectivity for the gillnets was available but was not included in the model. Lake trout nets were assumed to be only 0.5 effective (XF). Whitefish are assumed to enter the commercial fishery at length 400 mm (XB) and to be fully recruited at 425 mm (XC).

Lamprey induced mortality is assumed to apply only to fish 400 mm and greater (XB).

Catchability

A Walford equation is used to predict length increments over the summer.

WL(1) = WL(1) * WG + XA

where XA is the fixed size at age 1, 160 mm
WG is a linear function of WB, the population biomass

WG=XJ+XK*WB
where XJ = 0.83, XK = -4.2E-4/A

Size at age 1 does vary, but there was no certainty as to whether the cause related to yearclass strength or climatic conditions.

Reproduction and YOY Survival

Maturation was set to begin at 400 mm (XB) and be completed at 475 mm (X5). The sex ratio was assumed to be 0.5 and the fecundity was set at 18,000 eggs/kg.

0.5 * 18000 = 9000 = X6

Eggs over-winter and enter the population as Age 1's a year after that. Survival from egg stage to age 1 was predicted by an exponential function of egg density.

WA(1) = WA(0) * EXP (X8 + X9 * WA(0) + 0.5 * ZR
Age 1 Eggs
where X8 = 7.26, X9 = 3.75 E - 6/A
ZR is a random normal deviate

Those parameter values were used during initial scenario development on October 6. They produce very high survival values which lend undue resilience to the whitefish population. Collins and Minns have since examined different values of X8 and it is likely it should be set at around -9. How the strength of the density effect should be maintained is uncertain. The values of key parameters in the whitefish component of the submodel appear in the following table:

Variable name	Values		Parameter represented (and units)
Xl	1.48E-9	)	Length/Weight coefficients
x2	3.31	)	mm kg
x3	0.4	)	Minimal natural mortality rate
x4	1E-3/A		Density effect on natural mort
x5	475		Size mm when fully mature
X6	9000		Eggs/kg mature biomass
X8	-7.26		Minimum mortality rate eggs Age 1
x9	-3.75E-6/A		Density effect of eggs on survival
XA	160		Size mm at age 1
XB	400		Size mm at first entry to Comm. Fishery
x c	425		Size mm at full recruitment to Comm. Fishery
XE	3.33-5		Trapnet catchability
XF	0.5		Proportion lake trout gillnets effective on whitefish
XI	2E- 5		Gillnet catchability
XJ	0.83		Maximum Walford growth rate
XK	4.2E 4/A		Density effect on growth rate

SALMON

State Variables

	Coho	Chinook
Stocking rate	S(1)	S(2)
# 2nd Spring	WS(1)	WS(2)
# 3rd Spring		WS(3)
# Riverrun/Escapement	WS(5)	WS(4)
WT. 2nd Spring (Kg)	WT(1)	WT(2)
WT. 3rd Spring (kg)		WT(3)

WP(1)	Salmon induced mortality rate of Prey 1	
WP(2)	Salmon induced mortality rate of Prey 2	
WP	Salmon angling harvest	MT (metric tons)
WK	Salmon excapement	MT
	Stocking Costs	$
Lengths (mm)	WU(1)	WU(2), WU(3)

Functional Relationships

Growth and Feeding

The growth increments in the 2nd and 3rd summers were assumed to be equal for Coho and Chinook, for a given prey biomass. The growth increment was described by a Type II Curve:

YC = YD * YT/(1 + YE * YT)

where YD = 3E - 5 : YE = 8,3E - 6

YT = P(1) + P(2) MT

Both Coho and Chinook were assumed to feed without preference on the two size categories of alewife. The values for YD and YE represent an empirical fit to a loosely described relationship between growth increments and prey biomass. A food conversion ratio of 5 (Y1) was used to estimate consumption. Salmon were assumed to be planktivores in their first summer. Coho grew to 0.57 kg (YG), Chinook to 0.34 kg (YK).

Natural Mortality and Exploitation

The survival of coho from stocking through to the 2nd spring was 0.25 (YF). The survival of chinook through to the 2nd spring was 0.15 (YT). Thereafter the natural mortality rate was set at 0.22 (YH).

The Lamprey mortality rates were received from the lamprey submodel in the array LS.

For exploitation, the catchability was estimated to be 3E - 4 per 1000 angler days (YA).

<u>Stocking Costs</u>

Coho cost	$0.2 per fish (YL)
Chinook cost	$0.05 per fish (YM)

Parameter	Values	
YA	3E- 4	Catchability
YD	3E-5)	Growth equation parameters
	)	
YE	8.3E- 6)	
YF	0.25	Coho survival first year
YG	0.57	Coho weight 2nd Spring kg
YH	0.22	Coho + Chinook natural mortality rate
YI	5.0	Food conversion ratio
YJ	0.15	Chinook survival first year
YK	0.34	Chinook weight 2nd spring kg
YL	$0.20	Cost per chinook stocked
YU	1E3	Conversion units kg to MT

PREY SUBMODEL

Summary of Equations and Variables for Prey Submodel

Change rules for both the Alewife/Smelt and Cisco/Herring components are based on a Deriso model with partial recruitment. The pre-recruits are considered juvenilles and the recruits are adults:

$$P(t)=P(t-1)S_p V(t)RS_p RS\,[P(t-1)-S_p(t-2)V(t-2)P(t-2)] + H(t) \quad (1)$$

$$B(t)=B(t-1)S_b + R_b S_b\,[B(t-1)-S_b(t-2)B(t-2)] + [1-V(t)]\,P(t-1) \quad (2)$$

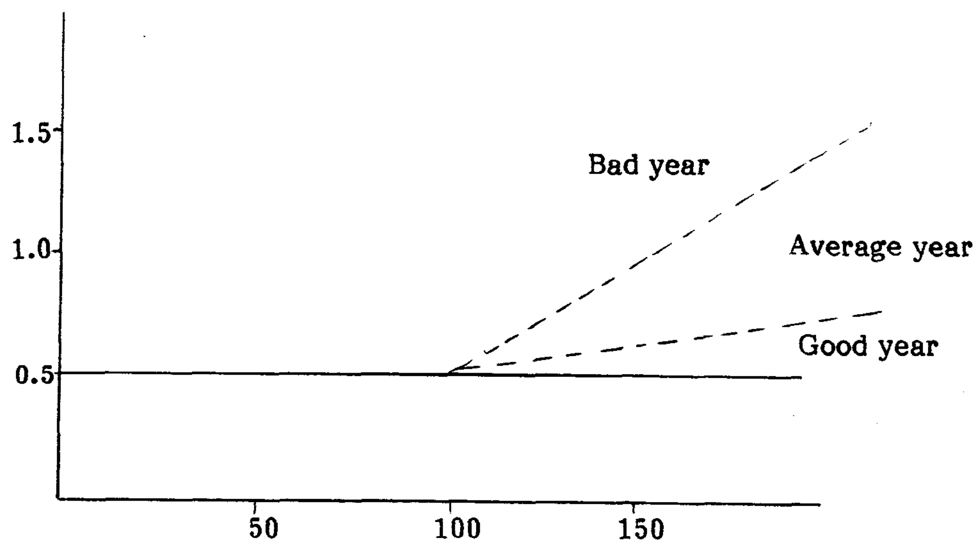
where H(t) is reproduction, S_p and S are survival of juveniles and adults respectively, and (V(t) is the fraction of juveniles b&coming adults during year t. The change rule for sculpins, however, is a simple logistic model:

$$P5(t) = p5(t-1)\ [l + QF - QF\ PS(t-1)/QE] \quad (3)$$

where QF and QE are constants estimated to allow a steady-state sculpin biomass of about 2000 MT.

Alewife/Smelt Component

Non-predatory mortality (i.e. excluding predation by Lake Trout, Salmon, and fishing) is assumed to increase with A/S density. At density less than a critical value, non-predatory mortality is constant, but above this critical threshold, mortality increases at a variable rate, which depends upon a random environmental factor:

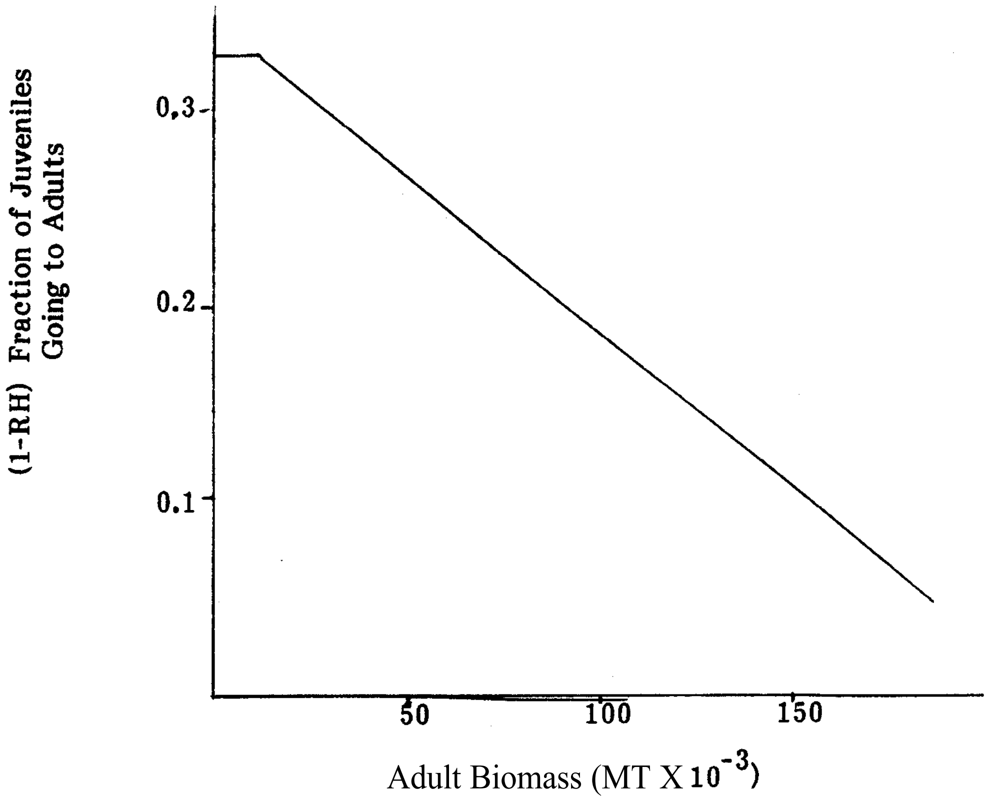


Total Alewife Biomass (MT X 10^{-3})

The random factor has a uniform distribution with a range of 0 to 1, and it determines one of three possible climatic effects on mortality: better than average (QR $<.2$), average ($.2 \geq QR \leq .8$), and worse than average (QR >.8). The slope of the mortality dependence on A/S biomass increases with worsening climatic effects. Reproduction (PH) in the A/S component is assumed to be a Ricker type function (i.e. In(PH/P2) = RL - R,*P2) of adult biomass. Initial parameters were estimated from historical observations of alewife in Lake Michigan and were RL = 1.5 and RM = 2.5×10^{-5} .

Cisco/Herring Component

Unlike the Alewife/Smelt component, the density dependent regulation of the C/H component is through reproduction and growth of juveniles. Growth rate is characterized as a functional relationship between the fraction of juveniles becoming adults (1-RH) and the biomass of juveniles in the same year:



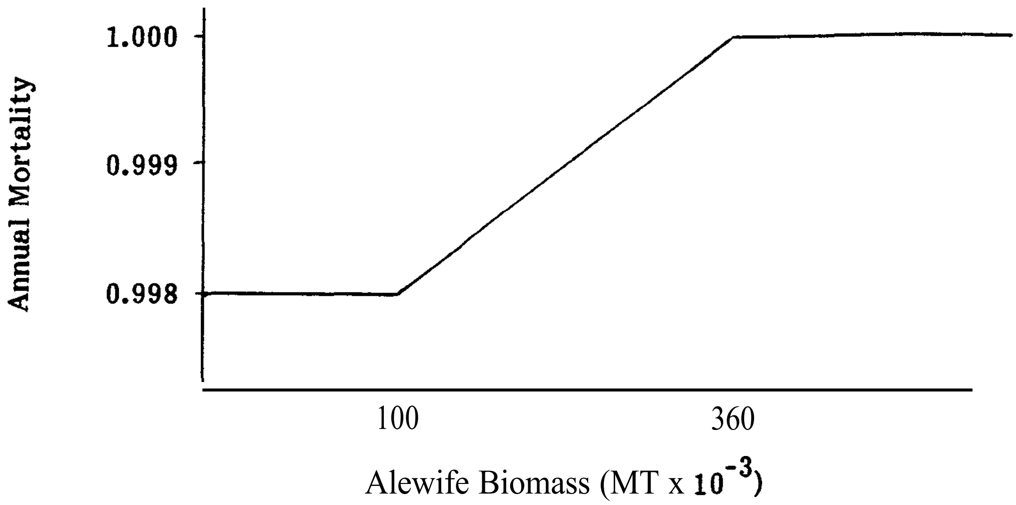
The relationship asserts that for a juvenile biomass less than 10,000 MT about 1/3 of the juveniles become adults and that this fraction decreases linearly to zero at 216000 MT. Reproduction is calculated directly from estimates of fecundity and survival to age 1. Biomass of yearlings expected from eggs produced by adults (assumed to have a 1:1 sex ratio) is

$$PH = RU*P4*RF/RV \qquad (4)$$

where RU is the number of eggs per adult, RV is the mean weight of an adult, and RF is the mean weight of a yearling at the start of the second year of life. Survival of juveniles during the first year of life was assumed to be a negative exponential function:

PH = PH*EXP [RZ*P4]

where RZ was estimated as 1.7 x 10^{-5} MT^{-1}. In addition to this functional relationship, mortality of young-of-the-year C/H was assumed to be affected by the total biomass of A/S according to the following:



Mortality of YOY C/H associated with A/S was thus

QX=RW+RX* [PT-RY] (6)

where RX was 0 for PT RY, and 1.0 x 10^{-8} for greater values. The maximum value for QX was 1.0. The predicted yearling production was obtained by pooling equation 5 and 6:

PH = PH* [1-QX] (7)

Changes in adult and juvenile biomass were then calculated as in equations 1 and 2.

Variables in the prey submodel are listed in Table 7.

SCENARIO ANALYSES

To illustrate the policy options for management, we established four sets of actions. These actions focussed on Lake Trout rehabilitation and included various combinations of sea lamprey control, trout stocking, and fishery regulation. Simulation 1 is the reference run and the other simulations represent slight modifications of it. Major actions in each of the simulations are summarized in Table 8.

All of the simulations shared some common assumptions. Although these assumptions are identified in the submodel discussions, a few of the most important are: 1) Lamprey have a high preference for Lake Trout over other prey species, 2) all stocked

Table 7. Variables for Prey Submodel

Code	Identification
P1	Alewife/Smelt Juvenile Biomass
P2	Alewife/Smelt Adult Biomass
P3	Cisco/Herring Juvenile
P4	Cisco/Herring Adult Biomass
P5	Sculpin Biomass
P6	Number of Adult Cisco
R1	Catchability of Adult Alewife by Trawling
R2	Catchability of Adult Cisco by Gillnets
R3	Fishing Mortality of Alewife
R4	Fishing Mortality of Cisco
R5	Baseline Non-pred. Mortality for Alewife
R6	Non-pred. Mortality Coefficient
R7	Non-pred. Mortality Factor for Good years
R8	Non-pred. Mortality Factor for Average years'
R9	Non-pred. Mortality Factor for Bad years
R0	Critical A/S biomass for Non-pred. Mortality
RA	Growth Rate Coefficient for Juvenile Alewife
RB	Growth Rate Coefficient for Adult Alewife
RC	Growth Rate Coefficient for Juvenile Cisco
RD	Growth Rate Coefficient for Adult Cisco
RF	Average Weight of Yearling Cisco
RG	Fraction of Alewife juveniles remaining Juvenile in t
RH	Fraction of Cisco juveniles remaining Juvenile in t
RI	Baseline value of RH
RJ	Coefficient of increase for RH
RK	Critical Cisco Juvenile Biomass for RH
RL	Stock-Recruitment coefficient for Alewife
RM	Stock-Recruitment coefficient for Alewife
RN	Last year's survival rate for juvenile Alewife
RO	Last year's juvenile alewife biomass
	Last year's survival rate for adult Alewife
RQ	Last year's adult alewife biomass
RS	Cisco Non-pred. mortality on juveniles
RT	Cisco Non-pred. mortality on adults
RU	Number of eggs per Cisco Adult
RV	Mean Weight of Adult Cisco
RW	Baseline Mortality Rate for YOY Cisco
RX	Coefficient of Increase for QX
	Critical Alewife Biomass for QX
E	Cisco Density Dependent Parameter for YOY survival
QA	Last year's survival rate for juvenile Cisco
QB	Last year's juvenile Cisco Biomass

QC	Last year's survival rate for adult Cisco
QD	Last year's adult Cisco Biomass
QE	Sculpin Carrying Capacity
QF	Sculpin growth rate
QG	Non-predatory mortality of sculpins
QH	Natural Mortality of Adult Alewife
QI	Total Mortality of Adult Alewife
	Juvenile Cisco Natural Mortality
QK	Total Adult Cisco Natural Mortality
QL	Total Sculpin Mortality
QM	Juvenile Alewife Survival
QN	Adult Alewife Survival
QO	Juvenile Cisco Survival
QP	Adult Cisco Survival
QR	Sculpin Survival
QS	Temporary Variable
QT	Temporary Variable
QU	Die-off of Alewife due to non-predatory mortality
QV	Upper boundary of good years for Alewife Mortality
QW	Lower boundary of bad years for Alewife Mortality
QX	Temporary variable in computing Alewife Mortality

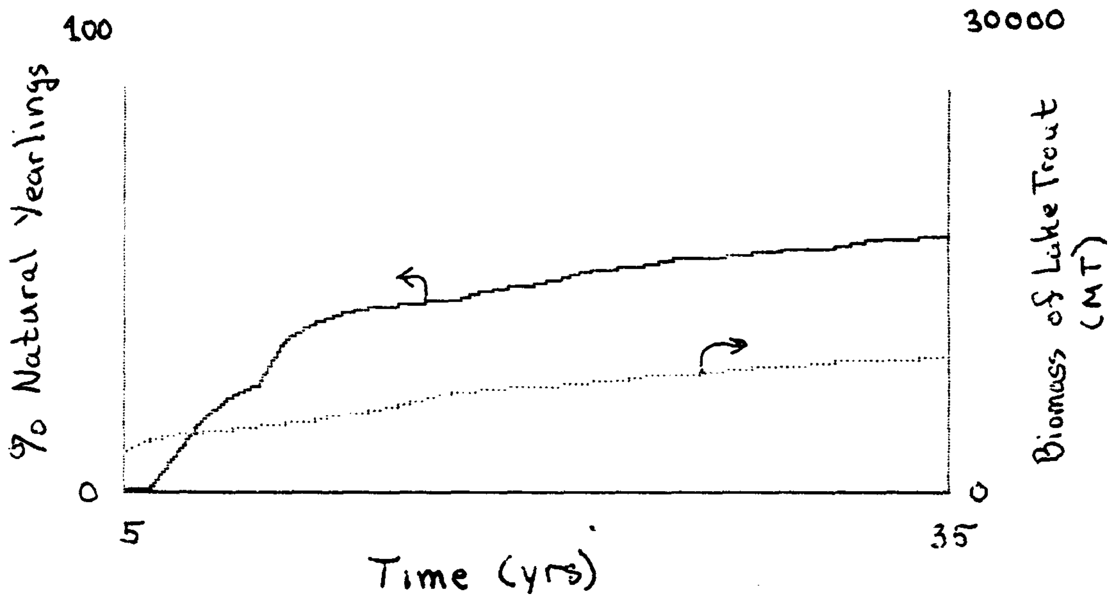
Note: Variables without values change during simulation.

Table 8. Summary of Differences in Simulations

Simulation	Lake Trout Stocking	Sea Lamprey Abundance	Fishery Regulation
1	3×10^6	50,000	Unregulated effort
2	3×10^6 to year 14, 0 year 15 on	50,000	Unregulated effort
3	3×10^6	50,000 to year 14 500,000 year 15 on	Unregulated effort
4	3×10^6	50,000	Commercial fishery effort restrictions

Lake Trout that survive to reproductive maturity spawn, 3) the species mix and lake **characteristics** were matched to Lake Michigan, and 4) 9 million salmon are stocked every year. Lamprey control in these scenarios was assumed to affect the abundance of parasitic phase animals, and the level of control would result in a constant abundance of lamprey. Finally, the graphical summaries of the scenarios do not show the pattern of the first 5 years of the simulation. This procedure was adopted to minimize the distraction of the initial condition transients in the model.

Simulation 1 represents a lake trout rehabilitation policy Similar to the Lake Michigan program. No natural Lake Trout existed in the lake prior to the start of the simulation, and lamprey control was assumed to be in place and result in a **constant** abundance of 50,000 parasitic lamprey each year. Fisheries, however, were not regulated. Under these conditions, Lake Trout biomass increased slowly. Natural reproduction accounted for about half of the yearlings after 35 years (Fig. 3). Lamprey attacks were low throughout the simulation (Fig. 4), and harvests of all species were low (Fig. 5). Finally, management costs remained near $10 million annually with return to the regional economy at about $140 million annually (Fig. 6). Rarely during this run was there a net positive return to the commercial fishery (Fig. 6).



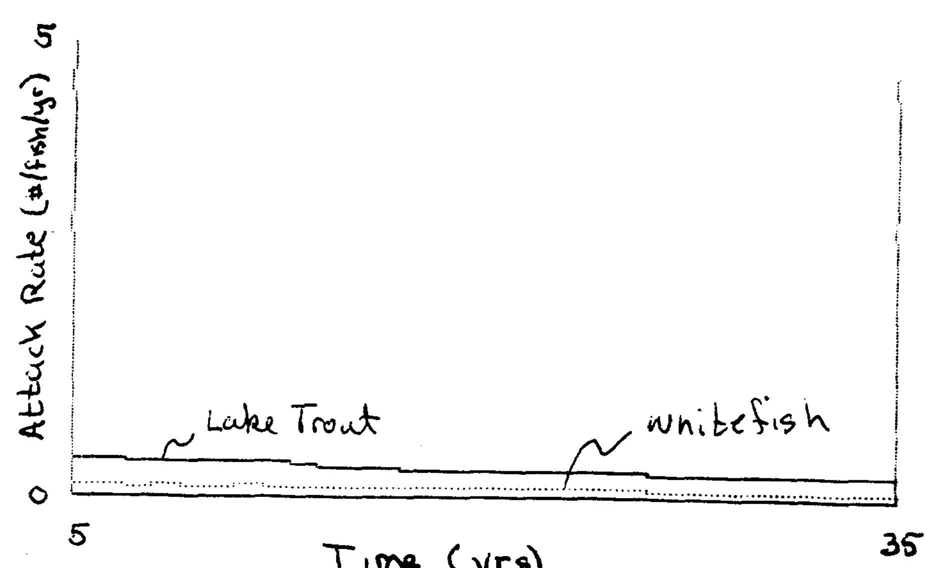
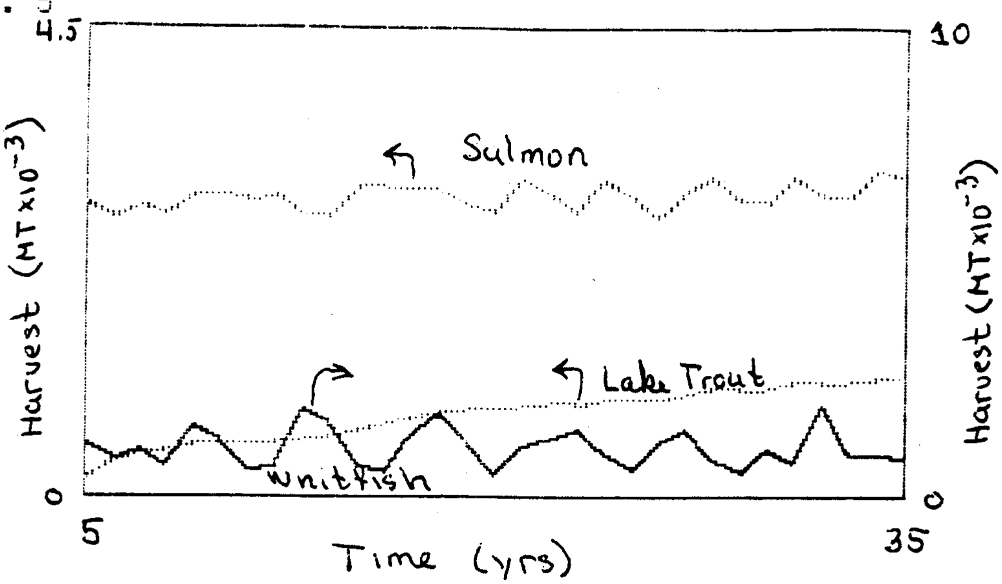
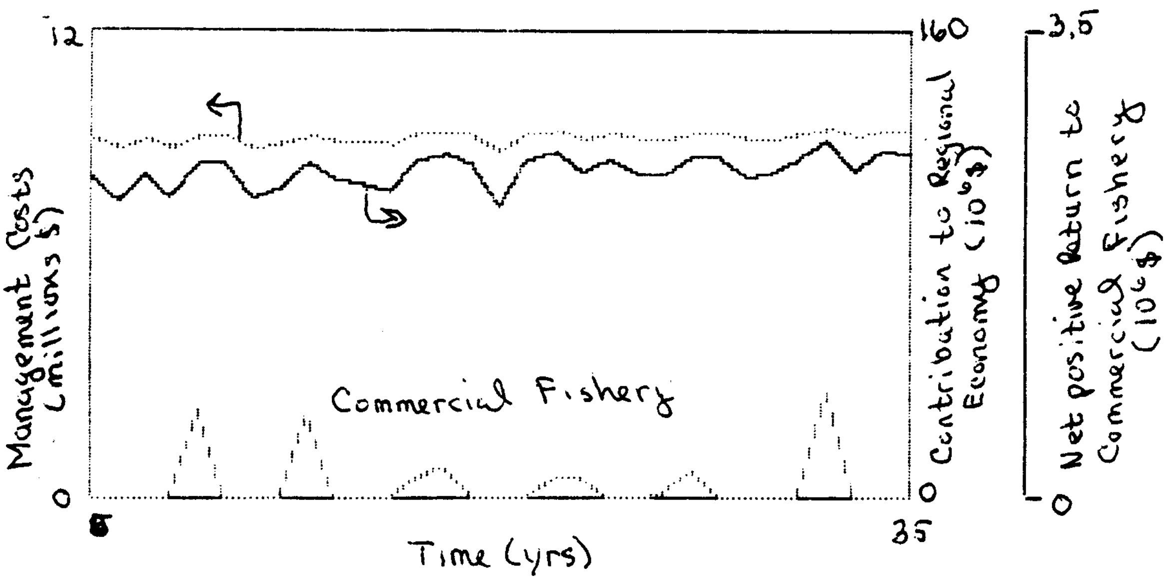


FIG. 5



4.5
10
Salmon
Harvest (MTx10^{-3})
Harvest (MTx10^{-3})
Lake Trout
Whitfish
0
0
5
35
Time (yrs)



12
160
3.5
Management Costs (millions $)
Contribution to Regional Economy (10^{6}$)
Net positive Return to Commercial Fishery (10^{6}$)
Commercial Fishery
0
0
0
35
Time (yrs)

In simulation 2, trout stocking was terminated at year 15. The rehabilitation of Lake Trout fared less well (Fig. 7), and natural reproduction alone could not maintain the population. Lamprey attack rates were not much different, but harvests of whitefish increased (Fig. 8). Halting stocking in year 15 reduced management Costs slightly, but led to lower contributions to the regional economy (Fig. 9).

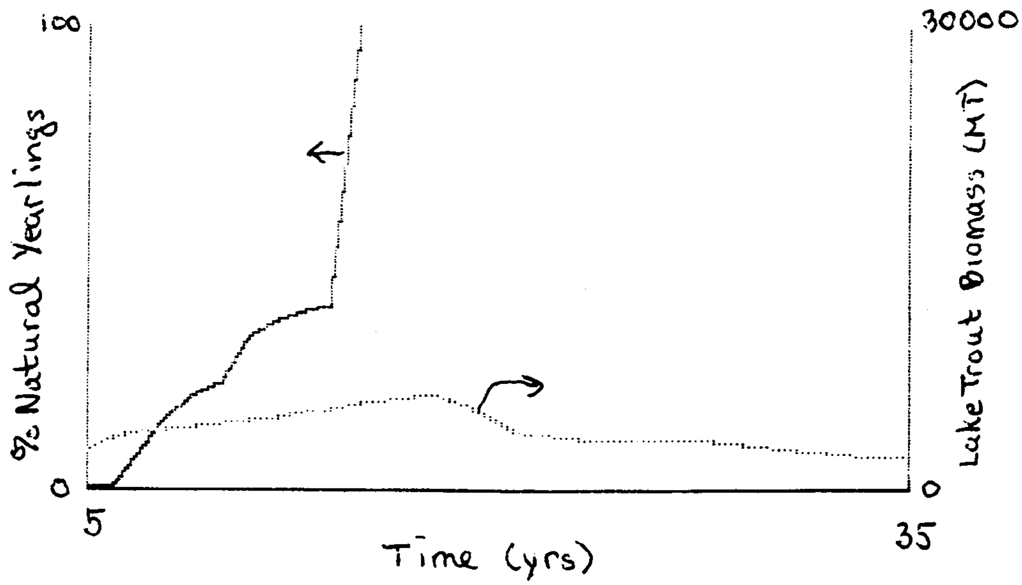


FIG. 8

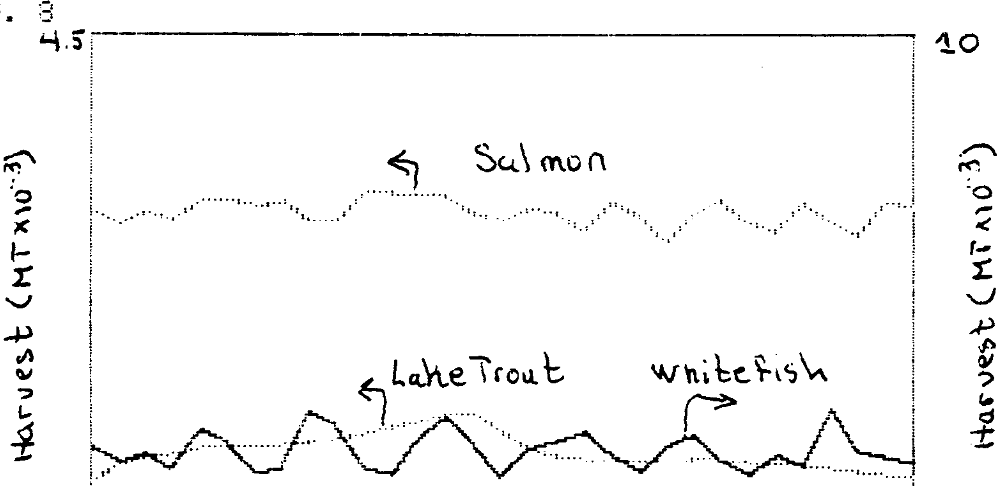
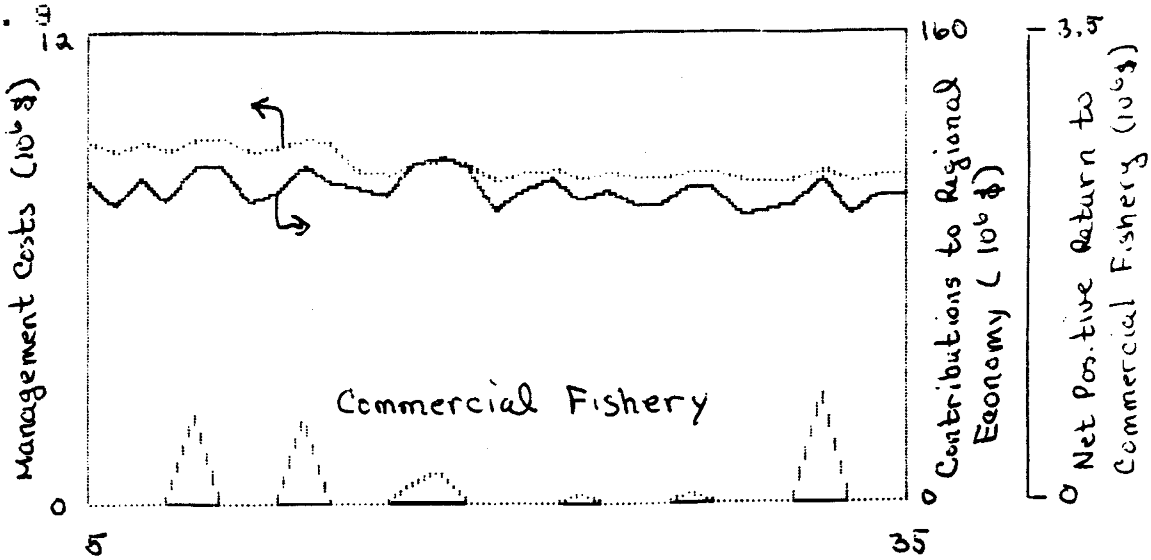


FIG. 9



The model seemed to be much more sensitive to lamprey abundance changes. For simulation 3, we assumed that lamprey control efforts were reduced in year 15 and that the abundance of parasitic lamprey increased to 500,000. The result of this policy change was a collapse of the Lake Trout population (Fig. 10). Only stocking maintained any lake trout with the proportion of natural yearlings declining toward zero. Lamprey attack rates increased dramatically and remained at a high level (Fig. 11). Harvests of all species deteriorated (Fig. 12), and the savings in management costs were accompanied by a severe reduction in the contribution to the regional economy (Fig. 13).

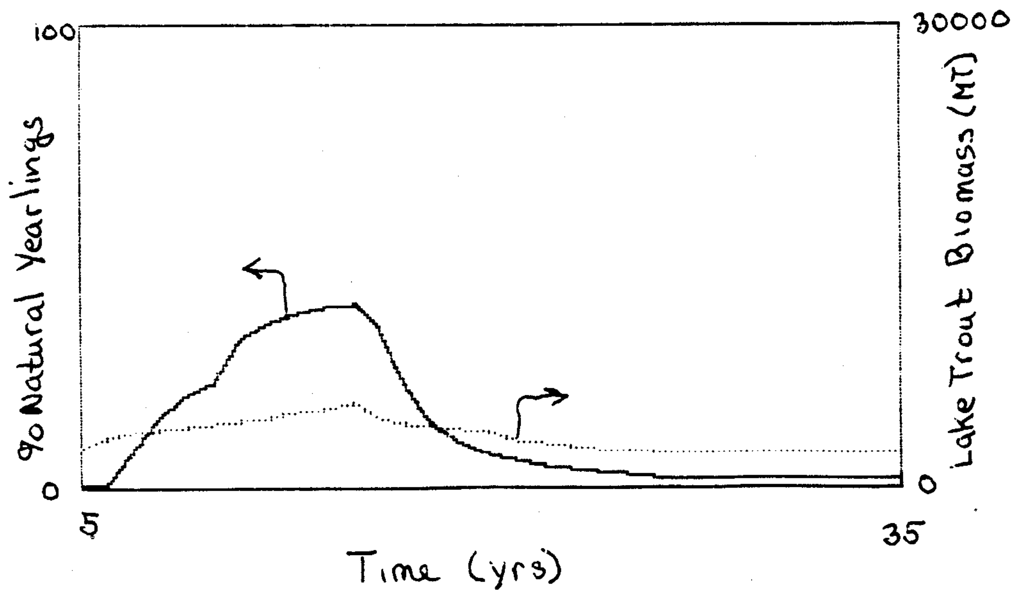
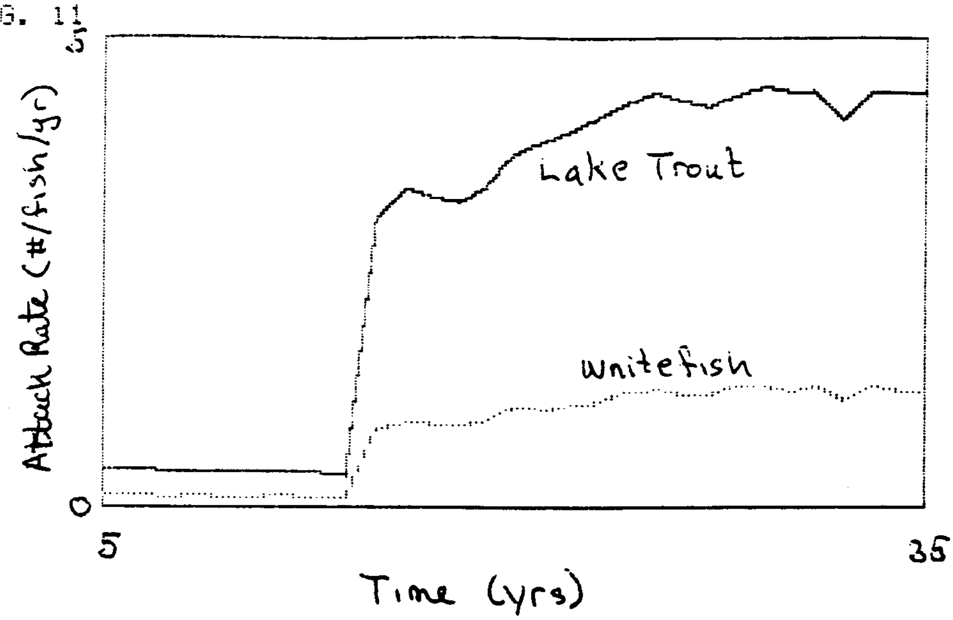
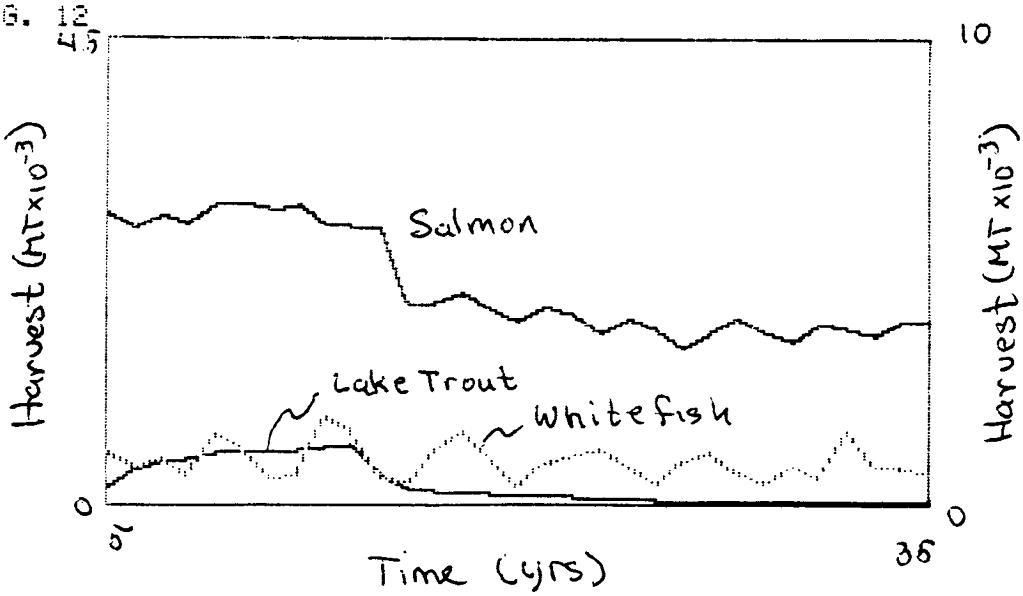


FIG. 11

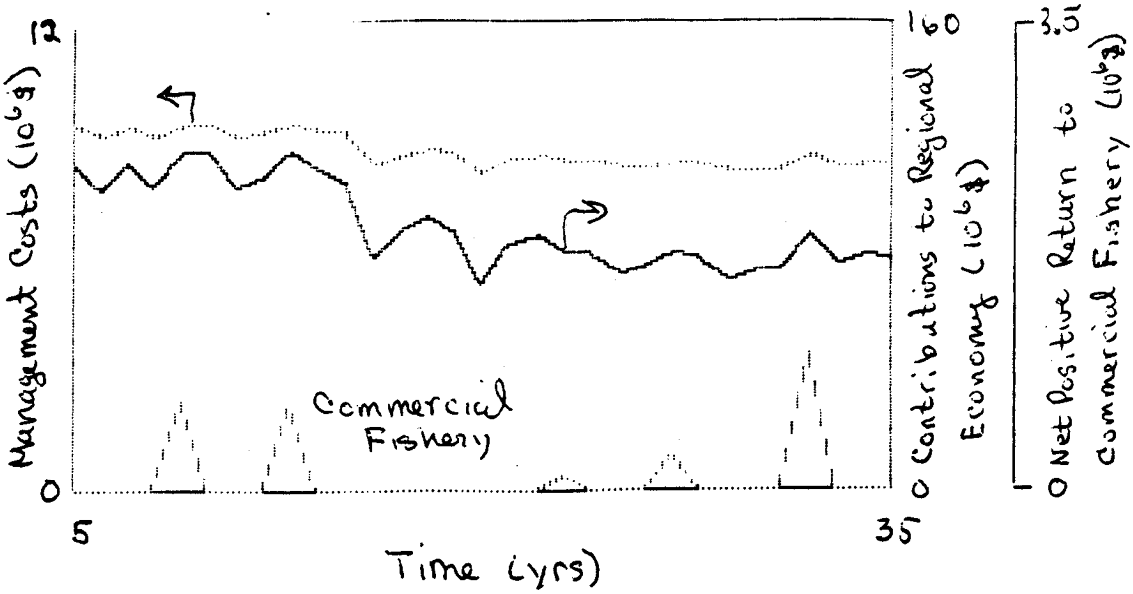


.5
Attack Rate (#/fish/yr)
0
5
35
Time (yrs)
Lake Trout
Whitefish

FIG. 12



45
Harvest (MTx10^{-3})
0
5
35
Time (yrs)
10
Harvest (MTx10^{-3})
0
Salmon
Lake Trout
Whitefish



The final scenario represents the best conditions for rehabilitation. In addition to lamprey control and a stocking program, effort restrictions are placed on the commercial fishery. The recovery of Lake Trout is much more rapid with about 80% natural yearling productivity by year 35 (Fig. 14). Lamprey attack rates are quite low, and the harvests improve greatly (Fig. 15). By year 35, the contribution to the regional economy increases to nearly $160 million annually, and the commercial fishery shows a substantial net profit increase (Fig. 16).

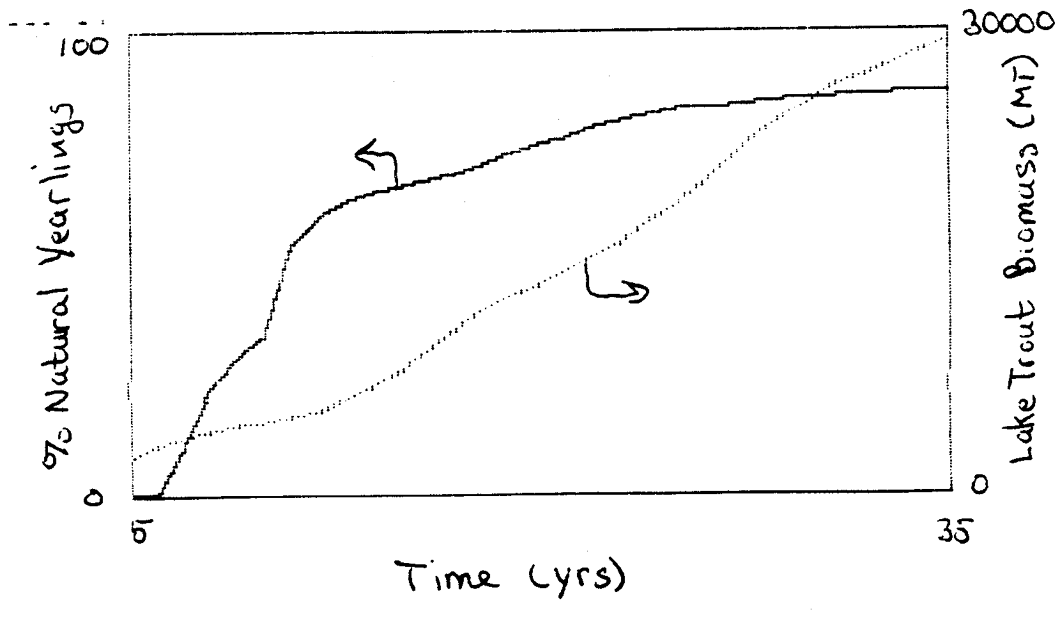
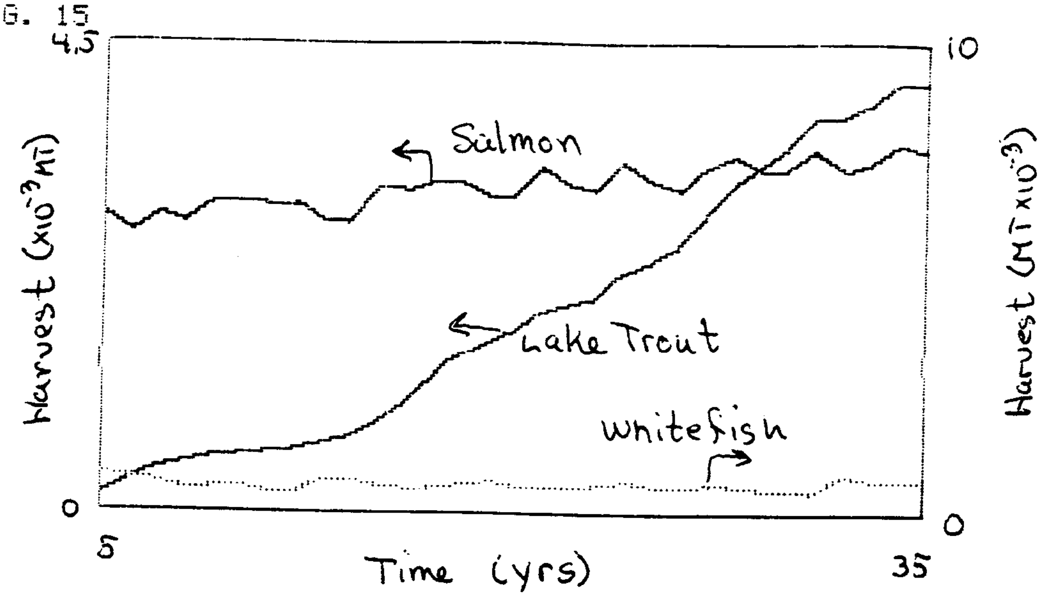
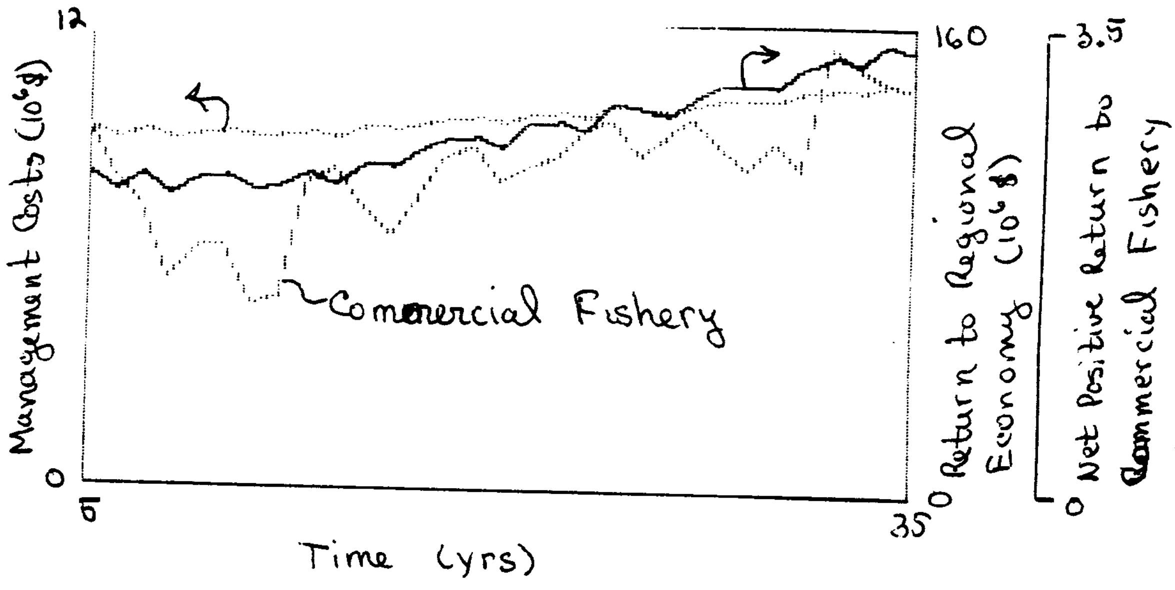


FIG. 15


4.5
0
10
0
Harvest (x10^3 MT)
Harvest (MTx10^3)
Salmon
Lake Trout
whitefish
0
35
Time (yrs)


12
0
160
0
3.5
0
Management Costs (10^6 $)
Return to Regional Economy (10^6 $)
Net Positive Return to Commercial Fishery
Commercial Fishery
0
35
Time (yrs)

APPENDIX A

User's Guide to SALMONID/LAMPREY DEMO

The simulation model developed at the Sault Ste. Marie Workshop is written in Applesoft BASIC and stored on 5¼" floppy disks written under Disk Operating System (DOS) 3.3. A complete listing of the program appears in Appendix F. The following instructions will enable the user to load and execute the simulation model and to recall several scenarios developed at the workshop. Appendix B provides a brief set of instructions for modification of the program to allow variations from the four currently available scenarios. Appendix C contains instructions and program listings for capturing the results of several simulations for subsequent demostration of multiple scenarios.

Running the program and recreating these scenarios requires a disk containing at least the following programs:

A 002 HELLO	simple greeting program
T 002 BLS	
T 002 TSS	files that set initial parameter
T 002 LCS	values for the various scenarios
T 002 RFS	
*A 042 SSM DEMO	SALMONID/LAMPREY simulation model
*T 003 ZM VALUES	file to "standardize" the output scaling to simplify comparisons between scenarios

In the output below, the USERS responses are underlined whereas the prompts and error messages generated by the computer are in normal upper case characters.

To start the simulation model with an Apple that is turned off, execute the following sequence of steps:

1) Insert SSM DEMO disk into disk drive and turn Apple's main power switch ON; (this is a COLD START)
2)] LOAD SSM DEMO
3)] RUN
4) FILE NOT FOUND — Do not worry that the Apple chirps at you!
5) BREAK IN 11
6)] LOAD SSM DEMO — Be persistent!
7)] RUN
8) ENTER COMMANDS, THEN CONT
9)] CONT
10) SIM FROM 0 35 — You may simulate over a period from zero to 35 (years), or a lesser period beginning from zero (but not less than 10)
11) You will now have to wait approximately 10 minutes while the Apple computes the simulation results. While you are waiting, rest assured that the error messages (4 and 5 above) will not appear if the Apple you are using has not

been turned OFF since the last time it ran a MICRO SIMCON simulation program (this is the apparent different between a COLD START and a WARM START). A WARM START would be as above without lines 4-7.

12) When the simulation is complete, a rectangular box will be drawn on the screen and the computer will request input from the user with the prompt:

PLOT VAR#

The user may respond with any of the following:

a) n — where n is the number from 1 to 20 corresponding to an indicator variable generated by the simulation model (see Table 3 in this report). For example, if the user types a 4 followed by a carriage return (required to terminate any input line), the computer will plot the total lake trout biomass (in metric tons) that has been calculated for the period of the simulation. Only the last 30 years will be shown as the first 5 years of results are not displayed on the screen. As the results are plotted, the maximum value for the Y-axis scaling will appear on a text line at the bottom of the plotting rectangle.

b) n/30 — This response will cause indicator variable number n to be plotted on a Y-axis scale of 0 to 30 (obviously not appropriate scaling for variable 4 discussed above). This allows the user to set a particular scaling value in order to compare biomass for two or more species.

c) n/1E4 P — This will plot a series of points for variable n scaled to a maximum value of ten thousand. The P parameter in this command suppresses the lines that would otherwise connect the points.

d) G — This clears the screen of any previously plotted results.

e) n ƀ CI — Plots variable n in any of the Apple colors numbered from 1 to 6. The "ƀ" represents a blank, the "C" character is required and the "I" is a numeric character from 1 to 6. Note that a command of 9 ƀ C 4 will appear to erase variable 9 from the screen if this variable has previously been plotted in a color other than 4. This is because color 4 is BLACK.

!!! Be very careful in using the following four commands!!!

f) S filename — Will cause the computer to store the current image of the graphics screen in a file by the name specified in the "filename" argument. This file will be written onto the disk currently residing in the disk drive.

g) R filename — This will ERASE THE CURRENT SCREEN IMAGE and replace it with an image previously stored by an S filename command.

h) (carriage return) The "return" key will send you back to step 8 above. That is, the computer will prepare for another simulation run. This means that you will have to wait another ten minutes or so to look at some new simulation results.

i) (Control C) This command will interrupt the computer from whatever it is doing. You may now type TEXT to eliminate the plotting rectangle and you can make whatever changes you wish in the basic structure of the simulation model or, perhaps you could change some of the initial values of the variables. To examine the current value of any of the variables in the model type PRINT nn where nn is the name of a variable in the model. For example, PRINT LT will display the current value for the instantaneous lake trout mortality coefficient.

Return to step 7 to re-run the model.

APPENDIX B

Scenario Generation

The SALMONID/LAMPREY DEMO disk is loaded with four demonstration scenarios that provide differing sets of initial conditions for contrasting a few management options. The table below identifies the basic differences between these scenarios and identifies them by name.

Initially, the model specifies that there is a very small native lake trout population and that stocking programs began at some previous time with 3 million trout per year, 6 million chinook, and 3 million coho. Lamprey control is at a fairly high level with a maximum of 50,000 parasitic lampreys in the lake. The model also assumes that hatchery trout will reproduce on a schedule similar to native trout and that the commercial fishery is essentially unregulated, i.e. responding only to fish availability and markets.

Alternate Scenario	Conditions Modelled
LCS	Cessation of lamprey control after 15 years (other conditions as specified above)
TSS	Cessation of lake trout stocking after 15 years
RFS	Unregulated sport fishery but effort controls applied to the commercial fishery.
BLS	This scenario restores the initial conditions discussed above.

To run a particular scenario, execute the steps 1-12 specified in Appendix A. When you have examined the results of the initial scenario to your own satisfaction, execute a CONTROL C (step 12i of Appendix A). Now choose the name of the alternate scenario you wish to examine, for example, LCS, and execute the following command:

E X E C ƀ L C S (Carriage Return)

A short series of square left brackets will appear vertically on the screen. Now, type RUN as in step 7 of Appendix A. In approximately 10 minutes you can examine the results of the LCS scenario.

One other useful file named ZM VALUES exists on the demonstration disk. This file allows the user to specify a constant set of maximum sealing values for the Y-axis so that comparisons between scenarios can be drawn without confounding by differing output scales. To prepare a simulation run using these fixed maximum scaling values, execute:

EXEC ZM VALUES prior to RUNning the model.

Each of the scenario files and the scaling file cause changes in the simulation program. To reinitialize the model to its original condition after running an alternate scenario, simply LOAD SSM DEMO, i.e. return to step 6 of Appendix A.

The contents of the scaling file and the alternative scenario files are listed below so the user can see which variables have been altered in order to generate the various changes in these scenarios.

```
]
]
]

] EXEC BLS

1 DIM 2(20,35),ZM(20)
130 EL(1) = 1E6:EL(2) = 20000:EL(3) = 155000:EL(4) = 200000:EL(5) = 100000:EL(6) =
      150000
2100 REM
3050 REM
10090 zs = zs + 5

] EXEC TSS

1 DIM Z(20,35),ZM(20)
130 EL(1) = 1E6:EL(2) = 20000:EL(3) = 155000:EL(4) = 200000:EL(5) = 100000:EL(6) =
      150000
2100 REM
3050 IF TI = 15 THEN TF = 0
10090 ZS = ZS + 5

] EXEC LCS

1 DIM 2(20,35),ZM(20)
130 EL(1) = 1E6:EL(2) = 20000:EL(3) = 155000:EL(4) = 200000:EL(5) = 100000:EL(6) =
      150000
2100 IF TI = 15 THEN L = 5E5
3050 REM
10090 ZS = ZS + 5

] EXEC RFS

1 DIM 2(20,35),ZM(20)
130 EL(1) = 1E9:EL(2) = 1000:EL(3) = 15500:EL(4) = 2000:EL(5) = 100:EL(6) = 1500
2100 REM
3050 REM
10090 zs = ZS + 5

] EXEC ZM VALUES

10102 ZM(1) + 1.5E6:ZM(2) = 4.5E3:ZM(3) = 1:ZM(4) = 3E4:ZM(5) = 12:ZM(6)= 1.6E8:ZM(7)
      =5E3
10104 ZM(8) = 4E3:ZM(9) = 1E4:ZM(10) = 1E4:ZM(11) = 5:ZM(12) = 5:ZM(13)=.25E6:ZM(14)
      = 3.5E6:ZM(15) = 2E3:ZM(16) = 2E5:ZM(17) = 25E3:ZM(18) = 30E3:ZM(19) =
      2E5:ZM(20) = 5E3
```

APPENDIX C

Capturing Multiple Scenarios

The following procedure and the program "OUTPUT SAVER" were developed by C. K. Minns for the purpose of contrasting the outcomes of several different scenarios. OUTPUT SAVER allows capture of scenario results (up to 20 indicator variables per simulation) from individual simulations. Up to 4 of these "saved results" files may be linked together in a single demonstration. To capture new scenarios:

1. RUN SIMCON
2. LOAD SSM DEMO (or whatever simulation model you wish to run)
3. EXEC OUTPUT SAVER
4. Make whatever changes you desire in the initial conditions and/or functional relationships in the model.
5. RUN This executes the new simulation and stores the values of the indicator variables if you respond as in step 6 below.
6. PLOT VAR # -- DS This saves SCENARIO results to the disk under the filename specified in step 7.
7. ENTER FILE NAME -- RESULTS1 (or whatever you want to name the file).

To display results of up to 4 different simulations:
(from a cold start)

1) RUN SIMCON
2) RUN SIMDEMO
3) ENTER COMMANDS, THEN CONT
4) CONT
5) SIM FROM -- GR This response opens the graphics window on the screen.
6) PLOT VAR # -- DL This loads the first 20 indicators into variable locations 1 through 20.
7) ENTER FILE NAME -- RESULTS1 This specifies the filename containing the previously saved results of a simulation.

Repeat steps 6 and 7 no more than 3 additional times.

8) PLOT VAR# -- N This response allows you to display the NAMES of the first 20 indicator variables (rather than their numbers).

9) ENTER NAMESFILE NAME -- SSM NAMES These are the variable names assigned to indicator variables 1-20 for the Sault Ste. Marie model.

10) PLOT VAR# -- 4 This will cause the lake trout biomass to be plotted on the screen with a variable name (LAKE TROUT BIOMASS) in the text window below the graphics screen. If you have saved the results of 4 simulation runs and wish to see the lake trout biomass plotted for each one, simply answer the prompt in step 10 in the following order: 64, 44, 24, 4. Note that any order which does not end with variable number 4 will not display the NAMESFILE label.

APPENDIX D

Acknowledgements and Disclaimer

It is impossible to properly acknowledge the efforts of all those who have contributed to the synthesis of information reflected in this adaptive management workshop. Most of whatever credit is due belongs to the earlier legions of managers and researchers who have pondered Great Lakes fishery management over the past century. The small group of contemporary practitioners who assembled the collection of rules manifest in this simple simulation model must carry the burden for inaccuracies of fact and misinterpretations inevitably buried within this model. We harbour no illusions that this is a "correct" reflection of reality. But, we can attest to the fact that the ideas examined during construction of this model have stimulated many of the participants to identify key uncertainties in their own understanding of Great Lakes salmonid management. We hope that the rigour of this experience has been as refreshing and rewarding to the other participants as it has been to us.

APPENDIX E

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APPENDIX F

Program Listings

```
1  DIM Z(2Ø,35),ZM(2Ø)
2  DIM WA(9),WL(9),WB(9),WS(5),WT(3),WU(3)
3  DIM
TA(1Ø),TW(1Ø),TC(5),TH(6),T6(6),TQ(6),T1(5),TU(5),T9(6),TX(1Ø),TV(6)
4  DIM LA(6),LC(6),LR(6),LF(2,6)
5  DIM P(6),PK(5,6),PC(5,6)
6  DIM EP(7),FE(6),FR(6),GF(6),EM(6),EL(6),GØ(7),G1(7),G2(7)
1Ø  FOR I = 1 TO 2Ø:ZM(I) = Ø: NEXT :NV = 2Ø
11  IF  PEEK (1Ø4) <  > 64 THEN  POKE 1Ø4,64: POKE 1Ø3,1: POKE
16384,Ø: PRINT  CHR$ (4);"RUN SIMCON"
12  PRINT "ENTER COMMANDS,THEN CONT": END
14  INPUT "SIM FROM ";A$: IF  LEFT$ (A$,2) = "GR" THEN 1Ø1ØØ
15 ZS =  VAL ( LEFT$ (A$,2)):NT =  VAL ( RIGHT$ (A$,3))
16  IF NT < 1 THEN NT =  VAL ( RIGHT$ (A$,2))
18  FOR TIME = ZS TO NT
9Ø  IF TI > Ø THEN 1ØØØ
91 I1 = 1:I2 = 2:I3 = 3:I4 = 4:I5 = 5:I6 = 6:I7 = 7:I8 = 8:I9 = 9
92 A = 582ØØ:V = 487Ø:G6 = 1.Ø6
93 S(1) = 3E6:S(2) = 6E6:LD = 1E6
94 IØ = Ø:II = 1Ø:L = 5E4
11Ø GA = 15ØØ:GB = .Ø2:GG = .Ø2:GK = 16:FE(1) = 4ØØØ
122 EP(1) = 45:EP(2) = 45:EP(3) = Ø:EP(4) = 2ØØØ:EP(5) = Ø:EP(6) =
25ØØ:EP(7) = 23ØØ
124 FE(4) = 15ØØØ:FE(5) = 6ØØØ:FE(6) = 12ØØØ
125 G3 = .Ø3:FL = 1ØØØØØØØ:FT = 9ØØØØØØ:FE(3) = 144ØØ:FE(2) = 15ØØ
126 FR(1) = 8:FR(2) = 4ØØ:FR(3) = 3ØØ:FR(4) = 2ØØ:FR(5) = 2ØØ:FR(6) =
25Ø
127 GF(1) = Ø:GF(2) = 4ØØ:GF(3) = 3ØØ:GF(4) = 2ØØ:GF(5) = 2ØØ:GF(6) =
25Ø:EM(1) = Ø:EM(2) = 2ØØ
128 EM(3) = 36Ø:EM(4) = 2ØØ:EM(5) = 2ØØ:EM(6) = 9Ø
13Ø EL(1) = 1E6:EL(2) = 2ØØØØ:EL(3) = 155ØØØ:EL(4) = 2ØØØØØ:EL(5) =
1ØØØØØ:EL(6) = 15ØØØØ
15Ø  REM
2Ø1 M1 = 3.8E - 5:M2 = 1:M3 = 356:M5 = 3.42:M4 = .292:K = 3.28E - 7
2Ø5 LR(1) = .1:LR(2) = .2:LR(3) = .4:LR(4) = .4:LR(5) = .4:LR(6) = .Ø5
2Ø6 LZ = .33:LF(2,6) = 28Ø
3ØØ  REM
3Ø1 TV(1) = 1ØØØ:TV(2) = 1ØØØ:TV(3) = 5ØØ:TV(4) = 15ØØ:TV(5) =
15ØØ:TV(6) = 1ØØØ
3Ø2 T2 = 1:T3 = 1Ø:T4 = 5
3Ø4 TØ = .ØØ1:TN = .26:TS = 1.2:TD = 5ØØØØ:TR = 15E6:TF = 3E6
3Ø5  FOR J = T2 TO T3:TA(J) = 1Ø: NEXT J
3Ø6 TX(1) = 91:TX(2) = 182:TX(3) = 4Ø9:TX(5) = 58Ø:TX(6) = 91Ø:TX(7) =
91Ø:TX(8) = 137Ø:TX(9) = 137Ø
3Ø7 T1(1) = 1:T1(2) = 1:T1(3) = 1:T1(4) = 1:T1(5) = 1:TX(1Ø) =
182Ø:TX(4) = 48Ø
3Ø8 TQ(1) = .ØØØ1:TQ(2) = Ø:TQ(3) = Ø:TQ(4) = 1.65E - 5:TQ(5) = 3.3E -
5:TQ(6) = 1.26E - 5
31Ø U1 = 1E6:U2 = 34:U3 = .ØØØ54:U4 = .ØØ428:U5 = 1.779:U8 = 8.8E -
3:U9 = 1ØØ:U6 = .5496:UØ = 1:UP = Ø
```

```
311 UP = 1
312  FOR J = T2 TO T3:UR(J) = T2: NEXT
313 TW(1) = 34:TW(2) = 107:TW(3) = 249:TW(4) = 573:TW(5) = 950:TW(6) =
1141:TW(7) = 2136
400 WN = 6:TW(8) = 2856:TW(9) = 3948:TW(10) = 6070
410  FOR I = 0 TO 8: READ WA(I),WL(I):WA(I) = WA(I) * A / 3: NEXT I
415  DATA
6E5,0,620,160,317,260,162,343,83,387,42,420,22,447,11,471,6,475
430 X1 = 1.48E - 9:X2 = 3.31:X3 = 0.4:X4 = 0
431 X5 = 475:X6 = 9000:X8 =  - 7.26:X9 =  - 3.75E - 6 / A:XA = 160
432 XB = 400:XC = 425:XD = 1 / (XC - XB):XE = 3.3E - 5:XF = 0.5:XI =
5.5E - 5:XJ = 0.83
433 XK =  - 4.2E - 4 / A:YL = 0.2
455 YA = 3E - 4:YD = 3E - 5:YE = 3.3E - 6:YF = 0.25:YG = 0.57:YH =
0.22:YI = 5:YJ = 0.15:YK = 0.34
465 YM = 0.05:YU = 1E3:YV = 2.39E - 9:YW = 3.291:WS(3) = YL *
S(2):WT(3) = YK + 3
500  IF TI > 0 GOTO 1000
501 O1 = 1:O2 = 2:O3 = 3:O4 = 4:O5 = 5:O6 = 6:O7 = 7
505 P1 = 2E4:P2 = 2E4:P3 = 1E3:P4 = 2E4:P5 = 2E3
507 R1 = 2E - 5:R2 = 3.3E - 5
520 R5 = .60:R7 = 7.5E - 7:R8 = 1.7E - 6:R9 = 6.25E - 6:R0 = 1E5
525 RA = .8:RG = .67:RL = 1.5:RM = 2.5E - 5:RB = .4
540 RN = .3:RO = P1:RP = .3:RQ = P2
551 RC = .67:RD = .63:RF = 1.5E - 5:RS = .5:RT = .5
554 RI = .67:RJ = 1.6E - 6:RK = 1E4
556 RU = 1E4:RV = .3E - 3:RW = .998:RX = 1.0E - 8:RY = 1E5:RZ = 1.7E -
5
560 QA = .3:QB = P3:QC = .3:QD = P4:P6 = P4 / RV
575 QE = 2E3:QF = 3:QG = .3
580 QW = .8:QV = .2
590 P(1) = P1:P(2) = P2:P(3) = P3:P(4) = P4:P(5) = P5:P(6) = P6
595 OR =  RND ( - 1)
680 G0(1) = 100:G0(2) = 100:G0(3) = 0:G0(4) = 3000:G0(5) = 0:G0(6) =
5500:G0(7) = 4000
681 G1(1) = 49E6:G1(2) = 49E6:G1(3) = 1E3:G1(4) = 45E4
682 G1(5) = 1E3:G1(6) = 17E5:G1(7) = 1.325E6
685 G2(1) = 5.5:G2(2) = 5.5:G2(3) = 0:G2(4) = 650:G2(5) = 0:G2(6) =
1000:G2(7) = 1000
690 GS = 750:GC = .15:FZ = 3500000:EA = 1:GD = .05:EC = .0009:ES =
.0003:GT = 0.22
1000  REM  BEGINNING OF SIMULATION
1100 FR(1) = TF(1) + WP / (FE(1) + .1):FW = FR(1) * FR(1):FE(1) = 1 +
GA * FW / ((GB + GG) * (GK + FW))
1200  FOR I = I2 TO I6:FR(I) = 0: FOR J = I2 TO I4:FR(I) = FR(I) +
PK(J,I) * EP(J): NEXT J
1201 FR(I) = FR(I) + TF(I) * EP(7) + EP(6) * WH(I) / (FE(I) + .01):
NEXT I
1250 GI =  - G3:FO = FL - FT: IF FO = 0 THEN FO = .01
1255  IF FO > I0 THEN GI = FO / (FT * G6)
1300  FOR I = I2 TO I6:FW = FE(I): IF FW = 0 THEN FW = EM(I)
```

```
1305 FE(I) = FE(I) + GI * FW * (FR(I) - GF(I)) * FT / (GF(I) * FO): IF
FE(I) < EM(I) THEN FE(I) = EM(I)
1310  IF FE(I) > EL(I) THEN FE(I) = EL(I)
1315  NEXT I
2100  REM
2310 LX = 0:LY = 0
2315  FOR J = I3 TO II:LX = LX + TA(J):LY = TA(J) * TL(J) + LY: NEXT
:LF(1,1) = LX:LF(2,1) = LY / LX
2325 LF(1,2) = WA(9):LF(2,2) = WL(9):LF(1,6) = P(6)
2330  FOR J = I1 TO I3:J1 = 2 + J:LF(1,J1) = WS(J):LF(2,J1) = WJ(J):
NEXT :KK = 0
2340  FOR J = I1 TO I6:LC(J) = K * LF(2,J) * LR(J):KK = LC(J) * M1 *
LF(2,J) * LF(1,J) + KK: NEXT
2350 KK = L / (1 + KK)
2360  FOR J = I1 TO I6:LA(J) = LC(J) * KK:J1 = LF(2,J) / M3:J1 = J1 *
M4 * (J1 < M5) + (J1 >  = M5)
2361 LC(J) = LZ * LA(J) * (1 - J1): NEXT
2365 LT = LC(1):LW = LC(2):LP = LC(6)
2370  FOR J = I1 TO I3:J1 = 2 + J:LS(J) = LC(J1): NEXT
2600 Z(11,TI) = LA(1):Z(12,TI) = LA(2)
3050  REM
3140 T = 0:TY = 0:TB = 0:TC = 0
3150  FOR J = T2 TO T3:TB = TB + ((TA(J) * TW(J)) / U1):TM = U3 *
TW(J) - U4
3160 TL(J) = 10 * (TW(J) / U8) ^ .33
3230  IF TM < 0 THEN TM = 0
3240  IF TM > 1 THEN TM = 1
3250 T = T + TM * TA(J) * U0
3255 TC = TC + TM * TA(J) * J
3260  IF TM > 0 THEN TE = TM * TA(J) * (U5 * TW(J) - U6) * (UR(J) + UP
* (1 - UR(J)))
3270 TY = TY + TE
3280  NEXT J
3290 TY = ((TY * T0))
3292 UR(0) = TY / (TY + TF):TY = TY + TF
3300 TJ = 0: FOR J = T2 TO T4:TJ = TJ + (P(J) * T1(J)): NEXT J
3330 TT = 0:U6 = TS * TB / (TJ + TD): FOR J = T2 TO T4:TK = P(J) *
T1(J) * U6:TT = TT + TK
3331 TU(J) = TK / P(J): NEXT
3380  FOR M = 1 TO 6:T6(M) = 0:T9(M) = T0(M) * FE(M): NEXT
3390  FOR J = T2 TO T3:TG = TX(J) * (TT / TB) / TS:TW(J) = TW(J) + TG
3450 T5 = 0:TZ = LT: IF J < 4 THEN TZ = 0
3460  FOR M = 1 TO 6: IF TW(J) > TV(M) THEN T5 = T5 + T9(M)
3461  NEXT
3465  IF J < 4 THEN T5 = T5 + T9(3)
3500 TZ = T5 + TN + TZ:T8 = 1 -  EXP ( - TZ):TA(J) = TA(J) * (1 - T8)
3510 U7 = TA(J) * T8 * TW(J) / (TZ * U1)
3520  IF J < 4 THEN T6(3) = T6(3) + U7 * T9(3)
3525 UH = 0
3530  FOR M = 1 TO 6: IF TW(J) > TV(M) THEN T6(M) = T6(M) + U7 *
T9(M):UH = UH + T6(M)
```

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3540  NEXT : NEXT
3545 UD = TA(T3) + TA(T3 - 1)
3550 TW(T3) = (TW(T3) * TA(T3) + TW(T3 - 1) * TA(T3 - 1)) / UD
3555 UR(T3) = (TA(T3) * UR(T3) + TA(T3 - 1) * UR(T3 - 1)) / UD
3570 TA(T3) = TA(T3) + TA(T3 - 1)
3575 VA = TC / T
3580  FOR J = T3 - 2 TO T2 STEP  - 1:TA(J + 1) = TA(J):TW(J + 1) =
TW(J):UR(J + 1) = UR(J): NEXT
3581 UR(1) = UR(0)
3620 TW(1) = 34:TA(1) = TY:Z(1,TI) = T:Z(2,TI) = UH:Z(3,TI) =
UR(1):Z(4,TI) = TB
3650  FOR I = I1 TO I6:TH(I) = T6(I):TF(I) = T6(I) / (FE(I) + .0001):
NEXT I
3660 Z(13,TI) = TY
4010 WB = 0: FOR I = I1 TO WN:WB(I) = X1 * WL(I) ^ X2:WB = WB + WB(I)
* WA(I): NEXT
4020 WW = X3 + X4 * WB: FOR I = I1 TO I7:WH(I) = 0: NEXT I
4025 XG = XE * FE(6):XL = XI * (FE(4) + XF * FE(5))
4030  FOR I = 1 TO WN
4040  IF WL(I) < XB THEN WY =  EXP ( - WW): GOTO 4150
4050  IF WL(I) >  = XB THEN WV = (WL(I) - XB) * XD: IF WV > 1 THEN WV
= 1
4070 WE = 0: IF WL(I) >  = XC THEN WE = XG
4090 WX = WW + LW + WV * XL + WE
4100 WY =  EXP ( - WX)
4110 WC = WB(I) * (1 - WY) * WA(I) / WX
4120 WH(4) = WH(4) + WC * WV * XL:WH(6) = WH(6) + WC * WE
4150 WA(I) = WA(I) * WY
4160  NEXT I
4165 WH(5) = WH(4) * XF * FE(5) * XI / XL:WH(4) = WH(4) * FE(4) * XI /
XL
4170  FOR I = I4 TO I6:WH(I) = WH(I) / YU: NEXT I
4200 WG = XJ + XK * WB: FOR I = I1 TO WN:WL(I) = WL(I) * WG + XA: NEXT
I
4300 WE = 0: FOR I = 1 TO WN
4310  IF WL(I) < XB THEN WV = 0
4315  IF WL(I) >  = XB THEN WV = (WL(I) - XB) / (X5 - XB): IF WV > 1
THEN WV = 1
4320 WE = WE + X6 * WA(I) * WB(I) * WV
4330  NEXT I
4370 WL(WN) = WA(WN) * WL(WN) + WA(WN - 1) * WL(WN - 1)
4380 WA(WN) = WA(WN) + WA(WN - 1):WL(WN) = WL(WN) / WA(WN)
4385  FOR I = WN - I2 TO I1 STEP  - I1:WA(I + 1) = WA(I):WL(I + 1) =
WL(I): NEXT I
4387  GOSUB 12000
4390 WA(1) = WA(0) *  EXP (.5 * ZR + X8 + X9 * WA(0)):WA(0) = WE:WL(1)
= XA
4400 WA(9) = 0:WL(9) = 0
4405  FOR I = I3 TO WN: IF WL(I) < XB THEN 4415
4410 WA(9) = WA(9) + WA(I):WL(9) = WL(9) + WA(I) * WL(I)
4415  NEXT I
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4420  IF WA(9) > 0 THEN WL(9) = WL(9) / WA(9)
4450 Z(9,TI) = WH(4) + WH(5) + WH(6):Z(10,TI) = WB / YU
4510 YB = FE(1) * YA:YT = P(1) + P(2):YC = YD * YT / (1 + YE * YT)
4520 WS(1) = YF * S(1):WT(1) = YG + YC
4530 WX = YH + LS(1) + YB:WY =  EXP ( - WX):WS(5) = WS(1) * WY
4540 WP = WS(1) * (1 - WY) * YB * WT(1) / WX
4550 WT = YI * WS(1) * YC
4600 WX = YH + LS(2) + YB:WY =  EXP ( - WX):WS(4) = WS(3) * WY
4605 WT(3) = WT(2) + YC
4610 WP = WP + WS(3) * YB * WT(3) * (1 - WY) / WX
4620 WT = WT + YI * WS(3) * YC
4650 WS(2) = YJ * S(2):WT(2) = YK + YC
4660 WX = YH + LS(2) + YB:WY =  EXP ( - WX):WS(3) = WS(2) * WY
4670 WP = WP + WS(2) * (1 - WY) * YB * WT(2) / WX
4680 WT = WT + YI * WS(2) * YC
4700 WP = WP / YU:WK = (WS(5) * WT(1) + WS(4) * WT(3)) / YU
4720 WR = S(1) * YL + S(2) * YM:WP(1) = WT / YU / YT:WP(2) = WP(1)
4740  FOR I = I1 TO I3:WU(I) = (WT(I) / YV) ^ (1 / YW): NEXT
4750 Z(8,TI) = WP:Z(15,TI) = WK
5000 R3 = R1 * FE(Q2):R4 = R2 * FE(Q3)
5155 PT = P1 + P2
5170 R6 = 0: IF PT < R0 GOTO 5220
5180 R6 = R8:QR =  RND (1)
5190  IF QR < QV THEN R6 = R7
5200  IF QR >  = QW THEN R6 = R9
5220 QH = R5 + R6 * (PT - R0):QS = QH:QH = QH + TU(1) + WP(1)
5250 QM =  EXP ( - QH)
5260 PH = P2 *  EXP (RL - RM * P2):PX = P2:PY = P1
5270 QI = QS + TU(2) + WP(2) + R3:QT = QI:QN =  EXP ( - QI)
5290 P1 = P1 * QM * RG + RA * RG * QM * (P1 - RN * RO) + PH
5295 P2 = P2 * QN + RB * QN * (P2 - RP * RQ) + (1 - RG) * PY
5300 QS = QS * (Q1 - QM) / QH:QT = QT * (Q1 - QN) / QI
5310 PK(Q2,Q2) = R3 * (Q1 - QN) / QI:PC(Q2,Q2) = PX *
PK(Q2,Q2):PK(Q2,Q2) = PK(Q2,Q2) / FE(Q2) * P2
5345 QU = QS * PY + QT * PX
5350 RN = QM * RG:RO = PY:RP = QN:RQ = PX
5420 QJ = RS + TU(Q3) + WP(Q3):QK = RT + TU(Q4) + WF(Q4) + R4 + LP
5440 QO =  EXP ( - QJ):QP =  EXP ( - QK)
5450 RH = RI: IF P3 < RK GOTO 5480
5460 RH = RI + RJ * (P3 - RK): IF RH > 1 THEN RH = 1
5480 QX = RW: IF PT < RY GOTO 5520
5500 QX = RW + RX * (PT - RY): IF QX > 1 THEN QX = 1
5520 QX = (1 - QX) *  EXP ( - RZ * P4)
5525 PH = QX * RU * P4 * RF / RV:PX = P4:PY = P3
5550 P3 = P3 * QO * RH + RC * QO * RH * (P3 - QA * QB) + PH
5555 P4 = P4 * QP + RD * QP * (P4 - QC * QD) + (1 - RH) * PY
5570 PK(Q4,Q3) = R4 * (1 - QP) / QK
5580 PC(Q4,Q3) = PX * PK(Q4,Q3):PK(Q4,Q3) = PK(Q4,Q3) / FE(Q3) * P4
5610 QA = QO * RH:QB = PY:QC = QP:QD = PX
5630 P6 = P4 / RV
5710 QL = QG + TU(5) + WP(5):QR =  EXP ( - QL)
```

```
5730 PX = P5 * QR:P5 = PX * (Q1 + QF * (QE - PX)) / QE
5800 Z(16,TI) = P1 + P2:Z(17,TI) = P4:Z(18,TI) = FE(4) +
FE(5):Z(19,TI) = QU:
5900 P(1) = P1:P(2) = P2:P(3) = P3:P(4) = P4:P(5) = P5:P(6) = P6
6800  FOR I = I2 TO I4:GH(I) = 0: FOR J = I2 TO I6:GH(I) = GH(I) +
PC(I,J): NEXT J: NEXT I:GH(6) = 0
6801 GH(7) = 0: FOR J = I2 TO I6:GH(6) = GH(6) + WH(J):GH(7) = GH(7) +
TH(J): NEXT J
6825 GH(1) = GH(1) + GH(2):GH(2) = GH(1):FW = GH(6):GH(6) = GH(6) + .4
* GH(7):GH(7) = GH(7) + .4 * FW
6850  FOR I = I1 TO I7:EP(I) = (G0(I) * G1(I) + G2(I) * GH(I) * GH(I))
/ (G1(I) + GH(I) * GH(I))
6851  NEXT I
6890 FL = 0:FT = 0: FOR I = I2 TO I6: FOR J = I2 TO I4:FL = FL + EP(J)
* PC(J,I)
6891  NEXT J:FL = FL + EP(6) * WH(I) + EP(7) * TH(I):FT = FT + FE(I) *
GF(I): NEXT I
6892 Z(14,TI) = FL - FT
6894  IF Z(14,TI) < 0 THEN Z(14,TI) = 0
6895 FD = LD + (TF * GT) + WR + PT(8) + GS * FE(1) + GC * FL + FZ
6900 FP = FP + EA * 1E - 6 * (FE(1) * 1E3 / GG + FL - FD - FT):EA = EA
* (1 - GD)
6901 FI = I6 * FL + FE(1) * 1E3 / (GG + GB):ER = EC * FL + ES * FE(1)
* 1E3 / (GG + GB)
6950 Z(5,TI) = FD * 1E - 6:Z(6,TI) = FI:Z(7,TI) = FE(1)
7000 Z(20,TI) = FE(6)
12000 ZR = 2 *  RND (15) - 1:ZR =  LOG ((1 + ZR) / (1 - ZR)) / 1.82:
RETURN
```

Output Saver

```
10145  IF  LEFT$ (A$,1) = "D" THEN 14000

14000 D$ =  CHR$ (4)
14010  INPUT "ENTER FILE NAME--";B$
14020  PRINT D$;"OPEN ";B$
14030  IF  MID$ (A$,2,1) = "L" THEN 14150
14040  IF  MID$ (A$,2,1) <  > "S" THEN 10140
14050  PRINT D$;"DELETE ";B$
14060  PRINT D$;"OPEN ";B$
14070  PRINT D$;"WRITE ";B$
14080  PRINT ZS: PRINT NT: PRINT NV
14090  FOR I = 1 TO NV: PRINT ZM(I)
14100  FOR J = ZS TO NT: PRINT Z(I,J)
14110  NEXT J: NEXT I
14120  PRINT D$;"CLOSE ";B$
14130  GOTO 10140
14150  PRINT D$;"READ ";B$
14160  INPUT ZS: INPUT NT: INPUT NV
14170  FOR I = 1 TO NV: INPUT ZM(I)
14180  FOR J = ZS TO NT: INPUT Z(I,J)
14190  NEXT J: NEXT I
14200  GOTO 14120
```

```
20
POPN FEMALE LAKE TROUT
LAKE TROUT HARVEST(MT)
% NATURAL AGE1 L.TROUT
LAKE TROUT BIOMASS(<0) (MT)
MANAGEMENT COSTS ($M)
CONTR. REGIONAL INCOME ($)
ANGLING EFFORT (1E3 DAYS)
SALMON ANGLING HARVEST (MT)
WHITEFISH HARVEST (MT)
WHITEFISH BIOMASS (MT)
LAMPREY ATT.RATE LTROUT
LAMPREY ATT.RATE WFISH
# AGE 1 LAKE TROUT
COMM.FISH.NET RETURN ($)
SALMON ESCAPEMENT (MT)
TOTAL ALEWIFE BIOMASS (MT)
ADULT CISCO BIOMASS (MT)
GILLNET EFFORT (KM)
NON-PRED ALEWIFE MORT (MT)
TRAPNET EFFORT (1E2 NIGHTS)
```

SIMNAMES

```
1  DIM Z(20,50),ZM(20),ZN$(20)

10146  IF  LEFT$ (A$,1) = "N" THEN 15000

10800  PRINT ZN$(I);"--";ZM(I)

15000 D$ =  CHR$ (4)
15010  INPUT "ENTER NAMESFILE NAME--";A$
15020  PRINT D$;"OPEN ";A$
15030  PRINT D$;"READ ";A$
15040  INPUT NV
15050  FOR I = 1 TO NV
15060  INPUT ZN$(I)
15070  NEXT I
15080  PRINT D$;"CLOSE ";A$
15090  GOTO 10140
```

```
]PR#0
]LOAD CREATE NAMESFILE
]LIST

1000  DIM ZN$(20):D$ =  CHR$ (4)
1010  INPUT "ENTER FILE NAME--";A$
1020  INPUT "NUMBER OF OUTPUT VARS (<=20)? ";NV
1030  IF NV < 1 OR NV > 20 THEN 1020
1040  FOR I = 1 TO NV
1050  PRINT "NAME OF VAR(";I;") ? ";
1060  INPUT "";ZN$(I)
1070  NEXT I
1100  PRINT D$;"OPEN ";A$
1110  PRINT D$;"DELETE ";A$
1120  PRINT D$;"OPEN ";A$
1130  PRINT D$;"WRITE ";A$
1140  PRINT NV
1150  FOR I = 1 TO NV
1160  PRINT ZN$(I)
1170  NEXT I
1180  PRINT D$;"CLOSE ";A$
1190  PRINT "FILE ";A$;" IS WRITTEN"
1200  END

]LOAD SIMDEMO
]LIST

1  DIM Z(80,35),ZM(80),ZN$(80)
2 LZ = 0
10  FOR I = 1 TO 20:ZM(I) = 0: NEXT :NV = 20
11  IF  PEEK (104) <  > 64 THEN  POKE 104,64: POKE 103,1: POKE 16384,0: PRINT  CHR$ (4);"RUN
12  PRINT "ENTER COMMANDS,THEN CONT": END
14  INPUT "SIM FROM ";A$: IF  LEFT$ (A$,2) = "GR" THEN 10100
15 ZS =  VAL ( LEFT$ (A$,2)):NT =  VAL ( RIGHT$ (A$,3))
16  IF NT < 1 THEN NT =  VAL ( RIGHT$ (A$,2))
18  FOR TIME = ZS TO NT
10000  FOR J = 1 TO NV
10020  IF Z(J,TI) > ZM(J) THEN ZM(J) = Z(J,TI)
10040  IF Z(J,TI) < 0 THEN Z(J,TI) = 0
10060  NEXT
10080  NEXT TIME
10100  HGR
10120  CALL 62450: HCOLOR= 3: HPLOT 0,0 TO 0,159 TO 279,159 TO 279,0 TO 0,0: VTAB 24
10140  INPUT "PLOT VAR#";A$
10145  IF  LEFT$ (A$,1) = "D" THEN 14000
10146  IF  LEFT$ (A$,1) = "N" THEN 15000
10150  IF  LEFT$ (A$,1) = "Q" THEN  GOSUB 13000: GOTO 10140
10160  IF  LEFT$ (A$,1) <  > "S" THEN 10240
10180 A$ =  RIGHT$ (A$, LEN (A$) - 2)
10200  PRINT  CHR$ (4);"BSAVE ";A$;",A8192,L8192"
10220  GOTO 10140
10240  IF  LEFT$ (A$,1) <  > "R" THEN 10320
10260 A$ =  RIGHT$ (A$, LEN (A$) - 2)
10280  PRINT  CHR$ (4);"BLOAD ";A$;",A8192"
10300  GOTO 10140
10320 Z6 = 0:Z5 = 0
10340  REM    SEARCH FOR MAX Z3ALES
10360  FOR I = 1 TO  LEN (A$)
10380  IF  MID$ (A$,I,1) = "/" THEN 10420
10400  NEXT : GOTO 10600
10420  FOR J = I + 1 TO  LEN (A$)
10440  IF  MID$ (A$,J,1) = " " THEN 10480
10460  NEXT :J =  LEN (A$):A$ = A$ + " "
10480 Z3 =  VAL ( MID$ (A$,I + 1,J - I))
```

```
10500  IF Z6 > 0 THEN 10540
10520 Z6 = 1:Z4 = Z3: GOTO 10560
10540 Z5 = 1:XT = Z3
10560 A$ =  LEFT$ (A$,I - 1) +  RIGHT$ (A$, LEN (A$) - J)
10580  GOTO 10360
10600  IF  LEN (A$) < 3 THEN 10640
10610  IF  MID$ (A$, LEN (A$) - 1,1) <  > "C" THEN 10640
10620 ZC =  VAL ( RIGHT$ (A$,1)):A$ =  LEFT$ (A$, LEN (A$) - 2)
10630  FOR I = 1 TO  LEN (A$): IF  RIGHT$ (A$,1) <  > " " THEN 10640
10635 A$ =  LEFT$ (A$, LEN (A$) - 1): NEXT
10640 ZP = 0: IF  RIGHT$ (A$,1) <  > "P" THEN  GOTO 10700
10660 ZP = 1
10680 A$ =  LEFT$ (A$, LEN (A$) - 1)
10700  IF  LEN (A$) > 4 THEN  GOTO 11060
10720 I =  VAL ( LEFT$ (A$,2))
10740  IF A$ = "G" THEN  GOTO 10120
10760  IF A$ = "" THEN  GOTO 10
10780  IF I < 7 THEN  HCOLOR= I: IF I = 4 THEN  HCOLOR= 5
10790  IF ZC <  > 0 THEN  HCOLOR= ZC:ZC = 0
10800  PRINT ZN$(I);"—";ZM(I)
10820 Z1 = 279 / (NT - ZS):Z2 = 1: IF ZM(I) > 0 THEN Z2 = 159 / ZM(I)
10840  IF Z6 > 0 AND Z4 > ZM(I) THEN Z2 = 159 / Z4
10860  HPLOT 0,159 - Z(I,ZS) * Z2:Z8 = ZS + 1
10900  IF ZP > 0 THEN  GOTO 10980
10920  FOR J = Z8 TO NT:Z8 = J - ZS
10940  HPLOT  TO Z8 * Z1,159 - Z(I,J) * Z2: NEXT
10960  GOTO 10140
10980  FOR J = Z8 TO NT
11000 Z8 = J - ZS
11020  HPLOT Z8 * Z1 - 1,159 - Z(I,J) * Z2 TO Z8 * Z1,159 - Z(I,J) * Z2: NEXT
11040  GOTO 10140
11060  HCOLOR= 5:I =  VAL ( LEFT$ (A$,2)):J =  VAL ( RIGHT$ (A$,2)):Z1 = 1:Z2 = 1
11140  IF ZM(J) > 0 THEN Z1 = 279 / ZM(J)
11160  IF Z5 > 0 AND XT > ZM(J) THEN Z1 = 279 / XT
11200  IF ZM(I) > 0 THEN Z2 = 159 / ZM(I)
11220  IF Z6 > 0 AND Z4 > ZM(I) THEN Z2 = 159 / Z4
11240  HCOLOR= 3
11250  IF ZC <  > 0 THEN  HCOLOR= ZC:ZC = 0
11260  HPLOT Z(J,ZS) * Z1,159 - Z(I,ZS) * Z2:Z7 = ZS + 1
11300  IF ZP > 0 THEN  GOTO 11380
11320  FOR Z8 = Z7 TO NT
11340  HPLOT  TO Z(J,Z8) * Z1,159 - Z(I,Z8) * Z2: NEXT
11360  GOTO 10140
11380  FOR Z8 = Z7 TO NT
11400  HPLOT Z(J,Z8) * Z1,159 - Z(I,Z8) * Z2: NEXT
11420  GOTO 10140
11440  END
12000 ZR = 2 *  RND (15) - 1:ZR =  LOG ((1 + ZR) / (1 - ZR)) / 1.82: RETURN
13000 D$ =  CHR$ (4):Q$ =  CHR$ (17)
13010  INPUT "PLOT TITLE?";T$
13020  PRINT D$;"PR#1"
13030  PRINT T$: POKE  - 12524,0: PRINT Q$
13040  PRINT D$;"PR#0"
13050  RETURN
14000 D$ =  CHR$ (4)
14010  INPUT "ENTER FILE NAME—";B$
14020  PRINT D$;"OPEN ";B$
14030  IF  MID$ (A$,2,1) = "L" THEN 14150
14040  IF  MID$ (A$,2,1) <  > "S" THEN 10140
14050  PRINT D$;"DELETE ";B$
14060  PRINT D$;"OPEN ";B$
14070  PRINT D$;"WRITE ";B$
14080  PRINT ZS: PRINT NT: PRINT NV
14090  FOR I = 1 TO NV: PRINT ZM(I)
14100  FOR J = ZS TO NT: PRINT Z(I,J)
14110  NEXT J: NEXT I
```

```
14120  PRINT D$;"CLOSE ";B$
14130  GOTO 10140
14150  PRINT D$;"READ ";B$
14160  INPUT ZS: INPUT NT: INPUT NV
14170  FOR I = 1 TO NV: INPUT ZM(LZ + I)
14180  FOR J = ZS TO NT: INPUT Z(LZ + I,J)
14190  NEXT J: NEXT I
14195 LZ = LZ + 20
14200  GOTO 14120
15000 D$ =  CHR$ (4)
15010  INPUT "ENTER NAMESFILE NAME--";A$
15020  PRINT D$;"OPEN ";A$
15030  PRINT D$;"READ ";A$
15040  INPUT NV
15050  FOR I = 1 TO NV
15060  INPUT ZN$(I)
15070  NEXT I
15080  PRINT D$;"CLOSE ";A$
15090  GOTO 10140
60000  REM  CAPTURES PROGRAMS IN SEQUENTIAL FILES
60020 D$ =  CHR$ (4)
60030  INPUT "ENTER FILE NAME--";A$
60040  PRINT D$;"OPEN ";A$
60050  PRINT D$;"DELETE ";A$
60060  PRINT D$;"OPEN ";A$
60065  PRINT D$;"WRITE ";A$
60070  POKE 33,30
60080  LIST 1,59999
60090  PRINT D$;"CLOSE ";A$
60100  TEXT
60110  END
```