GREAT LAKES FISHERY COMMISSION

1996 Project Completion Report[1]

Compensatory Mechanisms in Larval Sea Lamprey Populations

by:

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April 1996

[1]Project completion reports of Commission-sponsored research are made available to the Commission's Cooperators in the interest of rapid dissemination of information that may be useful in Great Lakes fishery management, research, or administration. The reader should be aware that project completion reports have not been through a peer review process and that sponsorship of the project by the Commission does not necessarily imply that the findings or conclusions are endorsed by the Commission.

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Report of a Workshop

April 10-11, 1996
Ann Arbor, Michigan

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Introduction

The sea lamprey, *Petromyzon marinus*, is an exotic fish species that has caused substantial damage to economically valuable fish stocks throughout the Great Lakes basin since its invasion of the basin early in this century. Since 1958 the U.S. and Canadian governments have undertaken to control populations of sea lamprey in order to allow recovery of the affected host populations. Principally, control has been achieved through the use of barriers that prevent access of the migratory lampreys to their spawning areas and chemicals which have been utilized as selective toxicants to the stream-dwelling larval lampreys (ammocetes). To date, extirpation of the pest has proven impractical, if not impossible, so that an important issue for the control agents has been to determine the degree of ongoing control that is economically achievable (Koonce et al. 1993). The costs of control, together with public concern about the use of a synthetic toxicant to suppress lamprey has led the Great Lakes Fishery Commission to consider alternative means of controlling sea lamprey (Great Lakes Fishery Commission 1992). The recent focus on alternative controls and economic optimization has renewed interest in a long-standing scientific issue surrounding sea lamprey control: to what extent can lamprey *compensate* for reductions in abundance caused by control measures by increasing the growth, survival, or other demographic attributes of the residual populations? This question was the focus of a workshop sponsored by the GLFC and held in Ann Arbor on April 10-11, 1996. This report summarizes the discussions that took place at this workshop.

Why is compensation important? Very simply, compensatory responses in animal populations counteract the effects of measures to control those populations. If the abundance of the juveniles in a population is reduced by 50% and as a result these juveniles survive twice as well, the adult population that results will be the same as if the population had not been reduced. Theoretically, compensation of this sort is to expected to occur whenever population growth is being regulated by *intraspecific* mechanisms, such as competition for food or space. Generally speaking, compensation is recognized to occur in fish populations - it is the basis of the well-known stock-recruitment models of Ricker (1954) and Beverton and Holt (1957). There is considerable debate, however, regarding the degree to which compensatory mechanisms have a strong regulatory influence on fish populations, particularly when they are at low population levels as is the case for sea lamprey in most areas of the Great Lakes.

Compensatory mechanisms involve density dependence. Essentially, compensation occurs whenever a demographic process such as growth or survival rates are affected by the density of the organisms in a particular area. As density declines, the likelihood that resources (food, space) limit these demographic processes will also decline. To determine whether compensatory mechanisms will affect the success of control measures we need to seek evidence of density dependent processes in lamprey populations. In recognition of the importance of this question to integrated management of sea lamprey the GLFC invited a number of lamprey experts (Table 1) to attend a two-day workshop in Ann Arbor. On the first day the invited experts made brief presentations on their research as it related to the question of compensatory mechanisms. The second day was devoted to a round-table discussion of opportunities for further analysis of existing data sets and for further data collection to address emerging questions. This report is divided into two sections, reflecting this subdivision of the workshop agenda. As well we provide an Appendix containing background material provided by the workshop participants.

Workshop Purpose

Robert Young (DFO, Sault Ste. Marie) welcomed all participants to the workshop and presented a brief summary of the rationale for and objectives of the workshop. As noted above, the primary purpose of the workshop was to discuss our current state of knowledge with regards to compensatory mechanisms in lamprey populations and examine options for further research (data collection, data analysis). Rob noted at least three reasons for wanting to understand more about compensatory mechanisms:

- to evaluate the likely effectiveness of alternative control strategies (e.g., barriers, sterile male);
- to understand the extent to which compensation occurs in residual populations of ammocetes (after TFM treatment); and
- because compensatory mechanisms are of general interest in the study of population dynamics, and sea lamprey control provides an unusual opportunity to study these mechanisms.

Rob introduced several participants whom he had asked to prepare presentations on the subject of compensation in lamprey with a view towards providing workshop participants with an overview of (1) who is collecting relevant data and (2) what we have learned so far from these studies. The first afternoon of the workshop was dedicated to the presentations and subsequent discussion. Rob then proposed that the second day of the workshop be given over to discussions of "where to from here":

- what additional analyses should be completed on existing data?
- should we collect more data and if so, what data and who should collect it?
- should we be considering modifications to the IMSL (Integrated Management of Sea Lamprey) model (see Christie presentation below) to reflect new knowledge about compensatory mechanisms?

Invited Presentations

Sea Lamprey Task Area - Steve Bowen briefly outlined the objectives of the Sea Lamprey Task

Area funded by the GLFC Board of Technical Experts (BOTE) - (Appendix 1-A). The task has two major components: (1) a behavioral, bioenergetics study of the trophic ecology of ammocetes and its relationship to habitat quality and larval density; and (2) a population-level study of density and habitat effects on lamprey recruitment (larval demographics and transformation). Further discussion of progress on these two components was deferred to later presentations (see Bowen, Morrison below).

Sterile Male Program Evaluation - Roger Bergstedt described the ongoing research program to assess the long-term success of the experimental release of sterilized male sea lampreys in the Great Lakes (Appendix 1-B). This program is explicitly concerned with compensatory mechanisms, in that the study design involves a sequence of tests to determine whether the introduction of sterile males into a spawning population ultimately leads to a reduction in the production of parasitic lamprey in the next generation. If the study demonstrates an effect up to a certain life stage (e.g., reduced production of viable eggs - already demonstrated) but not beyond that life stage (e.g., no reduction in the production of age-1 ammocetes - the object of the current phase of the study) this provides strong evidence that compensation is occurring. This study thus provides an excellent opportunity for detailed examination of compensatory mechanisms.

Sea lamprey assessment program - John Heinrich outlined the sea lamprey assessment program, a key component of the overall GLFC control program (Appendix 1-C). The primary purpose of the assessment program is to annually determine which streams should be given priority for treatment based on assessment of stream larval densities and size distributions. As well the program is used from time to time to monitor the success of chemical treatments by returning to streams after treatment - this may provide valuable data on the dynamics of residual populations which could prove useful for the assessment of density dependence (see Cuddy below). Adult monitoring is also an important element of the assessment program, and may provide useful data for looking at stock-recruitment relationships on streams where both adults and larvae are assessed (see Young below).

IMSL - LCSS model assumptions and needs Gavin Christie briefly described the IMSL sea lamprey population simulation model that is a central component of the LCSS (Lamprey Control Selection System). He noted that the ammocete submodel incorporates assumptions about density dependent survival and growth of ammocetes (Appendix 1-D). The density-dependence assumptions were derived at a 1982 workshop (Spangler and Jacobsen 1985), and have not been evaluated against empirical data since that time. Gavin also noted that the IMSL model, while having a relatively complex spatial structure, retains a very simple demographic model. He stressed the need to re-evaluate the demographic assumptions of the model and the central role that more recent evidence for compensatory mechanisms should play in this re-evaluation.

Stock and recruitment data sets Rob Young presented three sets of data that allow investigation of stock-recruitment relationships in Great Lakes sea lamprey populations: (1) St. Mary's River; (2) six Lake Superior streams, and (3) four Lake Ontario streams (Appendix 1-E). For each data set, he examined the fit of the data to Ricker, Beverton-Holt and density-independent (i.e. linear) stock-recruitment models, primarily by regressing log(recruits/spawner) versus the abundance of spawners.

For the St. Mary's River dataset, he used spawner estimates derived from a tagging program. By assuming an average generation time of six years he was able to use spawner abundance six years as his recruitment estimate. The time series of spawner abundance (1965-1992) show a trend towards declining abundance during the 1965-1975 period (early control program), followed by a gradual but steady increase since about 1980. The analysis showed a weak fit to a Ricker model which suggests density-dependence. Rob noted, however, that the increase in spawners in recent years is correlated with a rise in bloater biomass in northern Lake Huron. Bloater are prey for recently transformed lamprey; thus the increase in spawners may be due to changing growth/survival rates for post-transformed lamprey. This implies a non-stationary stock-recruitment relationship (i.e., one that is changing over time) which poses problems for an a analysis that implicitly assumes a stationary relationship.

The Lake Superior and Lake Ontario datasets were derived from trapping data for spawning phase lamprey (stock) and fall assessment estimates of age 1 larvae in the subsequent year (recruitment). For Lake Ontario an index of spawner abundance was also derived from the Humber River trap, where a large fraction of the total Lake Ontario spawner trapping occurs. The results for both lakes are variable, with some streams showing evidence of compensation (significant declining log(recruits/stock) versus stock) but others not. When all streams were combined for Lake Superior in an analysis of covariance, there was a weak effect of spawner abundance, although differences among streams (possibility in terms of productive potential) may have seriously confounded this effect. Few of the streams showed a complete absence of density dependent effects (Appendix 1-E).

<u>Density-growth interactions interpreted from assessment data</u> Doug Cuddy presented an analysis of larval assessment data which looked for covariates that explained variation among populations (streams) in lengths of age 1+ ammocetes (Appendix 1-F). There was no correlation between larval density (as estimated from electrofishing CPUE and Type 1 habitat area) and size at age 1+. On the other hand, in those cases where assessments were conducted in both years 1 and 2 after treatment there was consistent evidence of smaller size-at-age for the second cohort than for the first, suggestive of a between-cohort interaction. Multiple regression analysis of the data revealed weak correlations between growth and latitude (growing degree-days) and between growth and stream alkalinity. These two effects are confounded, however, as the high alkalinity streams tend to be in the southern part of the basin.

<u>Density effects on ammocete assimilation efficiency</u> Steve Bowen presented findings from his part of the BOTE Sea Lamprey Task Area, in which he looked at habitat-density-feeding interactions in ammocetes.. They found highest densities of ammocetes in a subset of Type I habitats they referred to as Type IA habitats. These areas tend to be depositional areas in streams, and have the highest food quality for ammocetes. Although the food quality is higher in these areas, the higher densities of ammocetes in these areas tended to counteract the potential beneficial effects of high food quality on growth rates. In both laboratory and field studies, they

observed a reduction in assimilation efficiency with increased ammocete density. Thus density-dependent digestive efficiency appears to compensate for the higher food quality present in the preferred, Type IA habitats.

Density effects at the population level Bruce Morrison summarized progress on the second half of the BOTE lamprey task, led by Bill Beamish (Appendix 1-G). This multi-year research project began in 1995, so only a single year of field research has been completed. The objective of the study is to investigate the influence of larval densities on demographic parameters, particularly sex ratios which have previously been shown to vary widely in lamprey populations. Several streams were surveyed in 1995 and some of these streams will be treated with TFM and subsequently re-seeded with a much smaller number of ammocetes than were present prior to treatment. Demographic responses will then be monitored. Perhaps the most surprising result to so far is that in several of the study streams, the investigators have found numerous individuals with highly atypical gonads, rendering sex determination problematical. This has made the calculation of population sex ratios for these streams impossible, because these individuals of unknown sex sometimes comprise in excess of 50% of the individuals whose gonads were examined.

Density effects on sea lamprey transformation rates Henry Quinlan presented the results of an analysis that he and Mike Fodale completed to ask the question: Is there a correlation between larval density and rate of transformation? (Appendix 1-H). They examined data collected from a number of streams during TFM treatment to determine the relationship (using logistic regression techniques) between lamprey length and the likelihood of the individual being a transformer. These data were combined with data from the same streams on larval densities to look at whether a relationship existed between density and probability of transformation at length (or length at 10% transformation). Although there are obvious outliers (see Appendix 1-H), there does appear to be a significant trend for lamprey to transform at a smaller size as densities increase.

Salem Creek post-treatment larval sea lamprey study Jerry Weise presented his results from several years' study of Salem Creek, a tributary to Lake Ontario, in which he has monitored patterns of growth and survival of four year-classes of lamprey (Appendix 1-I). This dataset provides a detailed confirmation of the among-stream evidence presented earlier by Cuddy, that the first year class subsequent to treatment produces a significantly higher biomass of larval lamprey than any subsequent year classes. Growth and survival of larval year classes was significantly dependent on the existing lamprey biomass in the stream. The Salem Creek study demonstrated that these effects were primarily manifested in the first year of life. Cohorts after the first post-colonization cohort were significantly smaller in size and lower in abundance than the first cohort. After age 1, growth rates did not differ greatly among cohorts. Jerry recommended that further studies be conducted in systems where recruitment can be controlled such as above existing barriers to further elucidate these compensatory mechanisms.

Discussion of Future Research/Data Analysis Needs

The second day of the workshop was dedicated to discussing the implications of the results presented on the first afternoon and considering options for further data collection and analyses of existing data. The following paragraphs summarize the salient details of these discussions.

First, the most obvious conclusion from the presentations was that evidence exists on a variety of fronts that compensatory mechanisms are operating on larval lamprey populations, even in the contemporary situation of reduced densities due to the control program. Larval feeding efficiency (Bowen), growth (Cuddy, Weise), survival (Weise) and transformation rates (Quinlan) all showed indications of density-dependent variations among populations. These studies do not tell enough about the strength of the compensatory mechanisms to allow inferences concerning the likely implications for alternative control strategies such as sterile male release and barriers. On the other hand, these findings confirm the importance of current research projects such as the sterile male release long term evaluation (Bergstedt) and the population component of the BOTE sea lamprey task (Beamish).

In fisheries management, compensatory mechanisms are commonly thought of in the context of the concept of stock and recruitment. As is the case for heavily exploited fish stocks, the concern for sea lamprey control centres around the character of the stock-recruitment relationship at low stock densities. The observation that sea lamprey populations were far more abundant prior to the control program strongly suggests that populations are presently operating at levels far below their carrying capacity. Normally it is presumed that density dependent mechanisms become less important as stocks decline in abundance below their unexploited (i.e., uncontrolled) carrying capacity. Nevertheless, the evidence discussed on the first day suggests that some compensatory mechanisms continue to operate, particularly in the sequence of years during which a stream is recolonized following treatment. This is an important finding for sea lamprey management, and one worthy of further investigation.

Perhaps the best evidence for compensatory mechanisms comes from Salem Creek, where the first cohort to colonize the stream after treatment enjoys greater survival and growth in their first year of life than do subsequent cohorts. These data come from a single inter-treatment period and thus potentially confounding year effects cannot be eliminated as an alternative explanation (i.e., the first year of the study may have happened to be an especially good year for larval lamprey growth and survival). The assessment data presented by Cuddy, however, suggest that a similar pattern is seen in other streams and years. Together these results suggest that the first year class of ammocetes after treatment partially saturates the available quality habitat, thereby reducing the available resources for growth and survival of subsequent year classes.

Salem Creek is known to be one of the more productive lamprey streams in the basin. It is thus important to be able to determine whether the Salem results are general, or whether the magnitude of compensatory effects is influenced by other, stream-specific factors such as productivity or growing season length. One possibility would be to implement a series of intensive studies similar to the Salem Creek project on contrasting streams throughout the basin. Perhaps more attractive, however, would be to adjust assessment priorities and procedures to obtain critical information on compensation by taking advantage of the extensive nature of the assessment program. The main implication of this recommendation for the assessment program would be to give priority to return visits to a subset of assessment streams, so that changes in cohort biomass in the years following treatment could be monitored.

Ideally, the data for a multi-stream assessment project would include information on densities, lengths, weights, and ages for all ammocetes sampled in the survey. This is unlikely to be practical for routine assessment, and would thus greatly restrict the number of streams that could be surveyed in this manner. A viable alternative is to simply collect density and length information, both of which are routine components of assessment. Length-frequency data could then be used to distinguish age 1 ammocetes from older larvae. Weight-length relationships could be used to convert lengths to weights and thus compute the biomass of age-1 larvae in any year surveyed. Because the Salem Creek data suggest that compensation occurs during the first year of life, consecutive years of age-1 biomass data should be sufficient to test for the existence of compensatory mechanism on a variety of streams. A two-way ANOVA could be used to test for year effects and stream type effects on biomass, with groups of streams similar in productivity (or some other attribute) as replicates for the year-effect test.

Finally, a recommendation to use assessment data in this fashion points to two other questions that require attention. First, length-weight relationships may vary among lamprey populations. Although the relationship is less likely to vary within a population but among cohorts, and thus confound the test for year effects on biomass of age-1 larvae, among-stream comparisons will be more meaningful if biomass estimates derived from length data are calibrated to a length-weight relationship appropriate for stream. Second, the estimates of larval abundance must be corrected for habitat availability (i.e., expressed as density per unit of habitat area). This begs the important question of what constitutes ammocete habitat. Because compensatory mechanisms likely operate through resource limitations, particularly space, a good understanding of what constitutes suitable habitat for ammocetes is likely to prove critical to properly understanding and quantifying mechanisms of compensation. This question is most likely to be reach a practical resolution through a combination of thorough process research such as the Bowen trophic ecology study and development of practical field habitat assessment tools that can apply this knowledge to quantifying habitat supply.

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Ricker, W. E. 1954. Stock and recruitment. Journal of the Fisheries Research Board of Canada. 11:559-623.

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Table 1. Participants at the sea-lamprey compensatory mechanisms workshop.

Roger Bergstedt	Lake Huron Biological Station, Hammond Bay, MI
Stephen Bowen[1]	Michigan Technical University, Houghton, MI
Gavin Christie	Great Lakes Fishery Commission, Ann Arbor, MI
Doug Cuddy	Sea Lamprey Control Centre, Sault Ste. Marie, ON
Michael Fodale	U.S. Fish and Wildlife Service, Marquette, MI
Alex Gonzalez	U.S. Fish and Wildlife Service, Amherst, NY
Lorne Greig	ESSA Technologies Ltd., Richmond Hill, ON
John Heinrich	U.S. Fish and Wildlife Service, Marquette, MI
John Holmes	University of Toronto, Scarborough Campus, Scarborough, ON
Michael Jones	Ontario Ministry of Natural Resources, Picton, ON
Ellie Koon	U.S. Fish and Wildlife Service, Ludington, MI
Joe Koonce	Case Western Reserve University, Cleveland, OH
Rod McDonald	Sea Lamprey Control Centre, Sault Ste. Marie, ON
Mike Millar	Great Lakes Fishery Commission, Ann Arbor, MI
Bruce Morrison	University of Guelph, Guelph, ON
Katherine Mullett	U.S. Fish and Wildlife Service, Marquette, MI
Henry Quinlan	U.S. Fish and Wildlife Service, Marquette, MI
Jeff Slade	U.S. Fish and Wildlife Service, Ludington, MI
Paul Sullivan	Dep't Fisheries and Oceans, Amherst, NY
Michael Twohey	U.S. Fish and Wildlife Service, Marquette, MI
Jerry Weise	Sea Lamprey Control Centre, Sault Ste. Marie, ON
Robert Young[1]	Sea Lamprey Control Centre, Sault Ste. Marie, ON

Appendices

Copies of overheads and notes from invited presentations

Sea Lamprey Task Area

1. Effects of Habitat and Density on Food Use by Lamprey Larvae (Behavior, Trophic Ecology)
   a. Diet
   b. Diet Quality
   c. Digestion and Assimilation
   d. Growth and Condition

2. Effects of Habitat and Density on Recruitment in Sea Lamprey (Population Level Processes)
   a. Growth
   b. Mortality
   c. Sex Ratio
   d. Fecundity
   e. Time to Transformation

Table 1.--Research questions addressing the long-term success of the experimental release of sterilized male sea lampreys in the Great Lakes.

1. Are male sea lampreys successfully sterilized?
2. Do sterilized males reach the spawning grounds and construct nests at the expected ratio of sterilized to resident males?
3. Do sterilized males attract females to nests and mate normally?
4. Does sterility persist through mating and is percent survival of embryos at hatch reduced in individual nests?
5. Is percent survival of embryos at hatch reduced in individual streams?
6. Is the abundance of year classes of burrowed larvae (after leaving the nest) reduced in individual streams?
7. Do reductions in abundance of larvae persist through the larval life stage and result in reductions in the number of metamorphosing sea lampreys in individual streams?
8. Is the number of parasitic-phase sea lampreys in the lake reduced?
9. Is damage to fish in the lake reduced?

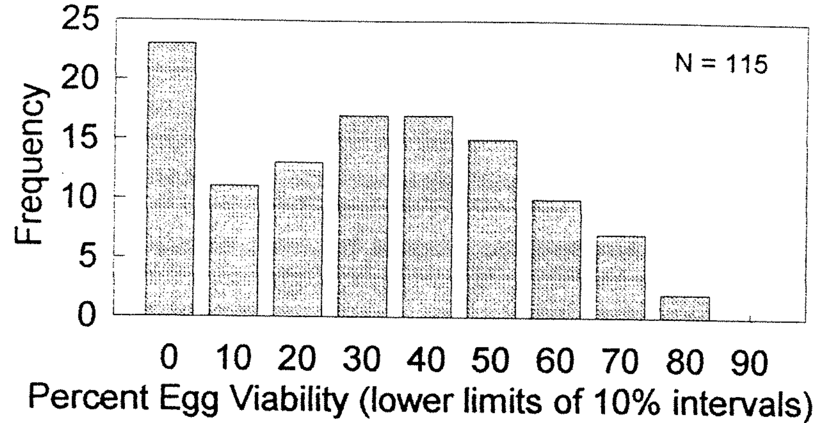

Ratio of Sterile to Resident Males
Observed
10
1
0.1
0.1
1
10
Expected

1-B

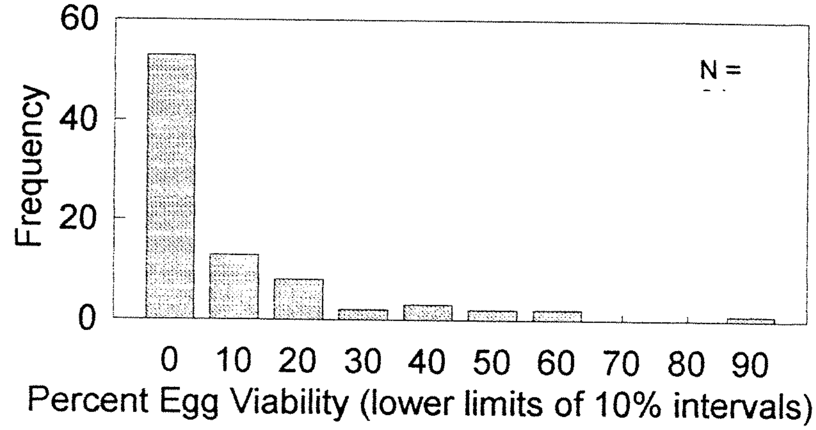
1-B

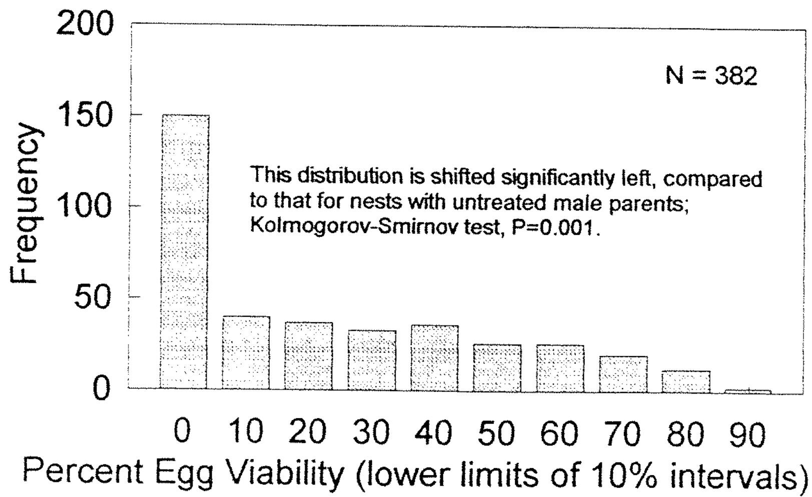
Egg Viability, All Streams Combined, 1992-95

Untreated Male Parents



Sterile Male Parents





■ = Strong (0:1) □ = Weak (3:1)

	A		B		C		D	
	1	2	3	4	5	6	7	8
Year 1 (20)	□ (1)	■ (4)	□ (1)	■ (4)	□ (1)	■ (4)	□ (1)	■ (4)
Year 2 (20)	■ (4)	□ (1)	■ (4)	□ (1)	□ (1)	■ (4)	□ (1)	■ (4)
Year 3 (20)	■ (4)	□ (1)	□ (1)	■ (4)	□ (1)	■ (4)	■ (4)	□ (1)
Total (60)	(9)	(6)	(6)	(9)	(3)	(12)	(6)	(9)

DEPENDENT VARIABLES:

The estimated number of viable eggs per female at hatch

Relative numbers of YOY per female in fall of the first year of life (for within-stream comparisons)

Lengths and weights of YOY in fall of the first year of life

The estimated number of YEARLINGS per female in fall of the second year of life

Lengths and weights of YEARLINGS in fall of the first year of life

POSSIBLE INDEPENDENT VARIABLES	POTENTIAL VALUES	TYPE
PAIR	A, B, C, D	CLASSIFICATION
STREAM	1, 2, 3, 4, 5, 6, 7, 8	CLASSIFICATION
TREATMENT	S, W (no SMR, SMR)	CLASSIFICATION
YEAR	1, 2, 3	CLASSIFICATION
DENSITY	? (competitors/m^2 in fall of 1st and 2nd year)	CONTINUOUS

OTHER INFORMATION:

Stream area by habitat classes (good, marginal, and uninhabitable)

Stream temperature

Water chemistry

COMMISSION VISION

- **Suppress sea lampreys to target levels through optimal program of control, assessment, and research.**
  - Development of quantitative assessment

1-C

ASSESSMENT

- Support to Control Program by measurement of sea lamprey populations before and after control actions.

1-C

ASSESSMENT

- **Larval**
- **Adult**
- **SMRT**
- **Risk to nontargets**

1-C

GREAT LAKES TRIBUTARIES

- 5,339 Tributaries
- 449 have produced lampreys
- 254 have been TFM'd
- 169 3-5 year cycle TFM

1-C

ASSESSMENT

- **Larval**
  - Streams to treat TFM
  - Production capacity
  - Reduction from control
  - Life history stuff

ASSESSMENT

- Larval - 1995
  - Surveyed 294 streams
    - 950 hrs (US only) backpack shocker
    - 57,000 m^2
    - Captured 17,500 larvae (US only)
    - Transformer production in 86 streams
    - St. Marys River 150 hrs. shocker

ASSESSMENT

- Larval 1988-95
  - Production capacity in 50 streams
  - Estimated habitat and density of larvae

ASSESSMENT

- **Adult - Spawners**
  - Trap in streams
  - Relative abundance
  - Estimate spawners in streams
  - Estimate spawners lakewide Superior and Huron

ASSESSMENT

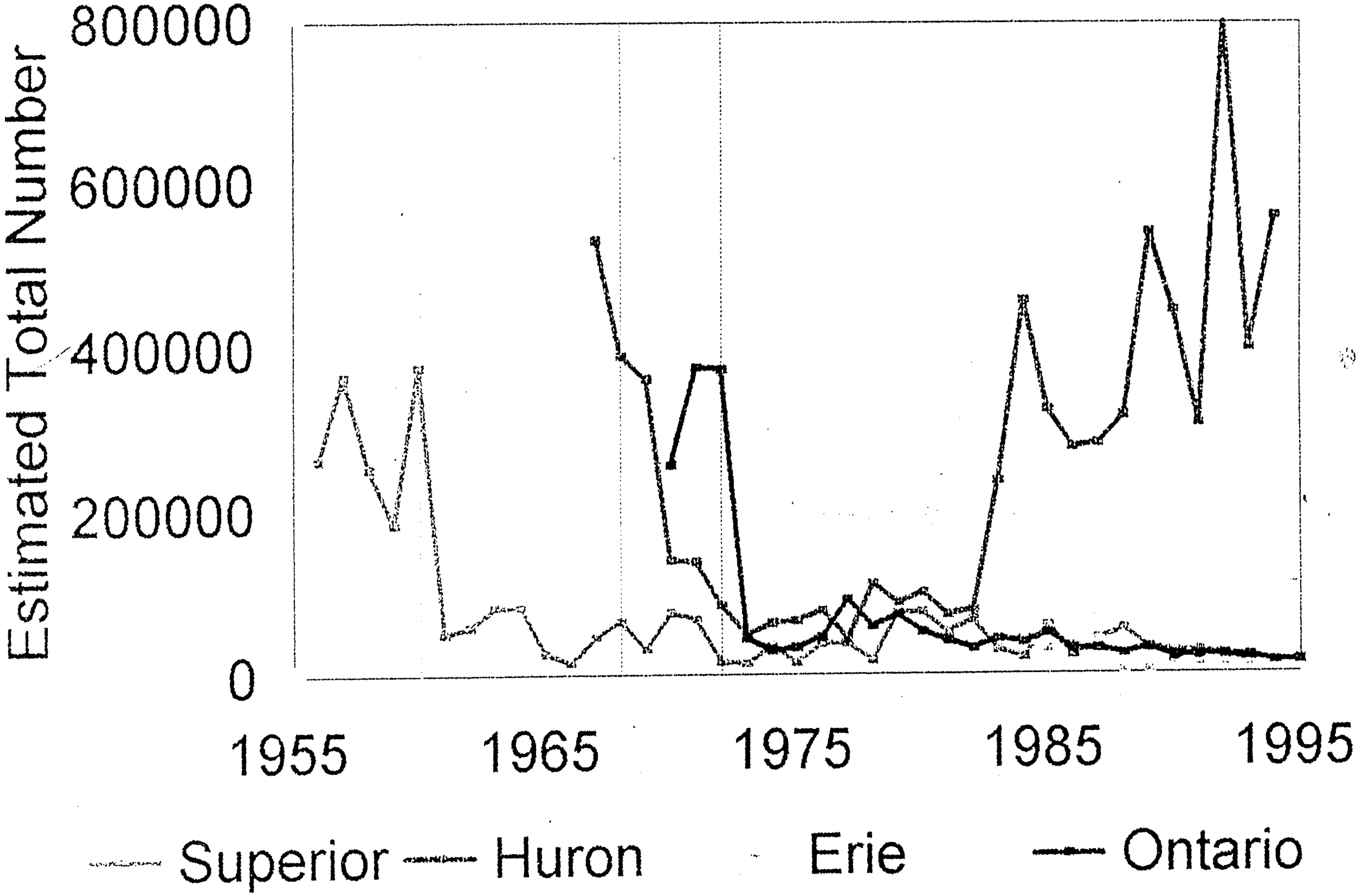
- Adult-Spawners in 1995
  - Trapped 66 streams
  - Captured 73,500 spawners
  - Estimated spawners in 40
  - Estimated spawners lakewide in Superior and Huron

ASSESSMENT

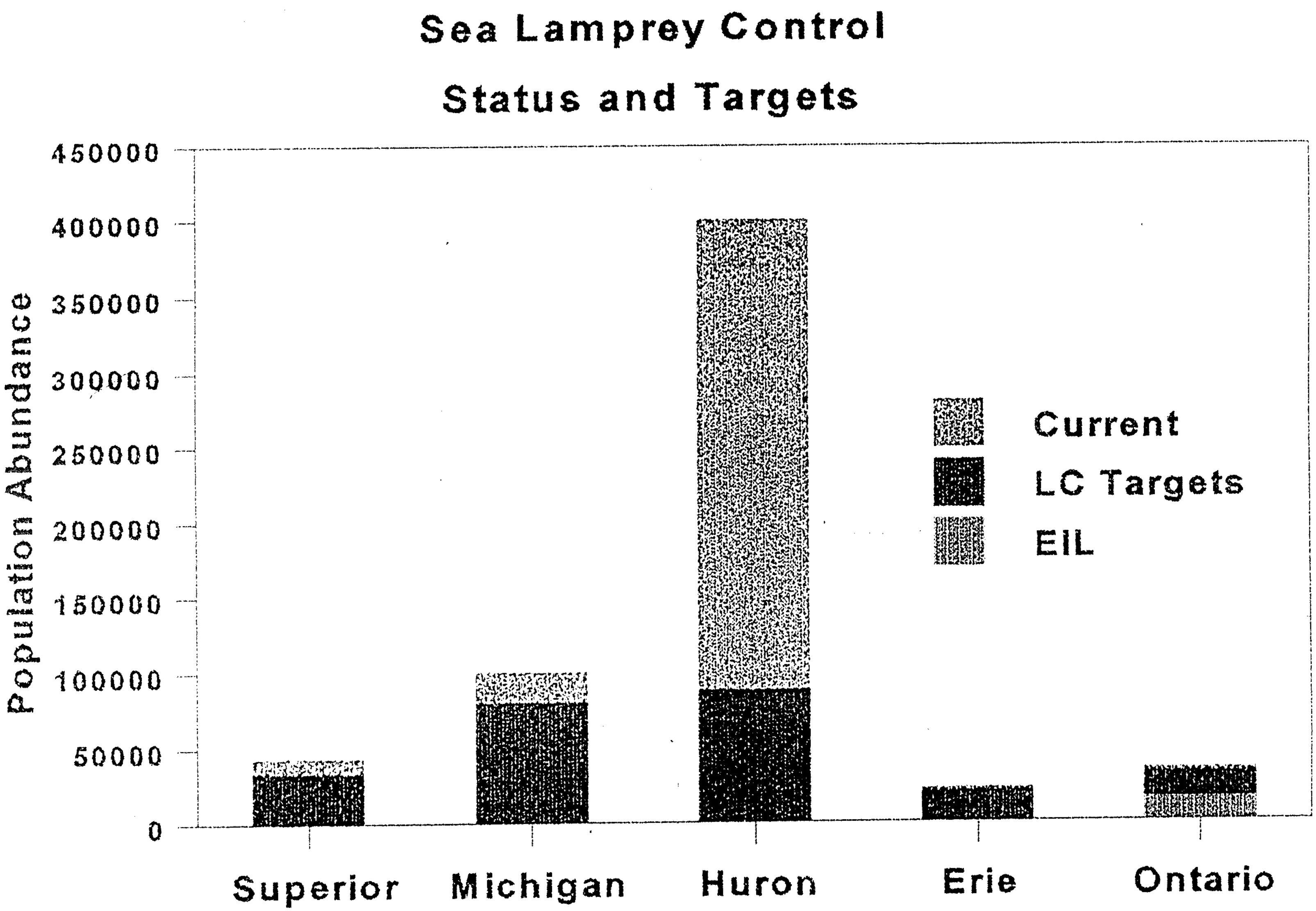
- Adult - Parasitics
  - Commercial fishermen
  - Sport fishermen

1-C

Parasitic-Phase Sea Lamprey



1-D



Sea Lamprey Control
Status and Targets
Population Abundance
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
Current
LC Targets
EIL
Superior
Michigan
Huron
Erie
Ontario

1-D

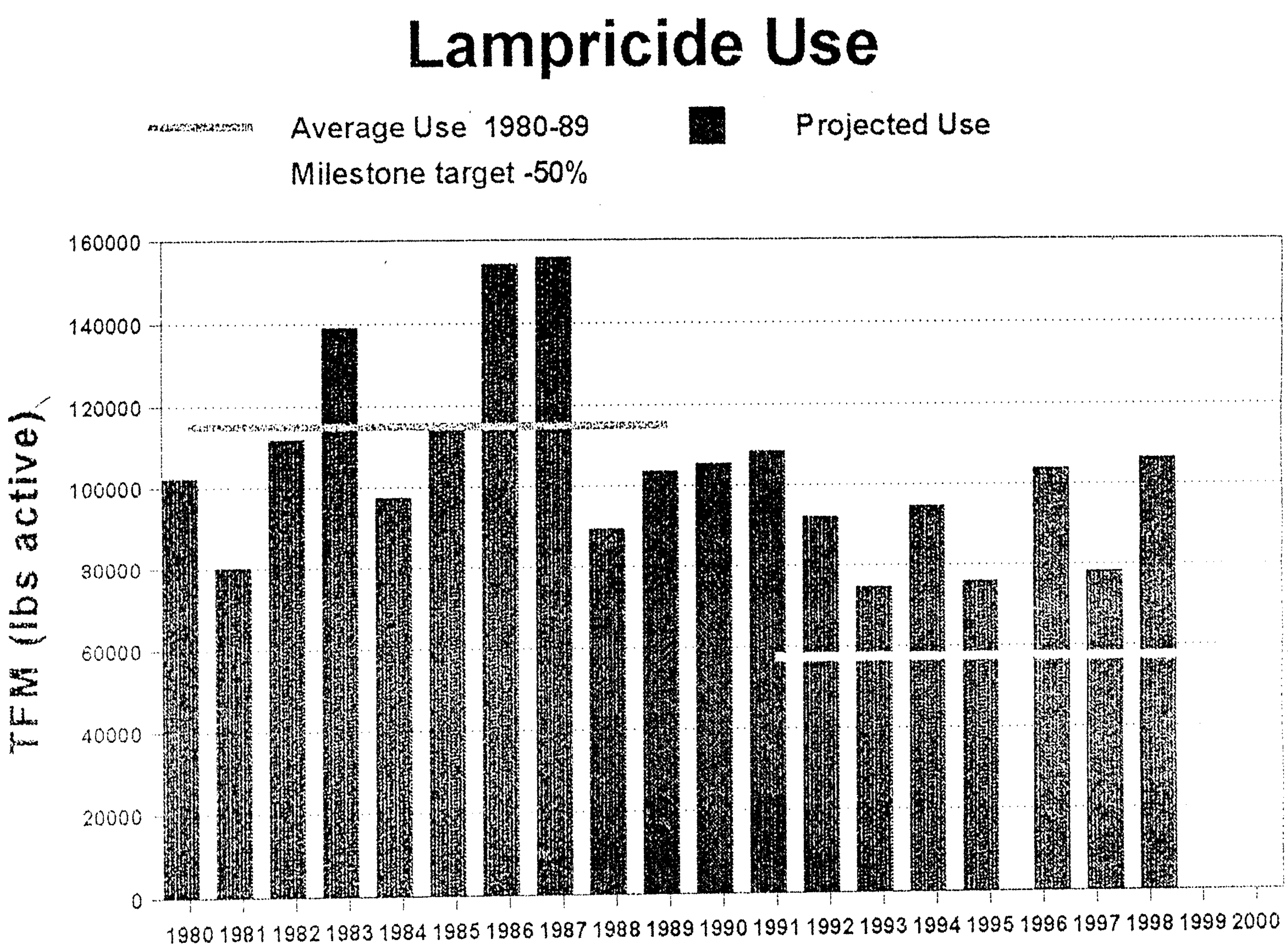
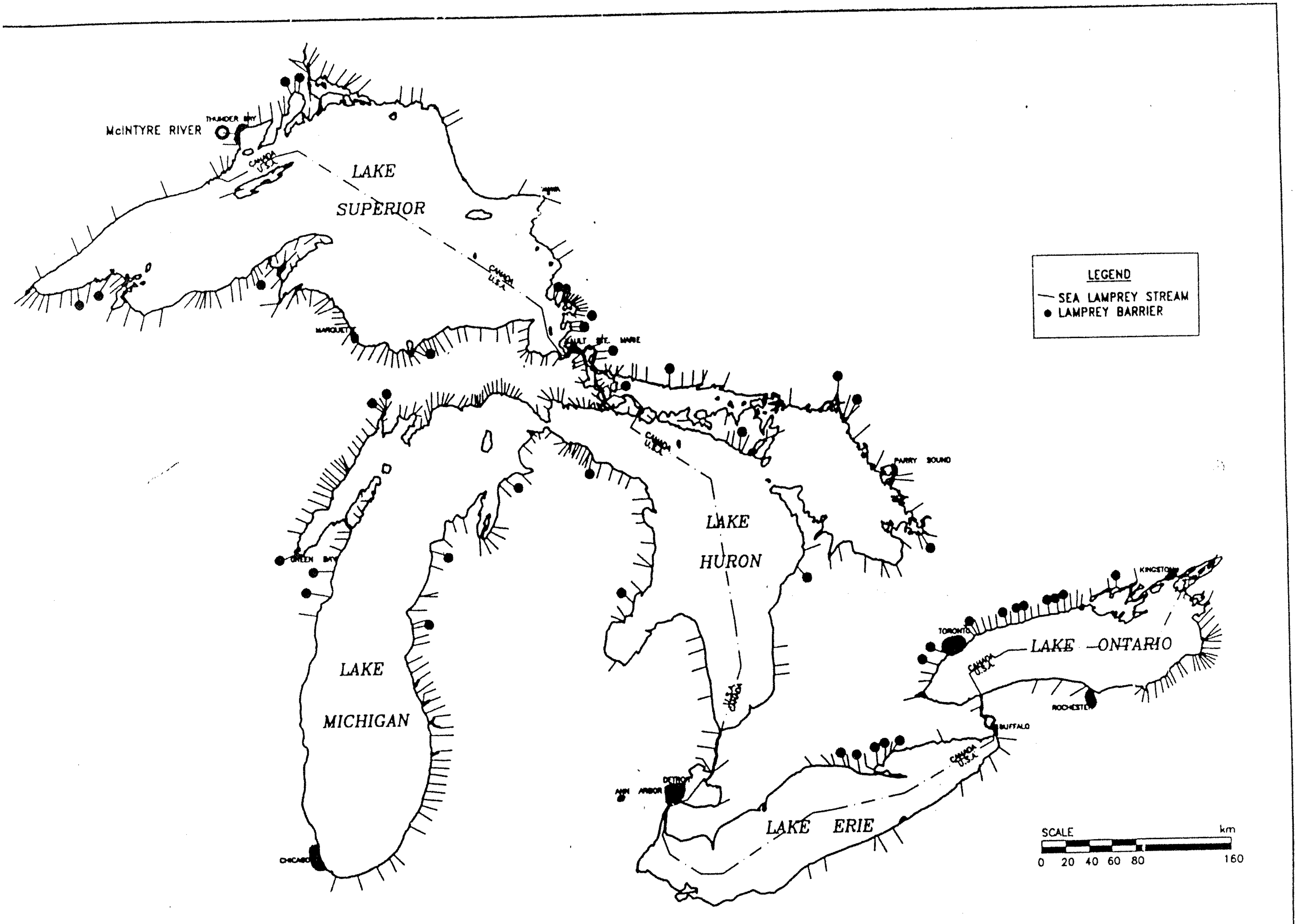


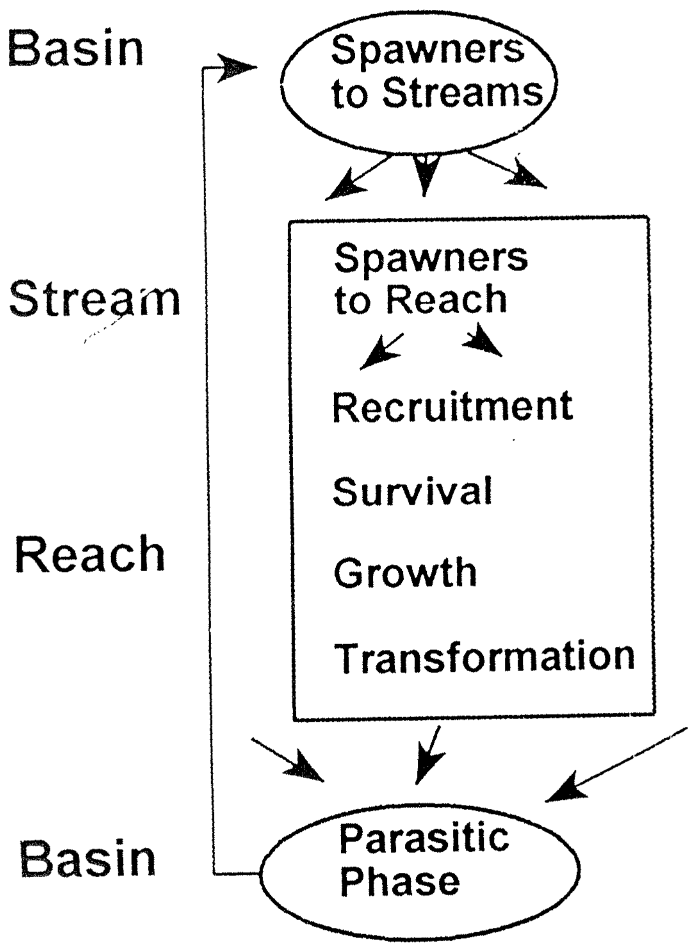
Figure 2. Basin-wide use of the lampricide TFM and the milestone of 50% reduction by the year 2000.



e 1.1 Great Lakes streams that have been used by sea lampreys and streams where lamprey barriers have been constructed.

1-7

Sea Lamprey Model



Actions	Measures
	Spawning Run Estimates
Traps	
Barriers	
SMRT	*Number/Density total/age*
	Size at Age
Lampricide Treatments	*Num/Den Transformers*
	Prop >120mm
	Parasitic Pop. Estimates
	Fish wounding mortality

1-D

1-D

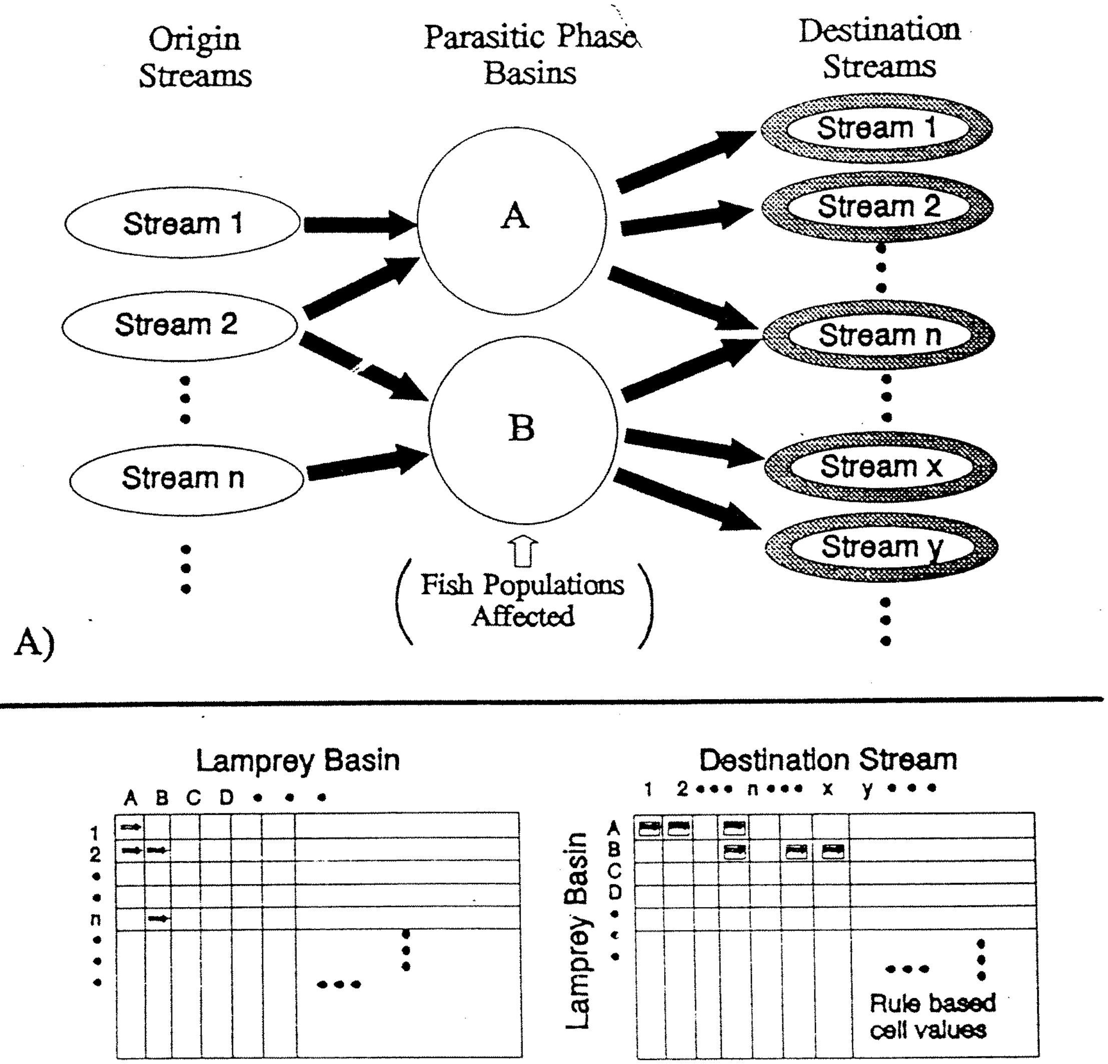
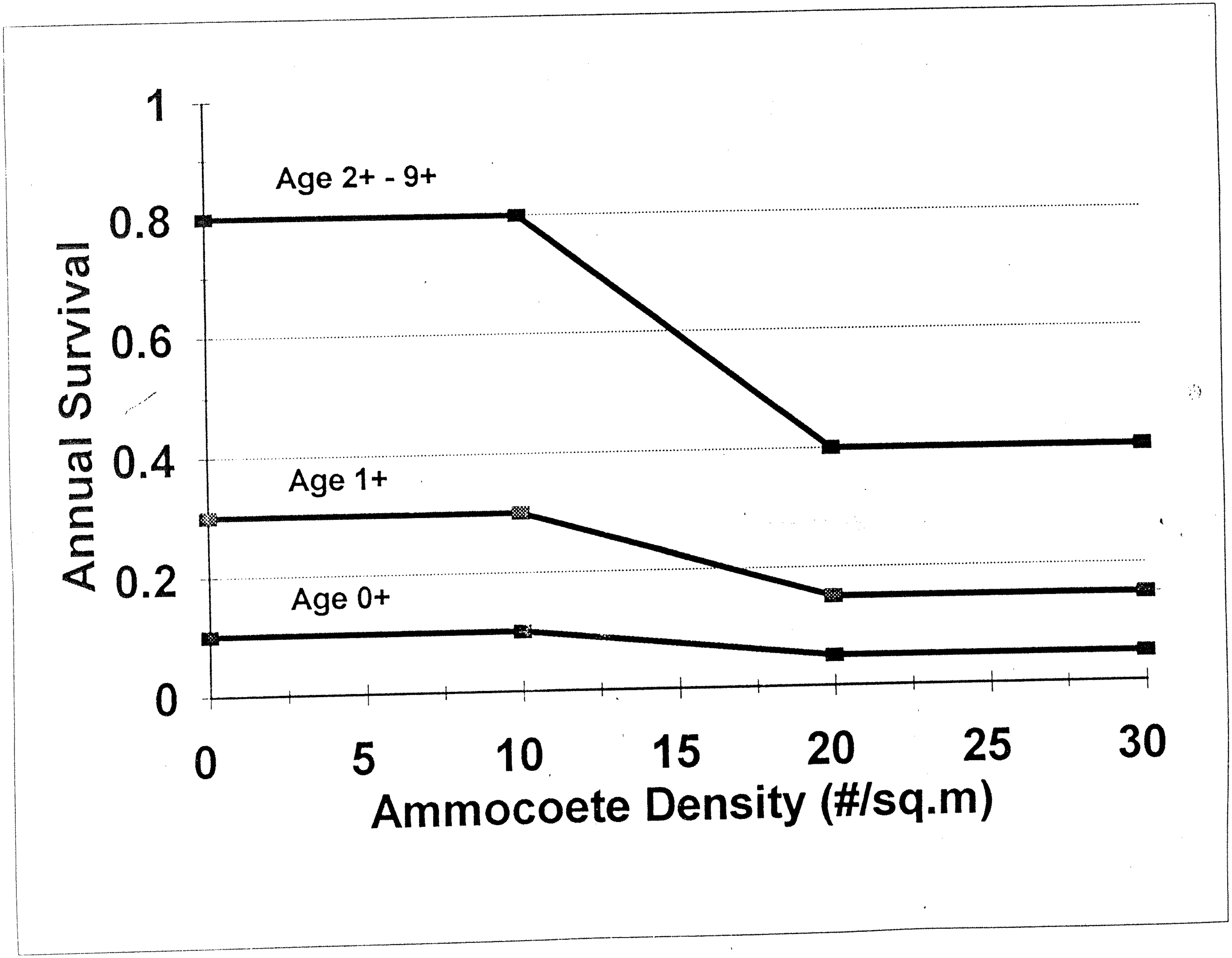
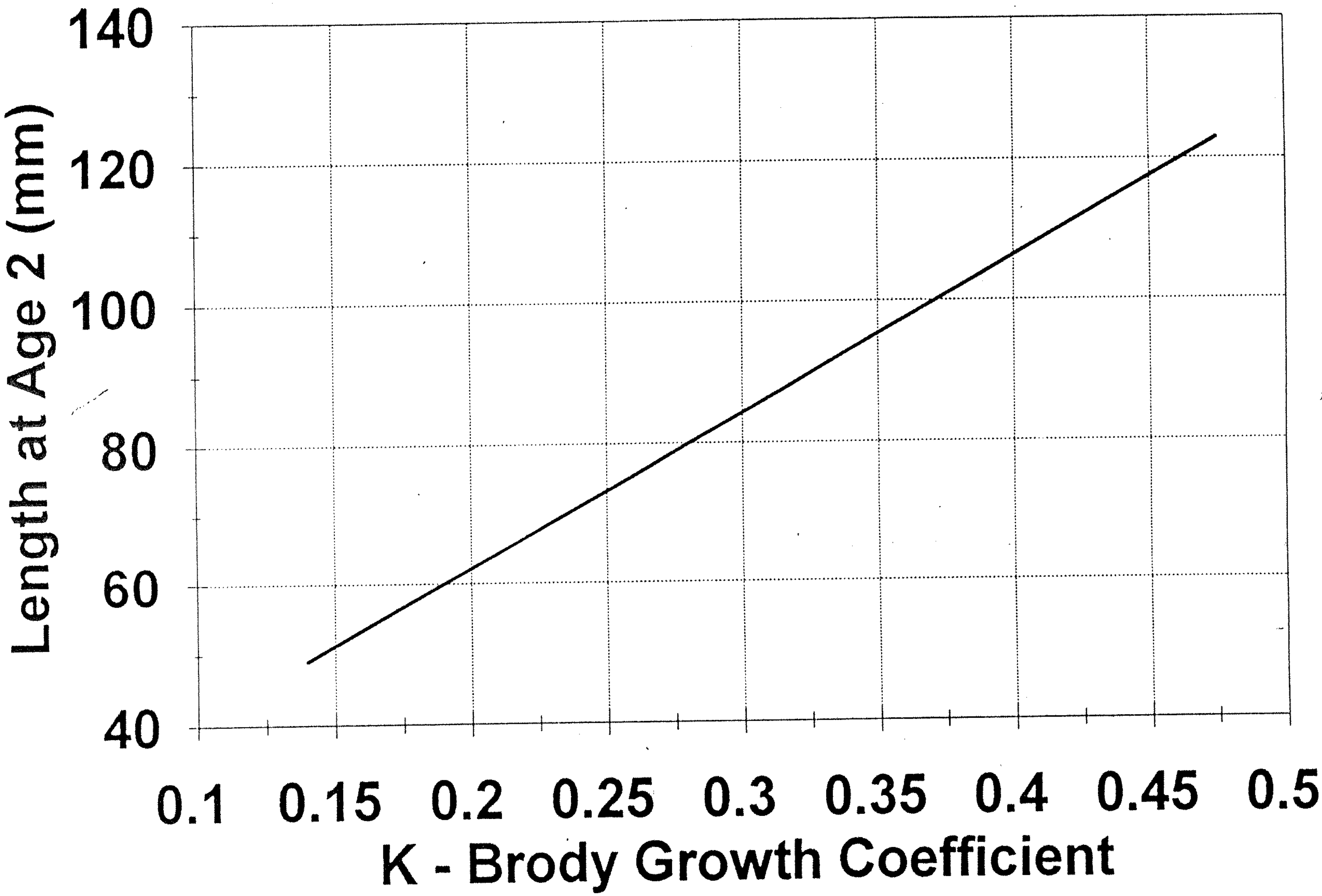


Figure A.2: Conceptual model for representing the spatial movements of transforming ammocete and spawning adults between streams and lake lamprey basins.

Density < 10/sqm
Density > 20/sqm
Annual Survival Rate
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9
10
Age


Age 2+ - 9+
Age 1+
Age 0+
Annual Survival
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30
Ammocoete Density (#/sq.m)

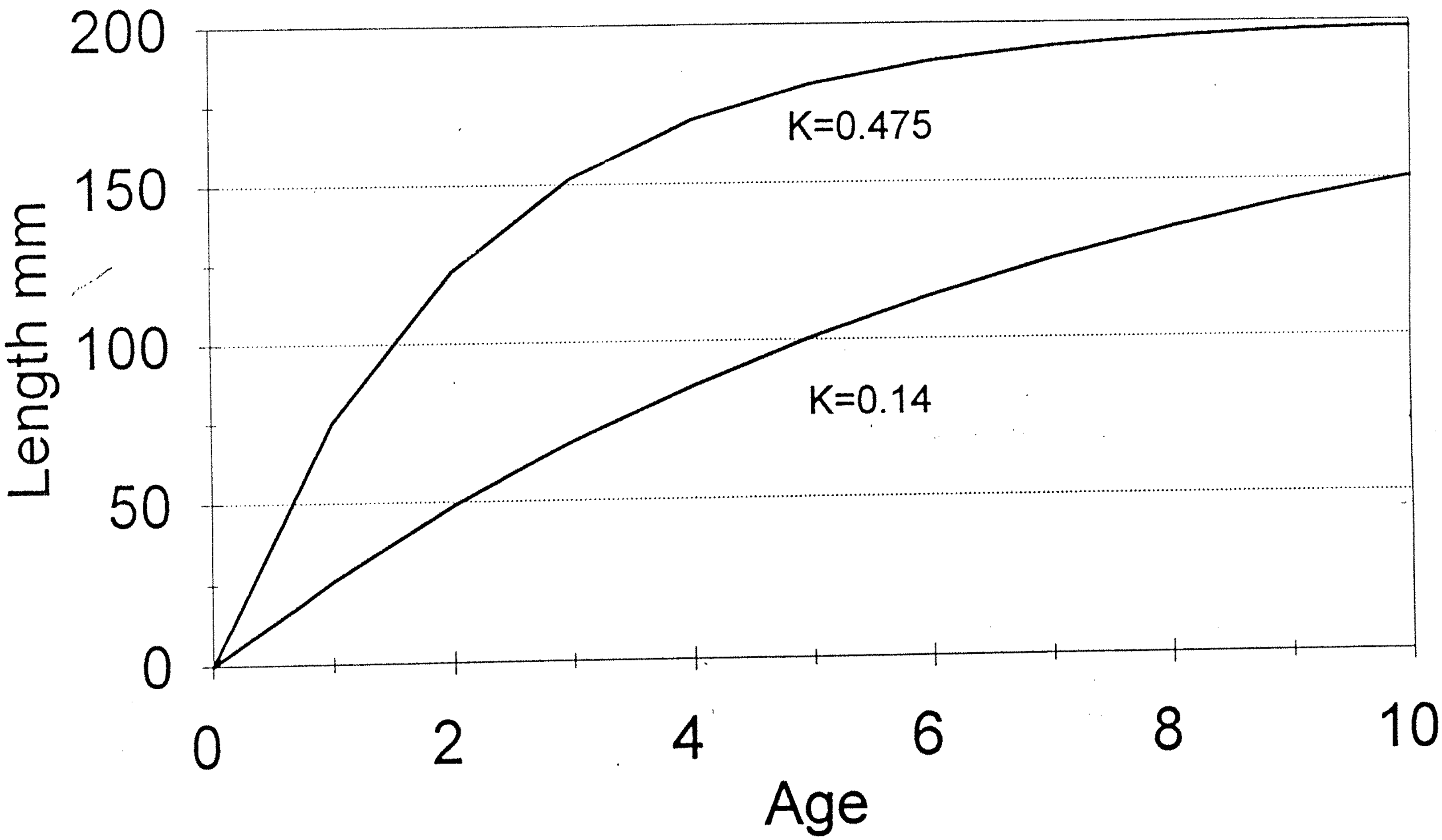
1-D

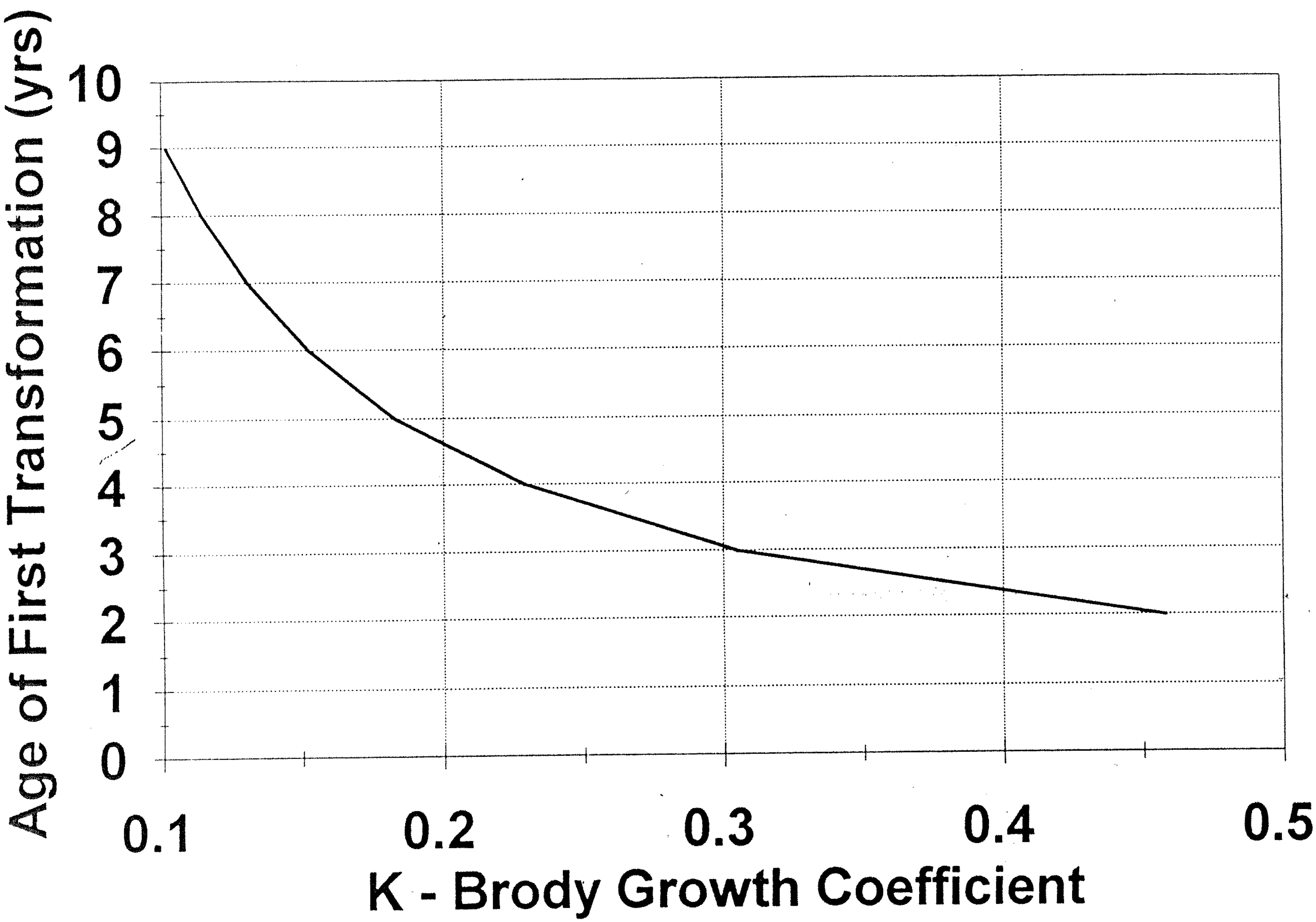


140
120
100
80
60
40
Length at Age 2 (mm)
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
K - Brody Growth Coefficient

von Bertalanffy Growth Curve

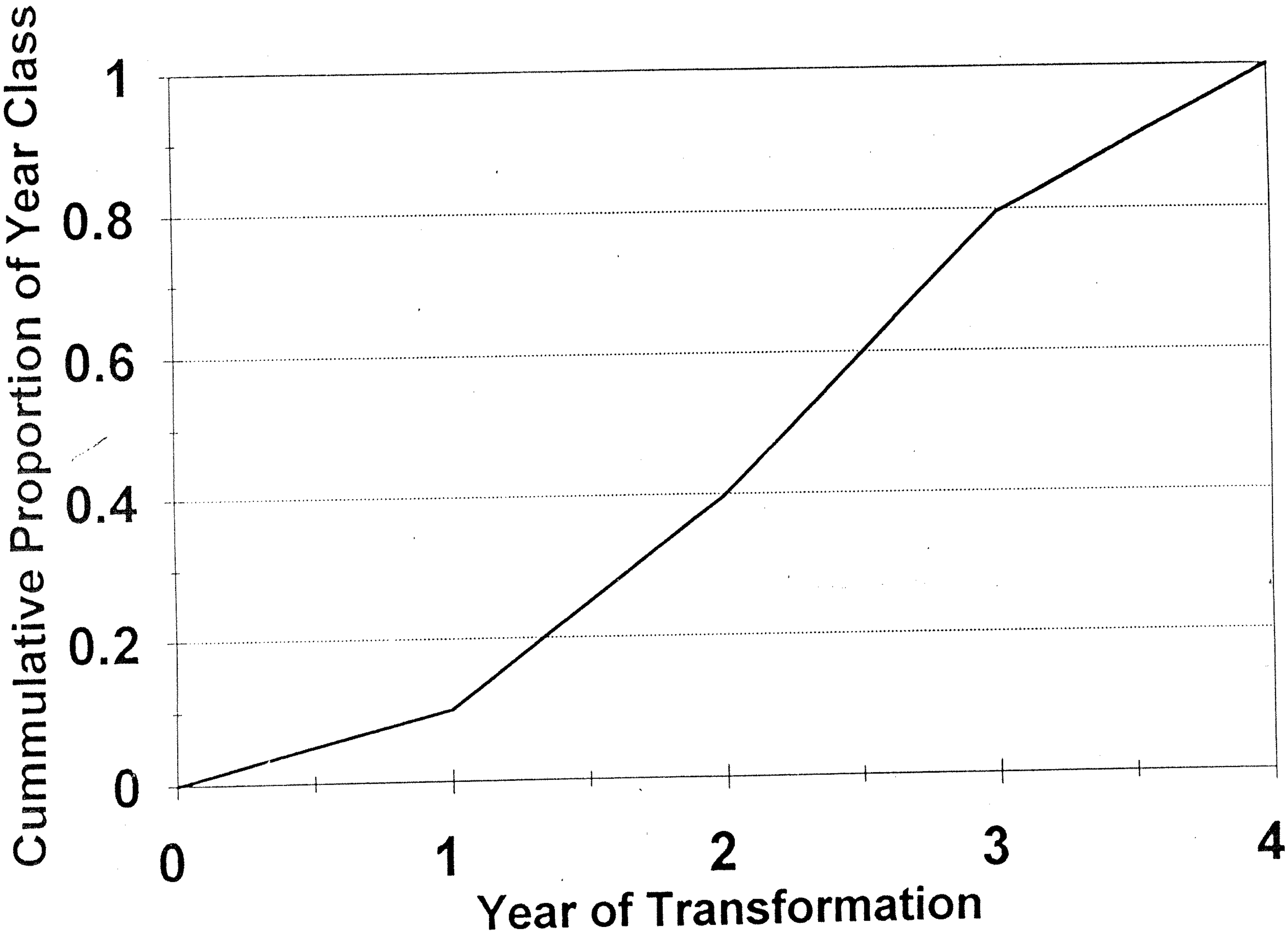
Linf=200



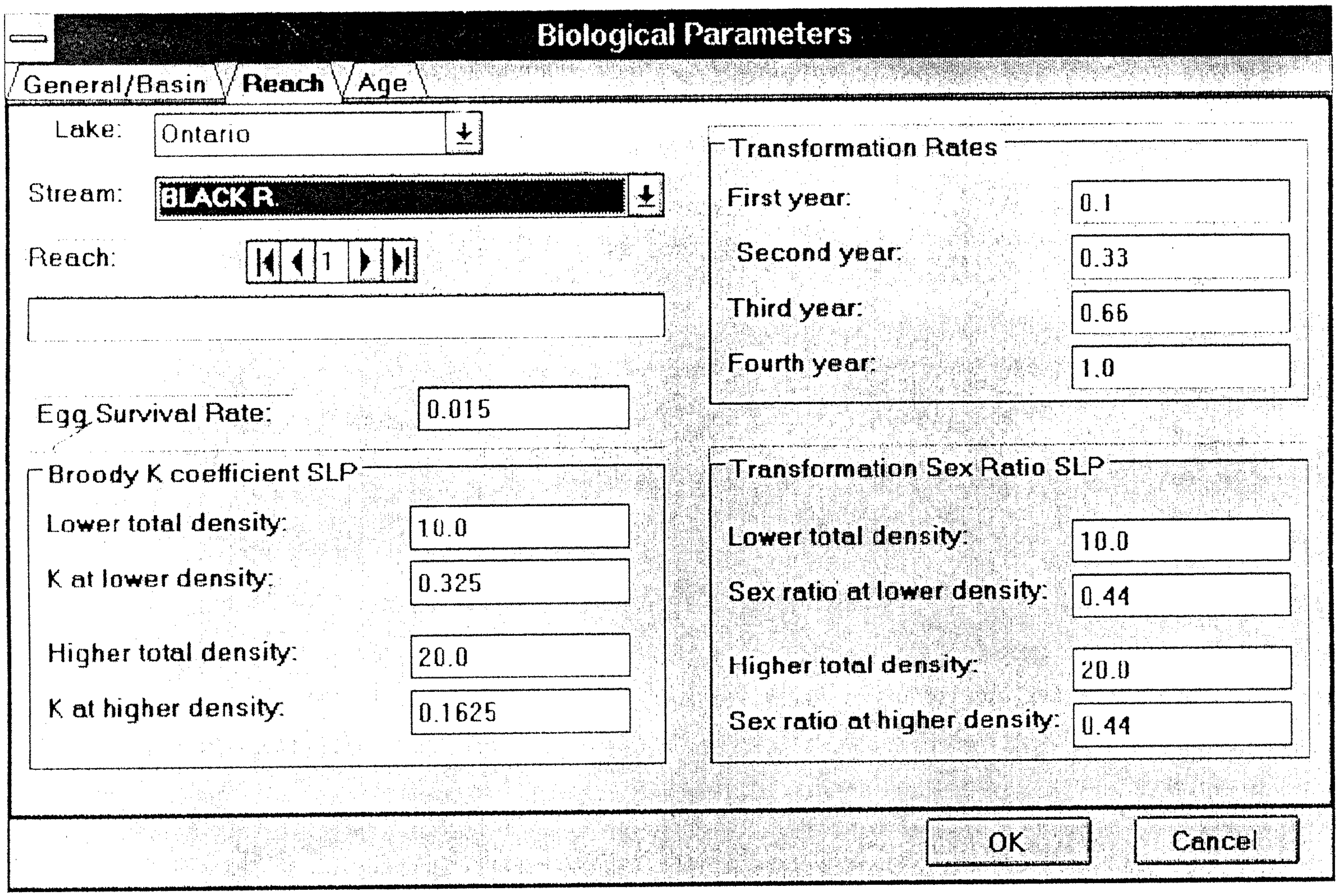


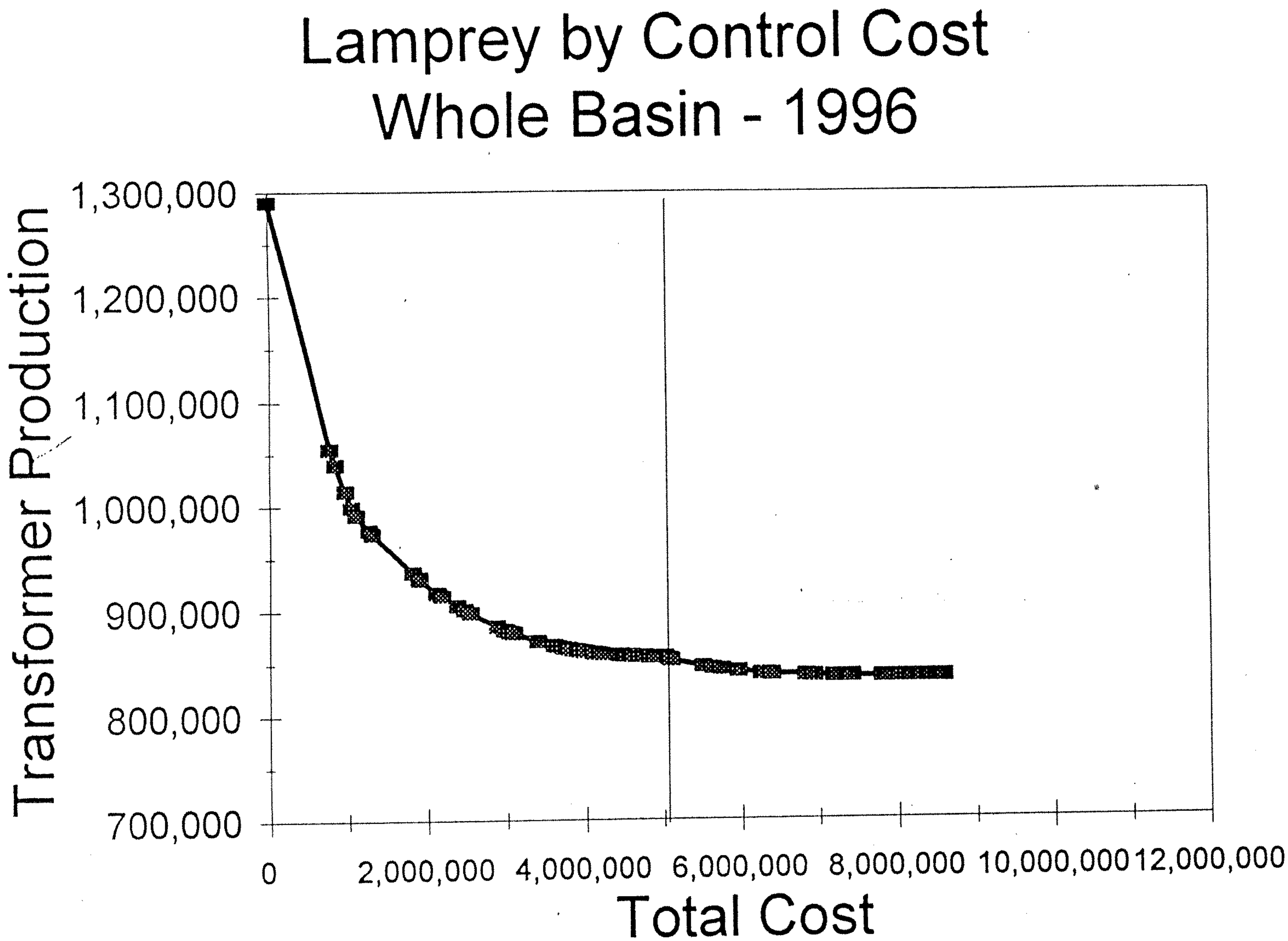
Age of First Transformation (yrs)
10
9
8
7
6
5
4
3
2
1
0
0.1
0.2
0.3
0.4
0.5
K - Brody Growth Coefficient

1-D


Cummulative Proportion of Year Class
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
Year of Transformation

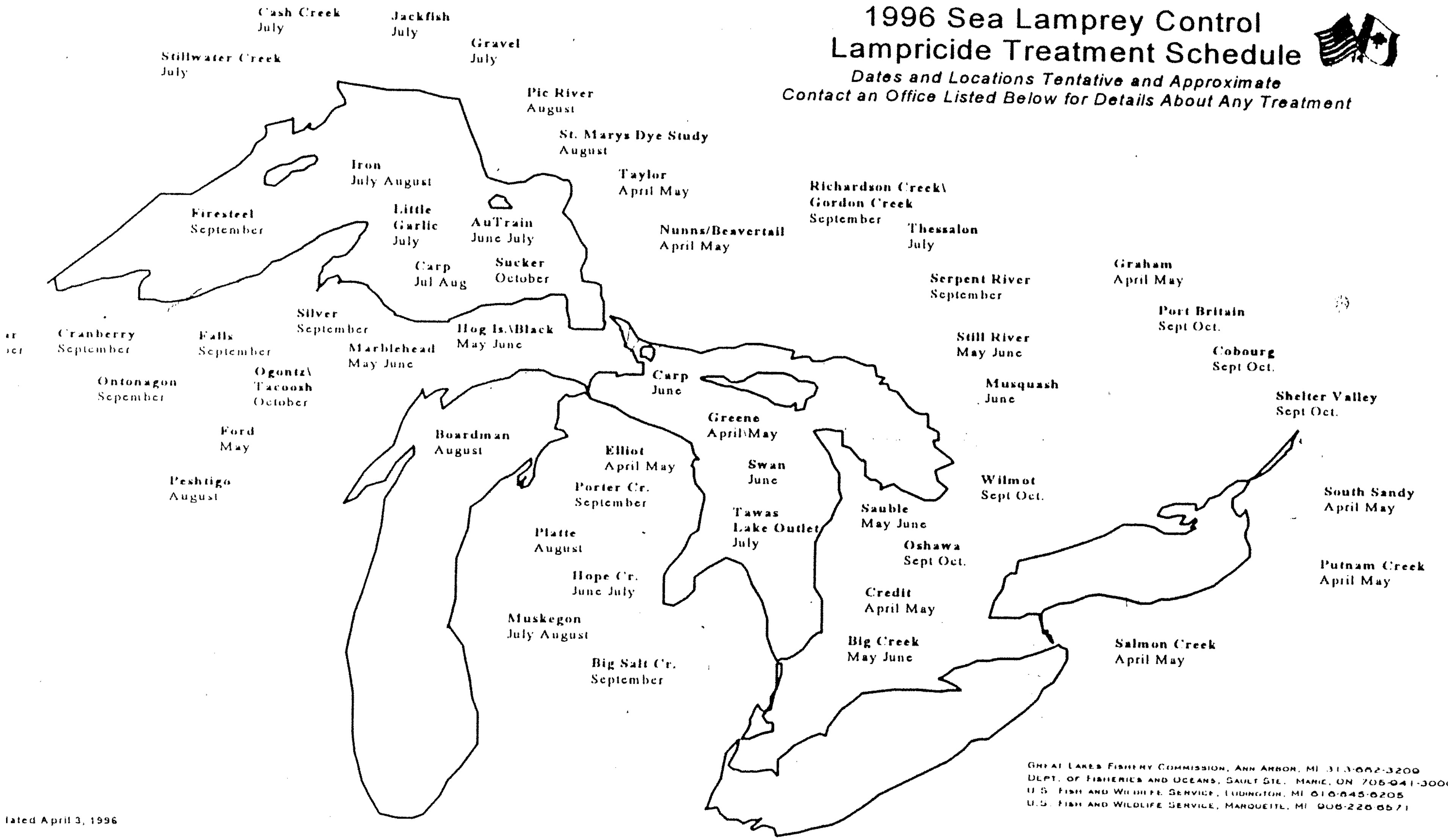
1-D


Biological Parameters
General/Basin
Reach
Age
Lake:
Ontario
Stream:
BLACK R.
Reach:
1
Egg Survival Rate:
0.015
Broody K coefficient SLP
Lower total density:
10.0
K at lower density:
0.325
Higher total density:
20.0
K at higher density:
0.1625
Transformation Rates
First year:
0.1
Second year:
0.33
Third year:
0.66
Fourth year:
1.0
Transformation Sex Ratio SLP
Lower total density:
10.0
Sex ratio at lower density:
0.44
Higher total density:
20.0
Sex ratio at higher density:
0.44
OK
Cancel


Lamprey by Control Cost
Whole Basin - 1996
Transformer Production
1,300,000
1,200,000
1,100,000
1,000,000
900,000
800,000
700,000
0
2,000,000
4,000,000
6,000,000
8,000,000
10,000,000
12,000,000
Total Cost

1996 Sea Lamprey Control
Lampricide Treatment Schedule

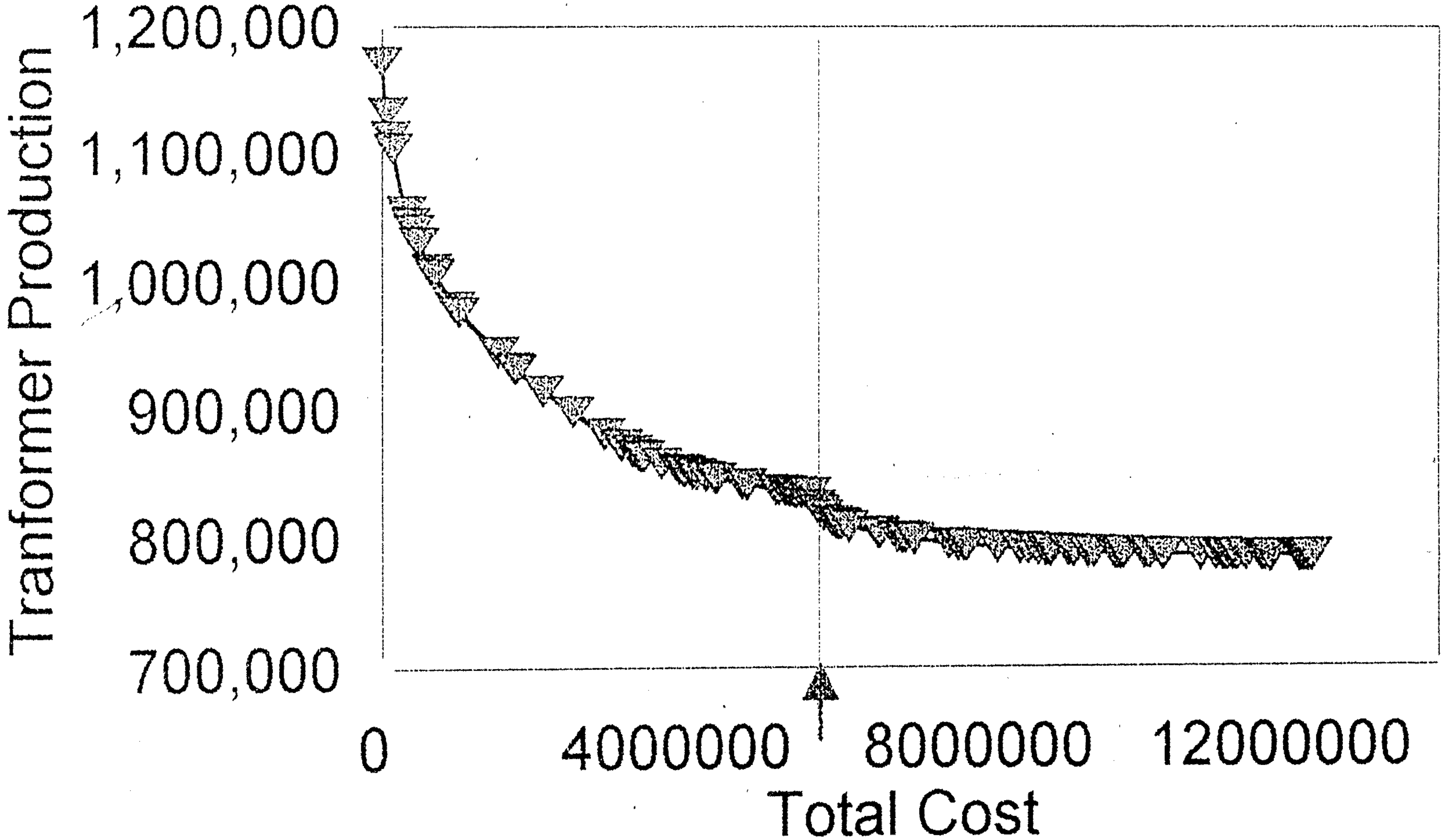
Dates and Locations Tentative and Approximate
Contact an Office Listed Below for Details About Any Treatment



Great Lakes Fishery Commission, Ann Arbor, MI 313-662-3200
Dept. of Fisheries and Oceans, Sault Ste. Marie, ON 705-941-3000
U.S. Fish and Wildlife Service, Ludington, MI 616-845-6205
U.S. Fish and Wildlife Service, Marquette, MI 906-226-6571

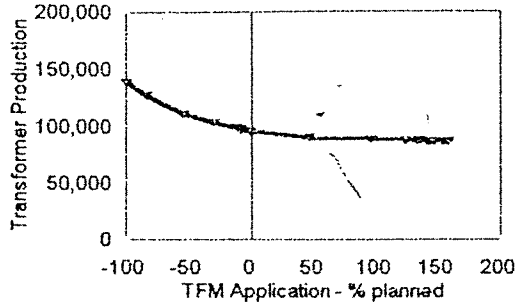
lated April 3, 1996

Lamprey by Control Cost
Whole Basin - 1995

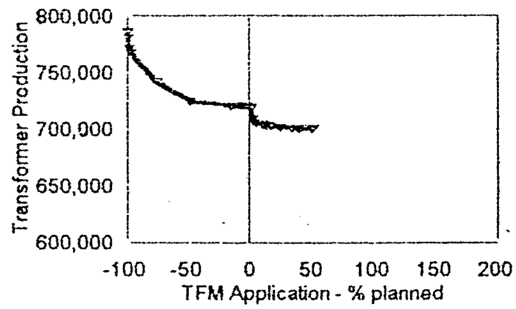


Lamprey versus TFM Use

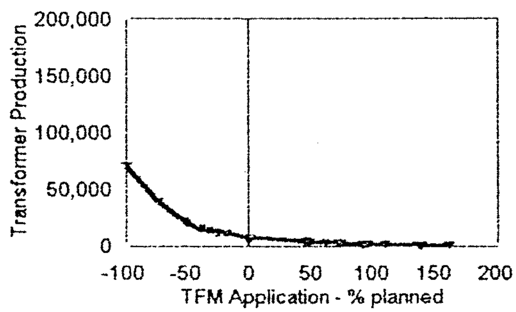
Lake Superior - 1995



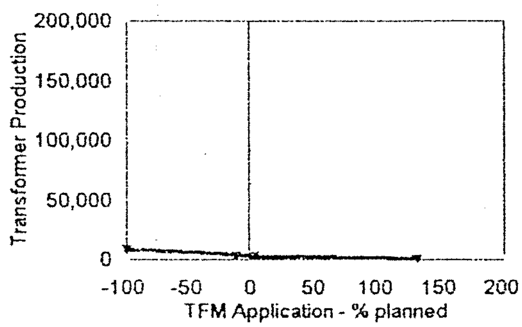
Lake Huron - 1995



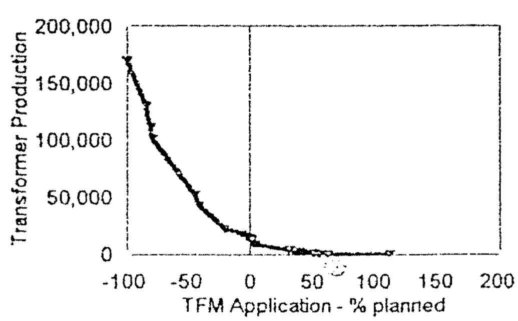
Lake Michigan - 1995

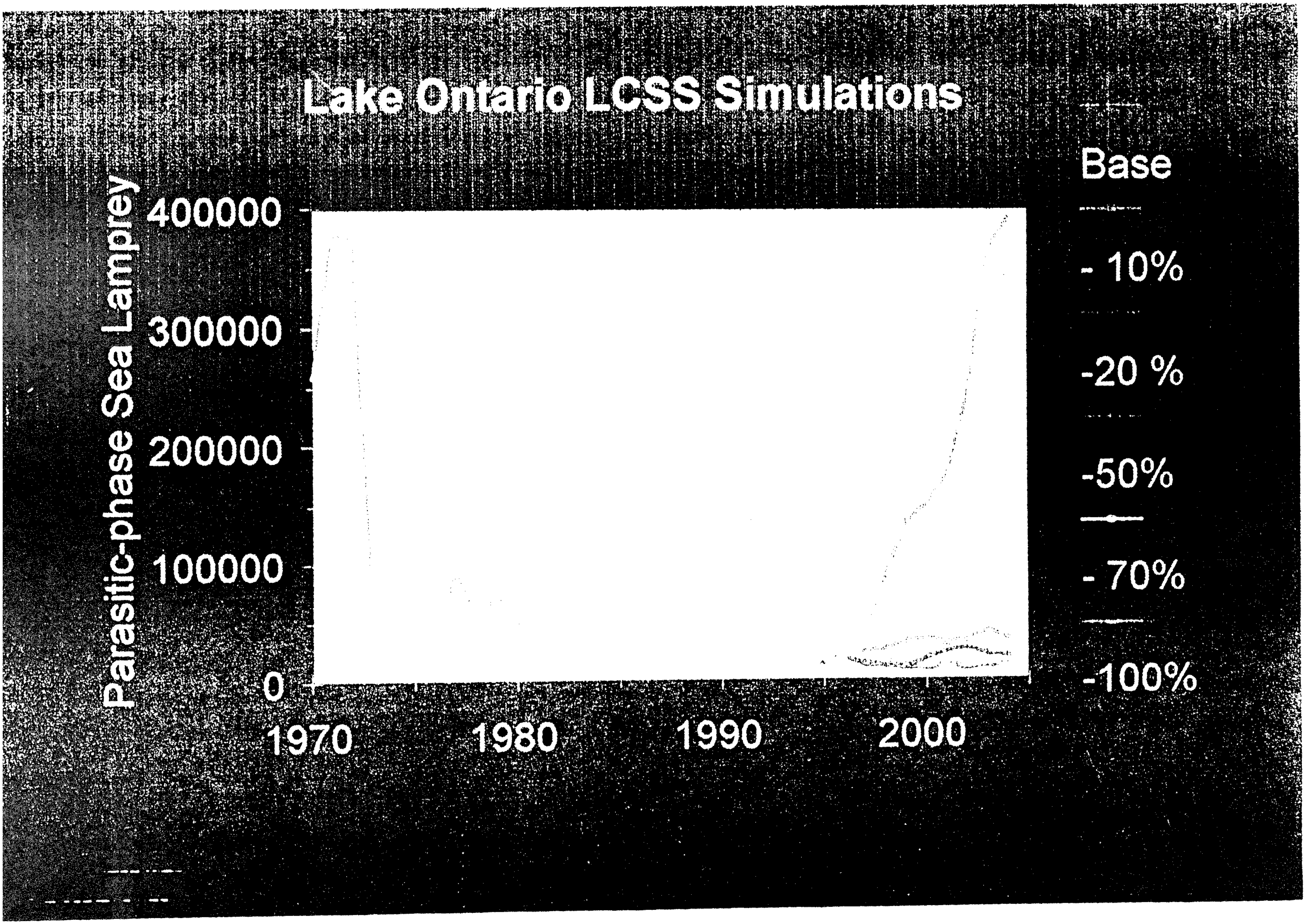


Lake Erie - 1995



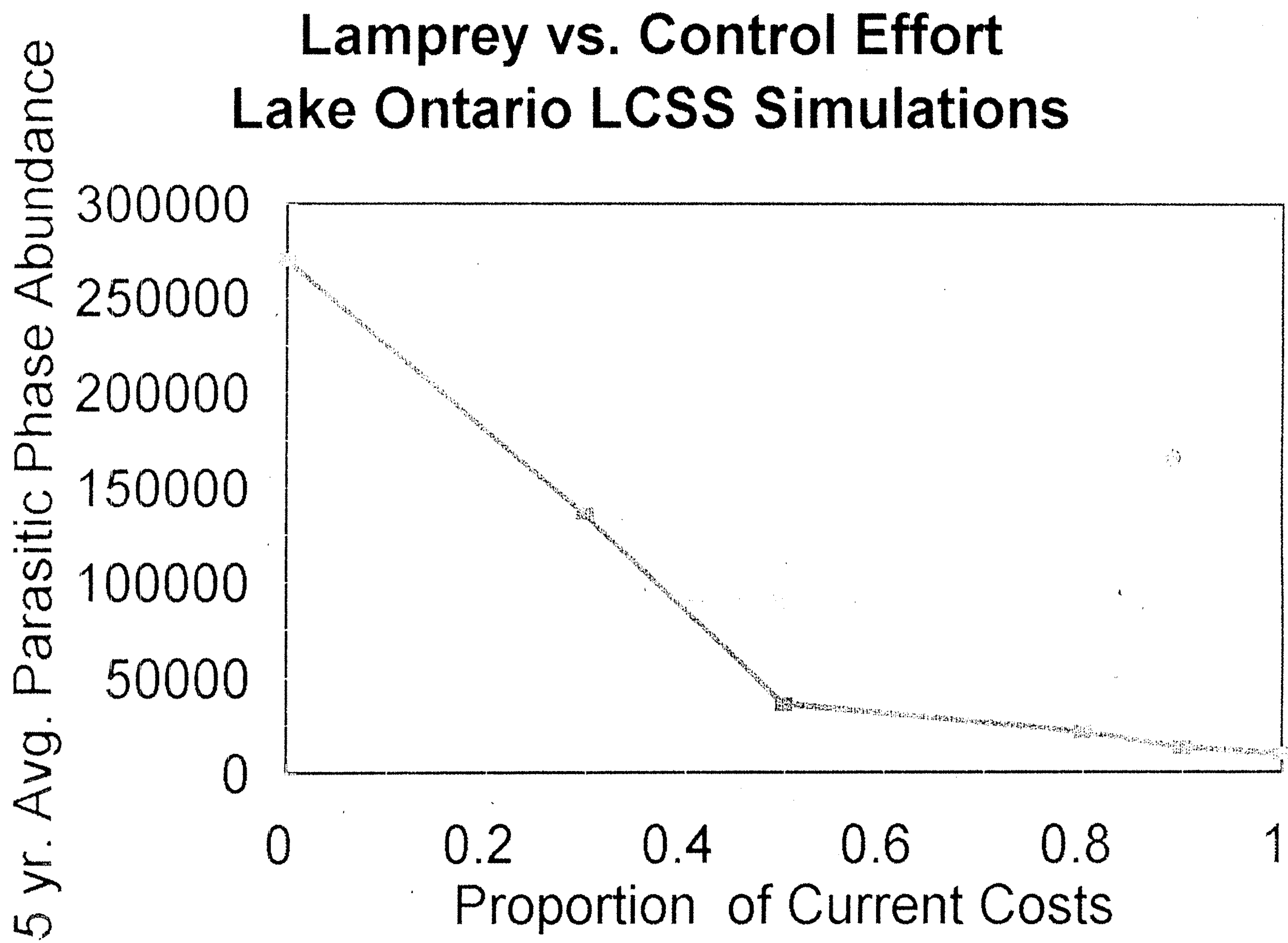
Lake Ontario - 1995





Lake Ontario LCSS Simulations
Parasitic-phase Sea Lamprey
400000
300000
200000
100000
0
1970
1980
1990
2000
Base
- 10%
-20 %
-50%
- 70%
-100%

1-D


Lamprey vs. Control Effort
Lake Ontario LCSS Simulations
5 yr. Avg. Parasitic Phase Abundance
300000
250000
200000
150000
100000
50000
0
0
0.2
0.4
0.6
0.8
1
Proportion of Current Costs

1-E

Sea Lamprey Stock and Recruitment

Department of Fisheries and Oceans
US Fish and Wildlife Service

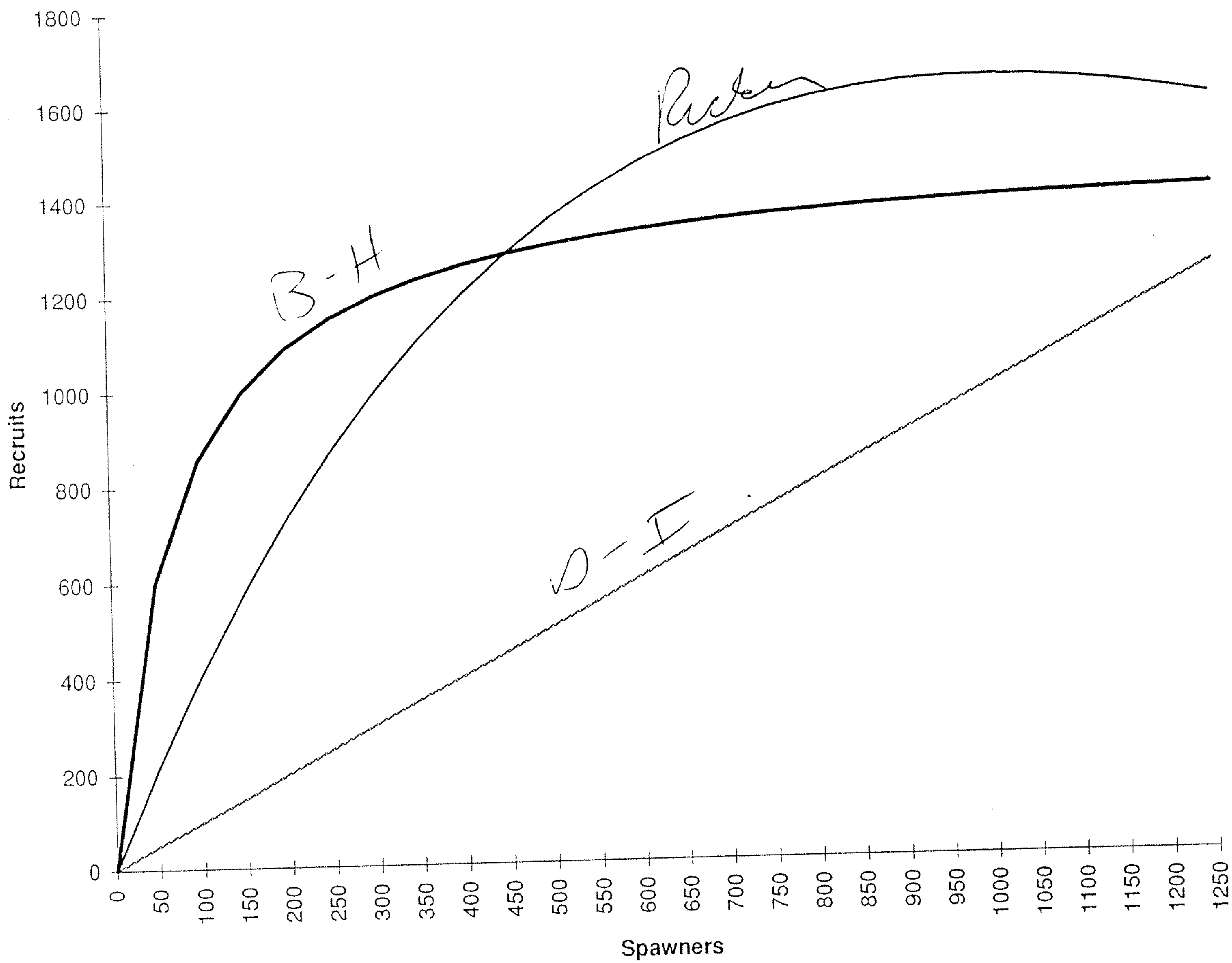
Stock and Recruitment Models

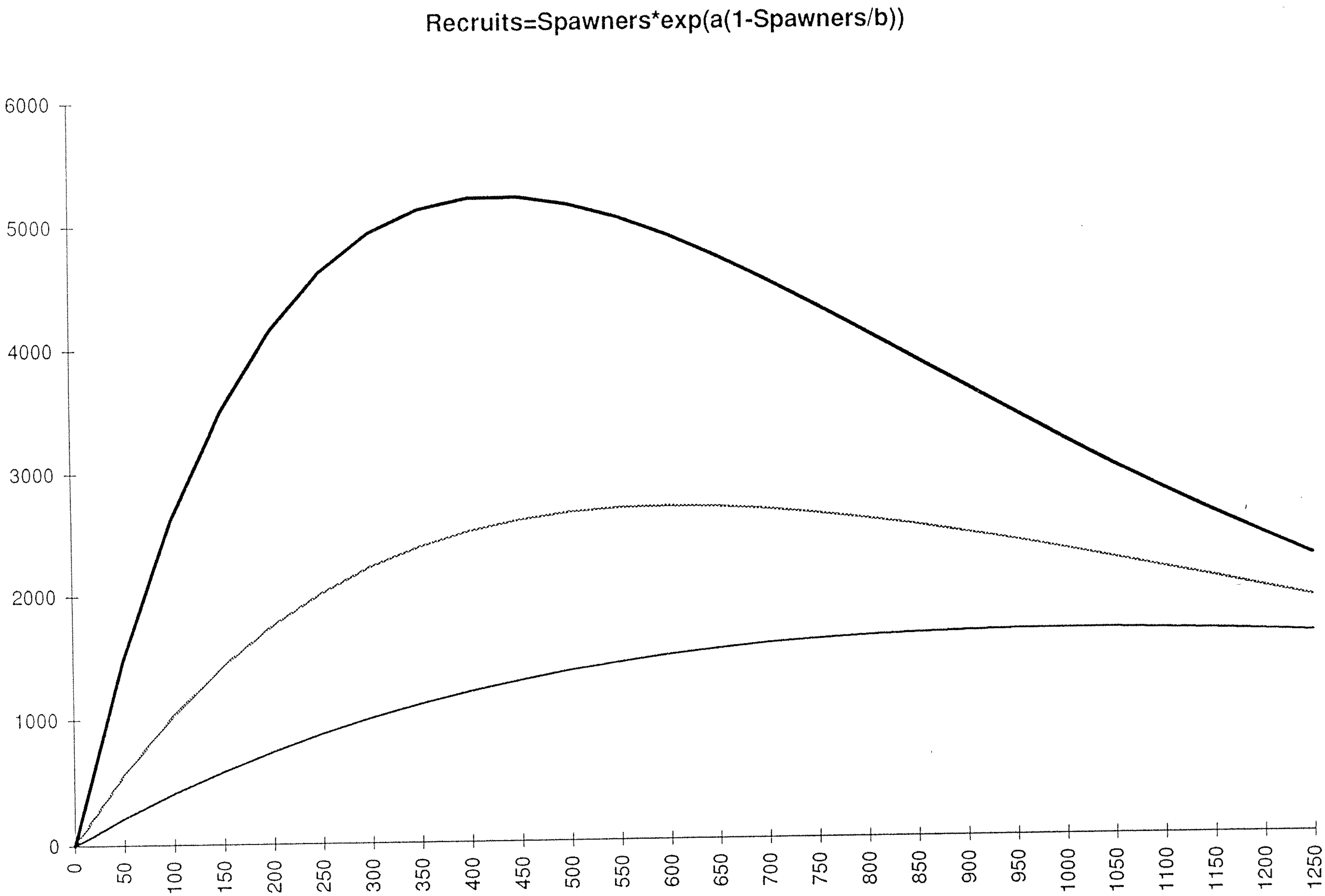
- Ricker: $R=S*\exp(a*(1-S/b))$ — a = slope = productivity; b = capacity
- Beverton and Holt: $R=(a*S)/(b+S)$
- Density Independent: $R=a*S$

Ricker: a = slope = productivity = density independent mortality
b = capacity = nature of density dependent mortality.

Beverton Holt = a/b is the slope
a = maximum recruitment
b = [illegible] needed to half the [illegible].

1-E


1800
1600
1400
1200
1000
800
600
400
200
0
Recruits
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000 1050 1100 1150 1200 1250
Spawners
B-H
D-I



Recruits=Spawners*exp(a(1-Spawners/b))
6000
5000
4000
3000
2000
1000
0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250

Data Sources

Recruits	1+ larvae
Spawners	Within stream estimates
	Lake wide estimates
	Minns and Moore (1987)

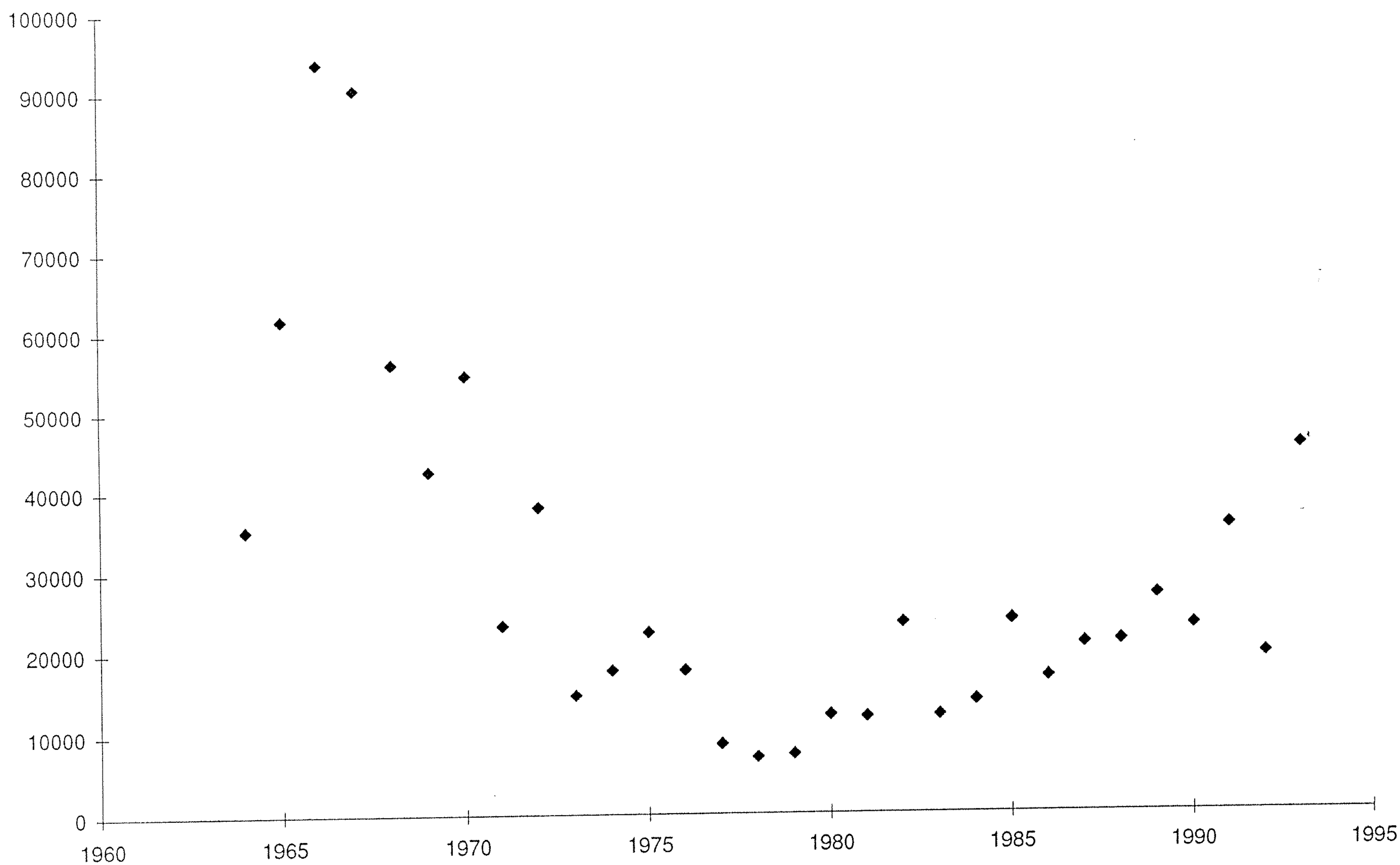
1-E

St. Mary's River

- Data from Minns and Moore (1987)
- Mean age of transformation 4.5 years, 1.5 years in the lake
- Recruits measured as six year lag of spawners

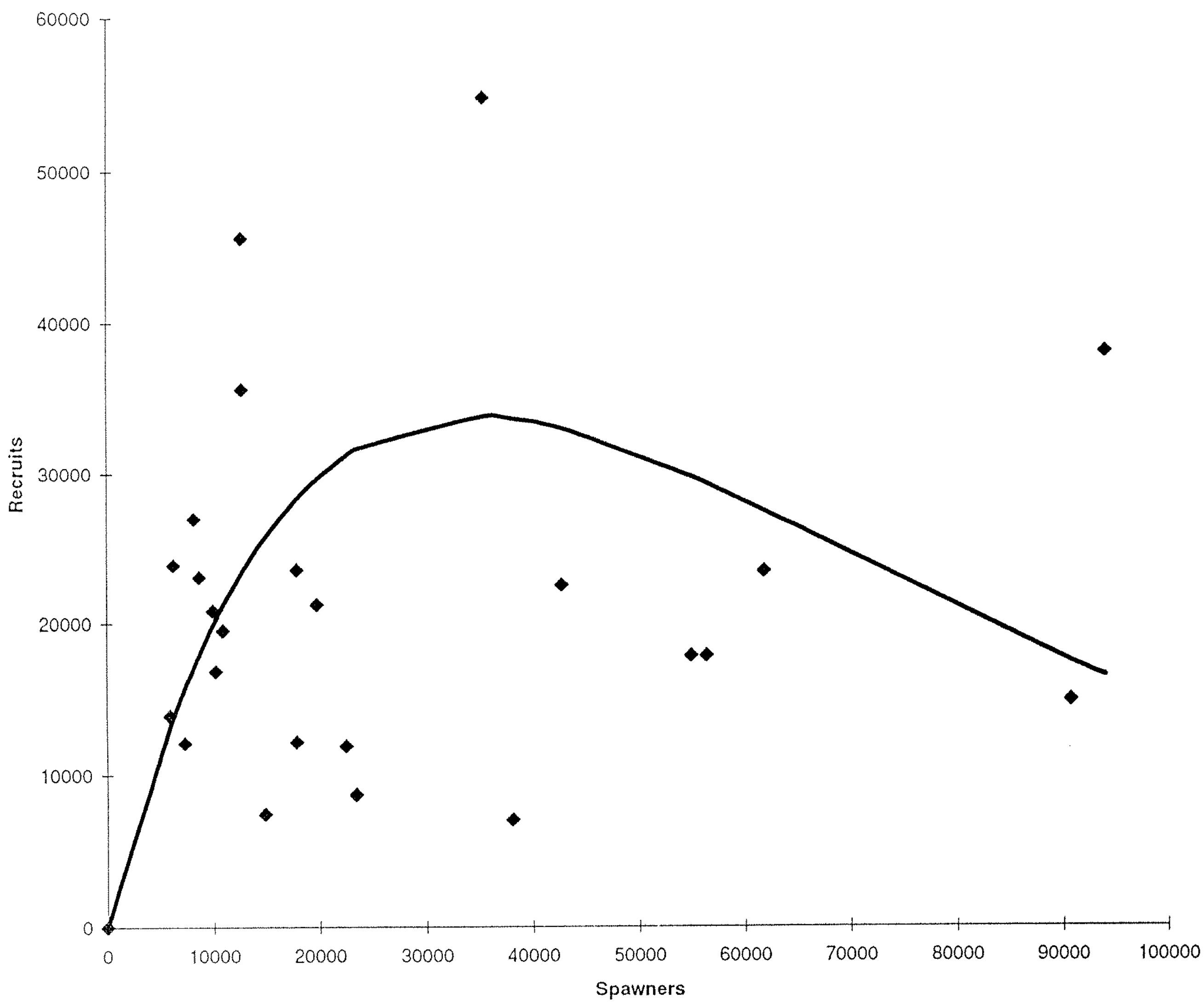
1-E

St. Mary's Spawning Run Estimates



I

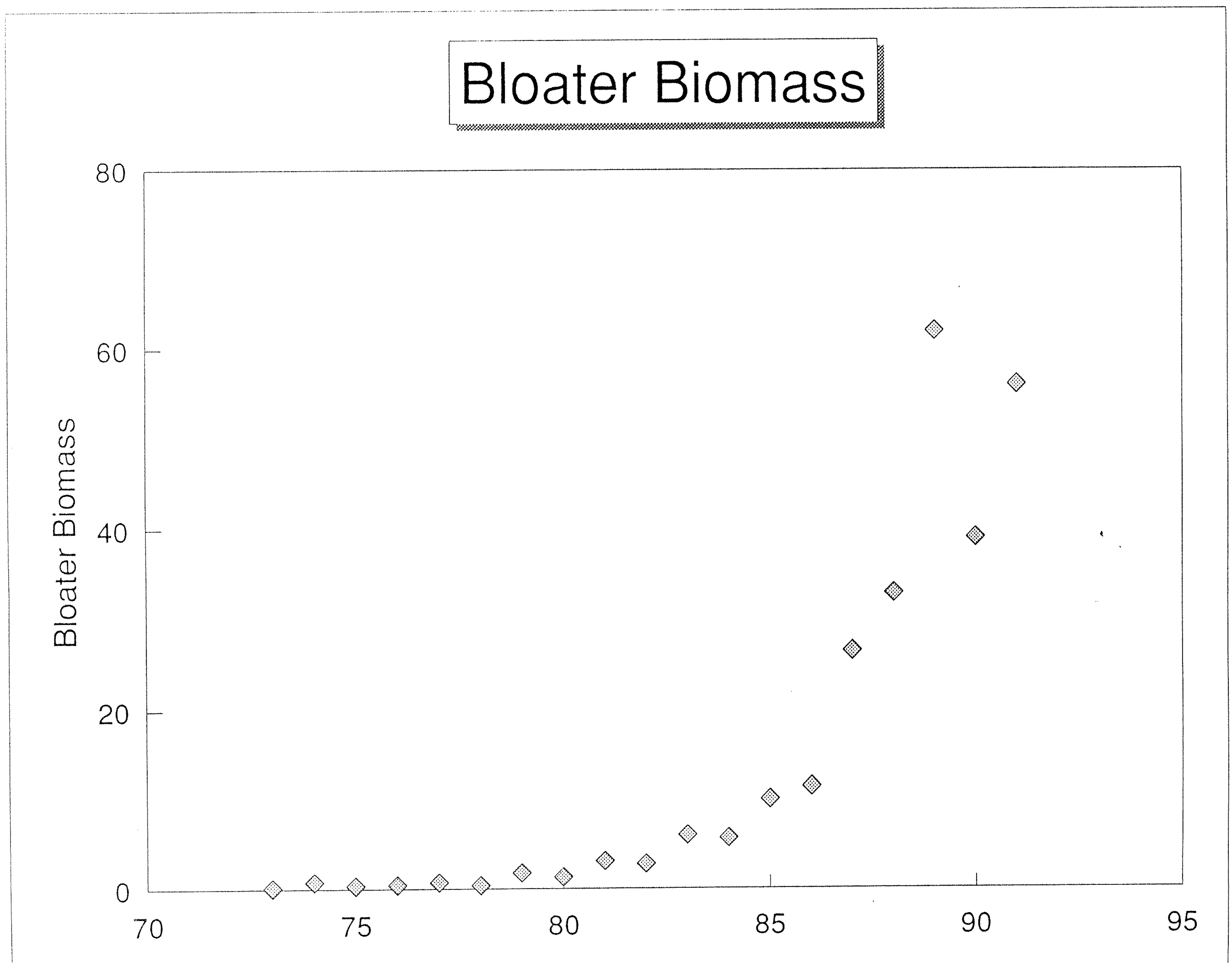
Ricker Model fit to St. Mary's River Spawning Data



I

Biologically Significant Data
St. Mary's River

Parameter	Estimate
R^2	.58
a^1	.98
b^1	33790
Optimal Stock Size ($S_{(msy)}$)	14600
Optimal Harvest Rate ($u_{(msy)}$)	.42
Spawner population for 75% reduction	2500-3000



E-1

Lake Superior

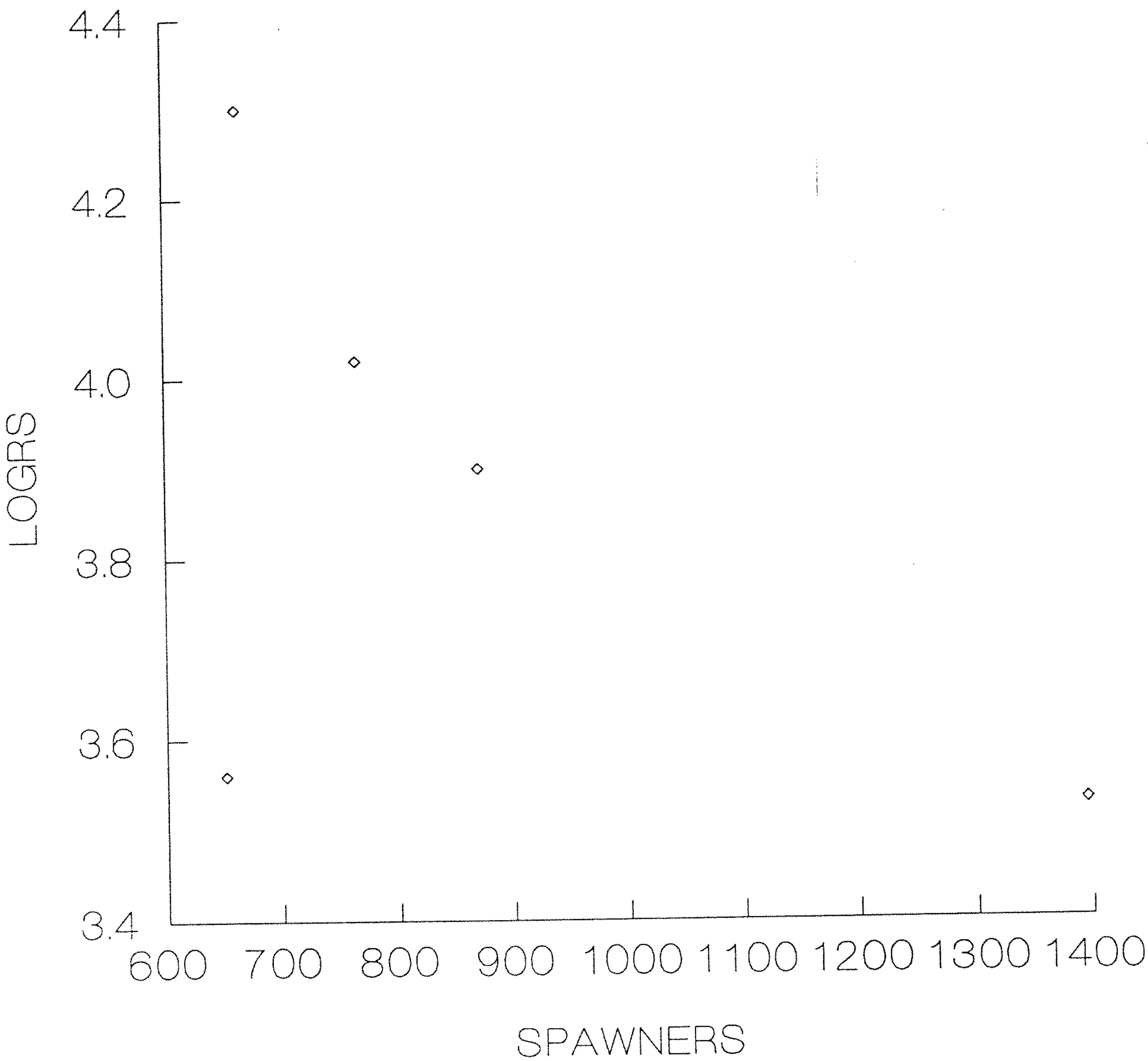
- six streams
- within stream estimates of spawning stock
- ANCOVA to test among streams

– slopes of the Ricker stock recruitment curve should be similar for streams of equal productivity.

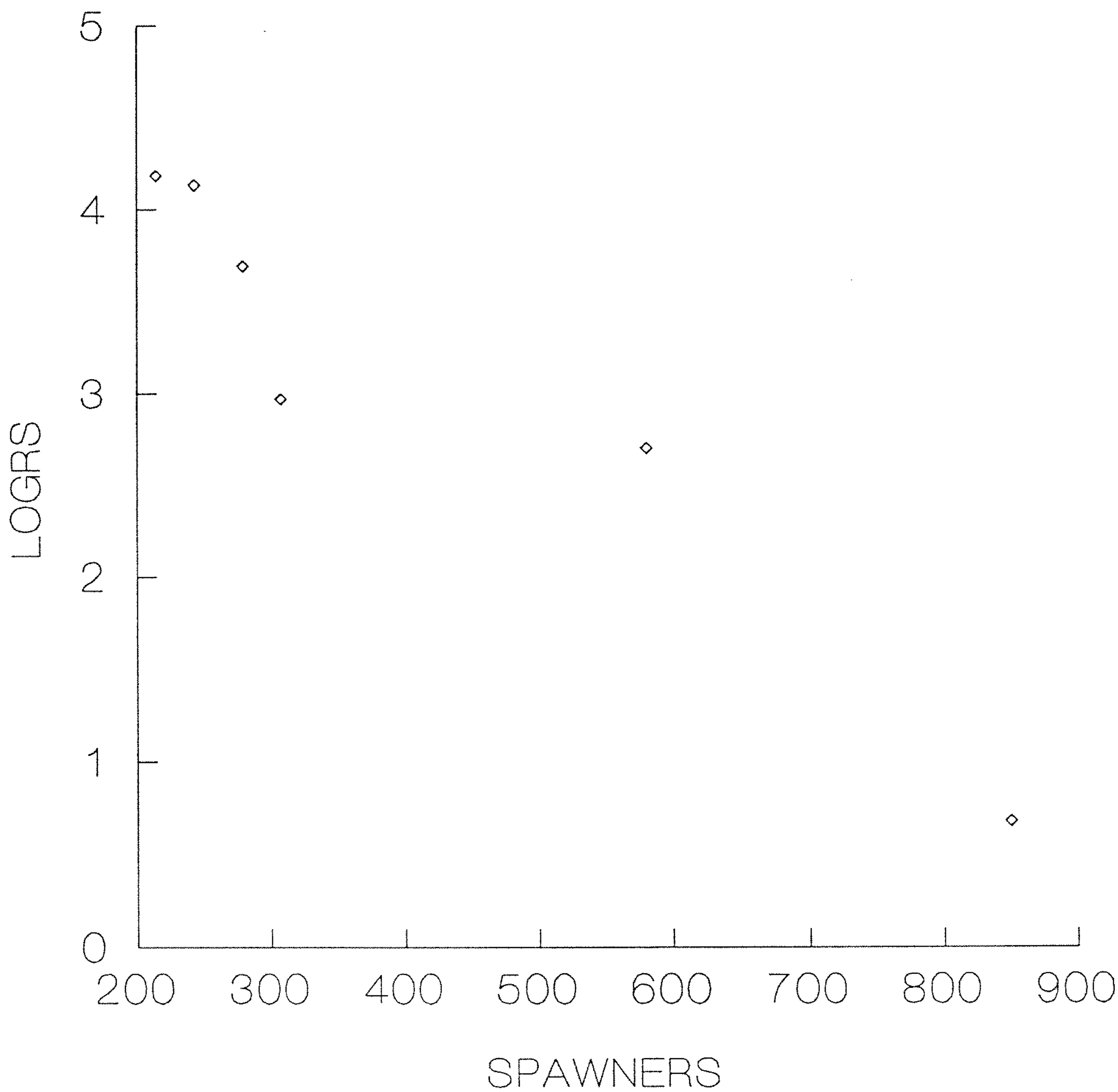
– to get similar results from the SMRT program slopes should be equal.

Lake Superior Summary

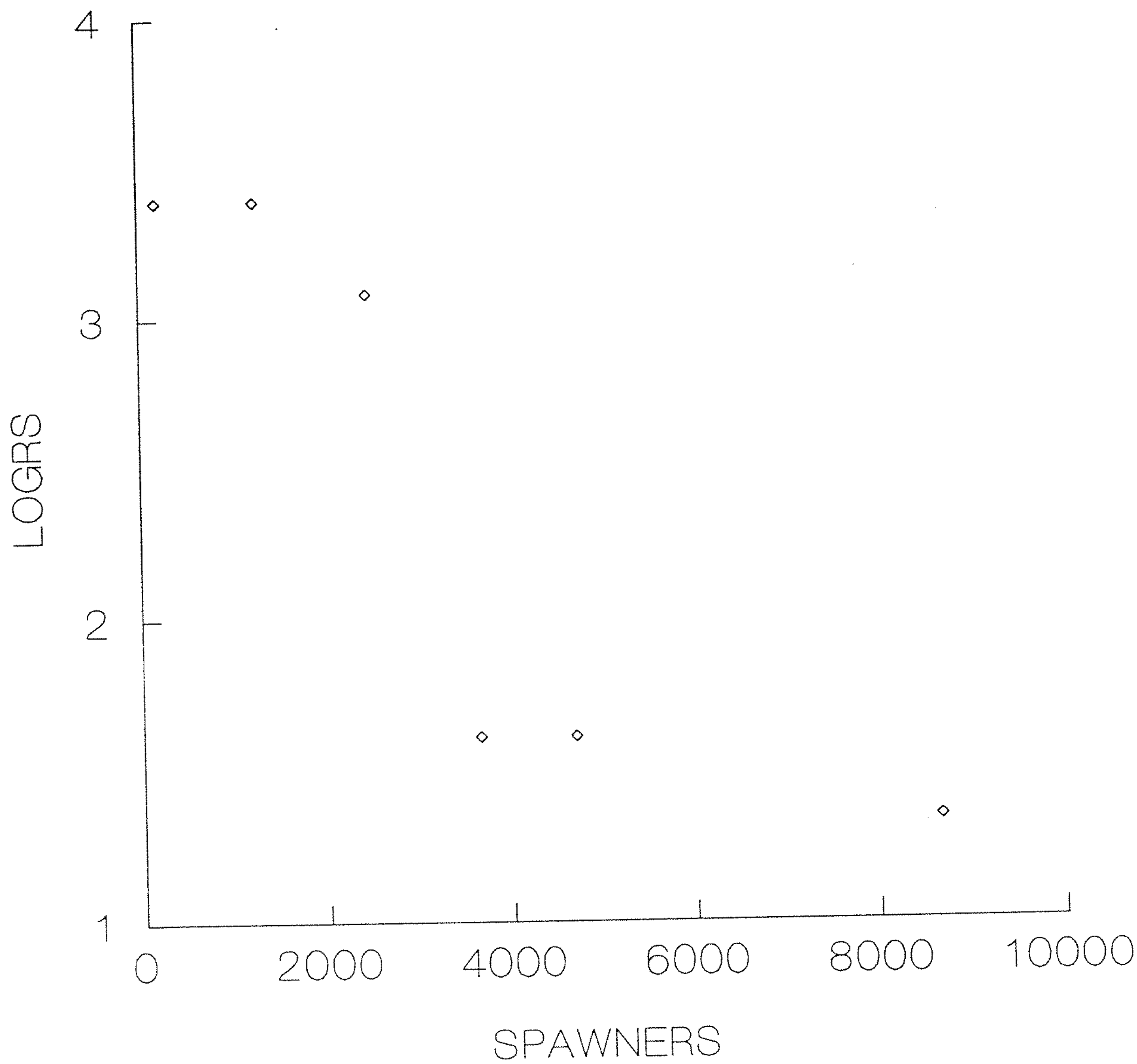
Stream	Ricker	Density Independent
Betsy	Y	N
Brule	Y	Y
Misery	N	N
Firesteel	N	N
Miners	N	N
Carp	N/A	N/A


4.4
4.2
4.0
3.8
3.6
3.4
LOGRS
600
700
800
900
1000
1100
1200
1300
1400
SPAWNERS

1-



1-E

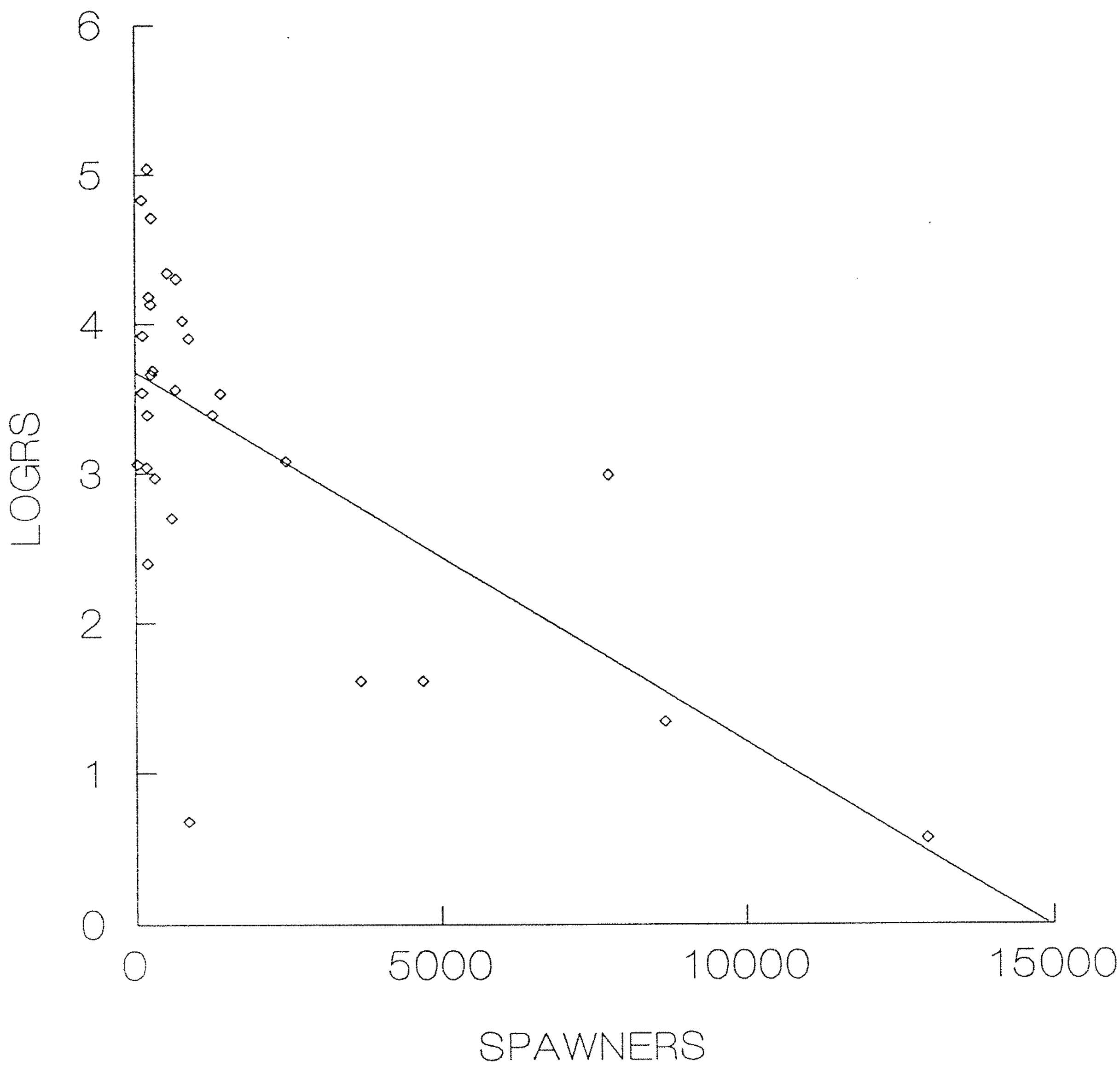


ANCOVA

- R/S = stream + spawners + stream*spawner

ANCOVA results

Source	P
Stream	0.073
Spawners	0.078
Stream*Spawners	0.006



6
5
4
3
2
1
0
LOGRS
0
5000
10000
15000
SPAWNERS

Lake Ontario

- four streams
- Within stream estimates of spawners
- Humber River estimates of spawners

1-E

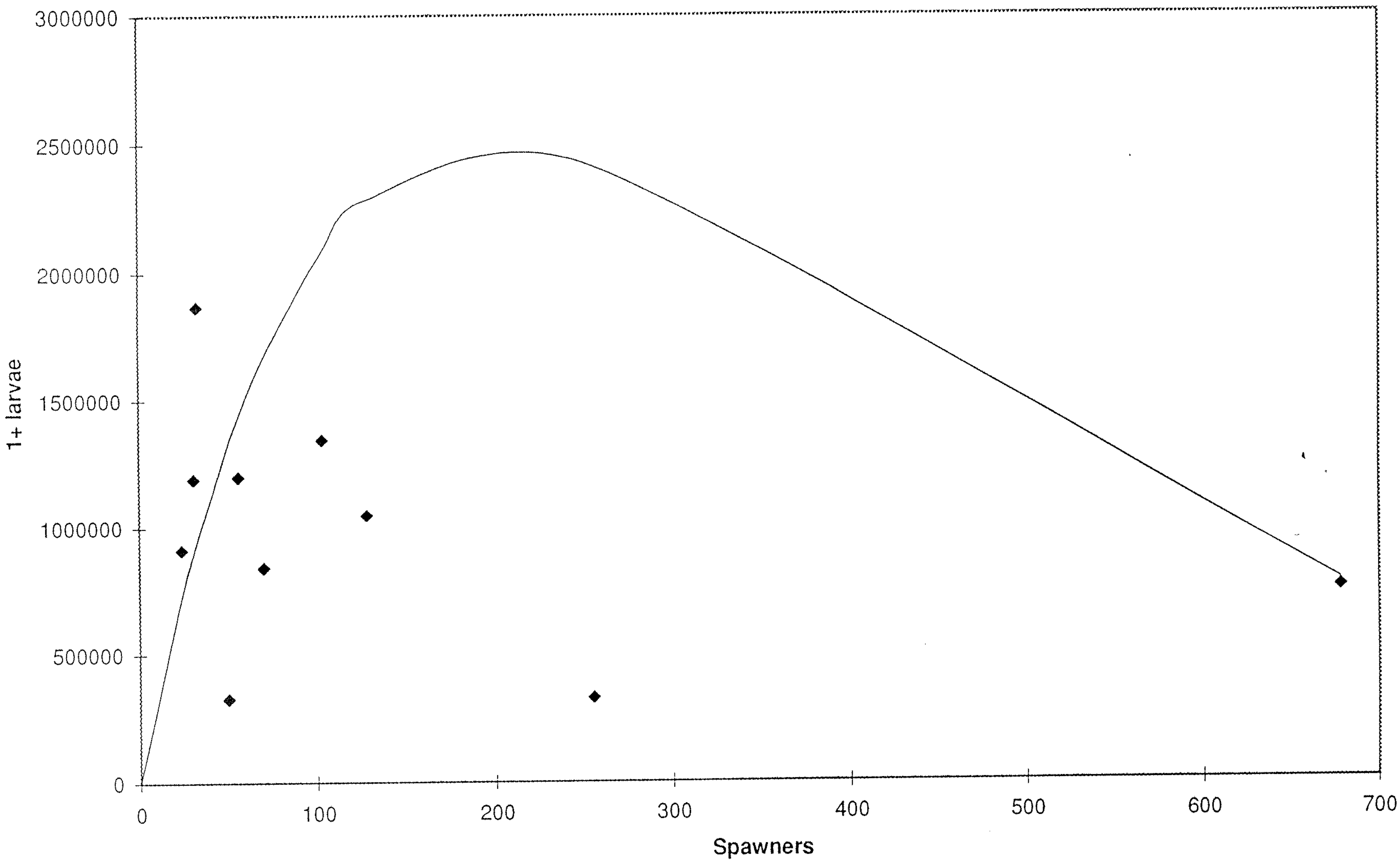
Model Summary

Stream	Ricker	Beverton/ Holt	Density Independent
Grindstone	Y	N	N
Bowmanville	Y	N	N
Sterling	N	N	N
Bronte	N	N	N ?

Summary of Parameter Estimates

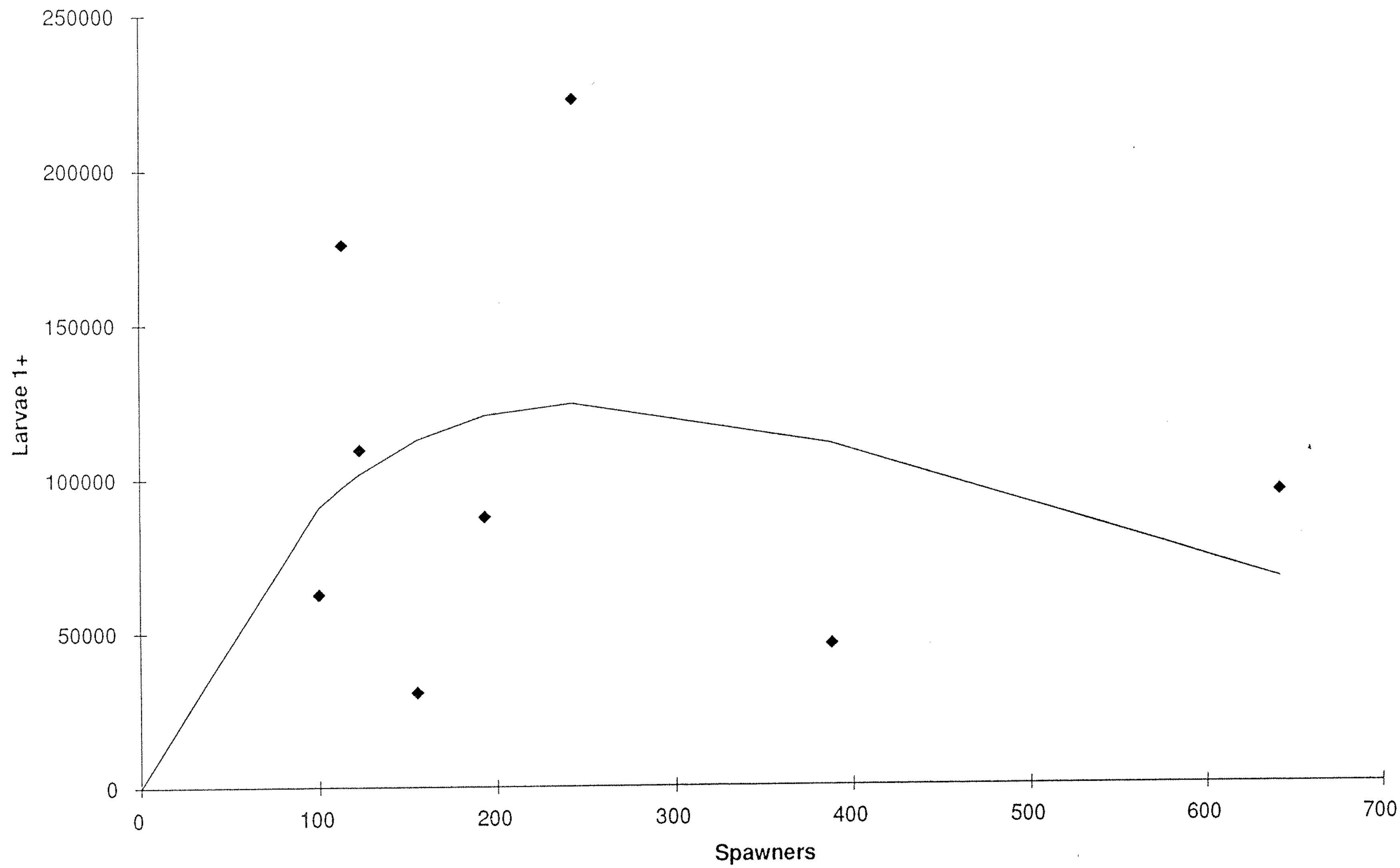
Parameter	Grindstone	Grind_humber	Bowman	Bow_humber
b0	10.059	7.44	6.936	4.895
b1	-0.005	-0.001	-0.004	-0.0005
Variance	0.739	0.206	0.55	0.563
R^2	0.64	0.73	0.48	0.52
a	10.059	7.44	6.936	4.895
b	2011.8	7440	1734	9790
a'	10.4285	7.543	7.211	5.1765
b'	2085.7	7543	1802.75	10353

Grindstone, New York

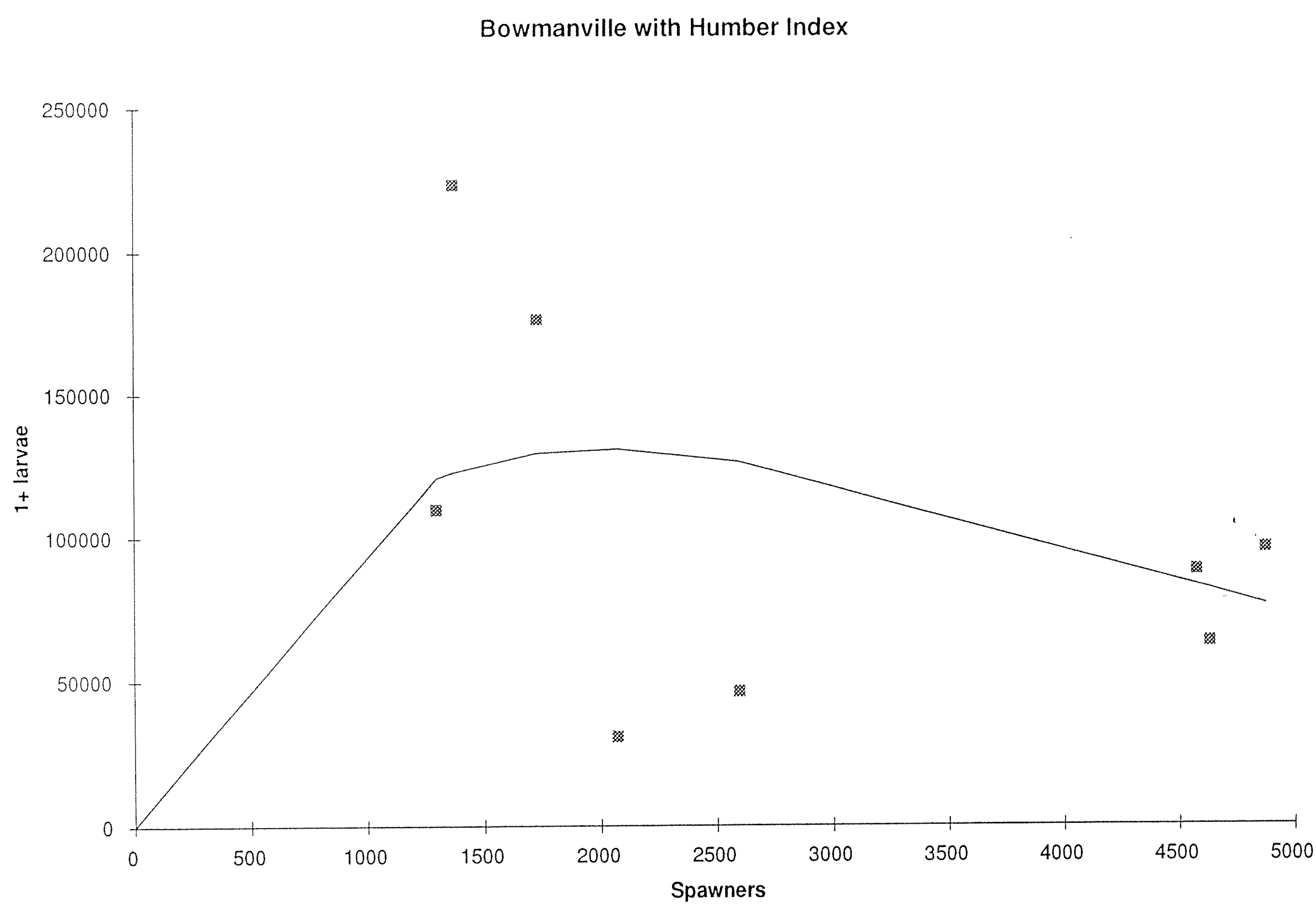


E-1

Bowmanville



1-E


Bowmanville with Humber Index
1+ larvae
250000
200000
150000
100000
50000
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Spawners

1-E

Summary of Potential Larval Sea Lamprey Growing Day Data by Latitude

Latitude Range	Avg Snow Free Days	Range Grow Degree Days	Avg Growing Degree Days	Grow Start	Grow Finish	Approx Larv. Burrow Date	Avg. # Growing Days Year 1	Avg. # Growing Days Years 1+
42 > 43	280	3750 - 4250	4000	5-Apr	15-Nov	15-Jun	153	224
43 > 44	265	3000 - 4150	3700	5-Apr	10-Nov	25-Jun	138	219
44 > 45	250	3000- 3750	3300	10-Apr	5-Nov	1-Jul	128	209
45 > 46	275	2800- 3100	3000	15-Apr	31-Oct	5-Jul	118	199
46 > 47	225	2250 - 3000	2600	20-Apr	25-Oct	15-Jul	102	188
47 > 48	,190	2000 - 2250	2125	5-May	15-Oct	15-Jul	92	163
48 > 49	205	1750 - 2250	2000	1-May	10-Oct	15-Jul	87	163
49 > 50	200	1750 - 2000	1900	10-May	10-Oct	25-Jul	77	153

Notes:
Data source was Enviornment Canada's1972 publication "The Climate Of The Great Lakes Basin"
Dates are averages based on available weather data and rounded to nearest 5 day monthly increment.
Average # of growing days for year 1 is the # of days that the mean daily air temperature was at or above 5°C. following burrowing date.
Average # of growing days for year 2 is the # of days that the mean daily air temperature was at or above 5°C.

Table 2

Growth Data All Lakes Cdn Agent

Stream Name	Lat	Degree Days(Agr.)	Alk mg/l	Flow m^3/s	N	Mean Length	Daily Growth mm	Len. at age 1.5	Density # / m^2 all Species
Cash Creek	49-50	1800	130	1	26	43.5	0.11	35.10	0.34
Nipigon River	49-50	1800	70	120	31	41	0.19	52.55	0.16
Polly Creek	49-50	1800	90	.2	6	29	0.14	41.62	0.33
Stillwater Creek	48-49	1800	45	.3	2	32	0.12	39.10	0.03
Cypress River	48-49	1850	13	2	205	44.02	0.17	51.30	13.10
Cypress River	48-49	1850	13	2	50	41.44	0.19	56.71	2.52
Gravel River	48-49	1850	45	8	72	42.54	0.17	50.62	4.45
Gravel River	48-49	1850	45	8	69	38.29	0.15	46.17	3.27
Jackfish River	48-49	1850	55	5	3	62.67	0.17	44.12	0.53
Jackfish River	48-49	1850	55	5	1	37	0.17	52.21	0.32
Little Gravel River	48-49	1850	16	.5	7	33	0.13	40.58	0.53
Pays Platt	48-49	1900	15	3.5	17	24.76	0.11	36.17	3.97
Pays Platt	48-49	1900	15	3.5	692	32.63	0.15	45.47	3.51
Prarie River	48-49	1900	100	2	39	30.43	0.12	39.10	2.17
Steel River	48-49	1900	50	8	60	33.85	0.14	43.56	1.64
Black Sturgeon River	48-49	2000	70	12	6	37.5	0.17	51.15	0.07
Pic River	48-49	2000	135	16	16	43.19	0.17	52.17	0.78
White River	48-49	2000	70	20	2	77	0.16	45.37	0.32
Wolf River	48-49	2000	85	7	49	54.86	0.24	68.71	2.43
Wolf River	48-49	2000	85	7	71	41.99	0.20	59.60	7.25
Gargantua River	47-48	2050	20	.3	40	45.45	0.21	61.51	1.88
Michipicoten River	47-48	2050	33	50	18	29.72	0.16	44.11	0.08
Cloud River	48-49	2250	50	.25	8	38.5	0.17	52.64	0.20
Kaministiquia River	48-49	2250	35	50	2	48.5	0.18	53.68	0.71
Neebing-McIntyre	48-49	2250	95	4	63	51.75	0.17	51.75	3.81
Neebing-McIntyre	48-49	2250	95	4	37	54.59	0.25	70.28	6.11
Pancake River	46-47	2250	15	2.0	68	48.5	0.09	34.00	8.68
Pancake River	46-47	2250	15	2.0	12	22.33	0.09	36.03	5.12
Pearl River	48-49	2250	85	1	6	60.17	0.16	47.88	0.21
Pigeon River	48-49	2250	30	10	4	40.25	0.19	56.06	0.06
Batchawana River	46-47	2300	21	8	172	42.19	0.15	52.55	4.08
Batchawana River	46-47	2300	21	8	35	34.31	0.15	50.20	1.24
Carp River	46-47	2300	16	1.2	70	32.71	0.13	47.63	6.40
Chippewa River	46-47	2300	21	3.5	3	45	0.18	55.50	5.81
Goulais River	46-47	2300	21	18	15	39.67	0.19	61.39	4.77
Big Carp River	46-47	2500	25	.7	17	37.59	0.13	47.38	5.25
Big Carp River	46-47	2500	25	.7	2	35	0.15	51.84	0.79
Echo River	46-47	2500	22	2.00	13	27.62	0.13	48.13	0.74
Echo River	46-47	2500	22	2.00	5	35.6	0.13	46.81	0.13
Garden River	46-47	2500	22	12.00	65	30.46	0.16	54.10	3.10
Garden River	46-47	2500	22	12.00	42	39	0.15	51.86	1.96
Little Carp River	46-47	2500	25	.4	6	51.83	0.14	49.20	8.87
Root River	46-47	2500	25	2.50	23	37.04	0.16	56.00	1.45
Root River	46-47	2500	25	2.50	203	46.67	0.19	65.31	13.56
Thessalon River	46-47	2650	30	6.00	18	82.61	0.16	55.81	3.81
Thessalon River	46-47	2650	30	6.00	4	59	0.12	43.12	0.86
Brown's Creek	46-47	2700	40	0.20	59	47.46	0.14	50.46	6.08
Brown's Creek	46-47	2700	40	0.20	86	32.17	0.17	57.00	4.41
Gawas Creek	46-47	2700	110	0.05	2	49.5	0.21	69.85	0.42

Growth Data All Lakes Cdn Agent

Lauzon Creek	46-47	2700	8	0.70	6	61.67	0.17	58.11	0.89
Mississagi River	46-47	2700	22	60.00	8	41.13	0.19	64.46	0.69
Gordon Creek	46-47	2750	50	0.10	56	34.55	0.15	52.33	2.75
Gordon Creek	46-47	2750	50	0.10	26	28.19	0.15	53.88	1.58
Koshkawong Creek	46-47	2750	90	0.35	9	41.67	0.17	58.86	1.97
Koshkawong Creek	46-47	2750	90	0.35	7	25	0.11	41.22	0.53
Richardson Creek	46-47	2750	140	0.25	5	67.6	0.16	56.21	0.53
Serpent River	46-47	2750	7	12.00	24	35.46	0.19	65.42	1.29
Serpent River	46-47	2750	7	12.00	10	51.3	0.18	62.33	1.95
Spanish River	46-47	2750	22	70.00	42	49.17	0.17	59.43	0.50
Twotree River	46-47	2750	145	0.25	6	56.83	0.18	60.56	0.49
Watson Creek	46-47	2750	50	0.15	15	47.07	0.22	73.19	1.49
Chikanishing River	45-46	2800	6	0.40	2	73	0.11	44.10	2.13
French R. (Old V. Chan	45-46	2800	20	0.30	32	58.65	0.18	66.23	21.91
Sand Creek	45-46	2850	140	0.25	3	42	0.16	60.03	0.39
Silver Creek	45-46	2850	160	0.55	26	74.46	0.16	60.88	1.25
Blue Jay Creek	45-46	2900	160	0.75	86	36.44	0.15	55.02	4.13
Boyne River	45-46	2900	10	1.00	124	38.56	0.14	53.62	6.26
Magnetawan River	45-46	2900	8	25.00	10	47	0.13	50.40	1.63
Magnetawan River	45-46	2900	8	25.00	19	51.05	0.11	43.36	0.41
Manitou River	45-46	2900	130	2.00	21	45	0.13	51.27	1.73
Manitou River	45-46	2900	130	2.00	23	80.74	0.18	65.85	4.64
Mindemoya River	45-46	2900	145	1.30	122	45.47	0.13	49.28	7.51
Mindemoya River	45-46	2900	145	1.30	58	41.72	0.16	59.84	2.71
Naiscoot River	45-46	2900	8	2.50	173	34.35	0.17	62.57	9.45
Naiscoot River	45-46	2900	8	2.50	139	36.44	0.15	55.27	19.26
Still River	45-46	2900	12	2.00	1	41	0.13	50.07	2.18
Timber Bay Creek	45-46	2900	170	0.30	211	37.27	0.10	40.23	12.56
Timber Bay Creek	45-46	2900	170	0.30	32	64	0.14	53.94	4.35
Musquash River	45-46	2950	10	10.00	2	45.5	0.15	56.03	0.08
Nottawasaga R. (main)	44-45	3100	220	13.50	3	70.33	0.20	77.67	0.71
Nottawasaga R. (Pine)	44-45	3100	220	13.50	205	70.85	0.21	78.71	16.70
Nottawasaga R. (Pine)	44-45	3100	220	13.50	103	71.85	0.22	84.64	11.28
Sauble River	44-45	3150	200	5.00	11	83.36	0.17	66.21	0.44
Colborne Creek	43-44	3650	210	0.4	3	48.67	0.21	84.33	0.46
Mayhew Creek	44-45	3650	175	0.25	52	41.58	0.21	83.08	2.38
Mayhew Creek	44-45	3650	175	0.25	78	50.82	0.24	93.83	3.76
Proctor's Creek	44-45	3650	230	0.2	17	80.06	0.19	77.94	3.26
Salem Creek	44-45	3650	180	0.15	172	44.2	0.20	80.00	9.38
Bowmanville Creek	43-44	3700	210	2	26	74.81	0.22	88.37	6.57
Bowmanville Creek	43-44	3700	210	2	15	61.07	0.13	53.79	9.22
Cobourg Brook	43-44	3700	210	1	60	77	0.23	90.19	6.56
Cobourg Brook	43-44	3700	210	1	90	45.28	0.19	76.11	5.41
Farewell Creek	43-44	3700	225	0.5	76	74.93	0.22	88.52	3.66
Farewell Creek	43-44	3700	225	0.5	1	52	0.20	82.10	0.32
Grafton Creek	43-44	3700	215	0.2	63	65.62	0.19	76.83	3.20
Graham Creek	43-44	3700	200	0.5	4	91.5	0.18	74.60	0.42
Lynde Creek	43-44	3700	215	0.6	76	71.58	0.21	84.48	5.78
Lynde Creek	43-44	3700	215	0.6	30	57.76	0.25	96.92	3.10
Oshawa Creek	43-44	3700	230	1.2	71	74.9	0.22	89.29	5.02
Oshawa Creek	43-44	3700	230	1.2	9	54	0.23	90.55	1.07
Port Britain Creek	43-44	3700	220	0.2	2	64.5	0.18	73.75	0.56
Salmon River	44-45	3700	95	6	18	45.83	0.20	82.05	1.05

Growth Data All Lakes Cdn Agent

Shelter Valley Creek	43-44	3700	210	0.5	10	37.1	0.15	62.36	1.45
Wilmot Creek	43-44	3700	210	1	83	69.59	0.20	81.34	4.46
Wilmot Creek	43-44	3700	210	1	157	42.06	0.17	69.84	8.52
Bronte Creek	43-44	3750	225	2.5	106	76.18	0.23	90.30	5.78
Bronte Creek	43-44	3750	225	2.5	86	67.07	0.27	105.42	4.24
Credit River	43-44	3750	200	7.5	24	50.46	0.24	94.56	1.29
Dufifns Creek	43-44	3750	235	2	5	31.8	0.31	118.99	2.65
Dufifns Creek	43-44	3750	235	2	2	69	0.30	117.18	0.36
Rouge River	43-44	3750	200	1.5	18	73.78	0.33	125.21	0.93
Rouge River	43-44	3750	200	1.5	5	65.4	0.21	84.69	0.39
Sixteen Mile Creek	43-44	3750	220	1.8	20	50.1	0.23	92.84	1.41
Big Creek	42-43	3800	200	5	34	52.44	0.20	85.17	4.17
Big Creek	42-43	3800	200	5	33	85.73	0.19	79.90	8.87
Black River	43-44	3800	35	45	4	40.5	0.18	74.38	0.10
Black River	43-44	3800	35	45	29	66.93	0.21	85.60	0.69
Catfish Creek	43-44	3800	70	1	18	57.72	0.17	70.03	1.07
Catfish Creek	43-44	3800	70	1	247	55.38	0.17	70.78	6.46
Deer Creek	43-44	3800	55	0.8	104	72.12	0.21	84.11	5.61
Deer Creek	43-44	3800	55	0.8	164	36.1	0.16	67.28	6.47
Grindstone Creek	43-44	3800	50	1.2	124	52.1	0.16	67.06	4.62
Grindstone Creek	43-44	3800	50	1.2	214	53.82	0.15	62.34	24.32
Lindsey Creek	43-44	3800	55	1	57	69.54	0.21	85.64	5.15
Lindsey Creek	43-44	3800	55	1	106	63.59	0.21	82.27	5.61
Lindsey Creek	43-44	3800	55	1	112	29.07	0.12	53.50	5.49
Little Salmon River	43-44	3800	50	3	28	61	0.18	74.60	3.20
Little Salmon River	43-44	3800	50	3	479	49.11	0.13	56.73	29.61
Little Salmon River	43-44	3800	50	3	279	38.35	0.17	71.00	10.82
Little Sandy Creek	43-44	3800	35	1.3	38	71.26	0.21	83.09	6.15
Little Sandy Creek	43-44	3800	35	1.3	191	41.78	0.20	79.50	7.79
Salmon River	43-44	3800	25	25	417	58.75	0.17	68.20	10.25
Salmon River	43-44	3800	25	25	653	32.67	0.14	59.60	3.27
Skinner Creek	43-44	3800	70	1.5	1	64	0.19	78.38	0.47
Skinner Creek	43-44	3800	70	1.5	2	69	0.23	89.53	0.47
Skinner Creek	43-44	3800	70	1.5	119	37.2	0.18	71.53	4.69
Snake Creek	43-44	3800	75	0.25	123	84.86	0.25	98.97	7.18
Snake Creek	43-44	3800	75	0.25	30	45.03	0.22	86.02	1.29
South Sandy Creek	43-44	3800	65	5	110	65.71	0.20	80.54	6.98
South Sandy Creek	43-44	3800	65	5	126	65.28	0.21	84.53	5.00
Young's Creek	42-43	3800	205	1	4	40.75	0.15	66.82	0.42
First Creek	43-44	3900	155	0.1	43	73.67	0.21	84.45	1.70
Fish Creek	43-44	3900	40	12	126	43.32	0.20	81.07	8.66
Ninemile Creek	43-44	3900	130	0.75	3	75	0.22	88.07	0.47
Ninemile Creek	43-44	3900	130	0.75	55	85.05	0.19	78.44	3.09
Oak Orchard Creek	43-44	3900	185	0.2	2	65.5	0.18	74.70	0.47
Red Creek	43-44	3900	160	0.9	10	66.7	0.21	85.29	0.73
Salmon Creek	43-44	3900	175	0.75	42	60.05	0.17	68.17	1.70
Sodus Creek	43-44	3900	200	0.3	2	67	0.19	76.67	1.93
Sterling Creek	43-44	3900	160	1.8	70	58.54	0.19	76.25	3.38
Sterling Creek	43-44	3900	160	1.8	103	75.45	0.23	89.42	6.07
Sterling Creek	43-44	3900	160	1.8	49	37.22	0.16	67.57	1.90
Big Bay Creek	43-44	4000	55	0.9	110	60.55	0.19	77.67	4.03

COMPENSATORY MECHANISMS WORKSHOP

SUMMARY OF ECOLOGY OF RECRUITMENT IN SEA LAMPREY

OBJECTIVE: Observe density influenced changes to sea lamprey larvae population characteristics such as mortality, growth, potential fecundity, sex ratio and age-at-metamorphosis.

Stationary study of 12 streams: the cumulative environmental influence of pH, alkalinity, temperature, food quality and quantity after successive years of TFM treatment on population characteristics.

METHODS: Develop background for each stream regarding previously mentioned characteristics and population estimates using Petersen mark-recapture.
8 streams have been selected based on the following criteria
1) pH <7.0 vs >7.0
2) treatment history
3) species composition
4) size of stream
All 8 streams are reduced to ~5% of population size prior to TFM treatment.

Streams were chosen from Lakes Ontario, Huron and Michigan. Because of the differences in latitude, water temperature has been monitored using Onset temperature loggers.

Length-frequency distributions were supported by age determination from statoliths.

Sex ratio has been determined by histological (not macroscopic) observation of larval gonads.

During the first year a total of 12 streams were sampled for MSc Thesis candidate. Population size was estimated using modified Zippens removal method on randomly chosen $100m^2$ sites. Food quality samples (water and substrate) were taken within each site. The method of analysis of these samples has yet to be determined but will likely be Bio-rad Protein Assay and Dichromate Wet Oxidation for protein and carbon respectively.

RESULTS: Growth rates were calculated using June 1 as a hatch date for all streams. Growth rates based on a mean total length at age regression appear to be similar among streams with pH > 7.0. However, based on our temperature data, sea lamprey larvae in northern streams with pH > 7.0 appear to be growing faster over a given season. If 10°C is taken as the minimum temperature for growth, northern Ontario streams appear to have 2 months less growing time than southern streams. Age-at-metamorphosis is 3 for southern streams and 4 in northern streams.

Density as measured by number of animals / total area of stream was not correlated to sex ratio or growth.

Visual sexing was not accurate for all streams, so lamprey were sexed based on histological examination. For most streams, larvae > 90mm had differentiated gonads, but for many streams, a large number of larvae of 'unknown' sex were present. Gonadal morphology varied from the description in the literature. Typical females made up ~ 5-60% of larvae, typical males ~ 1-3%, with the remaining larvae displaying typical female morphology, but with few or no oocytes.

Statoliths were not always present in larvae and metamorphosing sea lamprey from northern streams. Some statoliths were atypical in Farewell Creek and displayed unusual growth band for the current year.

DISCUSSION: Larvae in northern streams attained same total length at age as compared to southern streams regardless of short growing season. Age-at-metamorphosis reflects the short growing season in northern streams. The extra year taken to metamorphose may indicate the need to build up lipids (Lowe et al. 1973; O'Boyle and Beamish 1977). Northern streams such as West Root River and Cannon Creek display 'no' statoliths or shrunken statoliths. These streams also have water chemistry suggestive of low nutrient streams. A result of this may be resorption of minerals such as calcium and subsequent atrophication of tissue such as statoliths in order to compensate for growth especially during metamorphosis.

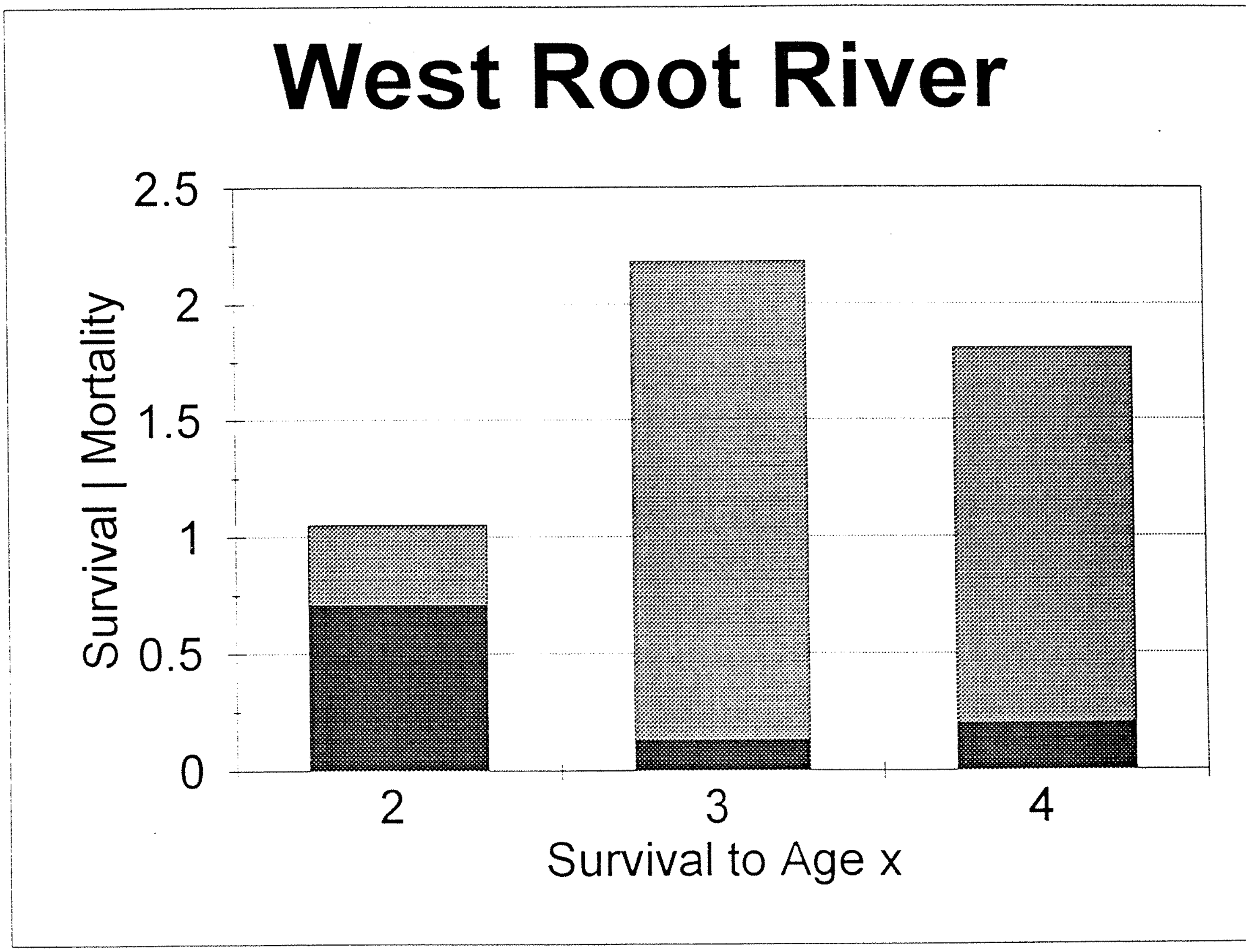
As part of a study for an undergraduate credit, Kym Harley measured annuli from larval statoliths for back calculation of age at length. From this information, one could theoretically calculate true growth rate (Ricker 1975), however results from statolith removal in West Root River, Cannon Creek and Farewell Creek jeopardize the validity of back-calculation for some streams.

Possible explanations for the unusual gonadal development in the larval and metamorphosing lamprey:

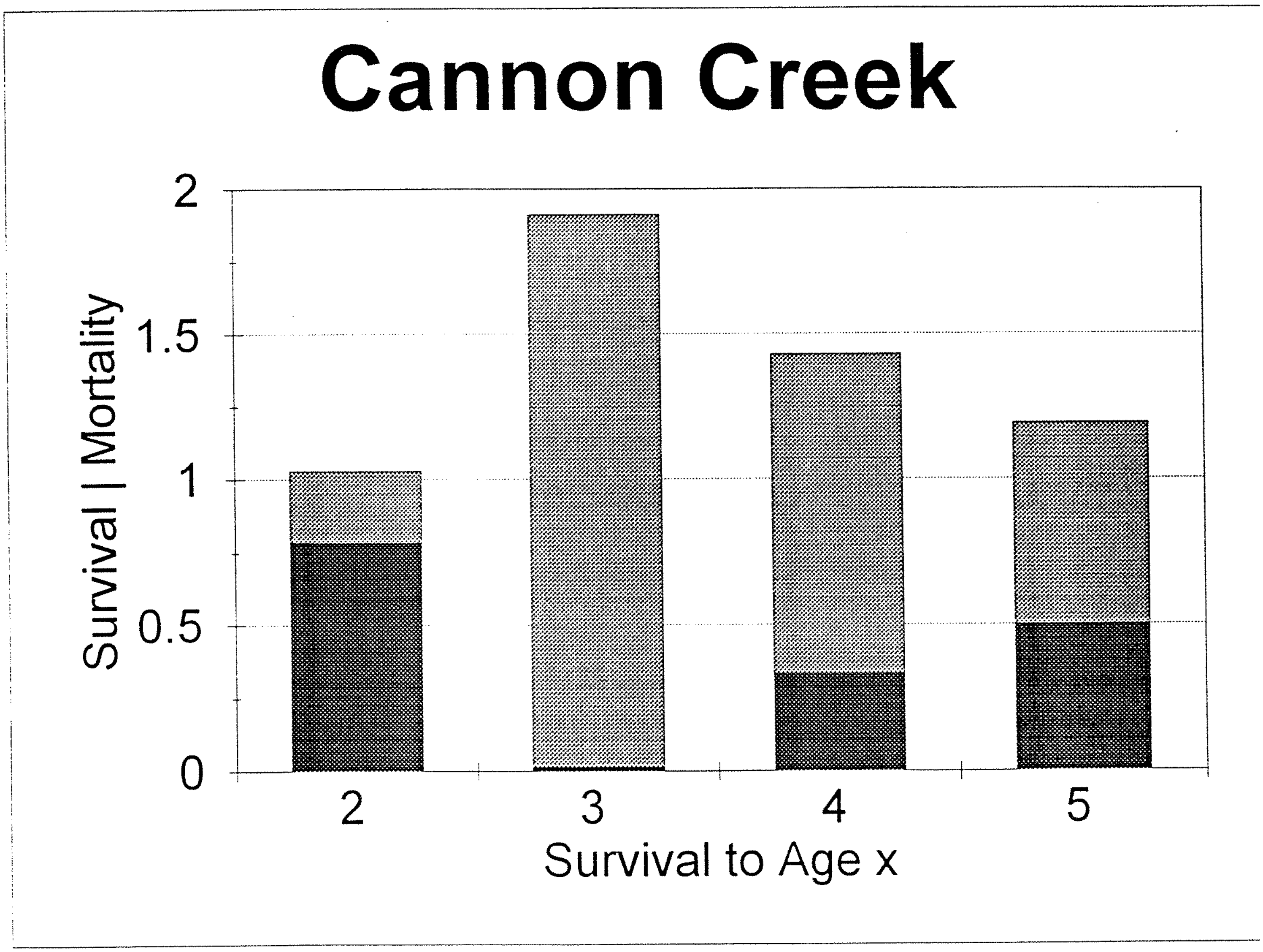
1) Changing densities due to TFM treatment cycle, and a few larvae inducing successive year classes by pheromones.
2) Size-induced sex ratio (Ross 1990)
3) Sex-induced ratio (Ross 1990)
4) Chemicals in the streams and lakes.

The larvae that we have examined are reaching gonadal stages 5 and 6 at sizes less than that found by Hardisty (1969).

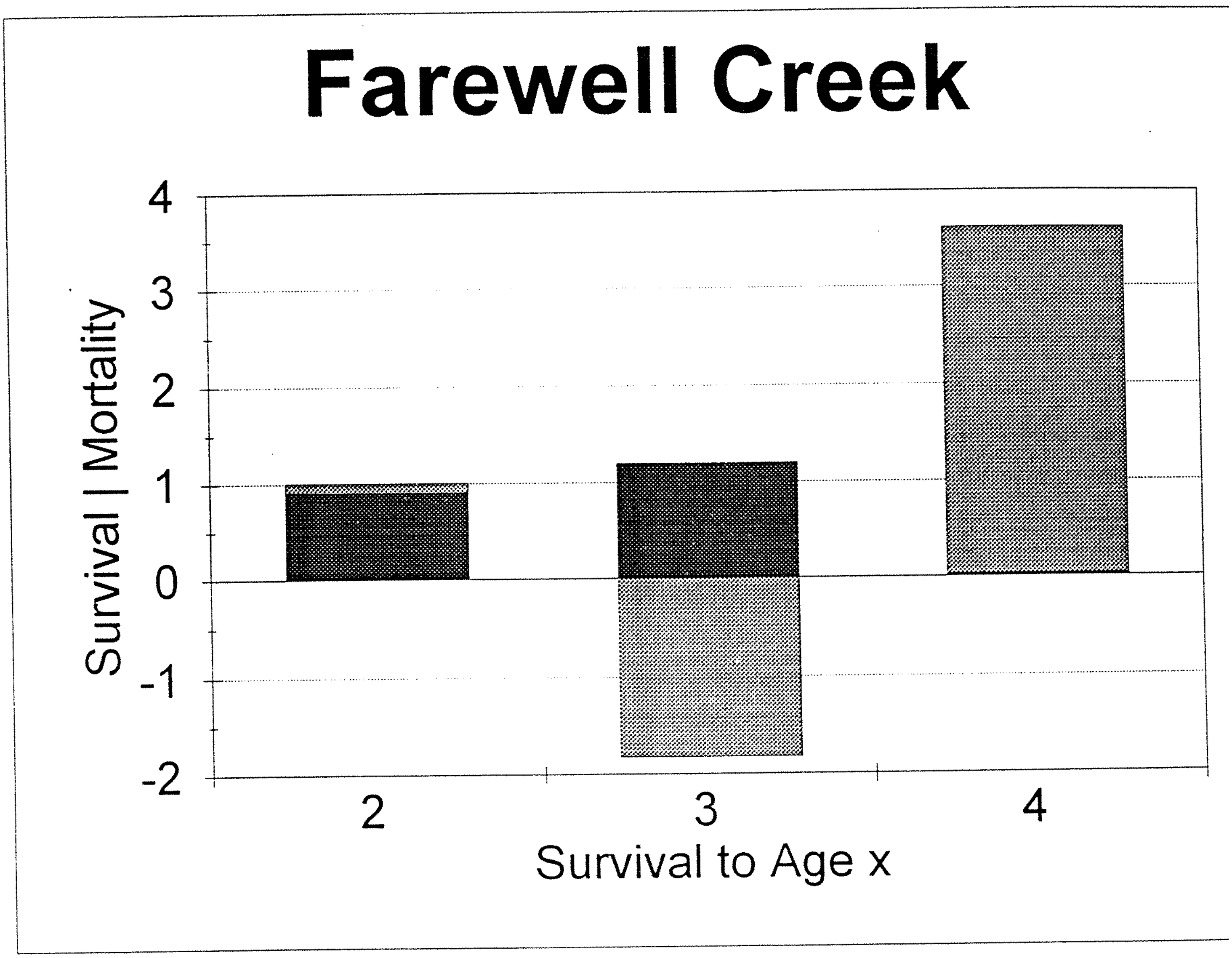
Potential fecundity may be an interesting compensatory mechanism, however the unusual gonads have been a stumbling block.


West Root River
2.5
2
1.5
1
0.5
0
Survival | Mortality
2
3
4
Survival to Age x

1-G

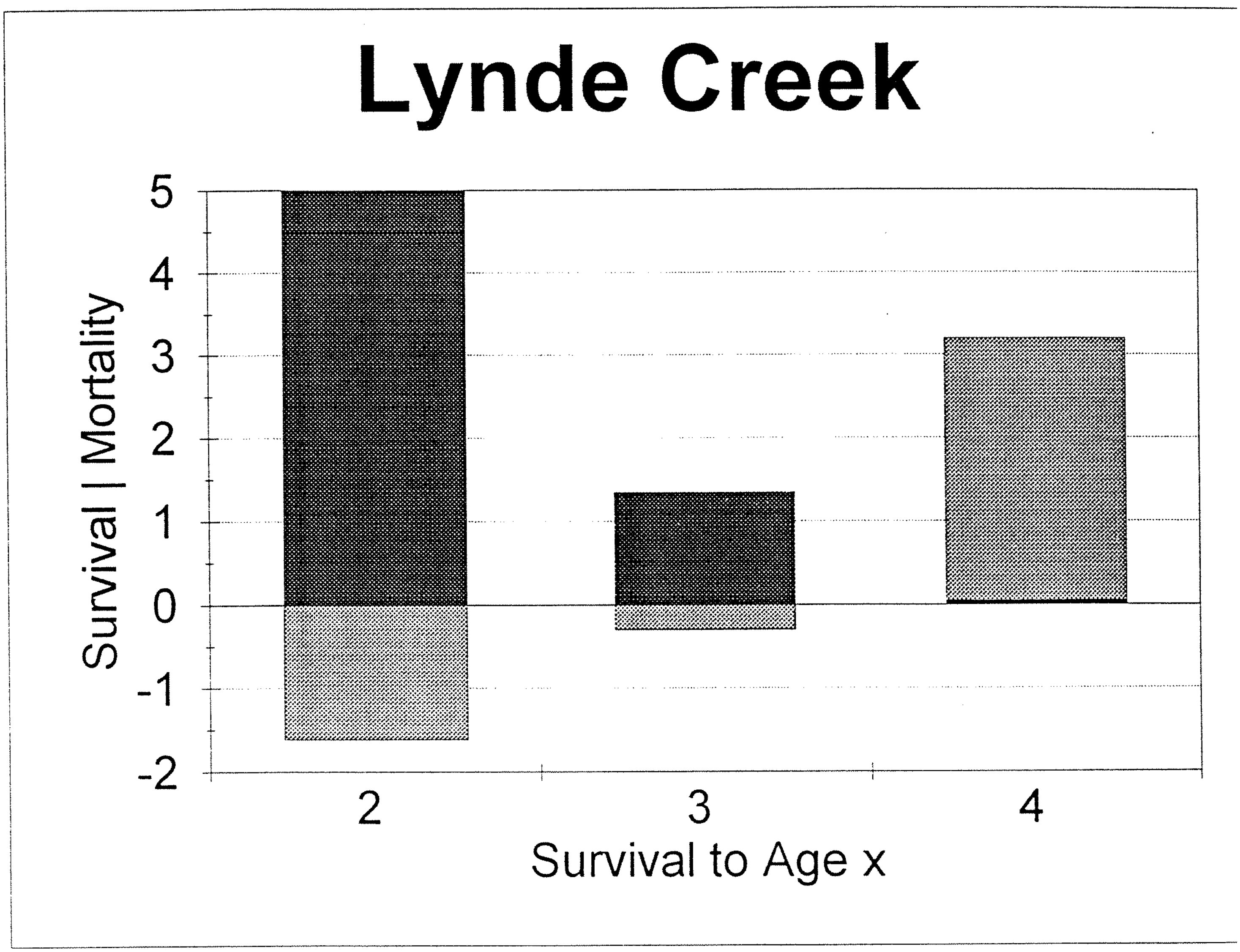


Cannon Creek
2
1.5
1
0.5
0
Survival | Mortality
2
3
4
5
Survival to Age x

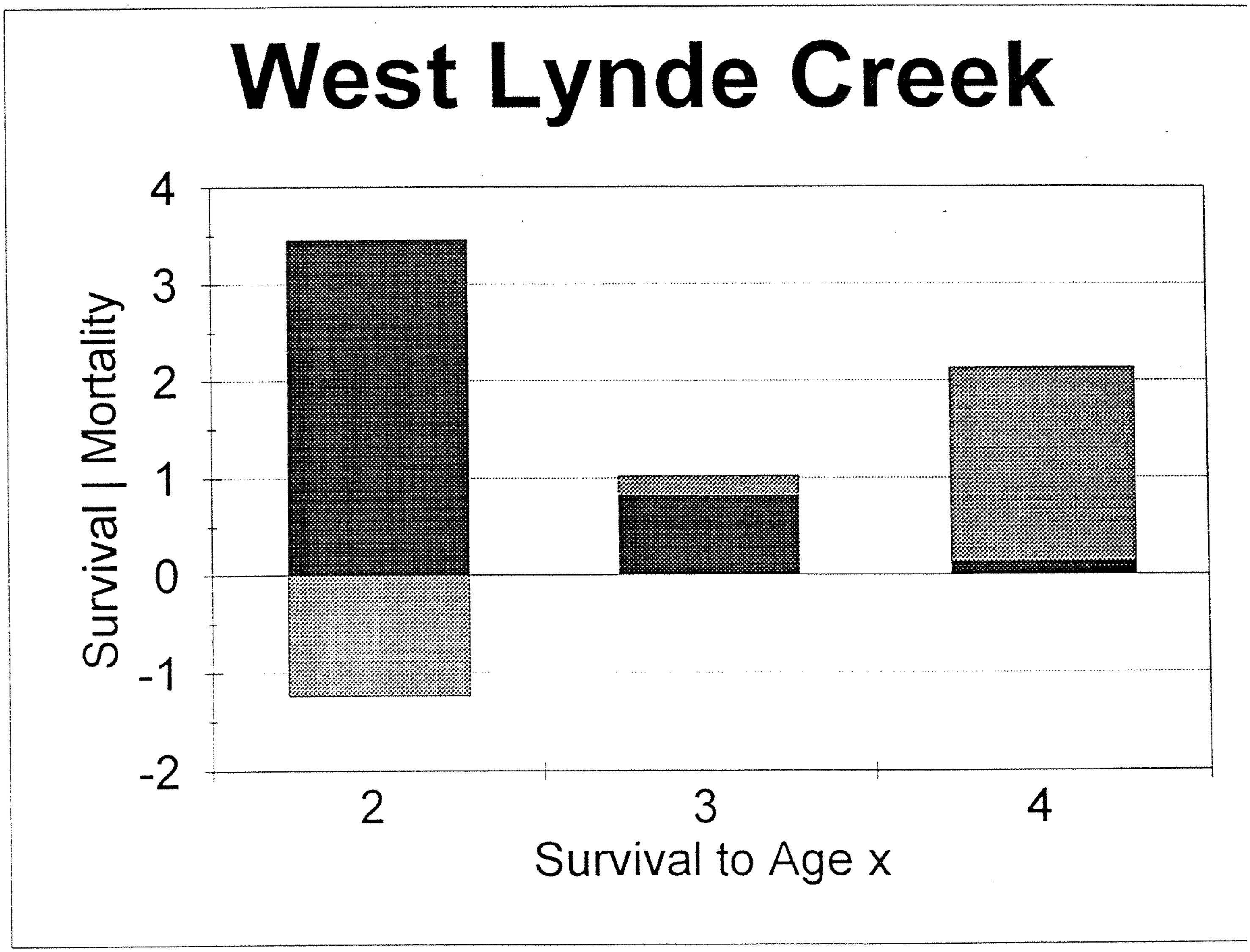


Farewell Creek
4
3
2
1
0
-1
-2
Survival | Mortality
2
3
4
Survival to Age x

1-G



Lynde Creek
5
4
3
2
1
0
-1
-2
Survival | Mortality
2
3
4
Survival to Age x


West Lynde Creek
4
3
2
1
0
-1
-2
Survival | Mortality
2
3
4
Survival to Age x

Appendix

Table 1. Sea lamprey (*Petromyzon marinus*) study streams' abiotic characteristics.

Great Lake	Stream	Mean Temperature (°C)	pH	Alkalinity ($mgl^{-}CaCO_3$)	Hardness ($mgl^{-}CaCO_3$)
Huron	Cannon Cr.	12.7*	7.5	17.1	18.0
Superior	Carp R.	11.0	8.0	83.0	145.0
Ontario	Farewell Cr.	15.9	8.8	200.0	240.0
Huron	Gordon's Cr.	14.8	7.4	80.0	66.0
Huron	Harris Cr.	18.1	6.8	21.8	22.3
Ontario	Lynde Cr.	16.2	8.4	210.7	254.4
Ontario	Mayhew Cr.	16.5	7.8	0.0	0.0
Ontario	Proctor's Cr.	15.1	8.9	222.0	246.0
Huron	Richardson's Cr.	14.8**	8.0	166.0	121.5
Huron	Spragge Cr.	14.0	6.8	19.0	15.8
Huron	Sturgeon R.	n/a	8.0	194.0	193.0
Huron	West Root R.	12.7	7.1	26.5	14.3

* The temperature for Cannon Creek was taken from West Root River because there was no temperature logger for Cannon Creek and both streams are tributary to the Root R.

** The temperature for Richardson Creek was taken from Gordon's Creek because the Richardson Cr. temperature logger has not been retrieved yet and these streams are in close proximity on St. Joseph's Island, Ont.

Note: Mean temperatures are based on hourly temperatures from June to October or November 1995.

1-G

Table 2. Abundance of larvae based on results of Mark-Recapture and Depletion Estimation Techniques for Sea Lamprey (*Petromyzon marinus*) in Tributaries to the Great Lakes.

	Population Estimates					
Stream Name	Petersen Mark-Recapture			Zippins Depletion Method		
	N	$N_{upper95\%}$	$N_{lower95\%}$	N	$N_{upper95\%}$	$N_{lower95\%}$
Farewell Creek	4449	5195	3890	3468	5167	1770
Lynde Creek-West	2028	3939	1365	1839	3103	575
Lynde Creek[1]	13722	*	*	na	na	na
Harris Creek	1814	4621	1129	496	1330	-338
West Root River[2]	7319	7679	6959	15010	39005	-8985
Cannon Creek[3]	18983	20628	17581	20868	47510	-5774
Mayhew Creek	na	na	na	29957	76109	-16195
Proctor's Creek	na	na	na	15550	37379	-6279
Sturgeon River[4]	na	na	na	33009	135952	-69934
Spragge Creek	na	na	na	602	1583	-379
Gordon's Creek	na	na	na	1020	2273	-233
Richardson Creek	na	na	na	1020	2954	-914
Little Gravel River[5]	na	na	na	2000	5000	101
Carp River	na	na	na	7571	12677	2465

1. This estimate for Lynde Creek includes Lynde Creek West. The number of sea lamprey larvae examined for marks was very low and the subsequent variance for the population estimate was too low to generate reliable confidence intervals.
2. West Root River is a tributary to the Root River H-3.
3. Cannon Creek is a tributary to the Root River H-3 and is also called the West West Root R.
4. Sturgeon River's population estimate includes *Ichthyomyzon* sp.
5. This is a post treatment estimate and was provided by Sea Lamprey Control, Canada.

Table 3. Proportion of female sea lamprey (*Petromyzon marinus*) larvae from streams tributary to the Great Lakes.

STREAM	% FEMALE $\bar{X}$	CI	SAMPLE SIZE	DENSITY larvae/m^2
Carp R.	56	10	71	0.25
Farewell Cr.	24	9	93	0.12
Gordon's Cr.	5	3	249	0.26
Lynde Cr.	43	10	156	0.11
Mayhew Cr.	58	11	142	1.26
Proctor's Cr.	12	7	86	4.71

Table 4. Populations of sea lamprey reduced by 95% of the original population before chemical reduction in 5 tributaries to the Great Lakes, Ontario, Canada.

Stream Name	*5% Replaced population Estimated (actual)
Farewell Creek	223 (223)
Lynde Creek	686 (387)
Harris Creek	93 (48)
West Root River	366 (366)
Cannon Creek	950 (950)

*Harris and Lynde Creeks have lower than 5% of the original populations because of difficult recapture conditions. The estimated populations represented were all calculated based on Petersen mark-recapture (Ricker 1975).

Table 5. Stream area and density of sea lamprey in 12 tributaries to the Great Lakes.

Stream Name	Area(m^2)	Density[1]	Density[2]	Growth Rate
Farewell Creek	30148	0.15	0.12	0.10
Lynde Creek West Branch	17955	0.11	0.10	na
Lynde Creek	52955	0.26	na	0.10
Harris Creek	4200	0.42	0.12	0.06
West Root River	63080	0.12	0.24	0.07
Cannon Creek	25833	0.73	0.81	0.08
Mayhew Creek	23823	na	1.26	0.08
Proctors Creek	3300	na	4.71	0.10
Sturgeon Creek	49500	na	0.67	na
Spragge Creek	2100	na	0.29	0.08
Gordon's Creek	3600	na	0.28	0.10
Richardson Creek	8707	na	0.12	0.11
Little Gravel River	22500	na	0.09	na
Carp River	30591	na	0.25	0.08

1.This density was estimated using the Petersen population estimate/area.
2.This density was estimated using a modified Zippins depletion method estimate/area.

Primary Tables and Information in Larval Database at U.S. Fish and Wildlife Service Marquette and Ludington Biological Stations

Table: SUMMARY
Current number of rows: 111421

No.	Column Name	No.	Column Name
1	ID	26	LARVAE%
2	OFFICE	27	SPAWN%
3	LAKE	28	WTRTEMP
4	TWP	29	TIMEEND
5	RANGE	30	ACT_TIME
6	SECTION_	31	TIMECOLL
7	STATE	32	AREA
8	STREAM	33	DISTEXAM
9	ZONE	34	COLLCOND
10	STATION	35	COLLPROB
11	LENTIC	36	LAMPREY%
12	MONTH	37	TYPESAMP
13	DAY	38	BEDROCK%
14	YEAR	39	boulslab
15	TYPESURV	40	RUBBLE%
16	COLLMETH	41	GRAVEL%
17	WTRLEVL	42	SAND%
18	DESCFLOW	43	SILT%
19	WIDTH_	44	CLAY%
20	DEPTH	45	detritus
21	DSCG	46	OTHER%
22	WTRCOLOR	47	GRANBAY
23	turbid	48	CONDUCT
24	TYPEI	49	PH
25	TYPEII	50	VERIFICATION

Table: LENGTH FREQUENCY

ID
LIFE STAGE = larvae or transformer
SEX
LENGTH
FREQUENCY

Table: SPECIES

ID
CONDITION CODE
SPECIES CODE
FREQUENCY
MIN. LENGTH
MAX. LENGTH

COMPENSATORY MECHANISM WORKSHOP NOTES

Henry Quinlan and Mike Fodale
Marquette Biological Station

Subject: Transformation Rates

Is there a correlation between larval density and rate of transformation?

Description of process used to evaluate question.

- Gathered records of sea lamprey collections during chemical treatments where:
  - Treatments occurred after July 31 (to ensure transformed sea lamprey could be present in collections).
  - The chemical treatment was not the first (original) for the stream.
  - Sea lamprey length was greater than 100 mm.
  - Treatment collections were made with hand held scap nets or fyke nets.

- Length, frequency at length, and life stage (transformer or larvae) data were pooled for **all** treatments (i.e. multiple years) for a particular stream.

- The data for each individual stream were run through a logistic regression model in SAS which produced a probability of transformation at each mm length increment. See sheet 1.

- The probabilities of transformation for all lengths (from 101-200 mm) were summed to give an accumulated percent transformation for a stream (**note**: the accumulated percent transformation is considerably >1 since the logistic regression model provides a probability at each length and not a cumulative probability for the entire data range).

- The probabilities of transformation for the length range 125-135 mm were summed to give an accumulated percent transformation for that range.

- The ratio of the accumulated percent transformation for the 125-135 mm range to the total accumulated percent transformation was determined. This ratio provided a measure of the relative area under the probability curve which allowed comparison among streams. See sheet 1.

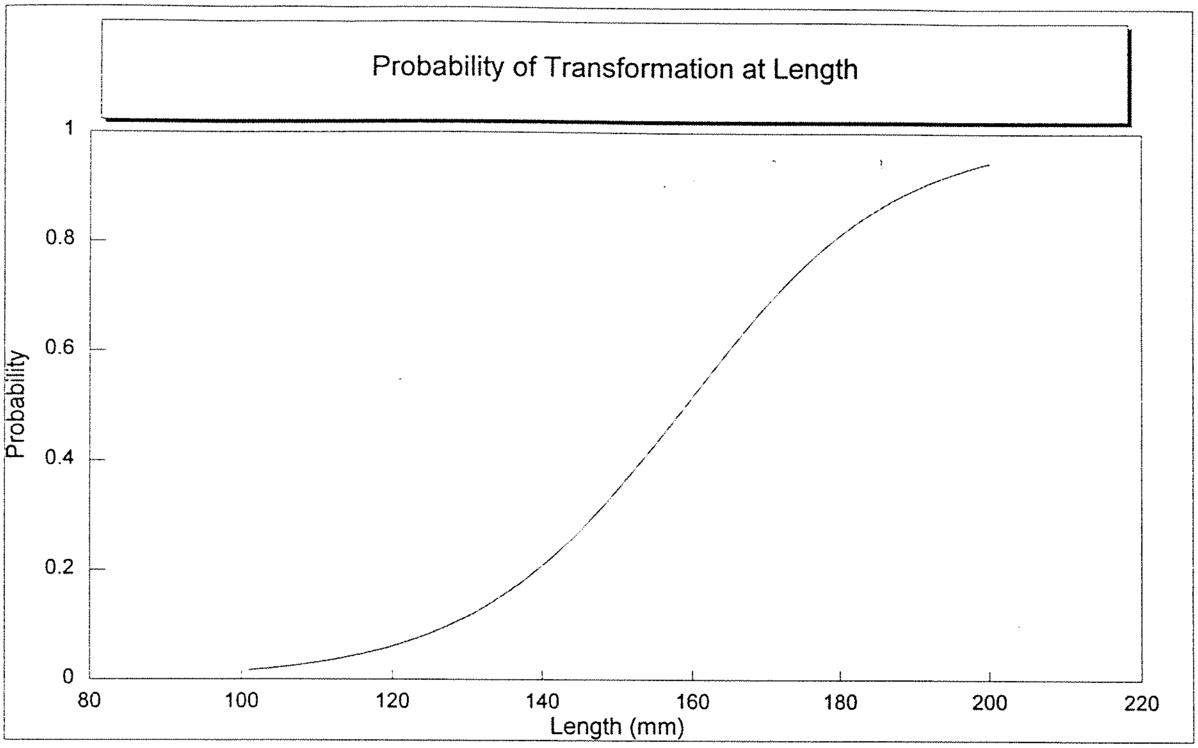
- An estimate of larval density in type 1 habitat for each stream was made using a stratified random transect approach with approximately 100 transects,
  - Density estimates were conducted once for each stream and generally included 3 or 4 year classes.

- The ratio for each stream was plotted against the larval density estimate for that stream. See sheet 2.

- The length at which 10% transformation occurs was also plotted against the larval density estimate for that stream. See sheet 3.

1-F

LOGISTIC REGRESSION MODEL OUTPUT



length	prob	length	prob	length	prob	length	prob
101	0.017	126	0.090	151	0.363	176	0.766
102	0.018	127	0.096	152	0.379	177	0.779
103	0.019	128	0.102	153	0.396	178	0.791
104	0.021	129	0.109	154	0.413	179	0.802
105	0.022	130	0.116	155	0.430	180	0.813
106	0.024	131	0.123	156	0.447	181	0.823
107	0.026	132	0.131	157	0.464	182	0.833
108	0.027	133	0.139	158	0.482	183	0.843
109	0.029	134	0.148	159	0.499	184	0.852
110	0.031	135	0.157	160	0.517	185	0.860
111	0.033	136	0.166	161	0.534	186	0.869
112	0.036	137	0.176	162	0.552	187	0.876
113	0.038	138	0.187	163	0.569	188	0.884
114	0.041	139	0.197	164	0.586	189	0.891
115	0.044	140	0.209	165	0.603	190	0.897
116	0.047	141	0.221	166	0.620	191	0.904
117	0.050	142	0.233	167	0.636	192	0.910
118	0.054	143	0.246	168	0.652	193	0.915
119	0.057	144	0.259	169	0.668	194	0.920
120	0.061	145	0.272	170	0.683	195	0.925
121	0.065	146	0.286	171	0.698	196	0.930
122	0.070	147	0.301	172	0.713	197	0.935
123	0.074	148	0.316	173	0.727	198	0.939
124	0.079	149	0.331	174	0.740	199	0.943
125	0.085	150	0.347	175	0.754	200	0.946

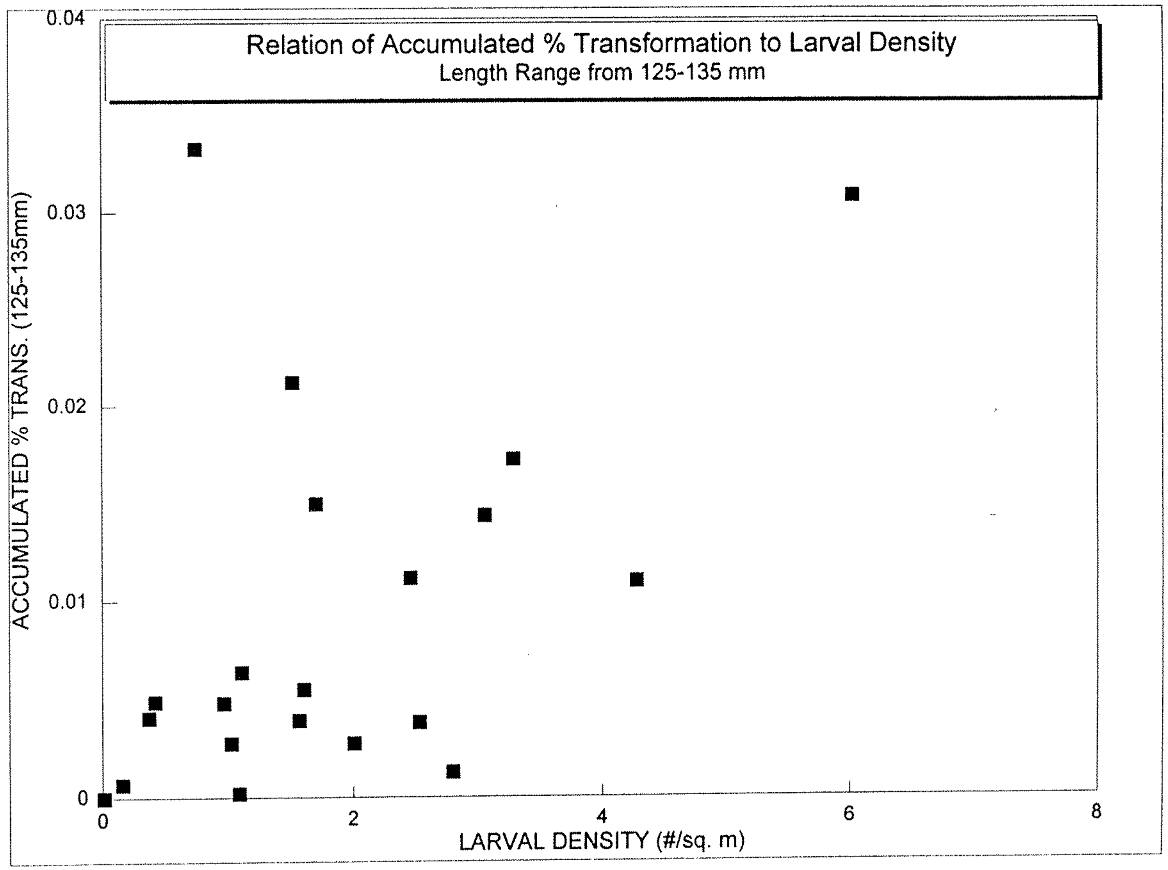
Accumulated Percentages

lengths		ratio of relative area under curve
125-135	1.29512	**3.0840%**
101-200	41.99467	

ream	mm length 125-135	density #/sq. m
nnicon	3.08%	6.03
arlow	1.10%	4.28
uron	1.43%	3.06
resteel	0.38%	2.53
emadji	0.07%	0.16
otato	3.33%	0.75
'aiska	0.00%	0.01
'ule	1.72%	3.29
'averse	0.13%	2.8
Garlic	1.12%	2.46
hocolay	0.27%	2.01
urgeon	1.49%	1.71
ntonagon	0.55%	1.61
iddle	0.39%	1.57
Sleeping	2.12%	1.52
wo Heart.	0.64%	1.11
iners	0.02%	1.09
isery	0.27%	1.03
etsy	0.48%	0.97
. Garlic	0.49%	0.42
al. Tr. Ho.	0.41%	0.37

Regression Output:

Constant		0.003475	
Std Err of Y Est		0.008663	
R Squared		0.230187	r = .47
No. of Observations		21	p>.95
Degrees of Freedom		19	
X Coefficient(s)	0.003141		
Std Err of Coef.	0.001318		



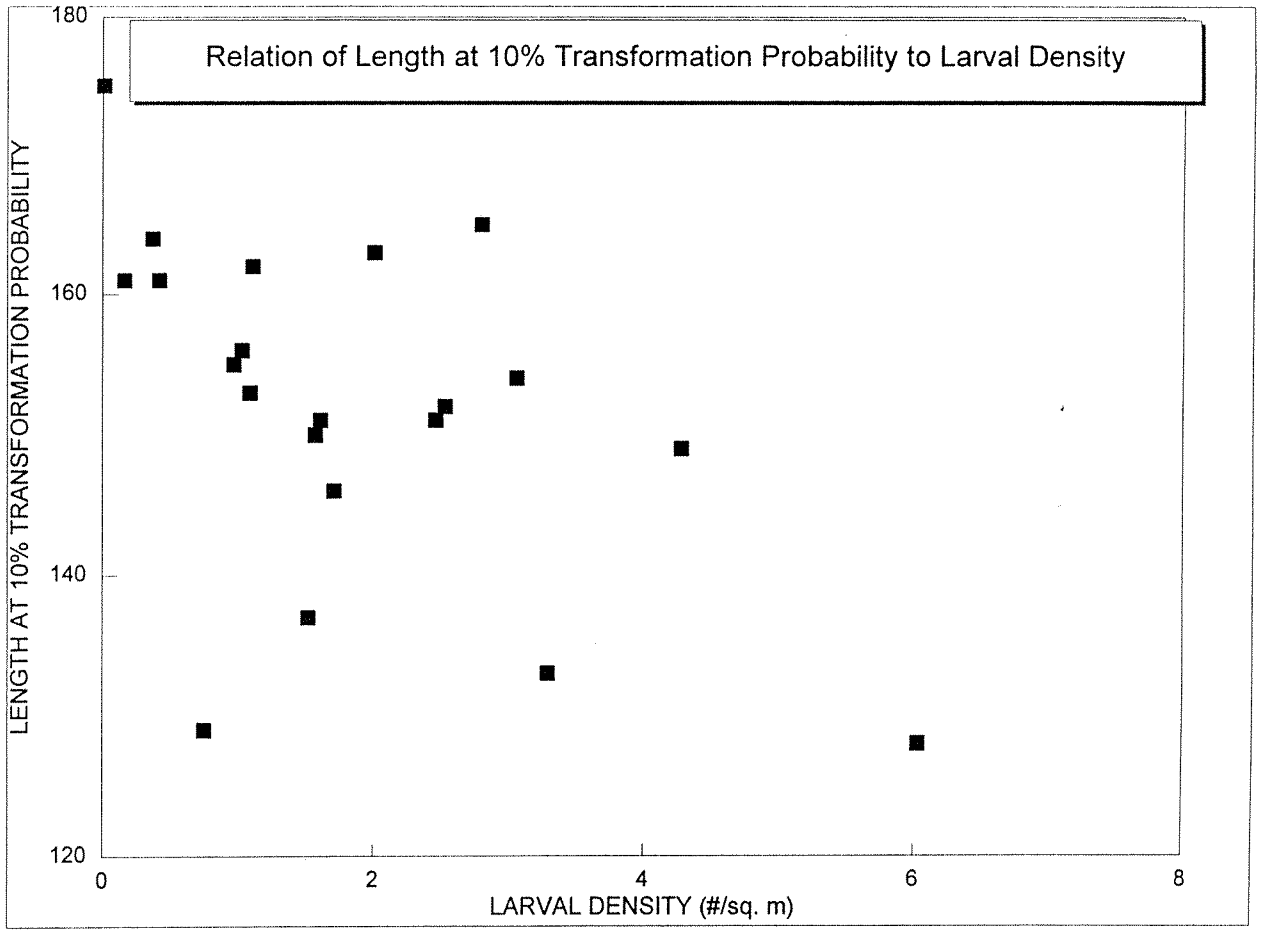
HEET 2

H-1

Stream	density #/sq. m	length (mm) @ 10% trans. probability
ımnicon	6.03	128
ıarlow	4.28	149
ıuron	3.06	154
·iresteel	2.53	152
ıemadji	0.16	161
·otato	0.75	129
Vaiska	0.01	175
ırule	3.29	133
·raverse	2.8	165
..Garlic	2.46	151
·hocolay	2.01	163
·turgeon	1.71	146
·ntonagon	1.61	151
·iddle	1.57	150
:. Sleeping	1.52	137
·wo Heart.	1.11	162
·iners	1.09	153
·isery	1.03	156
·etsy	0.97	155
·. Garlic	0.42	161
·al. Tr. Ho.	0.37	164

Regression Output:

Constant		160.2385	
Std Err of Y Est		10.67781	
R Squared		0.277075	r = .53
No. of Observations		21	p>.98
Degrees of Freedom		19	
X Coefficient(s)	-4.38394		
Std Err of Coef.	1.624561		



SHEET 3

1 - 7

Changes in Larval Sea Lamprey Year Class Mean Length, Density, and Biomass in Salem Creek, 1991 - 1994.

Presented to the GLFC sponsored Compensatory Workshop, April 10, 1996 by Jerry Weise.

Salem Creek is about 150 km east of Toronto, it has 2.8 km inhabited by sea lamprey, it averages less than 5 m wide, has a normal summer flow less than 0.2 $m^3.s^{-1}$, has a total surface area of 1.4 ha and 80% of the substrate is larval habitat.

Sampling was done with AbP-2 electrofishers, shocking 4 m^2 plots using depletion methodology at a rate of 15 min per pass

Larval year class strength and mean length were estimated using maximum likelihood method developed by MacDonald & Pitcher (1979)

Summary of spring sampling 1991 - 1994 are presented in table 1.

Mean lengths of year classes are presented in table 2. Estimated age was based on the peak spawning period of June 1

Density was estimated using a relationship of: electrofishing captures from randomly selected sites to; captures from those same sites when TFM was applied to the stream (normally within 2 weeks of electrofishing sampling) (Pajos & Weise 1994)

Biomass was estimated by using a weight-length relationship calculated from the May 4, 1994 sampling of Salem Creek. This relationship was calculated using preserved larva.

The average annual decrease in density of the first year class to establish was 15% and the graphed change was best described by a power curve fit (density = 104.Age $^{-0.40}$, r^2 = 0.94, P< 0.001)

The average annual decrease in density of the second year class to establish was 38% and the graphed change was best described by a power curve fit (density = 106.Age $^{-1.33}$, r^2 = 0.99, P = 0.01)

There was very little change in density of the third (1992) year class to establish

Note that the density in 1991 is almost the same as that in 1994 even though it had more than doubled in 1992 when the 1991 year class was sampled

Mean length of the first year class (1990) increased at the rate of 20 $mm.yr^{-1}$ (r^2 = 0.97, P = 0.01)

Mean length of the second year class (1991) increased at the rate of 14 $mm.yr^{-1}$ ($r^2 = 0.93$, $P = 0.17$)

There was no difference in growth of these two year classes (ANOVA, $r^2 = 0.98$, $P = 0.26$) and the mean length adjusted for age was significant (ANOVA, $r^2 = 0.95$, $P = 0.01$)

Biomass of the 1990 year class increased steadily at the rate of 28 $g.m^{-2}$ (1991 - 1994, spring sampling) $r^2 = 0.99$, $P = 0.004$

There was virtually no change in biomass of all year classes establishing after the initial colonization

Mean length at age 1 of each year class to establish decreased at the rate of 5 $mm.yr^{-1}$ ($r^2 = 0.85$, $P = 0.08$)

Mean length at age 2 of each year class to establish decreased at the rate of 11 $mm.yr^{-1}$ ($r^2 = 0.98$, $P = 0.08$)

There was no significant difference in the rate of decline age 1 or 2 larva (ANOVA, $r^2 = 0.98$, $P = 0.12$) and the mean length adjusted by year class was significant (ANOVA, $r^2 = 0.95$, $P = 0.01$)

Growth of larvae was seasonal, concentrated during the summer months. The mean length of individual year classes in the fall was consistently longer than that observed the following spring. This suggests differential mortality or shrinkage over the winter period. Morman (1987) observed shrinkage of caged larvae during winter and summer months and larvae held in laboratory conditions also demonstrate shrinkage (Steve Bowen and John Holmes observation at the presentation)

Growth of the 1990 year class was not monitored through the summer 1991 but the 1991, 1992 and 1993 year classes grew at the rate of 53, 44, and 46 $mm.yr^{-1}$ respectively during their second summer of growth

Growth of the 1990, 1991, and 1992 year classes grew at the rate of 41, 45, and 52 $mm.yr^{-1}$ respectively during their third summers of growth

The seasonal growth of all year classes was analyzed to estimate daily growth between April 23 and October 25. Daily growth varied from 0.11 - 0.20 $mm.yr^{-1}$, homogeneity of slopes was plausible (ANOVA, $r^2 = 0.99$, $P = 0.78$), and the year class mean length adjusted for age was significant (ANOVA, $r^2 = 0.98$, $P < 0.001$). Average seasonal growth was 0.14 $mm.day^{-1}$ or 4.13 $mm.month^{-1}$

Transformation was observed in 1993 and 1994. An electrofishing sample during August 8 - 16, 1993 captured 3,190 larvae including 9 metamorphosing animals. The number of the 1990 year class that were metamorphosing was 1.1%. Random fyke net and area sampling during the TFM application on September 21, 1994 resulted in the capture of 1,487 larvae including 26 metamorphosing animals. The number of larvae of the 1990 year class (the 1991 year class was too small to transform although they were 3.5 years old) that were metamorphosing was 3.0%.

The smallest metamorphosing larval sea lamprey collected from Salem Creek was 115 mm long in 1994. Another 117 mm metamorphosing larvae was also caught in 1994. Estimates of metamorphosis were calculated as cumative frequency of larvae greater than 100 mm.

Four lampricide applications of Salem Creek have been conducted when metamorphosing larvae were present. The original treatment was conducted in October 1971 and the frequency of larvae over 100 mm that were transforming was slightly over 30%. The September 1985 and August 1989 lampricide treatments resulted in larval collections with 17 - 20% frequency of larvae over 100 mm transforming. These were all biased scap net collections where staff concentrated their collecting efforts on transformers.

In August 1989, when there were 4 year classes present in the stream, 4 areas (about 30 m^2) were collected intensively resulting in a collection of 2,894 larvae and 7 transformers. This collection was compared to the biased scap net collections where 4,017 larvae were collected and 157 were transforming. The biased scap net collection had 16.6% of the larvae over 100 mm transforming compared to the unbiased, random collection which had only 3.8% of those larvae over 100 mm transforming.

In September, 1994, when there were 5 year classes present in the stream, 2 areas (8 m^2) and 8 fyke net sets (all randomly selected) were intensively collected. A total of 1,434 larvae and 26 transforming animals were caught. All larvae that were metamorphosing were considered to be from the 1990 year class based on growth and maximum likelihood estimates of year class strength. With one extra year of growth (compared to the 1989 sample), there were 6.4% of larvae over 100 mm metamorphosing.

There has been only 1 study of larval sea lamprey that followed growth for more than a few years, the Big Garlic River study in Lake Superior (Manion and Smith 1978). The study followed the 1960 year class of larvae for 12 years, sampling every October. A comparison of larval sea lamprey annual growth between the first 4 yrs of the 1990 year class in Salem Creek (spring measurements) and the first 5 yrs of the 1960 year class in the Big Garlic River (fall measurements) was made. Surprisingly (because I had always been told that the Big Garlic river growth and transformation of larval sea lampreys was atypical) the annual growth of larval sea lampreys in both streams was identical, 19.9 $mm.yr^{-1}$, $r^2 = 0.98$, $P = 0.001$. The homogeneity of annual growth was plausible (ANOVA, $r^2 = 0.995$, $P = 0.98$) and the mean length adjusted for age was significant (ANOVA, $r^2 = 0.98$, $P < 0.001$).

Growth of larval sea lampreys of a single year class in the Big Garlic River over 12 years of study was characteristically asymptotic but it could also be described as two independent periods of varying growth. The first 6 years (1960 - 1965) before metamorphosis occurred had rapid growth (18.5 $mm.yr^{-1}$, $r^2 = 0.98$, P <0.001) and the next 8 yrs (1965 - 1972) had slow growth (3.2 $mm.yr^{-1}$, $r^2 = 0.90$, P <0.001). The point of intercept of these two lines (4.9 yrs, 105 mm) coincides with the age and mean length when metamorphosis was first recorded from this stream. The mean length of the 1960 year class was 92 mm in October 1964, the year before metamorphosis began and it was 107 mm in October 1965.

In Salem Creek, the mean length of the 1990 year class was 95 mm in October 1992, the year before metamorphosis was first recorded and 108 mm in August 1993 when metamorphosis was observed (1% of the 1990 year class). In September 1994, the mean length of the 1990 year class was 105 mm when metamorphosis was observed at 3% of the 1990 year class. Mean length of the 1991 year class was only 87 mm in September 1994 and length of metamorphosing larvae were too large to be considered as part of the 1991 year class (based on maximum likelihood analysis).

Conclusions:

i) An appropriate measure of density to describe growth and survival characteristics is biomass

ii) Growth and survival of larval year classes are highly dependent on the existing biomass in the stream

iii) There was no significant difference in annual or seasonal growth of larval sea lamprey in Salem Creek but the mean length at age 1 when sampling began was significantly different

iv) Metamorphosis of the oldest year class was 1% during the first year after reaching a mean length over 90 mm and 3% the following year

v) Although Salem Creek has a relatively high biomass of larval sea lampreys, review of routine larval sea lamprey sampling supports the fact that all larval year class growth is subject to compensatory growth mechanisms from established larval biomass

vi) In order to quantify the responses of larval growth and survival relative to recruitment, it is recommended that researchers study populations where controlled recruitment to areas above existing barriers over several years can be maintained. These studies should continued for several years of metamorphosis.

vii) Three streams in Lake Ontario; Port Britain, Grafton, and Shelter Valley creeks with Salem Creek as a control are all within 25 km of each other and would provide an ideal study location for larval sea lamprey growth, survival and numerous other questions.

1-7

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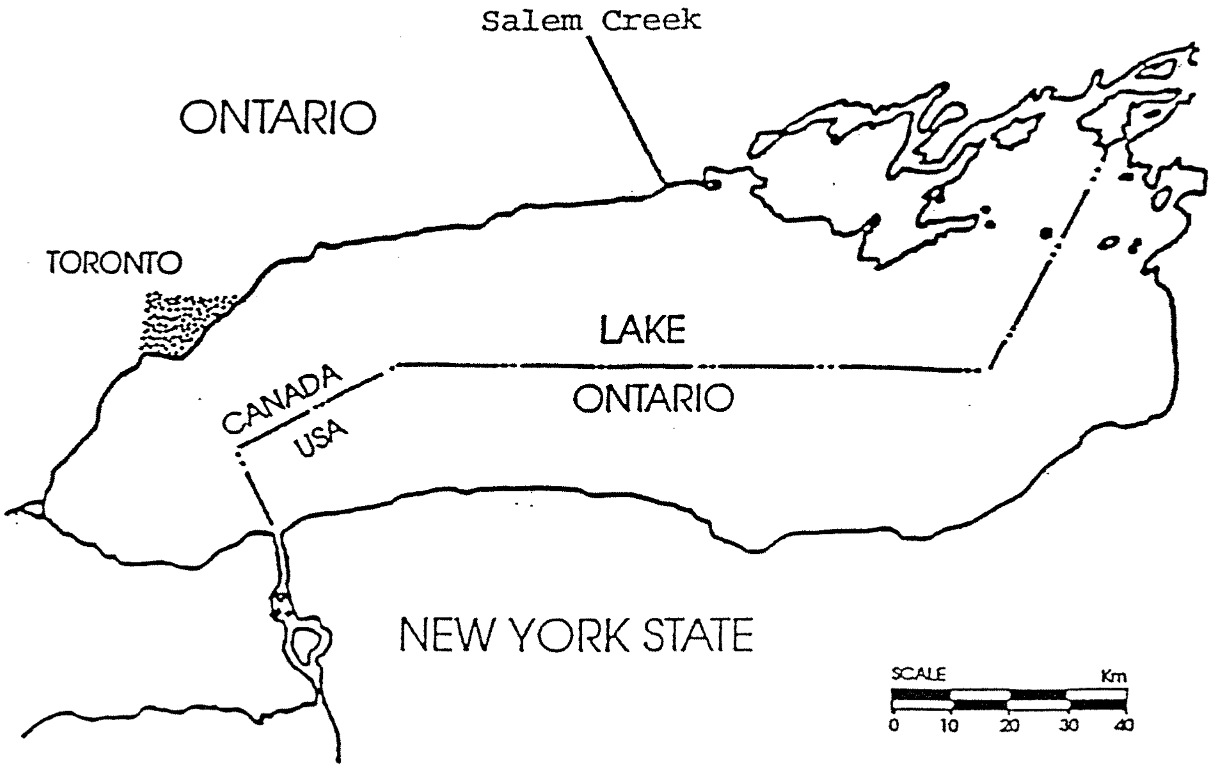
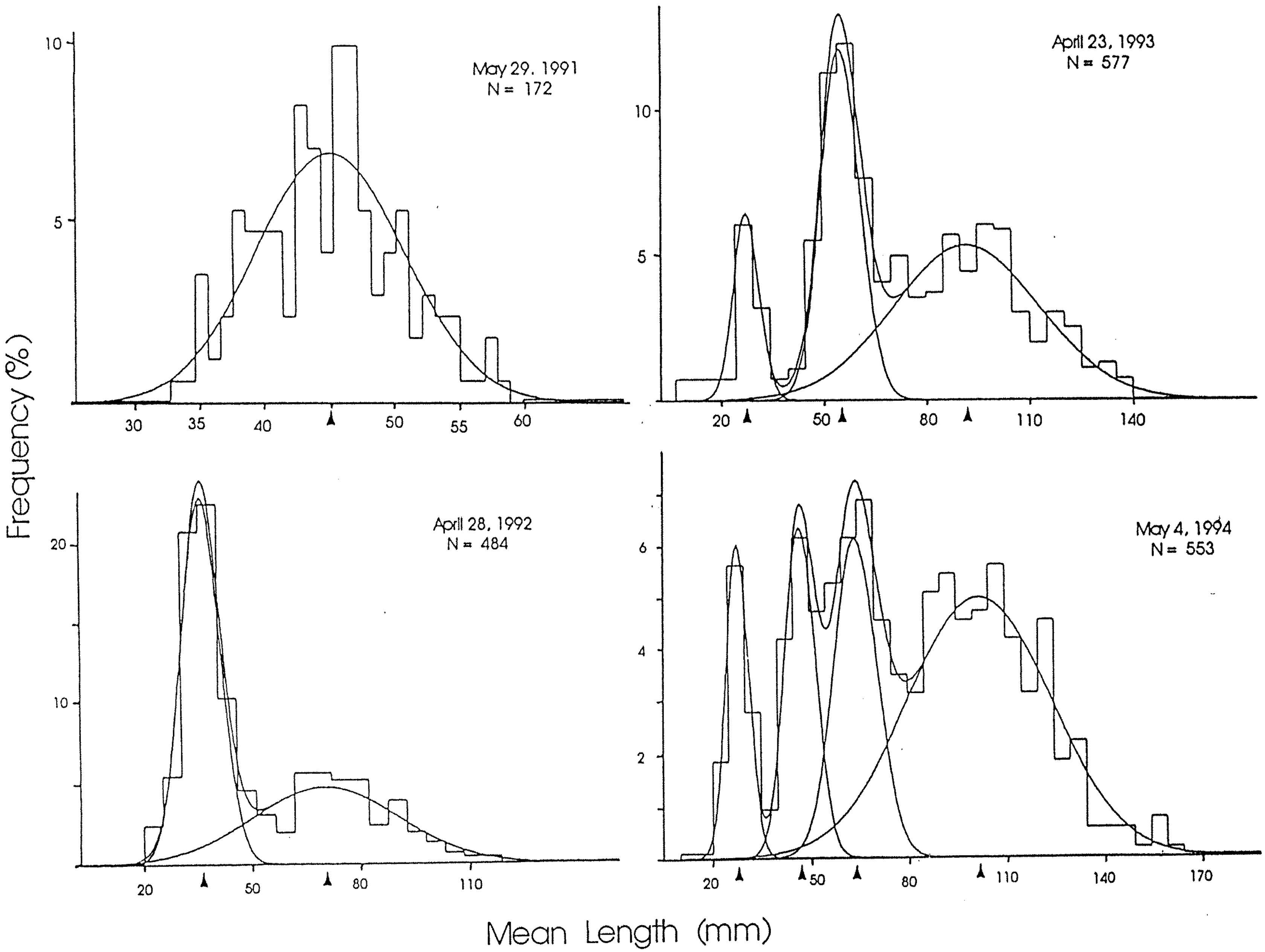
Manion, P. J. and B. R. Smith. 1978. Biology of larval and metamorphosing sea lampreys (Petromyzon marinus) of the 1960 year class in the Big Garlic River, Michigan, Part II, 1966-72. Great Lakes Fisheries Commission Technical Report No. 30. 36 p.

Morman, R. H. 1987. Relationship of density to growth and metamorphosis of caged sea lampreys, *Petromyzon marinus* Linnaeus, in Michigan streams. Journal of Fish Biology 30: 173-181.

Pajos, T. A., and J. G. Weise. 1994. Estimating populations of larval sea lamprey with electrofishing sampling methods. North American Journal of Fisheries Management 14: 580-587.


Salem Creek
ONTARIO
TORONTO
LAKE
ONTARIO
CANADA
USA
NEW YORK STATE
SCALE
Km
0
10
20
30
40


May 29. 1991
N = 172
April 23, 1993
N = 577
April 28, 1992
N = 484
May 4, 1994
N = 553
Frequency (%)
Mean Length (mm)

Year Class	Measure	1991	S.E.	1992	S.E.	Year of Sampling 1993	S.E.	1994	S.E.
1990	Length (mm)	44.63	0.466	69.39	2.123	92.72	2.344	103.12	3.263
	Density ($\#.m^{-2}$)	*101.27	N.A.	86.08	0.033	63.51	0.037	60.43	0.052
	Biomass ($g.m^{-2}$)	17.72	**	49.93	**	80.02	**	100.92	**
1991	Length (mm)			36.45	0.377	56.48	0.550	63.70	2.277
	Density ($\#.m^{-2}$)			109.12	0.033	38.94	0.035	25.73	0.078
	Biomass ($g.m^{-2}$)			10.91	**	12.85	**	11.78	**
1992	Length (mm)					29.03	0.530	48.34	1.022
	Density ($\#.m^{-2}$)					13.44	0.014	10.70	0.045
	Biomass ($g.m^{-2}$)					0.81	**	2.35	**
1993	Length (mm)							30.01	0.417
	Density ($\#.m^{-2}$)							11,24	0.013
	Biomass ($g.m^{-2}$)							0.67	**

Table 1. Summary of larval sea lamprey (Petromyzon marinus) year class mean length, density and biomass from spring sampling in Salem Creek, 1991-1994.

* estimated from 1992 density assuming 15% mortality

** biomass = density x efficiency (S.E. = 0.537) x weight (aL^b, S.E. = 0.055) at mean length

Table 2.

Summary of Salem Creek Larval Sea Lamprey Growth By Year Class, 1991 - 1994

Date of Sampling	Age (days)	1990 YC	1991 YC	1992 YC	1993 YC	1994 YC
May 29/91	350	44.63				
Apr 28/92	682	69.39	36.45			
June 4/92	719	85.38	43.91			
Aug 20/92	796	81.98	56.9	17.14		
Oct 25/92	862	94.97	63.23	26.06		
Apr 23/93	1044	92.72	56.48	29.03		
July 3/93	1113	96.75	67.28	40.16		
Aug 16/93	1157	107.51	70.1	41.55		
May 4/94	1418	103.12	63.7	48.34	30.01	
June 15/94	1460	110.28	72.91	59.32	38.26	
July 27/94	1502	107.49	86.39	64.45	41.64	17.93
Sept 7/94	1544	105.1	86.82	66.81	49.67	23.7

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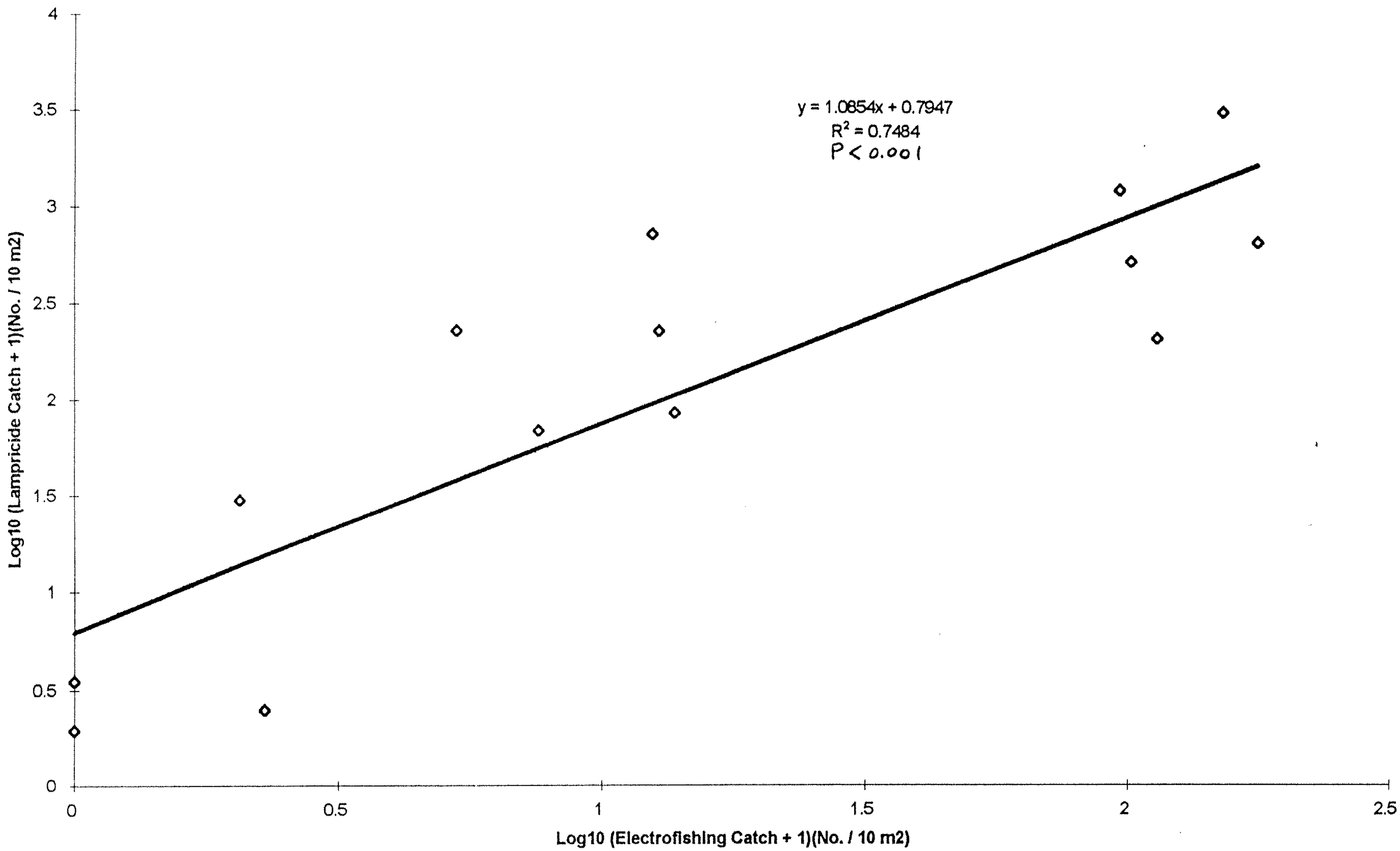
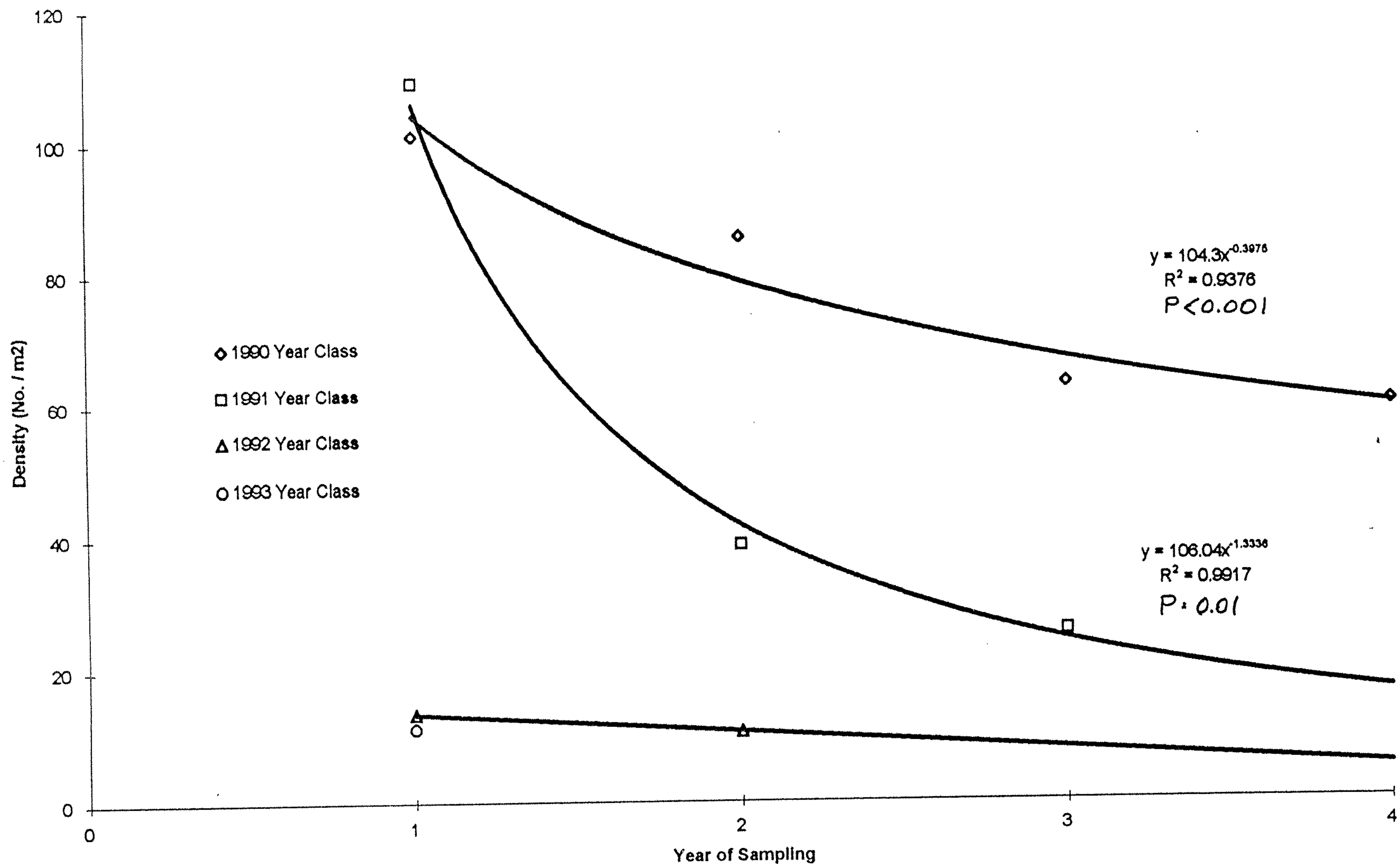
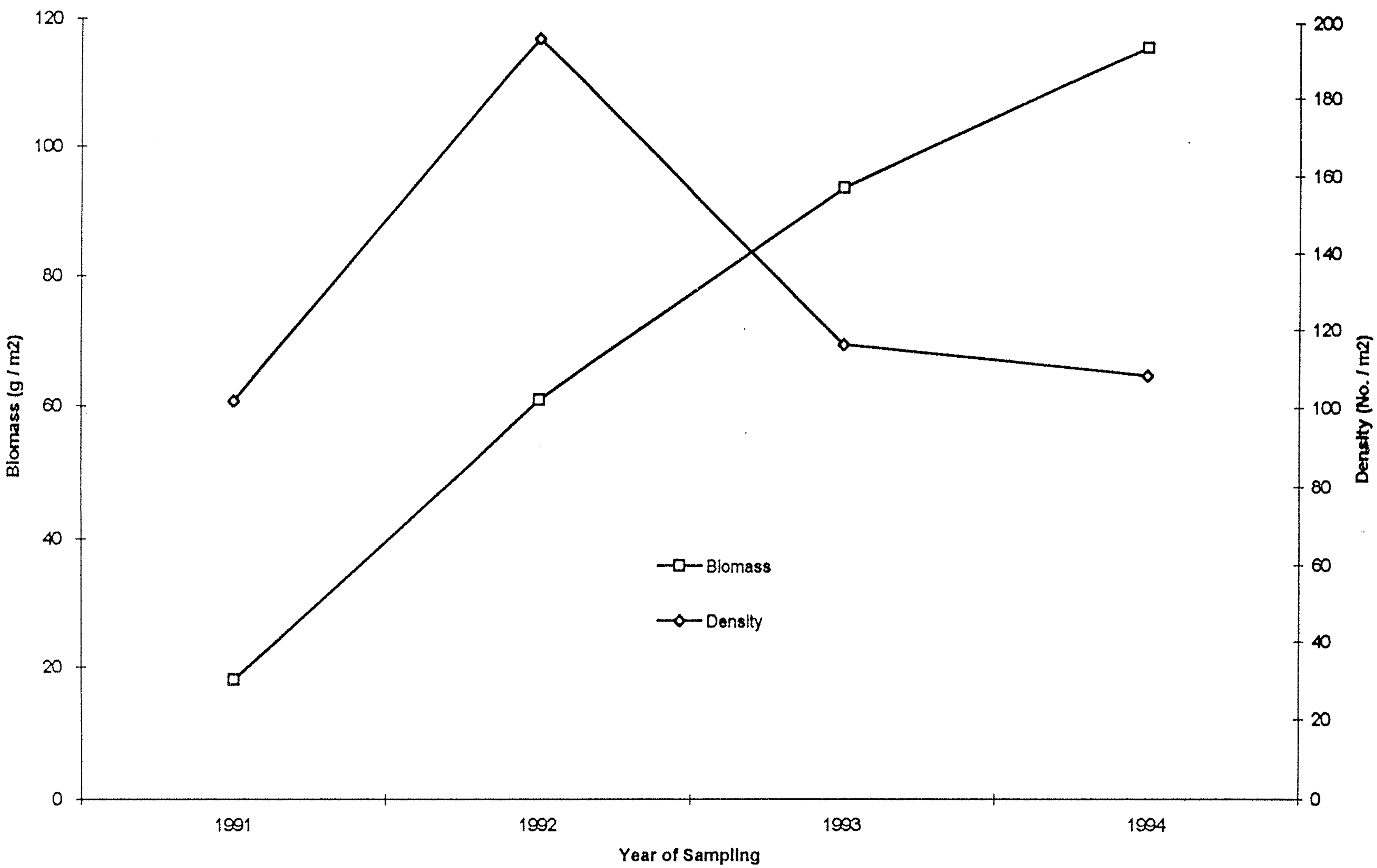
Relationship of Larval Sea Lamprey Density Observed During Lampricide Application to Electrofishing Captures at the Same Site



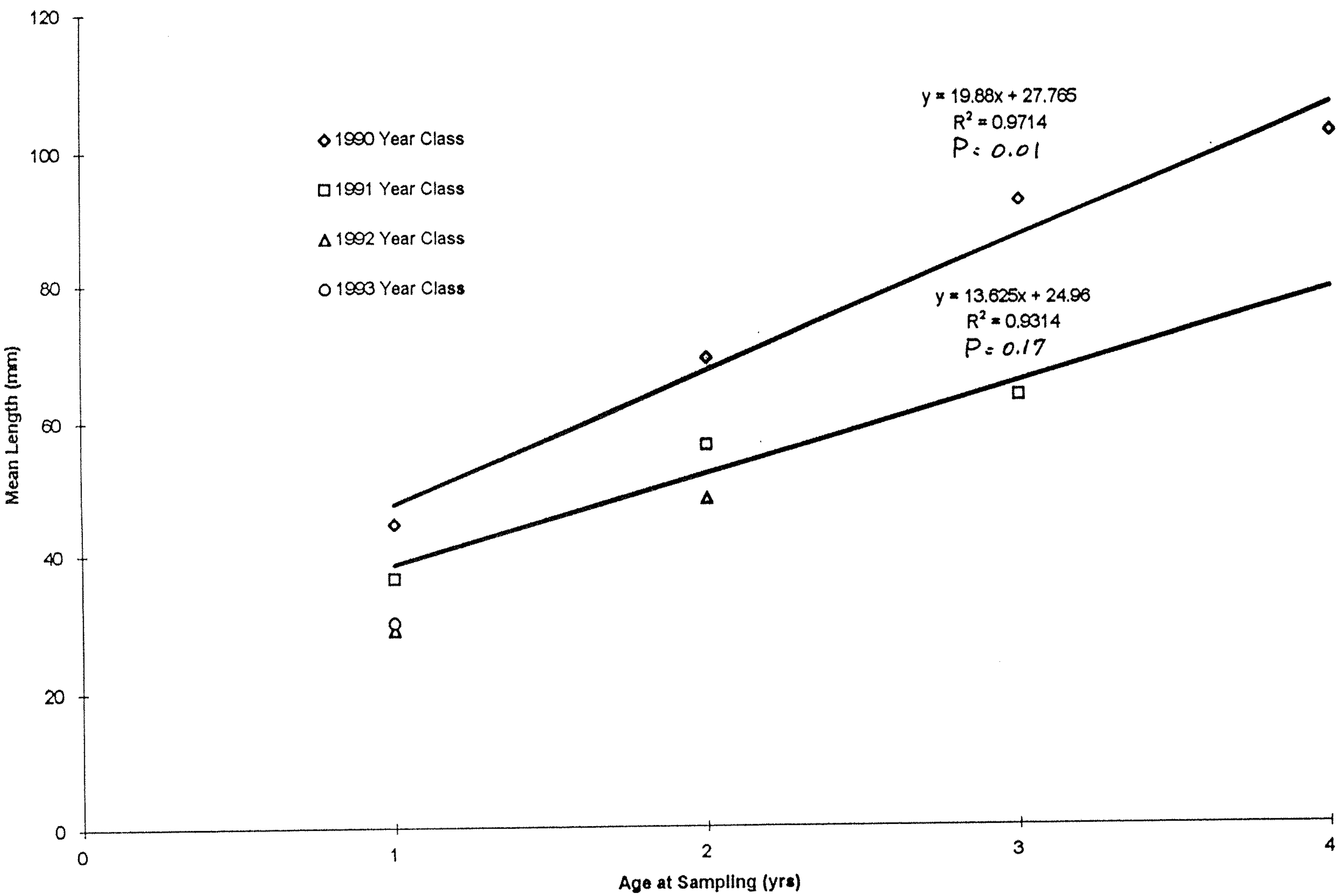
Change in Larval Sea Lamprey (Petromyzon marinus) Density by Year Class in Salem Creek, 1991 - 1994, Spring Sampling.



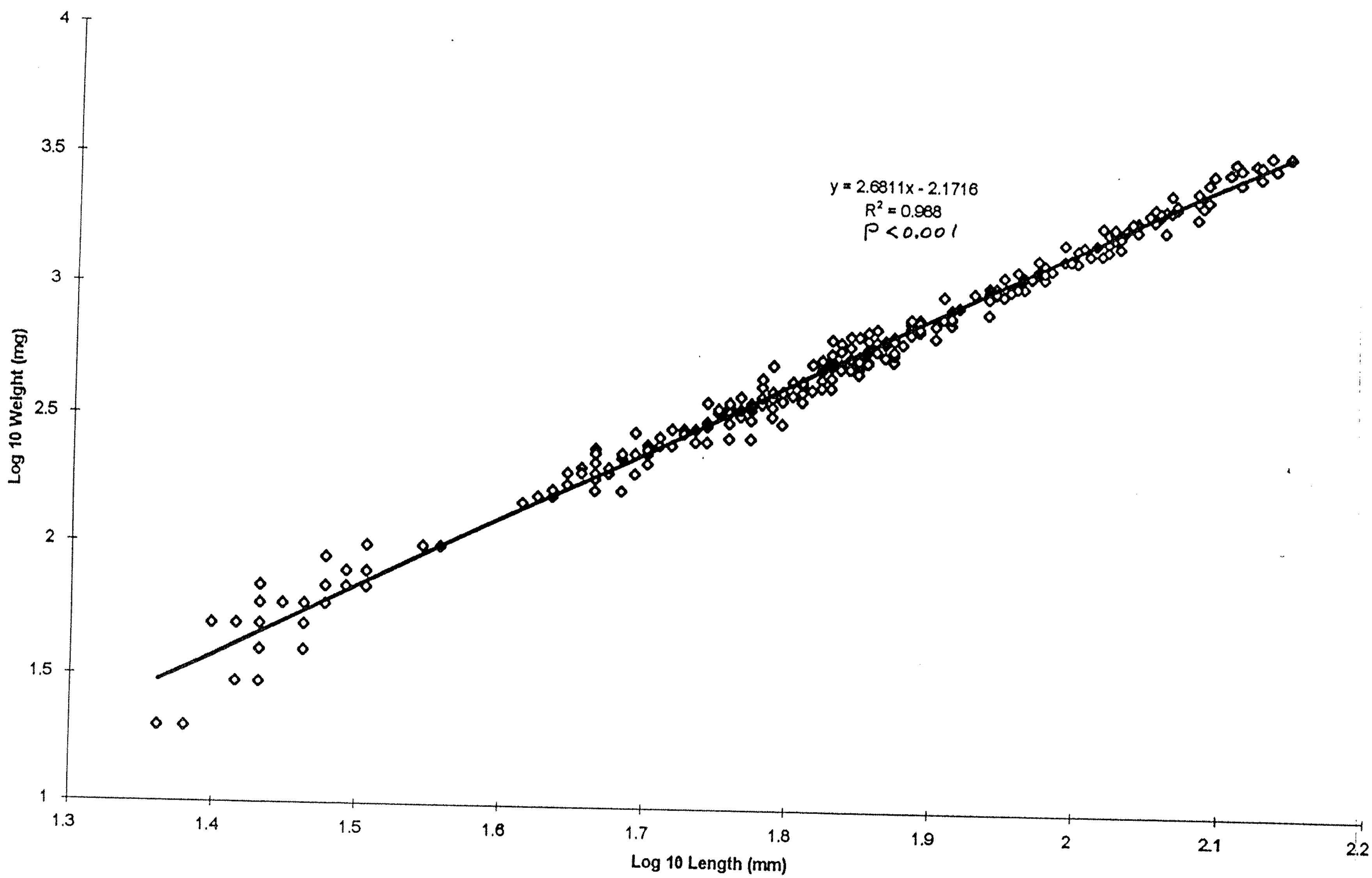
Change in Larval Sea Lamprey (Petromyzon marinus) Biomass and Density in Salem Creek, 1991 - 1994, Spring Sampling.



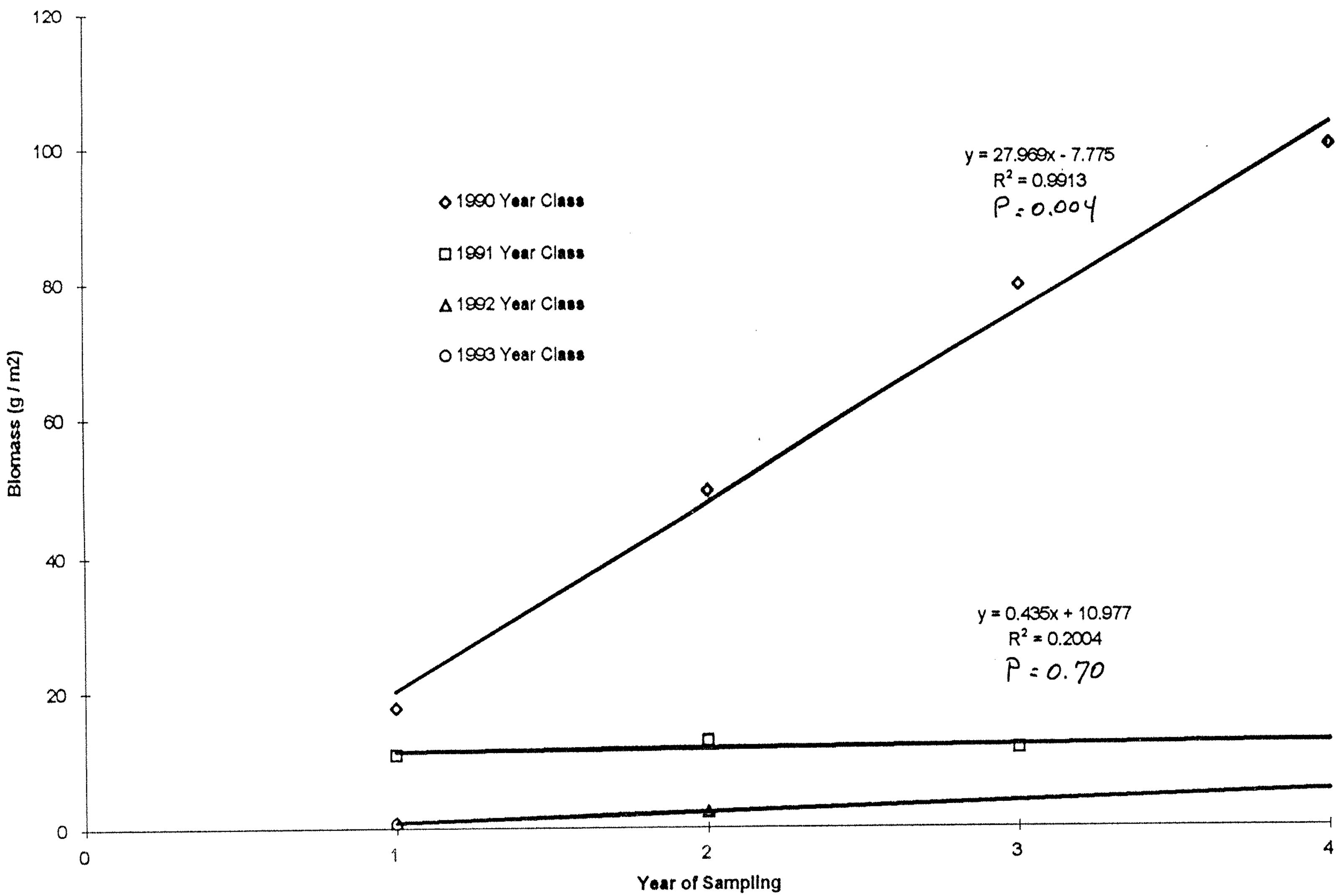
Change in Mean Length of Larval Sea Lamprey (Petromyzon marinus) by Year Class in Salem Creek, 1991 - 1994, Spring Sampling.



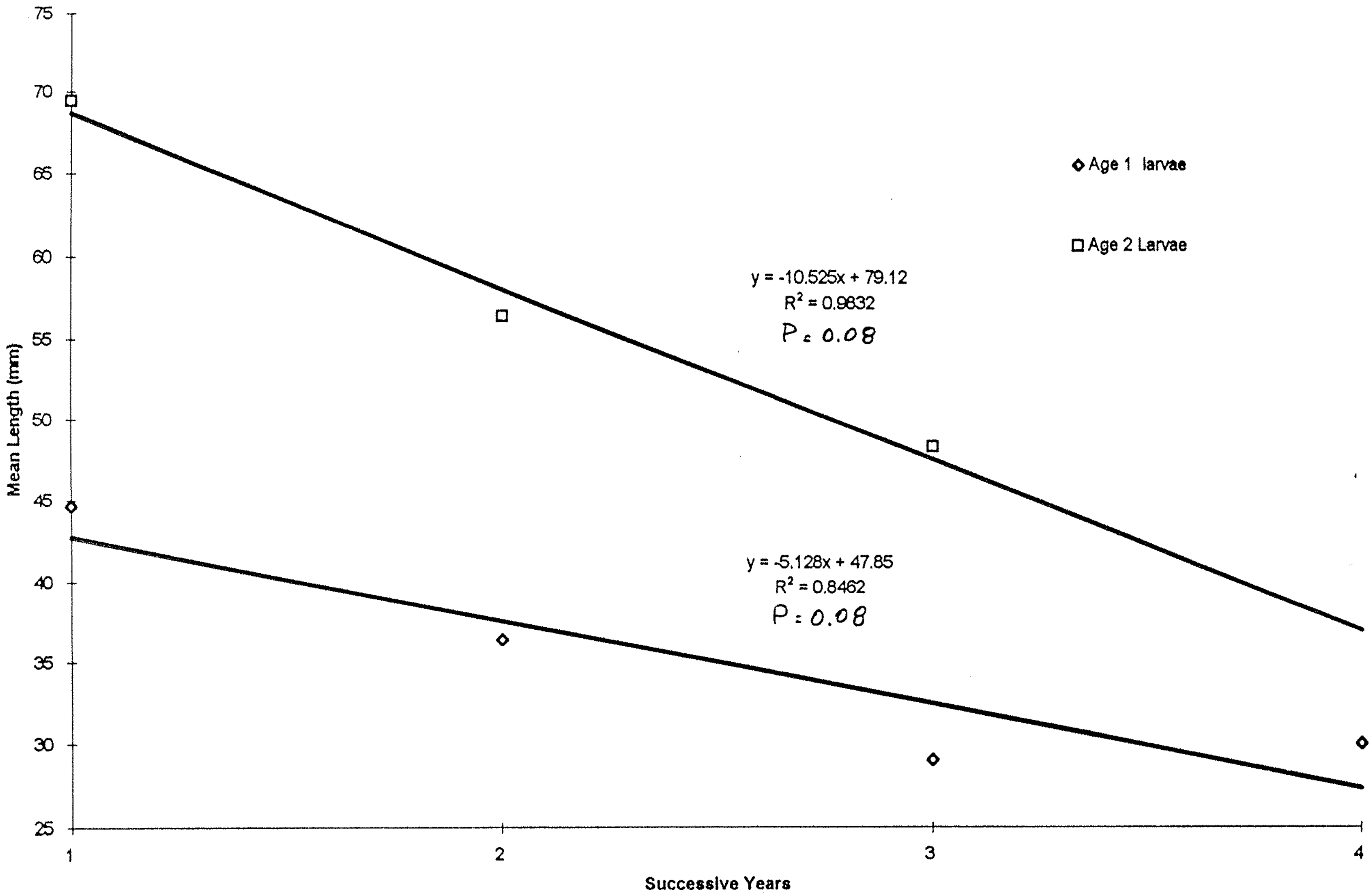
Weight - Length Relationship of Preserved Larval Sea Lamprey From Salem Creek, May 4,

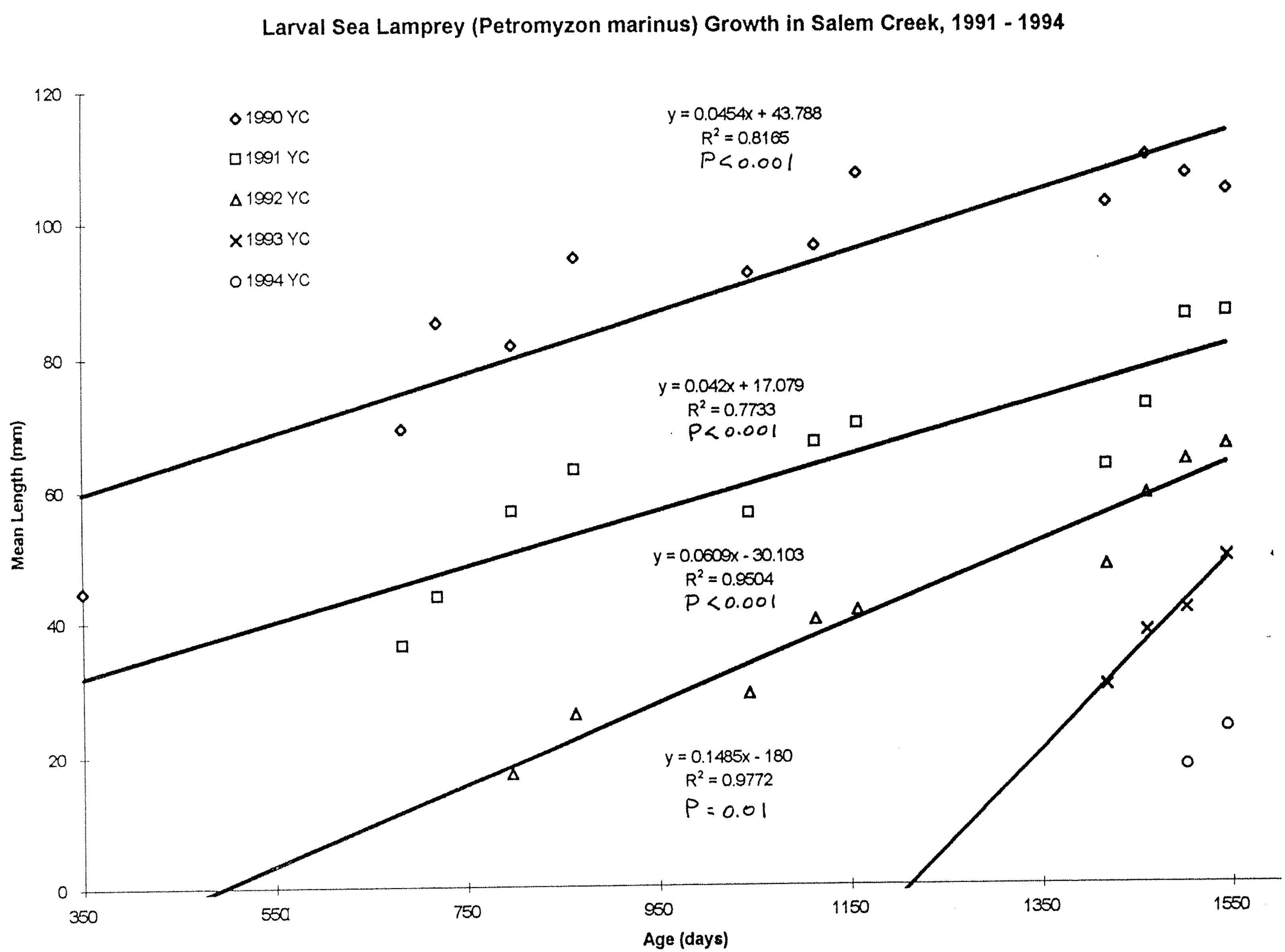


Change in Larval Sea Lamprey (Petromyzon marinus) Biomass by Year Class in Salem Creek, 1991 - 1994, Spring Sampling.



Change in Mean Length of Successive Year Classes of Larval Sea Lamprey (Petromyzon marinus) in Salem Creek, 1991 - 1994.

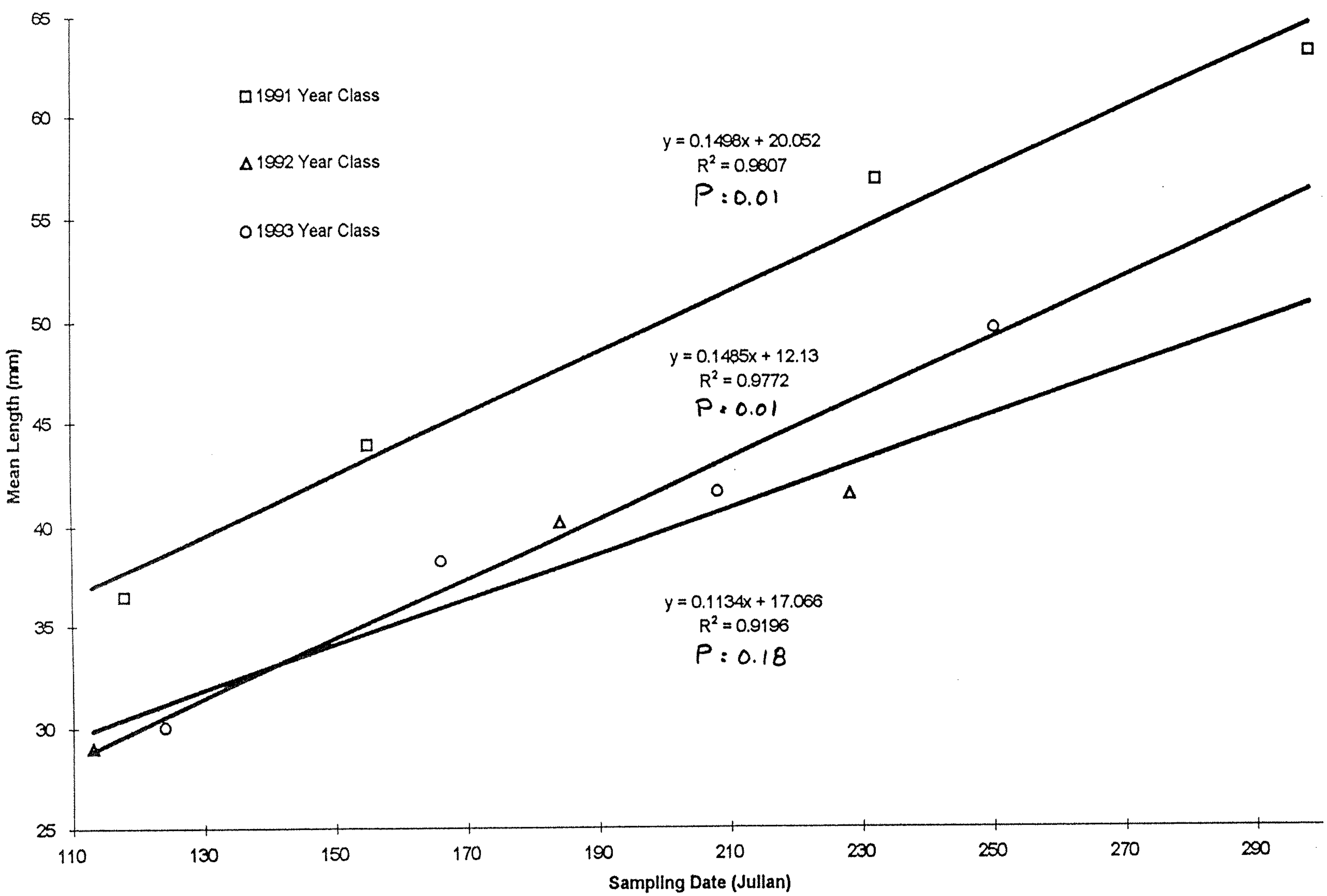




Larval Sea Lamprey (Petromyzon marinus) Growth in Salem Creek, 1991 - 1994
1990 YC
1991 YC
1992 YC
1993 YC
1994 YC
y = 0.0454x + 43.788
R2 = 0.8165
P < 0.001
y = 0.042x + 17.079
R2 = 0.7733
P < 0.001
y = 0.0609x - 30.103
R2 = 0.9504
P < 0.001
y = 0.1485x - 180
R2 = 0.9772
P = 0.01
Mean Length (mm)
0
20
40
60
80
100
120
Age (days)
350
550
750
950
1150
1350
1550

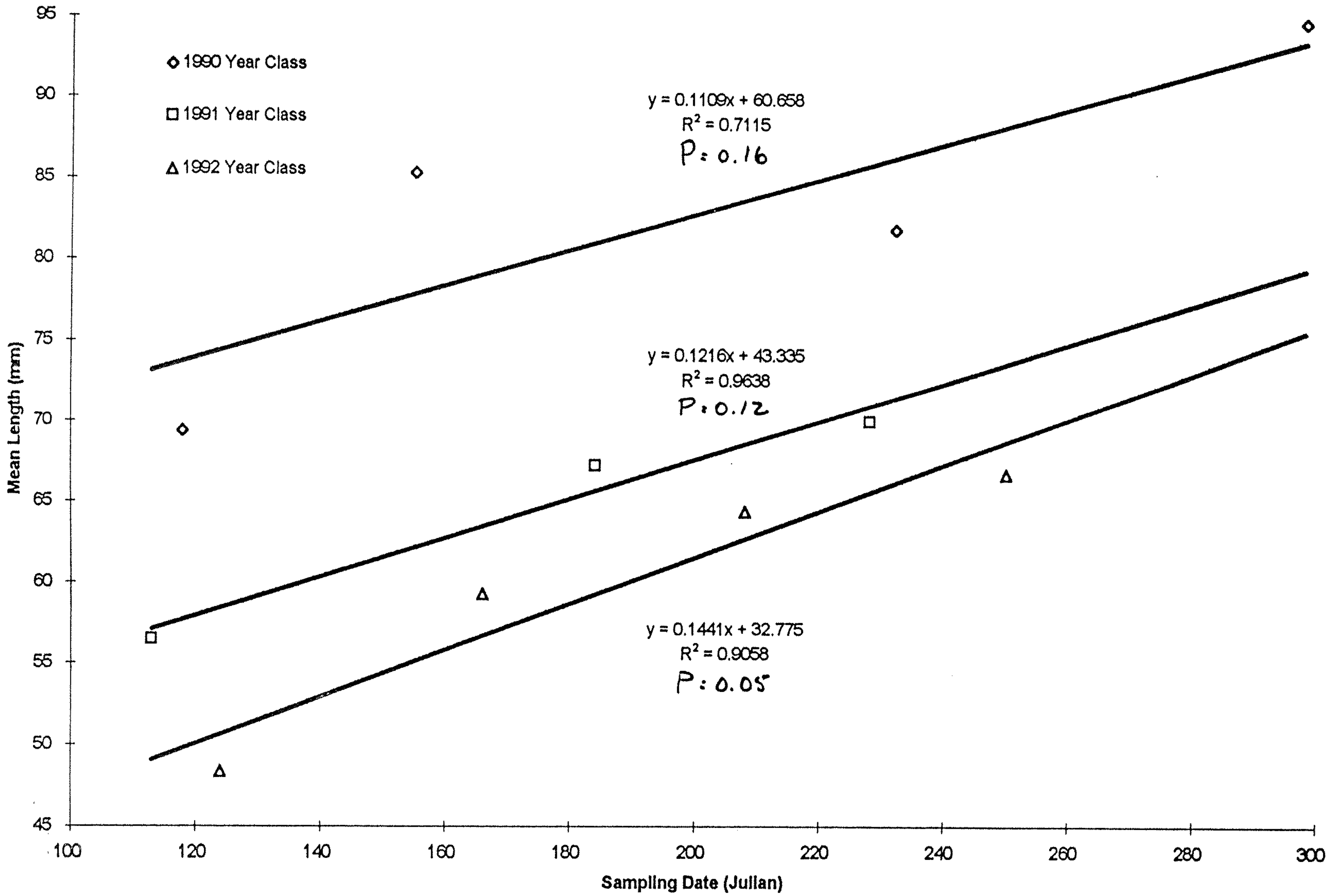
I-1

Daily Growth of Larval Sea Lamprey in Salem Creek, Lake Ontario, at Age 1.

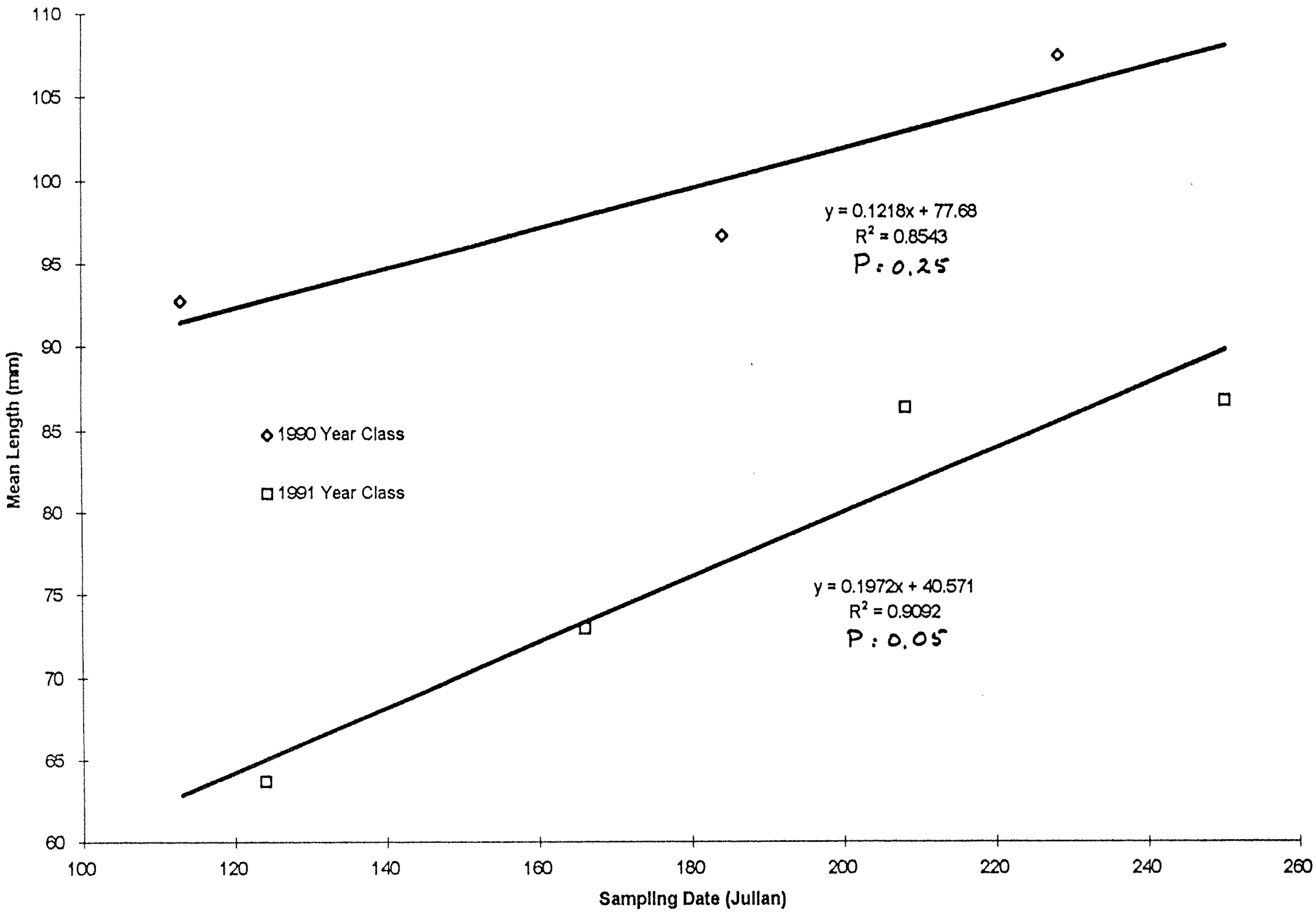


I-J

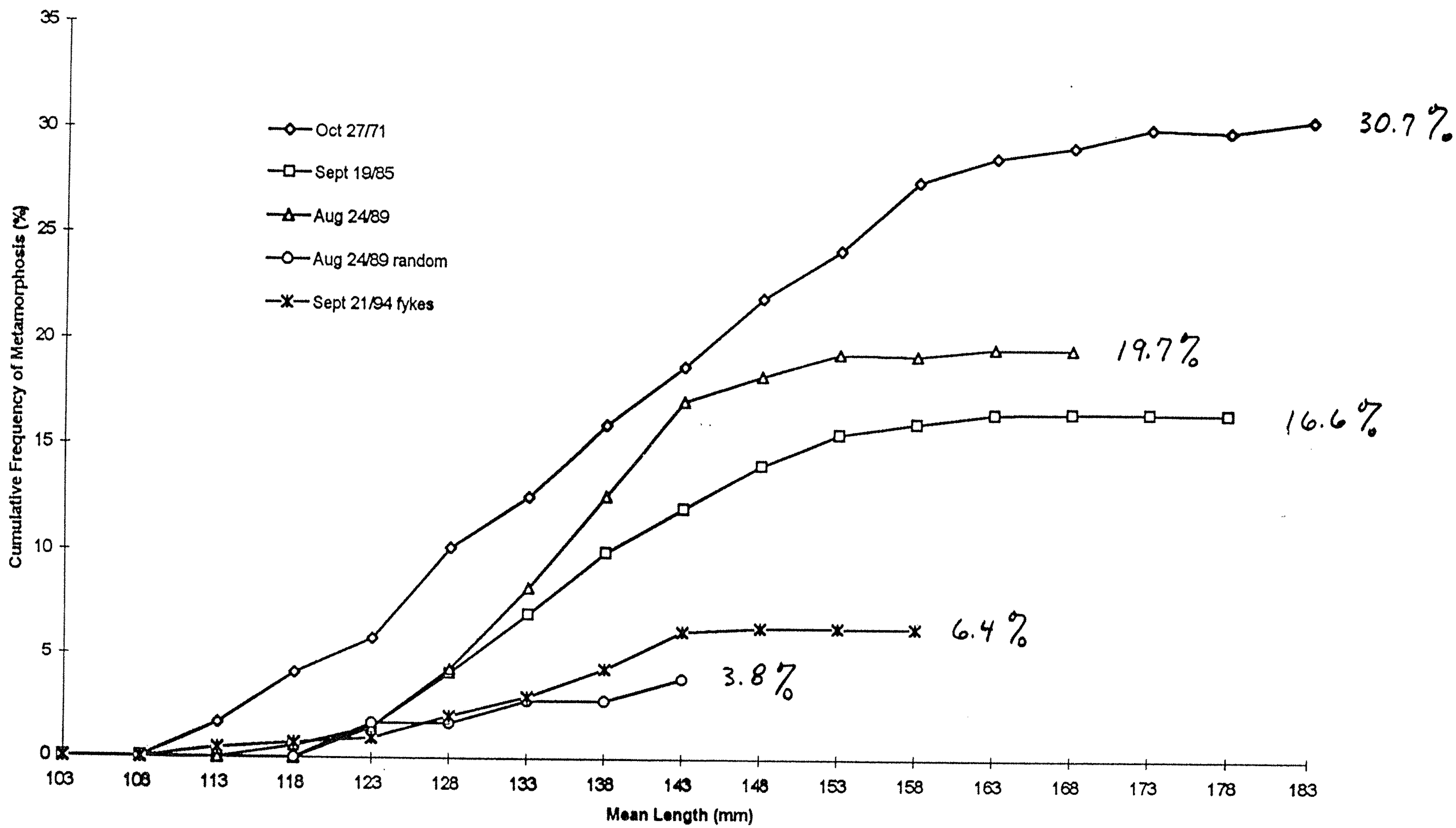
Daily Growth of Larval Sea Lamprey in Salem Creek, Lake Ontario, at Age 2.



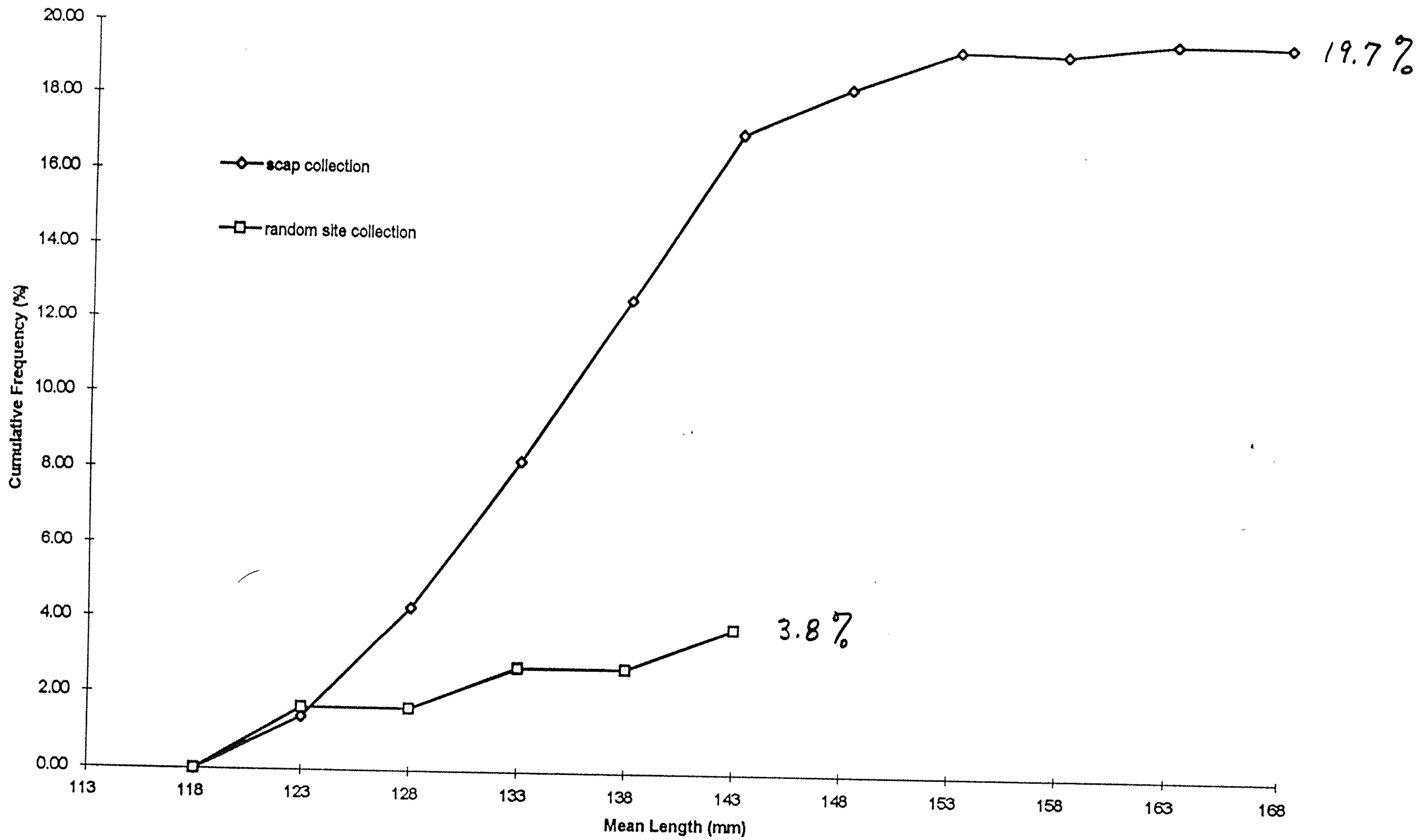
Daily Growth of Larval Sea Lamprey in Salem Creek, Lake Ontario, at Age 3.



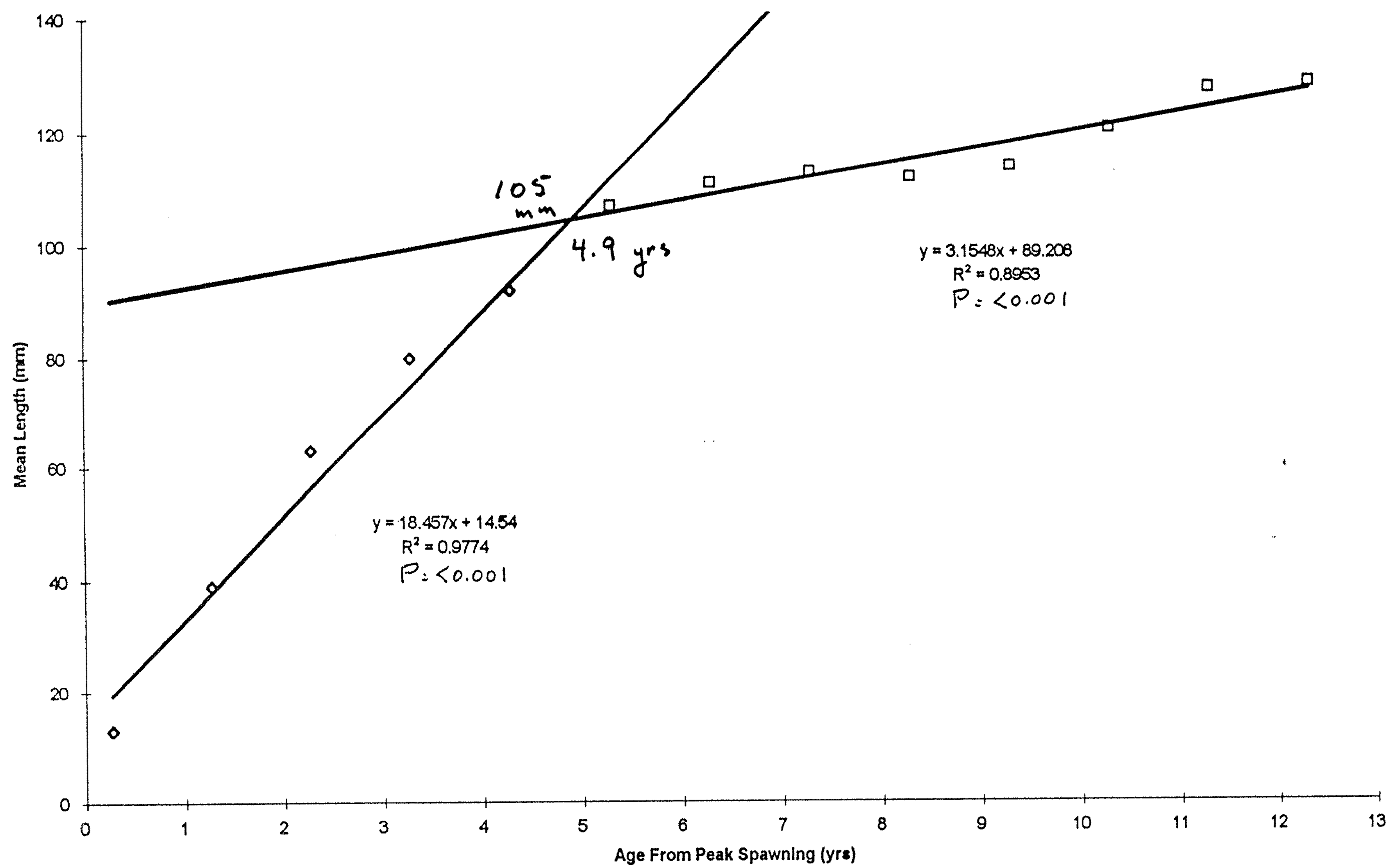
Cumulative Frequency of Larval Sea Lamprey Metamorphosis From Salem Creek Lampricide Applications, 1971 - 1994.



Comparison of Larval Sea Lamprey Metamorphosis Over 100 mm From Salem Creek, August 24, 1989.



Growth of a Single Year Class of Larval Sea Lamprey in the Gig Garlic River, 1960-1972.



I-1

Growth of a Single Year Class of Larval Sea Lamprey