A statistical assessment of sea lamprey populations (Petromyzon marinus) in Lake Huron

Chris LaRocque
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A STATISTICAL ASSESSMENT OF SEA LAMPREY POPULATIONS
(PETROMYZON MARINUS) IN LAKE HURON

by

CHRIS LAROCQUE (812921)
DEPARTMENT OF GEOGRAPHY
UNIVERSITY OF WINDSOR

A thesis presented to the University of Windsor
in partial fulfillment of the thesis requirement for the degree of
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Chapter I

1.1 Introduction

The Great Lakes system has long been recognized for its richness in fish stocks, which supports valuable sport and commercial industries. Since the late 1930's, the Great Lakes have been under attack from an aquatic parasitic species known as the sea lamprey (Petromyzon marinus) (Figure 1). According to the literature (for example, Applegate 1950, Miller 1979, and Wadden 1968) the sea lamprey was first observed and documented in the Great Lakes in 1937. However, Smith and Tibbles (1950) claim it is reasonable to assume that sea lampreys were present, but not observed or documented for several years before 1937.

Sea lampreys were originally found throughout the Eastern Seaboard, extending along the Atlantic coast from Labrador, southwards to the Florida coast. During the spawning season, the sea lamprey migrate into freshwater streams and into gravel-based tributaries to spawn.

Sea lamprey were prevented from entering the rest of the Great Lakes system by Niagara Falls, a natural protected barrier to further eastern expansion. According to Miller (1979), Wadden (1968) and others, in 1829 the opening of the Welland Canal allowed sea lamprey free passage into the
FIGURE 1. THE SEA LAMPREY

upper Great Lakes, which has caused significant damage to fish stocks throughout the Great Lakes.

Since the 1930's, many types of controls have been implemented within the Great Lakes and their tributaries in an attempt to control sea lamprey numbers. However, results from these controls have been varied and not entirely successful. Therefore, it is essential to implement appropriate research and study results throughout the Great Lakes system to gain a better understanding of sea lamprey-fish interaction and to assess whether there is a resurgence of sea lamprey in Lake Huron (area of study), and the rest of the Great Lakes.

1.2 Statement of the Problem
The spread of the sea lamprey into the Upper Great Lakes has created serious biological and economic consequences. Smith and Tibbles (1980) found that in Lake Huron, Lake Trout (Salvelinus namaycush) production dropped dramatically from 2,058 tonnes in 1938, to 69 tonnes in 1954. Production continued to decline until the fishery collapsed in 1959 (Figure 2). According to Smith (1968) and Christie (1974), rapid growth of certain fish species in Lakes Huron, Michigan, and Superior in 1940 was attributed to sea lamprey predation on selected species. Decline of the Lake Trout (Salvelinus namaycush), Burbot (Lota lota), and Salmon (Oncorhynchus tshawytscha, O. kisutca, O. nerka, etc.) neces-
sitated a shift in fishery preferences as these valuable fish stocks declined in number.

To date, it has been found that the sea lamprey has no natural enemies or controls per se. Thus it has become necessary to initiate some kind of integrated control program to keep sea lamprey in check. Pfeiffer and Fletcher (1964), in their experimentation, revealed that the sea lampreys are rarely found in the stomachs of fish species. This has been attributed to a distasteful secretion produced by the granular cells of the lamprey's skin, which protects it from predacious fish species.

In order to regulate lamprey numbers, various controls have been implemented. According to Smith and Tibbles (1980), an integrated sea lamprey control program should include the following: (1) chemical lampricides (T.F.M., Bayer 73); (2) attractants/repellents; (3) biological; (4) genetic; and (5) mechanical (all to be discussed later). During the 1960's and 1970's, selective combinations of both T.F.M. (3-trifluoromethyl-4-nitro phenal) and Bayer 73 have been utilized in Lake Huron stream spawning beds and in the other Great Lakes to control lamprey ammocoetes (larvae stage of sea lamprey). These controls were implemented to reach some degree of biological stability.

Despite the success of the various controls, there have been numerous undocumented reports from Lake Huron camp owners and commercial and sport fishermen that lamprey pop-
FIGURE 2. COMMERCIAL PRODUCTION OF LAKE TROUT IN MILLIONS OF POUNDS IN LAKE HURON FROM 1885 THROUGH 1977

Source: Great Lakes Fishery Commission, Lake Huron Committee Minutes of 1981 Annual Meeting.
ulations are increasing. These allegations are based on the increasing number of lamprey-inflicted wounds and scars found on fish catches.

Therefore, it is necessary to initiate a study to investigate whether there is a resurgence of sea lampreys in Lake Huron. Failure to initiate a study in the immediate future could jeopardize Ontario's valuable fish stocks, and threaten both commercial and sport fisheries.

1.3 The Sea Lamprey

The sea lamprey (Petromyzon marinus) is a primitive species that is parasitic in nature, that has killed valuable commercial and game fish populations, and almost destroyed the Lake Trout species before controls were implemented in the early 1960's (Wadden, 1968). Sea lamprey are wrongly named because they are not eels. Most scientists consider lamprey as not a true fish species because of the cartilage construction and absence of a backbone (Wadden 1968).

The sea lamprey's distinctive features include a circular tooth-filled mouth and seven gill openings located at both sides of the head (Arms and Camp, 1979). According to Vladykov (1966), lamprey's teeth are not identical to true teeth of other vertebrates. They are hollow, stratified cones. The mouth of the lamprey is funnel-shaped and lined with three rows of teeth, four-plus teeth on each row and each side of the funnel opening (Figure 3).
The sea lamprey's body is snake-like in appearance, and is usually blue-black in color on the backside, and light colored on the belly (Figure 3). According to Farmer and Spanish (1973) and Sillot (1978), when sea lampreys attach prey, they tear into the flesh with their teeth and wrapping tongue, and suck out blood and bodily fluids. According to Farmer and Spanish (1973), most attacks occur between the head and caudal peduncle of the fish, and mainly in the area between the head and Figure 4. Figure 5, Figure 6, attacked the largest individuals to smaller specimens. It was observed that sea lampreys did not attack fish with lamproyan larvae are visible. The dissection shows lamprey from the sea lamprey control in the Great Lakes, Department of Fisheries and Oceans, Canada.
The sea lamprey's body is snake-like in appearance, and is usually blue-black in colour on the backside, and light coloured on the belly (Figure 1).

According to Wadden (1968), Farmer and Beamish (1973) and Miller (1979), when sea lamprey attack prey, they tear into the flesh with their teeth and rasping tongue, and suck out blood and bodily fluids. According to Farmer and Beamish (1973), most attacks occur between the head and caudal peduncle below the lateral line, and mainly in the area behind the pectoral fins (Figure 4, Figure 5, Figure 6, and Figure 7). The sea lamprey attacks the largest individuals of any species, as opposed to smaller specimens. It has also been found that the presence of lamprey on fish did not further an attack by additional lamprey. Rarely are fish fortunate enough to be able to dislodge lamprey from their bodies.
FIGURE 4. TWO LAMPREY ON FISH

Source: Sea Lamprey Control In The United States, U.S. Department Of Fish And Wildlife, Michigan, 1981.

FIGURE 5. ONE LAMPREY ON FISH

Source: Fish Habitat: The Foundation Of Canada's Fisheries, Department Of Fisheries And Oceans, Ottawa, 1982.
FIGURE 6. WOUNDED FISH CAUGHT IN DERBY

Source: Pictures Taken In The C.F.P.S. Chantry Chinook Classic Fish Derby, 1986.
**FIGURE 7. WOUNDED FISH CAUGHT IN DERBY**

Source: Pictures Taken In The C.F.P.S. Chantry Chinook Classic Fish Derby, 1986.
1.4 **Sea Lamprey Life Cycle**

According to Wadden (1968), Purvis (1980) and Potter (1980), young sea lamprey are called ammocoetes. This is a harmless larval stage of lamprey which extends from four to seven years. Ammocoetes are sedentary burrowing animals that become active and move at night. After the larval stage, the parasitic stage begins and lasts for up to two years, after which the lamprey migrate to spawning streams to mate and die. Most lamprey in the upper Great Lakes migrate to spawning streams from May to July. Both sexes build a nest in shallow water gravel sections of tributaries, where the female deposits up to 60,000 eggs and covers them with gravel and sand (Wadden, 1968). Both sexes die after their spawning rituals. The eggs are the size of a pinhead and hatch in about two weeks (note Figure 8).

Ammocoetes live their larval stage within the stream bottom sediments, consuming small plants and aquatic animals. Worm-like in shape, ammocoetes emerge from their burrows at night to feed. Algae is found to be the most dominant food source of larvae and anadromous (spawning) sea lamprey (Moore and Beamish, 1973). The number of algae cells eaten per unit weight of sea lamprey decreases inversely with size of larvae. In winter, the amount of algae found to be consumed was three times less than during the summer consumption rates (Moore and Beamish, 1973).
According to Mucken (1969), anadromous sea lampreys reach the adult stage at a length of approximately six inches, then move into the lake to assume the role of parasitic predator. During this phase, they grow to an average length of 43.7 cm. and a weight of approximately 3.6 kg. During the summer months, lampreys locate in deeper water, then move to shallow water during the winter months.

**FIGURE A: SEA LAMPREY LIFE CYCLE**

According to Wadden (1968), ammocoetes reach the adult stage at a length of approximately six inches, then move into the lake to assume the role of parasitic predator. During the parasitic stage, the lamprey can grow to an average length of 45.7 cm. and a weight of approximately 3.6 gm. During the summer months lampreys locate in deepwater, then move to shallow water during the winter months.

1.1.1 Objectives

The objectives of the study are: (1) to assess whether there is a resurgence of sea lamprey (*Petromyzon marinus*) populations in Lake Huron; and (2) to recommend the most effective and lamprey control strategy in Lake Huron.

1.1.2 Significance

The hypotheses of the study are: (1) There is a resurgence of sea lamprey (*Petromyzon marinus*) in Lake Huron waters; and (2) Decline in fish stocks in Lake Huron reflects the increase in the sea lamprey population.

The proposed study will therefore provide a comprehensive account of the abundance, distribution, and characteristics of sea lamprey in Lake Huron. This will be accomplished by undertaking field inventory and sampling studies during the
Chapter II

2.1 Rationale for Study

Lake Huron has long been recognized as a major area for both sport and commercial fishing industries. The key reason for selecting Lake Huron is to investigate numerous claims, by camp owners and sport and commercial fishermen, that of late, there are increased numbers of lamprey-inflicted wounds and scars on captured fish.

2.1.1 Objectives

The objectives of the study are: (1) to assess whether there is a resurgence of sea lamprey (Petromyzon marinus) populations in Lake Huron; and (2) to recommend the most effective sea lamprey control strategy in Lake Huron.

2.1.2 Hypotheses

The hypotheses of the study are: (1) There is a resurgence of sea lamprey (Petromyzon marinus) in Lake Huron waters; and (2) Decline in fish stocks in Lake Huron reflects the increase in the sea lamprey population.

The proposed study will therefore provide a comprehensive account of the abundance, distribution, and characteristics of sea lamprey in Lake Huron. This will be accomplished by undertaking field inventory and sampling studies during the
years 1986 and 1987 at the proposed areas of study, extending from Kincardine to Dowdenvale, Ontario (see Figure 9). Data collected from the Sea Lamprey Control Stations located in Marquette, Michigan and from Sault Ste. Marie, Ontario will also be analyzed.
FIGURE 9. THE STUDY AREA

Source: U.S. Fish and Wildlife Department, Marquette Michigan, 1986.
2.2 The Study Area

The areas of study chosen for the investigation in Lake Huron include: Howdenvale, Sauble Beach, Southampton, and Port Elgin (Figure 9), and the overall spatial area of Lake Huron in both U.S. and Canadian waters. These selected study sites (Howdenvale, Sauble Beach, Southampton, Port Elgin and Kincardine) were also chosen because they will provide the main source of data from the C.P.P.S. Chantry Chinook Classic, a fish derby which extended for the period August 8-23, 1986. Each study area will have a weigh-in-station, where all data will be compiled. Howdenvale is situated along the eastern shoreline of Lake Huron and lies north of Sauble Beach.

Sauble Beach is on the eastern shore of Lake Huron, at the base of the Bruce Peninsula. The Sauble River and its tributaries provide spawning grounds for various fish species, including salmon and trout. The Sauble Falls provide a ladder for fish to climb into the upper river system.

Both Southampton and Port Elgin (south of Sauble Beach) provide rich fishing grounds for both sport and commercial fisheries. According to Smith and Tibbles (1980), Denny's Dam is located in Southampton's tributary of the Saugeen River. This multipurpose dam was constructed between 1969 and 1970. The primary purpose of the dam is to allow passage of spawning fish species (trout and salmon) upstream to their spawning grounds, while prohibiting migrating sea lam-
prey from entering the upper river system. The fishladder is operated by the Ontario Ministry of Natural Resources (O.M.N.R.). The last treatment (with T.F.M. and/or Bayer 73) of the Saugeen River was in 1971 (Smith and Tibbles, 1980).

Kincardine is south of Port Elgin and provides spawning grounds to fish species in both the North and South Penetangore Rivers. Kincardine's large harbour provides feeding grounds for many fish species, and provides excellent fishing grounds offshore for both sport and commercial industries. Kincardine is also located just south of the Bruce Nuclear Power Plant (B.N.P.P.). This site is unique in that the plant discharges millions of gallons of wastewater each day, which is warmer than surrounding waters. This attracts many varieties of baitfish and other fish species to the area, year-round, and provides an excellent fishing ground for sport and commercial industries.

2.3 Methodology

2.3.1 Data Collection
The proposed study is geared towards providing a comprehensive account of sea lamprey abundance, distribution, and characteristics in Lake Huron. This will be initiated by undertaking a field inventory and sampling studies during the year 1986/1987, for the selected study areas.
The first source of data will be obtained from the C.F.P.S. Chantry Chinook Classic Fish Derby, which extends from August 8 to 27, 1986/1987. Data will be collected from daily records of fish catchings from all study areas. Weigh-in sheets (questionnaires - see Appendix A) and creel census forms (Appendix B) will be distributed to all weigh-in stations to collect information such as: 1) the type of fish species caught; 2) fish weight; 3) time spent fishing; 4) number of fish caught per species; and 5) number and type of fish caught which had lamprey markings/wounds.

Data will be obtained from the U.S. Fish and Wildlife Service pertaining to information such as: 1) the number of parasitic-phase sea lampreys captured per 100 trap net lifts in the statistical districts of Lake Huron, 1971-1985; 2) spawning-phase lamprey counts from systematic collections in both U.S. and Canadian tributaries from 1960-1986 inclusive; 3) the incidence of sea lampreys and number of lake trout and chinook salmon taken by the charter boat fishery, 1985; 4) the number of sea lamprey wounds per 100 lake trout and chinook salmon taken by the charter boat fishery in 1985; 5) the number of parasitic-phase sea lamprey collected by the commercial industry, 1967-1986; and 6) the number of parasitic-phase sea lampreys collected by sport fisheries in 1985.

A third source will be obtained from the Sea Lamprey Control Centre located in Sault Ste. Marie, Ontario. Data will
be obtained pertaining to the distribution and morphological characteristics of lampreys in Lake Huron.

Information gathered from weigh-in and creel census forms from the C.F.P.S. Chantry Chinook Classic Derby will be summarized to yield the following totals, averages and percentages such as: 1) total numbers of fishing participants; 2) average hours per angling day spent; 3) total number of fish caught; 4) number of fish caught per person per day; 5) number of angling hours per fish caught; 6) total number of fish caught per species; 7) number of fish per species wounded by lamprey; and 8) total percentage of lamprey marked fish per species.

2.3.2  Data Analysis

The acquired data described above will be first summarized and then graphically presented with histograms, pie charts, frequency polygons, and cumulative frequency polygons. The cumulative frequency distributions will then be compared with those of several theoretical distributions in order to determine whether the collected sample data on lamprey numbers fit any of the known continuous theoretical distributions. If usual comparisons of plotted sea lamprey numbers cannot yield clues of appropriate theoretical distributions, then a GOODNESS-OF-FIT program (see Philips 1972; Lakhan 1982) will be used to test whether a set of empirical observations conform to any of the known theoretical distributions. The Kolmogorov-Smirnov test will be used to test for GOODNESS-OF-FIT.
Since sea lamprey numbers change through time, two aspects of time series analysis will be considered. This will involve (i) the measurement of growth and decline and (ii) identification of trends and fluctuations. Based on recommendations by Hammond and McCullagh (1977), data on sea lamprey numbers, sea lamprey catches, sea lamprey wounds, fish populations, etc. will be analyzed for:

(a) the over-all long-term trend,
(b) periodic fluctuations of a rhythmic nature, and
(c) irregular or random fluctuations.

Trend lines will be fitted with both linear and nonlinear methods.

To provide information on the spatial distribution of sea lampreys, choropleth maps will be produced. Spatial statistics will also be obtained by using the percentage of lampreys caught at each field site for both U.S. and Canadian sides. The question to be answered will be: "Is there a significant degree of spatial autocorrelation between the percentages at the 0.05 level?". From the spatial analysis, conclusions will be made concerning the areas of Lake Huron which are most susceptible to sea lamprey predation.

2.4 Probable Results
The major objective of this study is to investigate whether sea lamprey resurgence has occurred, of late, in Lake Huron's waters. As evidenced from past documentation, such
vide more effective control measures for lamprey populations and to re-establish biological stability. Another control strategy could be the establishment of controlled hunts for lamprey, serving to reduce populations, and to maintain stability.

It is also possible that sea lamprey resurgence and reduced fish stocks have not occurred. In this situation, it could be inferred that present sea lamprey control strategies are effective in managing lamprey numbers, and provide a means to maintain biological stability. Furthermore, it can be inferred that present control strategies should be maintained, while closely monitoring predator-prey interaction within the ecosystem.

Both the Ministry of Natural Resources (Ontario Government) and Fisheries and Oceans Canada (Federal Government) are making a concerted effort to manage and improve fish stock resources for commercial and recreational purposes. It is therefore justifiable to initiate this study to investigate claims by commercial and sports fishermen, and camp owners that lamprey populations are increasing in Lake Huron. These allegations are based on the increased fish attacks, scars, and open wounds found on fish catches. This study can offer the potential and eventual benefit of preserving and improving the productivity of fish stocks. If sea lamprey resurgence is found to have occurred in Lake Huron, based on the study results, then identification and
control of this predatory aquatic species, at the earliest possible time, can only result in the implementation of effective controls to remove a threat from the aquatic environment.

With continued vigilance, and the application of research findings to management control strategies, the value of fisheries in Ontario should continue to rise. The sea lamprey continues to exist as a potential risk to fish habitats, and populations must continually be investigated and eliminated. Once the sea lamprey can be fully controlled, both sport and commercial fisheries sectors will be a consistently viable contributor to Ontario's economy.

2.5 Model Design and Explanation

Given the fact that initial data analyses show that sea lamprey numbers in Lake Huron are on the rise, then this study will present a diagrammatic model (Feedback Control Biological Systems Model for Sea Lamprey Management) to control sea lamprey numbers in Lake Huron. This model (Appendix C) displays various inputs involved in the interacting ecosystem (e.g., controls, fish stocks, sport and commercial fishermen and sea lamprey). Based on these interactions, a series of outputs are generated, which the authority in charge must evaluate, using appropriate tests (e.g., cost/benefit analysis). Once a complete and exhaustive analysis is performed, the evaluator must devise a control program which should
exhibit an effective and cost efficient strategy to maintain biological stability within the study area (Note: all definitions of terms used in the model explanation are found in Appendix D).

2.6 Operation of the Model

In the first phase of the Feedback Control Biological Systems Model, the input variables are injected into the system. These inputs are: (1) sea lamprey; (2) fish stocks; (3) sport and commercial fishermen; (4) controls, which are broken down into five categories: (A) mechanical (electrified weirs, barrier dams); (B) attractants/repellents; (C) genetic (sterilization program); and (D) biological (experimental stages on parasites, animals, competitive displacement, and psychological alteration of lamprey ammocoetes to prevent metamorphisis).

The second phase of the model involves the introduction of input variables into the ecosystem (Lake Huron), where predator-prey roles evolve under the natural laws of survival.

In phase three, a series of outputs are generated from the interaction of inputs into the ecosystem. These outputs are analyzed in terms of both monitor and assessment stages. If no inputs are implemented in the model, a positive feedback situation arises. Lamprey numbers remain unchecked without controls placed upon them, resulting in expanding lamprey populations and increased fish stock predation.
Therefore, absence of controls leads to increased disorder within the ecosystem (Lake Huron), and is an undesirable output of the model.

Sport and commercial fishermen reduce the fish stock population from catchings, and have no direct control over lamprey numbers. However, by reducing fish stock populations, lamprey numbers are indirectly controlled. In other words, as fish stocks decline, less food is available to sea lamprey populations, thus reducing sea lamprey numbers. However, unless limits are enforced on fish catches, this input defeats the purpose of maintaining biological stability within the ecosystem. Therefore, both positive and negative feedback situations can arise under these conditions.

Concerning mechanical controls, lamprey barrier dams are designed to block migrating lamprey from entering upstream spawning beds. This type of control has been effective in many areas (e.g., the Saugeen River), but has also produced variable results. Therefore, dams have reduced lamprey numbers to a limited degree, and have reduced lamprey predation on fish stocks. Since 1959, these dams have been removed as major control, and are used to assess the success rate of other controls (e.g., T.P.M.). For example, barriers are now used to count upstream migration of spawning lamprey, and the accumulated rates are used to determine the success rate of other controls. Therefore, dams are useful, if integrated with other controls, and provide a negative feedback situation within the model.
The disadvantages of dams and barriers are: (1) they could block the upstream migration of other aquatic life; (2) they raise water levels and flood lands behind the structure; (3) that lamprey have been found to get around these barriers; and (4) that dams are not a total control to regulate lamprey numbers.

The success of electrified weirs to regulate lamprey numbers is limited. These controls have also been utilized to assess the rate of success of other controls. Electrified weirs are effective when applied to other controls strategies, and aid in producing a negative feedback situation. The costs of electrified weirs are that they: (1) present a potential danger to other aquatic life in the system; (2) are expensive; (3) could pose a potential threat to area recreation; and (4) are not a complete control to regulate lamprey numbers.

Attractant/repellents are found to be effective to regulate sea lamprey numbers when applied to other control strategies. They are effective in reducing lamprey predation on fish stocks, and in creating a negative feedback situation within the ecosystem. The costs of these controls are: (1) they are expensive; (2) that they dilute when applied to the water body; (3) that there are unknown effects to surrounding aquatic life; and (4) they do not represent a total control in regulating lamprey numbers.
Biological controls are, at present, in the developmental stages and represent a positive-feedback situation within the ecosystem. To date, experiments have proven ineffective in sea lamprey control, allowing sea lamprey numbers to persist, resulting in continued lamprey predation on fish stocks. Biological controls are also: (1) expensive; (2) time consuming in development; (3) entail extensive funding, planning, and expertise; and (4) an inadequate total control strategy in lamprey management.

Genetic controls (sterilization of male lamprey) are effective in controlling lamprey numbers when integrated with other control strategies. They, therefore, represent a negative feedback situation in the ecosystem. Lamprey numbers are therefore, reduced, and some stability to fish stock populations occurs. Costs of genetic controls include: (1) the programs are expensive; (2) other non-parasitic species of lamprey are affected which don't have to be, which adds to the expense of application; and (3) they are not a total control to regulate sea lamprey numbers.

Chemical controls (T.F.M. and Bayer 73) are found to be the most effective in regulating lamprey numbers, and creates the strongest negative feedback situation in this ecosystem. The benefits of chemical controls are: (1) fish stocks are best maintained under this control strategy; (2) monitored results indicate a significant decline in preda-
tion on fish stocks; (3) since the 1950's, lamprey numbers have been reduced as much as 80%; (4) presents minimal toxicity to surrounding aquatic life; (5) T.F.M. in small doses kills ammocoetes within 16 hours of application; and (6) can be used with a 2% ratio of Bayer 73, which reduces T.F.M. use by 50%.

The costs of chemical controls are: (1) they are expensive; (2) must perform several bio-assays (tests) to water conditions before application (e.g., pH, depth, velocity, clarity, size of water body, seasonality, etc.); and (3) despite chemical controls being the most effective in lamprey control, they still fail to represent a total sea lamprey control strategy.

The fourth and final stage of the model deals with the formulation of a sea lamprey control program. The authoritative body responsible for developing a program should follow a logical, orderly, scientific, and exhaustive approach, to ensure the program reflects the best possible controls to maintain biological stability in the ecosystem, and to maintain acceptable prey-predator levels in Lake Huron.
The sea lamprey is a primitive species that is parasitic in nature. Wadden (1968) found that sea lamprey are wrongly named because they are not eels. Most scientists consider lamprey as not a true fish species because of the cartilage construction and absence of a backbone. When sea lamprey attack prey, they tear into the flesh with their teeth and wrasping tongue, and suck out blood and body fluids (Wadden 1968; Farmer and Beamish 1973; Miller, 1979). Most attacks occur between the head and caudal peduncle below the lateral line, and mainly in the area behind the pectoral fins (Farmer and Beamish, 1973). Sea lamprey attack the largest individuals of any species, as opposed to smaller specimens. It has also been found that the presence of lamprey on fish did not further an attack by additional lamprey. Rarely are fish fortunate enough to be able to dislodge lamprey from their bodies.

There are five species of Petromyzonidae found in the Great Lakes region (Wadden 1968; Manion and Hanson, 1980; and Vladykov and Kott, 1980). Three of these five are parasitic in nature (Petromyzon marinus, Ichthyomyzon inicus-pis, and I. castaneus). The remaining two species are non-
parasitic (I. forser and Lethenteron lamotlenu). A sixth species (Lamectra alpytora) is non-parasitic in nature and can be found in the Lake Erie basin.

The fish species composition in the Great Lakes (Huron, Michigan, Superior, Ontario) have undergone a parallel series of stock changes since the earliest records were kept. A major cause of species succession was due to the invasion of sea lamprey, and their intensive selection of certain fish species (Smith 1968; Christie 1974).

Before 1930, major changes in fish stocks were not detected (Smith, 1968; Christie, 1974). However, around 1940, a rapid growth of some fish species in the Great Lakes was found to be caused by lamprey predation. This problem led to a shift in importance of the commercial fishing industry in terms of species harvested, as major species declined (Smith 1968; Christie 1974).

The first species to decline and collapse were the Lake Trout (Salvelinus namaycush) and Burbot (Lota lota), which are deep water predators (Smith 1968; Christie 1974). The next species to be affected were the Chub (Leucichthys spp.). Mainly the largest of the species were preyed upon. With the relaxation of predation pressure, the rainbow smelt, deepwater cisco and alewife stocks (Alosa pseuda harenus) increased.

Lake Ontario differed from the other Great Lakes in that it contained both alewife and sea lamprey before the turn of
the century. Lake Ontario acts as a reservoir for these species to enter the Upper Great Lakes. Evidence suggests that sea lamprey became a significant factor in the loss of fish species in Lake Ontario. Predation centered on ciscoes and smelt, and contributed to the collapse of herring following a similar sequence in the Upper Great Lakes. Lake Erie was also affected by loss of predator stocks, but many other factors were collectively responsible for this situation.

Coinciding with the control of sea lamprey in Lakes Superior, Michigan, Ontario and Huron, new programs of hatcheries and stocking were implemented and led to the reintroduction of Lake Trout, Chinook Salmon (Oncorhynchus tshawytscha), Coho Salmon (O. kisutch), Kokanee Salmon (O. nerka) and Splake (Salvelinus fontinalis) (a hybrid cross between a brook trout and lake trout). These programs were established to create a new balance between species in the Great Lakes system. Lark (1973) and Smith and Tibbles (1980) found that the sea lamprey entered the Upper Great Lakes in the late 1930's, and had seriously damaged fish species stocks by the mid 1940's in Lakes Huron and Michigan. Wadden (1968) states that sea lamprey were first identified in Lakes Michigan in 1936, Huron in 1937, and Superior in 1946. Sea lamprey sharply reduced the commercial fishery catchings in the Upper Great Lakes in both the U.S. and Canada from 33,069 tonnes to 661 tonnes in 1965.
Morman et al., (1980) analyzed the factors influencing the distribution of sea lamprey in the Great Lakes. Sea lamprey are widely distributed over the Great Lakes but are scarce in large areas of the watershed (Morman et al., 1980). Since 1957, lamprey larvae have only been detected in 433 (7.5%) of the 5,747 streams of the Great Lakes Basin (Morman et al., 1980). Furthermore, there are many environmental conditions which influence sea lamprey distribution, such as: (1) streamflow and temperature, which are vital factors in attracting spawning runs into streams; (2) dispersal of adult spawners in streams are influenced by blockages, water temperature, current, bottom type, and presence of inland lakes; (3) embryo development and survival is affected by water temperature. Eggs must have constant temperatures for successful hatching (from 12°C - 26°C), and slightly beyond these constraints (McCauley, 1963); (4) lamprey larval distributions are limited by barriers that block adult spawning runs, warm temperatures, low unstable flows, hard stream bottoms, and pollution. Yet larvae have been found under habitats exhibiting these constraining factors; and (5) interconnecting waterways and attachment to fish and boats which is considered a major factor in lamprey movement.

Since there are no natural enemies or controls per se, within the Great Lakes to keep sea lamprey numbers in check, some kind of integrated program must be initiated. Lamprey
and ammocoetes are rarely found in the stomachs of salmonids or other fish (Pfeiffer and Fletcher, 1964). Feeding experiments revealed that many fish will not eat lampreys due to a distasteful secretion which is produced from the granular cells of lamprey skin. This secretion is suspected of being biologically significant in protecting the lamprey from predacious fish.

Pearce et al. (1980), analyzed sea lamprey distribution and control in the lower Great Lakes. Specifically, the study covers Lakes Erie, Ontario, finger lakes Oneida, Champlain, and their connecting tributary waters. According to Pearce et al. (1980), sea lamprey are located in all of several areas in the St. Lawrence River system, between Lake Huron and Moses-Saunders Power Dam, below Lake Ontario.

As mentioned earlier, an integrated program to effectively control sea lamprey consists of five integral parts which are: 1) chemical (lampricides); 2) attractants-repellents; 3) biological; 4) genetic; and 5) mechanical. According to Wadden (1968), Sprules (1976) and Smith and Tibbles (1980), 6,000 or more chemicals were tested under controlled conditions for their ability to effectively and efficiently control lamprey populations. Lampricides T.F.M. (3-tri-fluoromehtyl-4-nitrophenal) proved to be the most effective in lamprey control. According to Miller (1979), T.F.M. is applied in small quantities and destroys lamprey larvae within sixteen hours of application. Agris (1967),
attributes T.F.M.'s effective toxicity towards lamprey to its' interaction with oxygen transport, which is more critical to sea lamprey than to fish species. Wadden (1968), found that T.F.M. use in Lake Superior in 1958 resulted in a 90% reduction in lamprey populations by 1966. Evidence also suggests that T.F.M. application in Lake Huron and other lakes are producing significant declines in lamprey numbers.

Before T.F.M. can be introduced into streams, the stream bodies must be analyzed in terms of certain water conditions, such as: pH, velocity, depth, size of streams, seasonality, among others. According to Wadden (1968), this analysis is called "BIO-ASSAY". In these tests, T.F.M. is placed, in various quantities, in containers holding both lamprey ammocoetes and fish, to determine the required dose of T.F.M. needed to effectively destroy the ammocoetes, while not harming fish species. Several of these tests must be performed prior to the actual stream treatment to ensure accuracy and effectiveness.

Another chemical agent (lampricide) found to be effective in controlling ammocoete numbers is "Bayer 73", which is used in a 2% ratio with T.F.M. to reduce T.F.M. by 50% in quantity (Wadden, 1968). The disadvantages in using T.F.M. are that it is very expensive, thus applying it in ratio to Bayer 73 reduces the cost of application. Secondly, T.F.M. is restrictive in use in that it can only be applied to stream beds where ammocoetes are located.
Repellents are applied in lamprey spawning streams to repel sea lamprey entry into spawnbed areas. This control is valuable in areas where other control measures are ineffective.

Attractants are used to direct spawning sea lamprey migrants into streams where they can be harvested, and to bring them to streams where other control measures have proven inefficient. Attractants can also be utilized to collect spawning sea lamprey for sterilization and release programs (Smith and Tibbles, 1980). One drawback to the release program is that eventual lamprey release allows for continued predation on fish stocks.

Biological controls have been utilized mostly in dealing with insects, and have produced mixed results. According to Smith and Tibbles (1980), little effort has been directed towards the development of biological controls for sea lamprey. Maclain (1952) experimented with a parasite found in sea lamprey in Lake Huron, but found no natural parasites to be effective in the control of lamprey.

There was also consideration towards controlling sea lamprey with the American eel (Anguilla rostrata), but its use was found to be impractical. This was supported by the fact that the American eel has been present in Lake Ontario for many years with no apparent effect on lamprey numbers (Smith and Tibbles, 1980).
Another consideration for biological controls is the competitive displacement by other species. However, a program of this scale would take extensive funding, planning, and expertise to produce desired results.

A final biological control is the psychological alteration of lamprey ammocoetes to prevent metamorphosis, which is still in the experimental stages (Smith and Tibbles, 1980).

Smith and Tibbles (1980) and Hanson and Manion (1979) found a major genetic control to be the sterilization and release of mature male sea lampreys in spawning streams. This would be an effective tool in an integrated approach to sea lamprey control.

According to Smith and Tibbles (1980), mechanical controls consist of lamprey barrier dams constructed with an overhanging lip of steel to prevent entry of lamprey further upstream to spawning beds. Since 1959, these dams have been used to assess the effects of T.F.M. treatments by counting the number of lamprey after T.F.M. application. This method is considered a reliable indicator of lamprey populations entering streams from lake systems (Miller, 1979).

Electrical weirs are used to trap sea lamprey migrating upstream to their spawning sites. They are also used to assess the success of other controls. Lamprey are captured and counted, and provide a reliable indicator of the size of lamprey populations entering streams.
Smith and Tibbles (1980) analysed the history of sea lamprey invasion and control in Lakes Huron, Michigan and Superior. The original surveys by Michigan authorities indicated that by 1948, 34 streams were infested by lamprey in Michigan (Smith and Tibbles, 1980). From 1932-1938, sea lampreys were observed in the Clinton River tributaries linked to Lake Erie. However, none were found in later surveys.

Initial attempts to control sea lamprey began in Michigan in the mid 1940's, with the construction of mechanical barriers along Lake Huron's U.S. shoreline to block spawning sea lamprey. According to Smith and Tibbles (1980), Michigan biologists installed a weir trap in the Acquioq River to study biological components of sea lamprey. Lamprey numbers ranged from 3366 in 1944, to a peak of 24,643 in 1949, to only 503 in 1977 (Smith and Tibbles 1980).

From 1952-1960, 132 electrical barriers were constructed along 132 tributaries of the Great Lakes (Smith and Tibbles, 1980). The electric shock program was created in 1956 to assess lamprey ammocoete numbers and it was instituted in 1961, in Michigan. In 1961, 33 U.S. streams contained lamprey larvae, which increased to 49 by 1978 (Smith and Tibbles, 1980).

Control measures did not become effective until the creation of the lampricide T.F.M. From 1958-1978, T.F.M. was applied 1223 times to 3334 tributaries in the upper Great
Lakes, of which 91 streams were Canadian and 243 U.S. (Smith and Tibbles, 1980). Evidence from the T.F.M. control program provided results such as: (1) reduced sea lamprey spawning runs measured by the number of adult lamprey taken by electrical barriers; (2) a significant decline of lamprey wounds on fish; and (3) by an increased response of major fish stocks after sea lamprey control (e.g., trout and salmon species) (Smith and Tibbles, 1980).

In Ontario, it was found that the North Channel of Lake Huron was under attack by sea lamprey. Therefore, the first studies took place in the surrounding streams. Traps were used to catch lamprey to assess their numbers (Smith and Tibbles, 1980). In each year from 1946-1949, catches went from 11 to 418 to 6245 to 6990 to 7459 respectively, indicating heavy concentrations of lamprey during this period.

In 1964, the Great Lakes Fisheries Commission installed electrical barriers in the Canadian tributaries of the North Channel, Georgian Bay, and all of Lake Huron (Smith and Tibbles, 1980). Twelve weirs were also installed in 11 tributaries along the Canadian shore, of which 8 were in continual operation between 1967 and 1975. These weirs indicated peak lamprey spawning runs in 1968, which fell to 4782 in 1969, 1588 in 1970, and 197 in 1973 (Smith and Tibbles, 1980).

Smith and Tibbles (1980) found that sea lamprey were also reported in a number of Canadian rivers in the late 1940's,
but were not documented until future surveys were made in 1956.

Sea lamprey occupy 105 of the 2000 streams in the Canadian Great Lakes (Wadden, 1968). Since these streams are relatively small, chemical treatment with lampricides is the most effective control.

The first lampricide program began in Lake Superior in 1958. Streams were normally treated about four to five times, because lamprey larvae live in stream bottoms from four to seven years of the larvae stage (Wadden, 1968). Therefore, repeated treatments are necessary to destroy the larvae.

A case study by Wadden (1968) revealed that most major lamprey producing streams in Lake Superior were treated with T.F.M. in 1959, but significant results were not obtained until 1962. The results indicated an 80% reduction in lamprey trapped in electrical barriers during spawning time (Wadden, 1968). From 1963 to 1965, lamprey numbers levelled off, but declined again by 50% in 1966. By 1967, all Lake Superior streams were being treated (Wadden, 1968).

After the treatments in 1960, commercial catches were found to be improving. However, around 1964, lamprey resurgence occurred in formerly treated rivers. These findings were supported by increasing predation of fish stocks. In response to these findings, the sea lamprey control program was reintroduced in 1966 on a regular basis (Smith and Tib-
bles, 1980). In the late 1960's, the St. Maries River and its tributary, the Root River, were found to be heavily infested with sea lamprey. In direct response to this situation, these rivers were treated with the lampricide Bayer 73, from the period 1971 to 1978 (Smith and Tibbles, 1980).

According to Wadden (1968), lampricide treatment programs expanded in 1960, from Lake Superior to Lake Huron where 38 lamprey streams were subjected to the lampricide control program. According to Wadden (1968) and Smith and Tibbles (1980), the 21 streams found in the Georgian Bay, North Channel areas, were treated in 1960 but financial constraints, coupled with greater interest for Lake Michigan control programs, led to the termination of the program.

In 1968-1969, U.S. authorities planted 1.6M Coho and Chinook Salmon in Lake Huron. It was believed that salmon would not be as vulnerable to lamprey predation as Lake Trout because of their quick growth and ravenous appetites. According to Smith and Tibbles (1980), it was found that lamprey scarring rates were 85% on mature Coho, and 62% on two year old Chinook, a drastic contrast from Lake Superior, where the wounding rates were less than 1% for Coho, and less than 5% for Chinook. Despite this problem, stocking continued from 1970 to 1978, while lamprey wounding rates remained high. In 1972, this trend reversed, as lamprey control programs took effect, reducing the wounding rates from more than 86% in 1973-1974, to 5% in 1975, to a low of 2.4% in 1976 (Smith and Tibbles, 1980).
Berst (1967) analyzed lamprey parasitism of rainbow trout in South Georgian Bay. In this study, 2,614 adult rainbow trout were sampled from the Nottawasaga River in Georgian Bay, between 1961 and 1967. Berst (1967) found that 7.1% of the trout had one or more lamprey marks on them, and the lamprey ranged in length from 25 to 84 cms. Furthermore, lamprey marks were only found on fish greater than 40 cms in length, and multiple scarring was found to be on 30% of the trout (Berst, 1967). The incidence of marked fish peaked in the spring of 1962 at 17.2%, then declined to 1.3% in the fall of 1962. This was attributed to lampricide treatments, and lamprey reduction from 1960 to 1961. Incidence of markings remained low for the next four years, however recruitment of metamorphosed lamprey substantially increased in 1966-1967 (Berst, 1967).

Between 1968 and 1971, Lake Ontario received stockings of both trout and salmon. These stockings proved to be disastrous. This was indicated by a limited survival rate and a high number of lamprey attack marks.

According to Pearce et al., (1980), studies are underway, with the view of including Lakes Oneida and Champlain in the chemical treatment program, to prevent lamprey from occupying these areas, and to improve fish populations. Lakes St. Clair, Erie, connecting waters, finger lakes, and the St. Lawrence River, below Lake Ontario, are not being considered for the program because sea lamprey numbers are not significant to warrant this action.
Despite various integrated control strategies, major problems still exist that must be resolved such as: (1) the existence of sea lamprey ammocoetes in areas where controls can't be used, or are ineffective; (2) many of the ammocoetes found in the mouths of tributaries, estuaries, or bow lakes, beaver flows, and streambed spawning areas sometimes survive treatments due to the dilution and poor circulation of lampricides; and (3) there is a need for more effective programs to monitor sea lamprey populations.

One of the first authorities to investigate sea lamprey was the Great Lakes Sea Lamprey Committee, in 1946. This committee was integrated with the Great Lakes Trout Commission in 1952 to form the Great Lakes Trout and Sea Lamprey Committee (Smith, 1971; Wadden, 1968; Crowe, 1975).

Individual delegates from the U.S. Fish and Wildlife Service, the Fisheries Research Board of Canada, the Ontario Department of Land and Forests, and each bordering U.S. state around the Great Lakes, served on these committees.

In 1953, all of these authorities were integrated to investigate the sea lamprey problem in the Canadian waters of the Great Lakes. The invasion of sea lamprey into the upper Great Lakes caused both U.S. and Canadian authorities to join in a treaty agreement which according to Fetterolf (1980), was signed in a new symposium to form the new Great Lakes Fishery Commission on September 10, 1954. The agreement was ratified on October 11, 1955, and established the
Commission's jurisdiction as including Lakes Superior, Huron, Erie, and Ontario (Wadden, 1968).

In 1956, the new Great Lakes Fishery Commission began development, coordination and implementation of lamprey control programs. The Commission also coordinated fish research programs and acted as advisor to both U.S. and Canadian governments in implementing improved measures to better the fisheries (Petterolf, 1980). During the 23 year history of the Commission, it has spent $54.5 million on lamprey control and research and will continue to seek more efficient cost effective management techniques (Petterolf, 1980).

The Great Lakes Fishery Commissions' agents, responsible for implementing sea lamprey control programs and research, are the U.S. Fish and Wildlife Service, and the Fisheries Research Board of Canada (Wadden, 1968). According to the authors cited above, the U.S. Fish and Wildlife Service is stationed in Marquette, Michigan and the Fisheries Research Board of Canada in London, Ontario, which was moved to Sault St. Marie in 1966. Both U.S. and Canadian headquarters are in close proximity to lamprey streams along Lakes Huron and Superior. It is estimated that 21 of 38 lamprey streams in Lake Huron are within a 100 mile radius of the Sault St. Marie headquarters (Wadden, 1968).

From 1966 to 1980, the Fisheries Research Board of Canada underwent a great transition. These changes, in order,
were: the Department of Fisheries and Forestry in 1971, the Department of Environment, Fisheries and Marine Science in 1976, the Department of Fisheries and Environment, and Fisheries and Marine Service in 1978, and the Department of Fisheries and Oceans since 1980 (Smith, 1971; Wadden, 1968).

Smith (1980) and Fetterolf (1980) examined the proceedings of the 1979 Sea Lamprey International Symposium (S.L.I.S.). The Symposium was created out of the need for a synthesis of opinion and recommendations for future planning. The 1979 Symposium was the fifth of a series of symposiums sponsored by the Great Lakes Fishery Commission.

The sea lamprey control program was the largest and most intensive of its kind to control vertebrates, and had impressive results (Smith, 1980).

As early as 1970, the Great Lakes Fishery Commission obligated itself to search for more effective, efficient, and economical methods to control the sea lamprey. At present, the most effective program consists of an integrated set of controls such as chemical, attractant/repellent, biological, genetic, and mechanical (as cited by Smith and Tibbles, 1980; Smith, 1980; Wadden, 1968). Smith (1980) believes the program must be monitored on occasion to update any problems encountered, and to create a report on present research. Thus, in 1975, the Great Lakes Fishery Commission (G.L.F.C.) appointed a steering committee to plan and implement the sea lamprey symposium. According to Smith (1980),
there are three main objectives of the S.L.I.S., which are:

(1) to organize, consolidate, and publicate the assembled information of sea lamprey control, and associated research;
(2) to assemble various experts in the field of lamprey research, and to express ideas and accumulated knowledge to the S.L.I.S.; and (3) to provide a forum whereby participating scientists can share individual findings, develop new initiatives to deal with the battle to control lamprey, and to further understand fish-lamprey interactions.

Farmer and Beamish (1973) conducted a study dealing with the predation on freshwater fish species of similar and different sizes. It was found that splake (Salvelinus namaycush and S. fontinalis), carp (Cyprinus carpio), white suckers (Catostomus commersoni), and whitefish were all attacked significantly more than walleye (Coregonus clupea formis), burbot (Lota lota), short head redhorse suckers (Moxostoma macrolepidotum), and brown bullheads (Ictalurus nebulosus).

Lett et al. (1975) developed a stochastic dynamic model to evaluate the simulated interaction of sea lamprey on lake trout. Results showed that an arithmetic increase in lamprey numbers caused a geometric decline in trout. These results were dependent on mean weight and age classes of trout (Lett et al., 1975). It was also indicated that large trout, when present, were attacked the most, allowing smaller trout to survive (Farmer 1973; Lett et al., 1975).
Peak predation on lake trout occurred exponentially with lamprey size, and seasonally, in fall, when lamprey feeding was at its peak (Lett et al., 1975). Lett then conducted simulation experiments regarding predation of lamprey on trout. Simulation suggests that sea lamprey and lake trout could coexist if large trout are not removed by commercial and sport fishing, and if some measure to control lamprey numbers was implemented.

Applegate (1965) examined the sex ratios and sexual dimorphism among recently transformed sea lamprey. Applegate (1965) compared the sex, length, and weight of transformed lamprey migrating downstream from the Carp Lake River in Michigan, in the fall, winter, and spring of 1960-1961. Similar studies were initiated in tributaries from Lakes Huron and Michigan. Results indicated a high male-female ratio of 324:100 in 1960-1961, and varied to 77-86:100 in other runs (Applegate, 1965).

According to Applegate (1965), the high male-female ratio was attributed to effective control programs, and the prevention of female lamprey transformation. The proportion of males to females declined as the runs progressed. Results indicated that males were smaller in size than females, and that a significant difference in the length/weight relationship occurred for each sex (Applegate, 1965).

Potter et al., (1974) examined the sex ratios and length of adult sea lampreys in the Humber River (Lake Ontario) from 1968 to 1972. Results indicated that mean lengths for
adult lamprey, between male and female, had little variation. This was also true of other studies in the upper Great Lake (Potter et al., 1974). Ratios of male to female ranged from 1:1 to 1.26:1, which confirmed estimates of long-established populations (Potter et al., 1974).

Potter (1980) conducted a study dealing with the ecology of larval and metamorphosed lampreys. According to Potter (1980), larvae growth is seasonal. At the end of the larval stage, ammocoetes stop growing in length and accumulate lipids (fat cells). Length-frequency curves and data on kidney growth indicate that ammocoetes are found in generally stable and productive sites, such as landlocked lakes, and take up to five years to reach metamorphosis length (Potter, 1980).

Data generated from isolated populations in the Big Garlic River and other tributaries within Lakes Michigan and Superior (some which are lampricide treated), reveal that the metamorphosis stage is variable and apparently related to growth rates and size of larvae (Manion, 1969; Potter, 1980). According to Potter (1980), a short larval life is usually associated with fast ammocoete growth rates, which sometimes occurs in streams where a lampricide is used, and density is reduced. Density appeared to be the dominant factor in regulating the length of larvae and transformed sea lamprey (Purvis, 1980; Torbla and Westman, 1980).
It is also true that land-locked lamprey metamorphoses at a longer length and age than other parasitic lampreys. According to Potter (1980), the metamorphosis stage occurs in summer, when lamprey length is stable, but weight is reduced in consequence to lipid mobilization. Feeding usually occurs 4 to 10 months between transformation from ammocoete to the parasitic stage (Potter, 1980).

Manion and Stauffer (1970) conducted a study dealing with the metamorphosis of land-locked sea lamprey and found that the external metamorphosis of the mouth is divided into four stages which are: (1) the mouth becomes reduced in size; (2) the mouth becomes fused; (3) the mouth encloses; and (4) the mouth elongates. During metamorphosis, the eye enlarges greatly, and the fleshy hood covering the snout and mouth transforms to a large sucking disk. The nasal and brachial area reduces in size, and body color changes from dark brown-yellow to blue-black dorsally, and white ventrally (Manion and Stauffer, 1970). Metamorphosis begins in early to mid July until August, and the external phase takes about three months under natural conditions (Manion and Stauffer, 1970; Beamish and Potter, 1972).

Manion and Hanson (1980) studied the spawning behaviour and fecundity of lampreys from the upper three Great Lakes - Huron, Michigan and Superior. Lamprey require certain physical factors for successful spawning such as suitable bottom structure, water flow, and temperature (Manion and Hanson,
1980). Nest construction is usually started by males, and takes place in gravel-based tributaries. The average spawning act lasts for approximately 2 to 5 seconds, and is repeated every 4 to 5 minutes. An estimated 86% of the 60,000 eggs are not deposited in the nest, however there is a 90% survival rate for those eggs in the nest (Manion and Hanson, 1980).

Heinrich et al. (1980) analyzed the changes in the biological characteristics of sea lamprey (*Petromyzon marinus*) as related to lamprey abundance, prey abundance and lamprey control. Lamprey abundance peaked in the Great Lakes before chemical control began. Length and weights were low when lamprey density was high, but increased when numbers were reduced by controls. Lamprey length and weight were also low when fish stocks were near depletion, but as fish stocks increased, lamprey length and weight increased (Heinrich et al., 1980).

For Lake Superior, detailed records have been compiled regarding change in lake trout stocks since 1959. According to Heinrich et al. (1980), a significant relationship exists between sea lamprey weight and lake trout abundance. As fish stocks decline, so does lamprey weight and visa-versa. Also, male sea lamprey were found to be the dominant sex during periods of fish stock abundance. Female domination occurred at times when fish stocks declined.
Farmer (1980) analyzed the biology and physiology of feeding adult lampreys. Land-locked sea lampreys attack all but a few fish species in the Great Lakes. Information related to the anadromous (upstream movement of spawning lamprey) is limited, however they are probably non-specific in prey choice (Farmer, 1980). Lamprey species differ in the relative proportion of blood and tissue consumed from victims. Land-locked lamprey feed on the blood of victims at rates of 3 to 33% of their wet body weight, and an estimated energy conversion efficiency of 39%. This is attributed partly to the nature of the sea lamprey's blood diet resulting in small energy losses of 3.4% of their total energy intake (Farmer, 1980). Maximum growth rates for sea lamprey occur at 20°C for lamprey weighing 10 to 30 grams, and 15°C for lamprey weighing 30 to 90 grams. It has also been found that lamprey growth rates decline with an increase in weight (Farmer, 1980; Purvis, 1980).

Land-locked sea lamprey prefer to attach to their prey more frequently than smaller prey (Wadden, 1968; Farmer and Beamish, 1973; Miller, 1979; Farmer, 1980). Furthermore, lamprey are not attracted to prey which already have a host lamprey attached to them. Farmer (1980) suggests that these factors aid in maximizing food intake, prolonging prey survival, and ensuring a constant energy content of food material. Daill and Mcdonald (1980) studied the effects of the control of sea lamprey on migrating and resident fish.
Mechanical and chemical controls have led to fish kills, which is an inescapable consequence of such controls.

At times tests do not reveal the full brunt of damage to the surrounding area being chemically treated (e.g., T.F.M.). It has been found that fish kills do occur but not often, and when kills do happen, it is only in localized areas and involves small numbers of fish (note Figure 10).

It is found that invertebrates (e.g., insects, snails, clams, etc.) are variable in their resistance to T.F.M. No evidence thus far reveals that T.F.M. has caused any catastrophic decline or disappearance of any species (Great Lakes Fishery Commission 1985). Only one reportable case has been documented regarding the near loss of the stone cat (Noturus flaves) from southwestern Lake Superior, which was attributed to chemical treatment (Dahl and Mcdonald, 1980). No other cases have been documented, however present information is not adequate to show long-term effects on species. As long as present control methods are continued and no matter what precautions are taken, fish populations will be effected (Dahl and Mcdonald, 1980).

According to Torbla and Westman (1980), sea lamprey ammocoetes are found in fewer locations now than before lampricide treatments began. Lamprey do not always return to streams post-treated with lampricide, that were previously infested. Abundance of ammocoetes and transformed metamorphosed animals has declined in most treated waters, but with
FIGURE 10. SENSITIVITY TO TFM

**SPECIES**

- **BLUESHILL**
- **NORTHERN PIKE**
- **WALLEYE**
- **LARGEMOUTH BASS**
- **WHITE SUCKER**
- **LAKE TROUT**
- **RAINBOW TROUT**
- **CHANNEL CATFISH**
- **SEA LAMPREY**

**LOW**

**HIGH**

---

some exceptions in areas where density-dependent factors may be influential (Torbla and Westman, 1980).

Moore and Schleen (1980) analyzed the changes in spawning runs of sea lamprey in selected streams of Lake Superior after chemical control. According to Moore and Schleen (1980), treating streams with lampricide will not effect lamprey spawning the following spring, which inhabit the Great Lakes at the time of lampricide treatment. Results indicate that adult lamprey captured from electrical barriers have declined in some streams by as much as 99% with large declines noted in treated streams late in the year.

Streams having a significant larvae population survival rate from lampricide treatment continued to attract adult lamprey. Thus, according to Moore and Schleen (1980), adult sea lamprey could be attracted to ammocoetes in streams or offshore areas. This could be an indicator to determine which rivers are suitable for spawning.

Gilderhus and Johnson (1980) studied the effects of sea lamprey control in the Great Lakes on aquatic plants, invertebrates, and amphibians. According to Gilderhus and Johnson (1980), the chemicals T.F.M. and Bayer 73 have been used for the past 20 years to control lamprey numbers. These chemicals cause some mortalities in some species of aquatic plants, invertebrates and amphibians. However, no evidence exists to conclude that these chemicals are responsible for catastrophic declines or extinction of any one
species. According to Gilderhus and Johnson (1980), the overall impact of chemical control of sea lampreys on aquatic communities has been minor compared to the benefits generated.

541.3.1. Districts

Lake Ontario District, 1964-1984

It should be noted that some districts in both Canada and the United States were analyzing certain years of data, or complete information. This may be due to insufficient data collected for the entire district, or the complete absence of data for certain years. However, this data indicates the overall situation regarding sea lamprey populations within the U.S. and Canadian waters of Lake Ontario.

The first set of histograms illustrate spawning-phase sea lamprey counts from systematic collections by fishery agencies in Lake Ontario tributaries for the period 1964-1984, inclusive.

Lake Erie Districts

At Lake Erie (figure 13), there appeared to be two periods of high lamprey numbers extending from 1946-1957 and 1964-1967. From 1968-1967, numbers ranged from 5.1 to 8 per 1,000 which occurred in 1969. In 1968-1969 values were from 18.9 to 28.9 per 1000 which peaked in 1968. Generally, most indications that sea lamprey numbers have decreased.
Chapter IV

DATA ANALYSIS

4.1 Histograms

4.1.1 Sea Lamprey Counts, 1944-1986

It should be noted that some districts in both Canada and U.S. waters are missing certain years of data, or complete districts. This may be due to insufficient data collected for the entire district, or the complete absence of data for certain years. However, this data indicates the overall situation regarding sea lamprey populations within the U.S. and Canadian waters of Lake Huron.

The first set of histograms illustrate spawning-phase sea lamprey counts from systematic collections by fishery agencies in Lake Huron tributaries for the period 1944-1986 inclusive.

4.1.1.1 U.S. Districts

In district MH-1 (Figure 11), there appears to be two periods of high lamprey numbers extending from from 1949-1957 and 1976-1986. From 1949-1957, numbers ranged from 8163 to a peak of 27406 which occurred in 1949. In 1976-1986 values were from 5232 to 20747 which peaked in 1984. Generally, MH-1 indicates that sea lamprey numbers have gradually
increased over the last ten years, with the greatest increase from 1982-1986.

In MH-2, data was only collected for certain years in the 1950's, 1970's and 1980's. However, highest lamprey numbers occur from 1950-1951 ranging in value from 1702 to 1903, which peaked in 1903. The remaining years to 1986 reveal low counts which range from 1 to 56. Thus, no evidence of high lamprey numbers is evident for the recent years of the 1980's (Figure 12).

In district MH-4 (Figure 13) data was only recorded for 1985-1986, with values of 690-441 respectively. Since no previous data is present no relative comparison of these numbers can be made.
FIGURE 11. SPAWNING PHASE SEA LAMPREY COUNTS FROM SYSTEMATIC COLLECTIONS BY FISHERY AGENCIES IN LAKE HURON TRIBUTARIES MH - 1 1944-1986 INCLUSIVE
FIGURE 12. SPAWNING PHASE SEA LAMPREY COUNTS FROM SYSTEMATIC COLLECTIONS BY FISHERY AGENCIES IN LAKE HURON TRIBUTARIES MH-2 1944-1986 INCLUSIVE
FIGURE 13. SPawning Phase Sea Lamprey Counts from Systematic Collections by Fishery Agencies in Lake Huron Tributaries MH-4 1944-1986 Inclusive
4.1.1.2 Canadian Districts

District NC-1 (Figure 14) indicates two periods of high lamprey numbers from 1946-1954, and 1983-1986. From 1946-1954 values range from 2534 to 11461 which peaked in 1946, and 5430 to 12977 from 1983-1986 which peaked in 1985. Generally, NC-1 indicates increased lamprey numbers for the recent years 1983-1986.

In district GB-3 (Figure 15) data is present only for the mid 1950's to the late 1970's. High numbers are found to occur from 1966-1969 with values extending from 937 to 7490 which peaked in 1968. Values remained very low from 1973-1978 which ranged from 1 to 30. Therefore, no analysis can be made for the past few years due to insufficient data.

District GB-4 (Figure 16) indicates high lamprey numbers for the period 1951-1956 with values ranging from 848 to a peak of 1999 in 1956. Values declined and increased from 1957-1968 with the lowest values occurring from 1959-1961. Low numbers were also found to occur from 1969-1981 (1 to 52) indicating a reduction in lamprey numbers these past few years.

In district OH-1 (Figure 17) one period from 1967-1969 was found to contain high numbers ranging from 1274 to 2404 which peaked in 1968. Values remained lower from 1970-1984 (36 to 391) with the exception of 1977 with 804.

District OH-3 indicates high lamprey numbers for the period 1950-1957. Values erratically vary from 195 to 11488.
FIGURE 14. SPAWNING PHASE SEA LAMPREY COUNTS FROM SYSTEMATIC COLLECTIONS BY FISHERY AGENCIES IN LAKE HURON TRIBUTARIES NC-1 1944-1986 INCLUSIVE
FIGURE 15, **SPAWNING PHASE SEA LAMPREY COUNTS FROM SYSTEMATIC COLLECTIONS BY FISHERY AGENCIES IN LAKE HURON TRIBUTARIES GB-3 1944-1986 INCLUSIVE**
FIGURE 16. SPAWNING PHASE SEA LAMPREY COUNTS FROM SYSTEMATIC COLLECTIONS BY FISHERY AGENCIES IN LAKE HURON TRIBUTARIES GB-4 1944-1986 INCLUSIVE
FIGURE 17. SPAWNING PHASE SEA LAMPREY COUNTS FROM SYSTEMATIC COLLECTIONS BY FISHERY AGENCIES IN LAKE HURON TRIBUTARIES OH-1 1944-1986 INCLUSIVE
which peaked in 1950. Numbers remained low from 1971-1981 ranging from 1 to 436, indicating low lamprey numbers for this period (Figure 18).

In district OH-4 (Figure 19) the period 1951-1969 indicates lamprey numbers which vary from 191 to 789. However, this period is not continuous and represents erratic periods. The peak in lamprey numbers occurred in 1967. From 1979-1980 values remained low (9 to 52) indicating low lamprey numbers.

All U.S. districts were then combined to show total sea lamprey numbers in Lake Huron. Two periods of high lamprey numbers are indicated in Figure 20. From 1949-1957 values ranged from 8163 to a peak of 27406 which occurred in 1949. A second period from 1976-1986 indicates another increase in lamprey numbers which range in value from 5321 to a peak of 20747 which occurred in 1984. Overall, the U.S. side of Lake Huron has experienced two surges in lamprey numbers from 1949-1951 and 1974-1986 indicating a present problem with lamprey populations despite ongoing control programs.

All Canadian districts were combined to show total lamprey numbers. Three periods are found to have occurred which were from 1946-1957, 1966-1969, and 1983-1986. From 1946-1957 numbers ranged from 6245 to a peak of 16368 which occurred in 1950. Values ranged for the period 1966-1969 from 4218 to 10938 which peaked in 1968. The final period 1983-1986 ranged in value from 3313 to a peak of 12977 in
FIGURE 18. SPAWNING PHASE SEA LAMPREY COUNTS FROM SYSTEMATIC COLLECTIONS BY FISHERY AGENCIES IN LAKE HURON TRIBUTARIES OH-3 1944-1986 INCLUSIVE
FIGURE 19. SPAWNING PHASE SEA LAM PREY COUNTS FROM
SYSTEMATIC COLLECTIONS BY FISHERY AGENCIES
IN LAKE HURON TRIBUTARIES
OH-4 1944-1986 INCLUSIVE
FIGURE 20. SPAWNING PHASE SEA LAMPREY COUNTS FROM SYSTEMATIC COLLECTIONS BY FISHERY AGENCIES IN LAKE HURON TRIBUTARIES ALL U.S. DISTRICTS 1944–1986 INCLUSIVE
1985. Generally, the Canadian half of Lake Huron has undergone three periods of lamprey surges, with the most significant period being from 1983-1986 which indicates high lamprey numbers despite ongoing control programs (Figure 21).

To gain a spatial outlook of all Lake Huron, lamprey numbers were totalled for both U.S. and Canadian districts combined (Figure 22). Generally, three periods of high lamprey numbers are found, extending from 1949-1957, 1966-1969, and 1976-1986. From 1949-1957 values varied from 8956 to a peak of 42764 in 1950. The second period, 1966-1969, ranged in value from 5862 to a peak of 14356 in 1968. The final period, 1976-1986, ranged in lamprey numbers from 7219 to a peak of 31760 in 1985.

Therefore, Lake Huron has experienced basically three surges in sea lamprey numbers with the highest recorded numbers occurring from 1949-1957. However, lamprey numbers are shown to have resurged during the 1976-1986 period despite continued sea lamprey control programs.

The second set of histograms were derived from data pertaining to parasitic-phase sea lamprey collected from commercial fishermen in Lake Huron for the period 1967-1986.
FIGURE 21. SPAWNING PHASE SEA LAMPREY COUNTS FROM SYSTEMATIC COLLECTIONS BY FISHERY AGENCIES IN LAKE HURON TRIBUTARIES ALL CAN. DISTRICTS 1944-1986 INCLUSIVE
FIGURE 22. **SPAWNING PHASE SEA LAMPREY COUNTS FROM SYSTEMATIC COLLECTIONS BY FISHERY AGENCIES IN LAKE HURON TRIBUTARIES CAN./U.S. COMBINED 1944–1986 INCLUSIVE**
4.1.2 Sea Lamprey Counts, 1967-1986

4.1.2.1 U.S. Districts

District MH-1 (Figure 23) indicates a period of increasing lamprey numbers from 1975-1985, ranging in value from 116 to a peak of 1302 in 1983. This coincides with that found in the period 1944-1986.

In district MH-2 (Figure 24) data is only present for 1980-1985 which indicates increasing numbers from 1981-1983 (56 to 165), peaking in 1983, then gradually decreasing to a value of 108 in 1985.

District MH-3 (Figure 25) only consists of data from 1970-1972 with values ranging from 9 to 40, indicating low lamprey numbers. However, insufficient data prohibits any kind of evaluation for the district.

In district MH-4 (Figure 26) the period 1981-1985 indicates the highest lamprey counts for the period, ranging from 46 to 83, peaking in 1983, which reveals low lamprey numbers.

District MH-6 (Figure 27) consists of data for only three years, 1970, 1971 and 1985, with values of 1, 15, and 14 respectively, indicating low sea lamprey numbers. Incomplete data is the result of infrequent data collecting.
FIGURE 23. PARASITIC-PHASE SEA LAMPREY COLLECTED FROM COMMERCIAL FISHERMEN IN LAKE HURON MH-1 1967-1986

TOTAL SUM

YEAR

FIGURE 24. PARASITIC-PHASE SEA LAMPREY COLLECTED FROM COMMERCIAL FISHERMEN IN LAKE HURON MH-2 1967-1986

[Graph showing the total number of parasitic-phase sea lamprey collected from commercial fishermen in Lake Huron from 1967 to 1986. The graph is a bar chart with years on the x-axis and total number of lamprey on the y-axis. The data range from 0 to 170 lamprey.]
FIGURE 25. PARASITIC-PHASE SEA LAMPREY COLLECTED FROM COMMERCIAL FISHERMEN IN LAKE HURON MH-3 1967-1986
FIGURE 26. PARASITIC-PHASE SEA LAMPREY COLLECTED FROM COMMERCIAL FISHERMEN IN LAKE HURON MH-4 1967-1986
FIGURE 27. PARASITIC-PHASE SEA LAMPREY COLLECTED FROM COMMERCIAL FISHERMEN IN LAKE HURON MH-6 1967-1986
4.1.2.2 Canadian Districts

In district NC1/3 (Figure 28) two periods of highest lamprey numbers were recorded, extending from 1967-1971 and 1983-1985. From 1967-1971 numbers ranged from 172 to a peak of 342 in 1969. Values from 1983-1985 went from 537 to 1070 which peaked in 1984. The most significant increase in lamprey numbers occurred during 1983-1985.

District OH1/3 (Figure 29) indicates two periods of highest lamprey numbers. From 1967-1969 values ranged from 931 to a peak of 1630 in 1967. A small increase in numbers occurred from 1983-1985 with values varying from 1067 to a peak of 1302 in 1983.

All U.S. districts were then combined to indicate total lamprey numbers in U.S. waters (Figure 30). Highest numbers occurred for the period 1977-1986, with values varying from 270 to a peak of 1378 in 1985. This indicates resurging numbers of lamprey for the latest period of data.

All Canadian districts were combined to show total lamprey numbers for the period (Figure 31). Two periods of high lamprey numbers are indicated, which occurred from 1967-1969, and 1983-1985. From 1967-1969 values ranged from 1273 to a peak of 1870 in 1967, and from 1983-1985, values varied from 834 to a peak of 1610 in 1984. Overall, the Canadian side of Lake Huron has gone through two periods of lamprey resurgence, with the most recent being from 1983-1985.
FIGURE 28. **PARASITIC-PHASE SEA LAMPREY COLLECTED FROM COMMERCIAL FISHERMEN IN LAKE HURON NC1/3 1967-1986**
FIGURE 29. *Parasitic-Phase Sea Lamprey Collected from Commercial Fishermen in Lake Huron OH-1/3 1967-1986*
FIGURE 30. PARASITIC-PHASE SEA LAMPREY COLLECTED FROM COMMERCIAL FISHERMEN IN LAKE HURON U.S. DISTRICTS COMBINED 1967–1986
FIGURE 31. PARASITIC-PHASE SEA LAMPREY COLLECTED FROM COMMERCIAL FISHERMEN IN LAKE HURON CAN. DISTRICTS COMBINED 1967–1986
Both U.S. and Canadian districts were combined to show the overall spatial picture of Lake Huron (Figure 32). Basically Lake Huron has undergone two periods of high lamprey numbers extending from 1967-1969, and from 1978-1985. The first period, 1967-1969, ranged in value from 1273 to a peak of 1970 in 1967. The second period, 1978-1985, was the most severe with values ranging from 427 to a peak of 2876 in 1984. Therefore, lamprey numbers have significantly increased during the 1978-1995 period, despite efforts through control programs to regulate their numbers.

From 1971-1986 parasitic phase sea lamprey were captured per 100 trap net lifts in Lake Huron district MH-1 (Figure 33). The period 1975-1985 reveals an erratic and variable increase in catches ranging in value from 13 to a peak of 145 in 1981.

Sea lamprey were collected in 1985 from the sport fisheries in Michigan districts MH-1 to MH-6. Statistics indicate highest lamprey counts from MH-3 with 823, followed by MH-5, MH-2, MH-4, MH-1, and MH-6 with values of 365, 318, 317, 161, and 16 respectively (Figure 34).
FIGURE 32. *Parasitic-Phase Sea Lamprey Collected From Commercial Fishermen in Lake Huron Can./U.S. Combined 1967-1986*
FIGURE 33, PARASITIC-PHASE SEA LAMPREY CAPTURED PER 100 TRAP NET LIFTS IN LAKE HURON MH-1 1971-1986
FIGURE 34. PARASITIC-PHASE SEA LAMPREY COLLECTED FROM SPORT FISHERIES IN LAKE HURON

MH-1/MH-6
4.2 Time Series (Regression) Analysis

The first set of regression figures were derived from data of spawning-phase sea lamprey counts from systematic collections by fishery agencies in Lake Huron tributaries for the period 1944-1986 inclusive.

All U.S. districts were combined to produce a regression line for the period (Figure 35). Based on the figure, from 1950-1970, there is a downward trend in lamprey numbers which is more severe from 1960-1970. The period from 1970-1986 is marked by increasing lamprey numbers, and thus, an increasing trend as indicated by the regression line. At a 95.5% confidence level, the regression line does not provide an accurate fit to the data, since more data points lie outside the confidence limit.

All Canadian districts were then combined to yield a regression line for the same period (Figure 36). As indicated by the figure, from 1944-1950 there is an upward trend in lamprey numbers as marked by the rising regression line. This trend reversed for the period 1950-1970 as lamprey numbers began to decline accompanied by a downward shifting regression line. Also, 1960-1970 was marked by a sharper decline in lamprey numbers for this overall period. From 1970-1986, the trend reversed as lamprey numbers began to increase. The period 1970-1980 indicates a slight increasing trend, but sharply increases from 1980 onward. At a 95.5% confidence level, the regression line provides a bet-
FIGURE 35. REGRESSION OF SPAWNING-PHASE SEA LAMPREY COUNTS FROM SYSTEMATIC COLLECTIONS BY FISHERY AGENCIES IN LAKE HURON TRIBUTARIES ALL U.S. DISTRICTS 1944-1986 INCLUSIVE

NUMBERS

30000

20000

10000

0


TIME
ter fit to the data than for all U.S. districts for the same period.

Both U.S. and Canadian districts were combined to produce a regression line to represent all of Lake Huron (Figure 37). From 1950-1970, lamprey numbers declined to a minimum in 1970, as indicated by a downward-sloping regression line, which declines more rapidly from 1960-1970. The remaining period from 1970-1986 is marked by an upward-sloping regression line accompanied by increasing lamprey numbers. At a 95.5% confidence limit, the regression line does not fit the data accurately, as indicated by more values falling outside the prescribed confidence limit.

Generally, the regression lines for both U.S., Canada, and U.S/Canada combined reveal a downward trend in lamprey numbers from 1940-1970, then a shift to an upward-sloping regression line from 1970-1986 indicating high lamprey numbers in Lake Huron waters despite ongoing efforts in controlling populations through fishery agency programs.

The next set of regression lines are from data on parasitic-phase sea lamprey collected by commercial fishermen in Lake Huron from 1967-1986.

All U.S. districts were summarized to produce a regression line in Figure 38. Generally, the period 1967-1974 was marked by declining lamprey numbers and a downward-sloping regression line. The trend reversed to one of increasing lamprey numbers from 1975-1983, followed by an upward-sloping regression line. From 1983-1986 lamprey numbers
FIGURE 36. REGRESSION OF SPAWNING-PHASE SEA LAMPREY COUNTS FROM SYSTEMATIC COLLECTIONS BY FISHERY AGENCIES IN LAKE HURON TRIBUTARIES ALL CAN. DISTRICTS 1944-1986 INCLUSIVE
FIGURE 37. REGRESSION OF SPAWNING-PHASE SEA LAMPREY COUNTS FROM SYSTEMATIC COLLECTIONS BY FISHERY AGENCIES IN LAKE HURON TRIBUTARIES CAN./U.S. COMBINED 1944-1986 INCLUSIVE
declined, marked by a downward-sloping regression line. At a 95.5% confidence limit, the regression line provides a good fit to the data, since most of the points fall within the proposed limits. This regression line indicates decreasing lamprey numbers for the 1983-1986 period as opposed to increasing lamprey numbers for the same period in Figure 33.

All Canadian districts were combined for regression as depicted on Figure 39. Based on the figure, lamprey numbers declined from 1967 to a minimum in 1974, following a downward-sloping regression line. From the period 1974-1984 there is an upward-sloping regression line, marked by increasing lamprey numbers. The period 1984-1986 indicates falling lamprey numbers and a downward-sloping sloping line. At the 95.5% confidence level, the regression line provides a good fit, as indicated by most values falling within the confidence boundary.

Both U.S. and Canadian districts were merged to produce the regression line in Figure 40. As indicated from the figure, there is a downward trend in lamprey numbers from 1967-1974 which corresponds to a downward sloping regression line. From the period 1974-1986 the trend reverses to one of increased lamprey numbers as shown by a steeply-rising regression line. Based on a 95.5% level of confidence, the regression line provides an excellent fit to the data with most of the values falling within the limits.
FIGURE 38  REGRESSION OF PARASITIC-PHASE SEA LAMPREYS COLLECTED BY COMMERCIAL FISHERMAN IN LAKE HURON ALL U.S. DISTRICTS 1967-1986

NUMBERS

1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

TIME
FIGURE 39. REGRESSION OF PARASITIC-PHASE SEA LAMPREYS COLLECTED BY COMMERCIAL FISHERMAN IN LAKE HURON ALL CAN. DISTRICTS 1967-1986

NUMBERS

1900 1800 1700 1600 1500 1400 1300 1200 1100 1000 900 800 700 600 500 400 300 200 100


TIME
FIGURE 40. REGRESSION OF PARASITIC-PHASE SEA LAMPREYS COLLECTED BY COMMERCIAL FISHERMAN IN LAKE HURON CAN./U.S. COMBINED 1967-1986

NUMBERS

3000

2000

1000

0


TIME
Generally, Lake Huron on the whole experienced a declining trend in lamprey numbers from 1967-1974, which then quickly changed to increasing lamprey numbers from 1974-1986. This indicates that over the recent years, lamprey continue to increase in number despite various control measures by fishery authorities. Both sets of data support these findings, which were from 1944-1986 and 1967-1986.

4.3 Summary of the C.P.P.S. Chantry Chinook Classic Statistics 1984-1986

The first set of diagrams represent derby statistics in 1984, from weigh-in stations of Kincardine, Port Elgin, Southampton and Sauble Beach.

In Port Elgin, a total of 431 fish were reported caught of which 394 were Chinook Salmon, 19 Coho Salmon, 12 Rainbow Trout, 1 Brown Trout, and 5 under the other category. Based on 431 fish, 102 were found to be lamprey-marked, which consist per specie of 82 Chinook Salmon and 2 Coho Salmon. Overall, 23.7% of all captured fish were lamprey-marked of which 80.4% were Chinook Salmon and 2% Coho Salmon (Figure 41).

Southampton weigh-in stations reported 107 fish captured of which 87 were Chinook Salmon, 14 Coho Salmon, 5 Rainbow Trout, and 1 in the other category. From 107 fish caught, 40 were reported as lamprey-marked consisting of 30 Chinook Salmon and 5 Coho Salmon. In all, 37.4% of all fish cap-
FIGURE 41. SUMMARY OF THE C.F.P.S. CHANTORY CHINOOK CLASSIC
FISH DERBY PORT ELGIN 1984

NUMBER OF FISH CAUGHT PER SPECIES

NUMBER & PERCENT OF MARKED FISH PER SPECIES

TOTAL NUMBER OF FISH CAUGHT 431
TOTAL NUMBER OF LAMPREY-MARKED FISH REPORTED 102
TOTAL PERCENTAGE OF MARKED FISH 23.7

SOURCE: Data From Keith Mombourquette C.F.P.S. Committee Member
tured were lamprey-scarred of which 75.0% were Chinook Salmon and 12.5% were Coho Salmon (Figure 42).

The town of Kincardine accounted for a sum of 164 captured fish of which 140 were Chinook Salmon, 12 Coho Salmon, 1 Rainbow Trout, and 11 in the other category. Based on 140 total fish caught, 55 were lamprey-scarred consisting per species of 53 Chinook Salmon and 2 in the other category. In sum, 33.5% of all fish captured were lamprey-scarred of which 96.4% were Chinook Salmon and 3.6% in the other bracket (Figure 43).

In Sauble Beach, a total of 148 fish were reported caught of which 73 were Chinook Salmon, 71 Coho Salmon, 2 Rainbow Trout, 1 Brown Trout, and 1 in the other bracket. Out of 148 total fish, 16 were found to be lamprey-wounded consisting per species of 12 Chinook Salmon and 2 Coho Salmon. Overall, 10.3% of all fish caught were lamprey-scarred of which 75.0% were Chinook Salmon and 12.5% Coho Salmon (Figure 44).

All districts were then summarized in 1984 for an overall analysis for the period. Generally, a total of 850 were captured of which 594 were Chinook Salmon, 116 Coho Salmon, 20 Rainbow Trout, 2 Brown Trout, and 18 in the other bracket. Out of 850 fish, 213 were reported as being lamprey-scarred consisting per species of 85.1% Chinook Salmon, 4.2% Coho Salmon, and 0.5% in the other bracket. Overall, 25.0% of all fish caught in the 1984 derby were lamprey-scarring (Figure 45).
FIGURE 42. SUMMARY OF THE C.F.P.S. CHANTRY CHINOOK CLASSIC FISH DERBY SOUTHAMPTON 1984

NUMBER OF FISH CAUGHT PER SPECIES

- Chinook Salmon: 87
- Coho Salmon: 14
- Rainbow Trout: 5
- Other: 1

NUMBER & PERCENT OF MARKED FISH PER SPECIES

- Chinook Salmon: 30 (75.0%)
- Coho Salmon: 5 (12.5%)

TOTAL NUMBER OF FISH CAUGHT: 107
TOTAL NUMBER OF LAMPREY-MARKED FISH REPORTED: 40
TOTAL PERCENTAGE OF MARKED FISH: 37.4%

SOURCE: Data From Keith Mombourquette C.F.P.S. Committee Member
FIGURE 43. SUMMARY OF THE C.F.P.S. CHANTRY CHINOOK CLASSIC FISH DERBY KINCAIDINE 1984

NUMBER OF FISH CAUGHT PER SPECIES

NUMBER & PERCENT OF MARKED FISH PER SPECIES

TOTAL NUMBER OF FISH CAUGHT 164
TOTAL NUMBER OF LAMPREY-MARKED FISH REPORTED 55
TOTAL PERCENTAGE OF MARKED FISH 33.5

SOURCE: Data From Keith Mombourquette C.F.P.S. Committee Member
FIGURE 44. SUMMARY OF THE C.F.P.S. CHANTERY CHINOOK CLASSIC
FISH DERBY SAUBLE BEACH 1984

NUMBER OF FISH CAUGHT PER SPECIES

NUMBER & PERCENT OF MARKED FISH PER SPECIES

TOTAL NUMBER OF FISH CAUGHT 148
TOTAL NUMBER OF LAMPREY-MARKED FISH REPORTED 16
TOTAL PERCENTAGE OF MARKED FISH 10.8

SOURCE: Data From Keith Mombourquette C.F.P.S. Committee Member
FIGURE 45. SUMMARY OF THE C.F.P.S. CHANTRY CHINOOK CLASSIC FISH DERBY ALL SITES COMBINED 1984

NUMBER OF FISH CAUGHT PER SPECIES

PERCENT OF MARKED FISH PER SPECIES

TOTAL NUMBER OF FISH CAUGHT 850
TOTAL NUMBER OF LAMPREY-MARKED FISH REPORTED 213
TOTAL PERCENTAGE OF MARKED FISH 25.0

SOURCE: Data From Keith Mombourquette C.F.P.S. Committee Member
The second series of diagrams represents the 1985 derby statistics from the districts of Kincardine, Port Elgin, Southampton, and Sauble Beach. It should be noted that the 1985 statistics are low. This is due to extended periods of bad weather during the derby which reduced significantly, the number of participants. However, a general indication of lamprey wounding rates can be formulated from the data.

Port Elgin reported a total of 153 fish captured during the period of which 92 were Chinook Salmon, 47 Pink Salmon, 13 Rainbow Trout, 4 Coho Salmon, 1 Brown Trout, and 6 others. Out of 153 fish, 24 were reported as being lamprey-scarred, consisting per species of 24 Chinook Salmon, 1 Rainbow Trout, and 1 Coho Salmon. In all, 15.7% of all captured fish were wounded by lamprey of which 91.7% were Chinook Salmon, 4.2% Rainbow Trout, and 4.2% Coho Salmon (Figure 46).

In Southampton, 174 fish were reported captured of which 107 were Chinook Salmon, 29 Rainbow Trout, 17 Pink Salmon, 7 Coho Salmon, 5 Brown Trout, and 9 others. Based on 174 captured fish, 39 were found to be lamprey-scarred, consisting per species of 32 Chinook Salmon, 4 Rainbow Trout, 2 Pink Salmon, and 1 Coho Salmon. In all, 22.4% of all fish caught were lamprey marked of which 82.1% were Chinook Salmon, 10.3% Rainbow Trout, 5% Pink Salmon, and 2.6% Coho Salmon (Figure 47).
FIGURE 46. SUMMARY OF THE C.F.P.S. CHANTRY CHINOOK CLASSIC
FISH DERBY PORT ELGIN 1985

NUMBER OF FISH CAUGHT PER SPECIES

NUMBER & PERCENT OF MARKED FISH PER SPECIES

TOTAL NUMBER OF FISH CAUGHT 153
TOTAL NUMBER OF LAMPREY-MARKED FISH REPORTED 24
TOTAL PERCENTAGE OF MARKED FISH 15.7

SOURCE: Data From Keith Mombourquette C.F.P.S. Committee Member
FIGURE 47. SUMMARY OF THE C.F.P.S. CHANTRY CHINOOK CLASSIC
FISH DERBY SOUTHAMPTON 1985

NUMBER OF FISH CAUGHT PER SPECIES

NUMBER & PERCENT OF MARKED FISH PER SPECIES

TOTAL NUMBER OF FISH CAUGHT 174
TOTAL NUMBER OF LAMPREY-MARKED FISH REPORTED 39
TOTAL PERCENTAGE OF MARKED FISH 22.4

SOURCE: Data From Keith Mombourquette C.F.P.S. Committee Member
The town of Kincardine reported 316 fish captured of which 206 were Chinook Salmon, 46 Pink Salmon, 32 Coho Salmon, 25 Rainbow Trout, 3 Brown Trout, and 4 others. In sum, 39 out of 206 fish were reported as lamprey-scarred consisting on a per species basis of 35 Chinook Salmon, 2 Rainbow Trout, 1 Coho Salmon, and 1 Pink Salmon. Overall, 12.3% of all fish captured were lamprey-scarred of which 89.7% were Chinook Salmon, 5.1% Rainbow Trout, 2.6% Coho Salmon, and 2.6% Pink Salmon (Figure 48).

Sauble Beach reported a sum of 65 fish caught of which 27 were Chinook Salmon, 12 Pink Salmon, 10 Rainbow Trout, 7 Coho Salmon, 1 Brown Trout, and 8 others. Based on 65 fish, 8 were accounted for as being lamprey-marked of which 5 were Chinook Salmon. As indicated, 12.3% of all captured fish were lamprey- scarred, with 62.5% accounted for by Chinook Salmon (Figure 49).

All districts were then combined to create an overall summation of the 1985 statistics. Overall, 708 fish were reported caught by all weigh-in stations of which 344 were Chinook Salmon, 128 Coho Salmon, 122 Pink Salmon, 77 Rainbow Trout, 10 Brown Trout, and 27 others. Of 708 fish, 110 were accounted for as being lamprey-scarred, consisting per species of 85.5% Chinook Salmon, 6.4% Rainbow Trout, 2.7% Coho Salmon, and 2.7% in the other category. Generally, 15.5% of all captured fish in the 1985 derby were wounded by lamprey (Figure 50).
FIGURE 48. SUMMARY OF THE C.F.P.S. CHANTRY CHINOOK CLASSIC FISH DERBY KINCAIDINE 1985

NUMBER OF FISH CAUGHT PER SPECIES

NUMBER & PERCENT OF MARKED FISH PER SPECIES

TOTAL NUMBER OF FISH CAUGHT 316
TOTAL NUMBER OF LAMPREY-MARKED FISH REPORTED 39
TOTAL PERCENTAGE OF MARKED FISH 12.3

SOURCE: Data From Keith Mombourquette C.F.P.S. Committee Member
FIGURE 49 SUMMARY OF THE C.F.P.S. CHANTRY CHINOOK CLASSIC FISH DERBY SAUBLE BEACH 1985

NUMBER OF FISH CAUGHT PER SPECIES

- Chinook Salmon: 27
- Coho Salmon: 7
- Pink Salmon: 12
- Brown Trout: 1
- Rainbow Trout: 10
- Other: 8

NUMBER & PERCENT OF MARKED FISH PER SPECIES

- Total number of fish caught: 65
- Total number of lamprey-marked fish reported: 8
- Total percentage of marked fish: 12.3

SOURCE: Data from Keith Mombourquette C.F.P.S. Committee Member
FIGURE 50. SUMMARY OF THE C.F.P.S. CHANTRY CHINOOK CLASSIC

FISH DERBY ALL SITES COMBINED 1985

NUMBER OF FISH CAUGHT PER SPECIES

PERCENT OF MARKED FISH PER SPECIES

TOTAL NUMBER OF FISH CAUGHT 708
TOTAL NUMBER OF LAMPREY-MARKED FISH REPORTED 110
TOTAL PERCENTAGE OF MARKED FISH 15.5

SOURCE: Data From Keith Mombourquette C.F.P.S. Committee Member
The final set of diagrams represents the 1986 statistics collected during the 1986 derby for the districts of Kincardine, Port Elgin, Southampton, Sauble Beach, and Howdenvale.

Port Elgin reported a total of 481 captured fish of which 422 were Chinook Salmon, 30 Coho Salmon, 4 Rainbow Trout, 3 Brown Trout, and 22 others. Statistics also indicate that 122 of the 481 fish were lamprey-marked of which 3.3% were accounted for by Coho Salmon, and 90.2% by Chinook Salmon (Figure 51).

The town of Southampton reported 273 fish caught for the period, of which 240 were Chinook Salmon, 11 Brown Trout, 10 Coho Salmon, 2 Rainbow Trout, and 10 others. Out of 273 fish, 67 were found to be scarred by sea lamprey which is accounted for by 63 Chinook Salmon. Overall, 24.5% of all captured fish were lamprey-scarred of which 94.0% were Chinook Salmon (Figure 52).

In Kincardine, 718 fish were reported captured of which 673 were Chinook Salmon, 15 Coho Salmon, 7 Rainbow Trout, 7 Brown Trout, and 16 others. Of 718 captured fish, 204 were found to be lamprey-scarred consisting per species of 198 Chinook Salmon, and 4 Rainbow Trout. Overall, 28.4% of all fish caught were lamprey-marked, and consisted of 2.0% Rainbow Trout, and 97.1% Chinook Salmon (Figure 53).

Sauble Beach reported a total of 157 captured fish of which 137 were Chinook Salmon, 5 Rainbow Trout, 5 Coho Salmon, 5 Brown Trout, and 5 others. In all, 64 of the 157 fish were found to be lamprey-scarred, which is represented per
FIGURE 51: SUMMARY OF THE C.F.P.S. CHANTRY CHINOOK CLASSIC FISH DERBY PORT ELGIN 1986

NUMBER OF FISH CAUGHT PER SPECIES

NUMBER & PERCENT OF MARKED FISH PER SPECIES

TOTAL NUMBER OF FISH CAUGHT 481
TOTAL NUMBER OF LAMPREY-MARKED FISH REPORTED 122
TOTAL PERCENTAGE OF MARKED FISH 25.4

SOURCE: Data From Keith Mombourquette C.F.P.S. Committee Member
FIGURE 52. SUMMARY OF THE C.F.P.S. CHANTRY CHINOOK CLASSIC

FISH DERBY SOUTHAMPTON 1986

NUMBER OF FISH CAUGHT PER SPECIES

- Chinook Salmon: 240
- Coho Salmon: 10
- Brown Trout: 11
- Other: 10
- Rainbow Trout: 2
- Other: 6

NUMBER & PERCENT OF MARKED FISH PER SPECIES

- Total number of fish caught: 273
- Total number of lamprey-marked fish reported: 67
- Total percentage of marked fish: 24.5%

SOURCE: Data From Keith Mombourquette C.F.P.S. Committee Member
FIGURE 53. SUMMARY OF THE C.F.P.S. CHANTRY CHINOOK CLASSIC
FISH DERBY KINCARDINE 1986

NUMBER OF FISH CAUGHT PER SPECIES

NUMBER & PERCENT OF MARKED FISH PER SPECIES

TOTAL NUMBER OF FISH CAUGHT 718
TOTAL NUMBER OF LAMPREY-MARKED FISH REPORTED 204
TOTAL PERCENTAGE OF MARKED FISH 28.4

SOURCE: Data From Keith Mombourquette C.F.P.S. Committee Member
species of 61 Chinook Salmon, 2 Rainbow Trout, and 1 Brown Trout. Furthermore, 40.9% of all captured fish were marked, represented by 95.3% Chinook Salmon, 3.1% Rainbow Trout, and 1.6% Brown Trout (Figure 54).

Howdenvale reported 70 captured fish for the period of which 66 were Chinook Salmon, 2 Coho Salmon, 1 Rainbow Trout, and 1 Brown Trout. Out of these 70 fish, 12 were found to be lamprey-marked, represented per species by 10 Chinook Salmon, and 2 Coho Salmon. Overall, 17.1% of all captured fish were marked, of which 83.3% were Chinook Salmon, and 16.7% Coho Salmon (Figure 55).

All districts were then combined to illustrate the overall statistics of the 1986 derby. As indicated, 1699 fish were caught, of which 1538 were Chinook Salmon, 62 were Coho Salmon, 27 Brown Trout, 19 Rainbow Trout, and 53 others. Also, 469 out of the 1699 captured fish were lamprey-marked, which are per species 94.2% Chinook Salmon, 1.3% Rainbow Trout, 0.85% Coho Salmon, and 0.21% Brown Trout. In summary, 27.6% of all fish caught during the 1986 derby were marked by sea lamprey (Figure 56).

In conclusion, several facts can be made concerning the C.F.P.S. Chantry Chinook Classic Fish Derby for the period 1984-1986. These are: (1) the dominant species captured throughout all districts and all years is the Chinook Salmon, which ranged in numbers caught from 344 to 1538; (2) Chinook Salmon also serve as the key indicator in sea lam-
FIGURE 54. SUMMARY OF THE C.F.P.S. CHANTRY CHINOOK CLASSIC FISH DERBY SAUBLE BEACH 1986

NUMBER OF FISH CAUGHT PER SPECIES

- Chinook Salmon: 137
- Coho Salmon: 5
- Rainbow Trout: 5
- Brown Trout: 5
- Other: 5

NUMBER & PERCENT OF MARKED FISH PER SPECIES

- Total number of fish caught: 157
- Total number of lamprey-marked fish reported: 64
- Total percentage of marked fish: 40.8

SOURCE: Data From Keith Mombourquette C.F.P.S. Committee Member
FIGURE 55. SUMMARY OF THE C.F.P.S. CHANTRY CHINOOK CLASSIC
FISH DERBY HOWDENVALE 1986

NUMBER OF FISH CAUGHT PER SPECIES

- Chinook Salmon: 66
- Coho Salmon: 2
- Rainbow Trout: 1
- Brown Trout: 1

NUMBER & PERCENT OF MARKED FISH PER SPECIES

- Chinook Salmon: 10 (83.3%)
- Coho Salmon: 2 (16.7%)

TOTAL NUMBER OF FISH CAUGHT: 70
TOTAL NUMBER OF LAMPREY-MARKED FISH REPORTED: 12
TOTAL PERCENTAGE OF MARKED FISH: 17.1

SOURCE: Data From Keith Mombourquette C.F.P.S. Committee Member
FIGURE 56: SUMMARY OF THE C.F.P.S. CHANTRY CHINOOK CLASSIC
FISH DERBY ALL SITES COMBINED 1986

NUMBER OF FISH CAUGHT PER SPECIES

PERCENT OF MARKED FISH PER SPECIES
TOTAL NUMBER OF FISH CAUGHT 1699
TOTAL NUMBER OF LAMPREY-MARKED FISH REPORTED 469
TOTAL PERCENTAGE OF MARKED FISH 27.6

SOURCE: Data From Keith Mombourquette C.F.P.S. Committee Member
prey wounding rates for the period, as indicated by high percentages that range from 93.1% to 94.2% respectively. Furthermore, these percentages of wound rates increased repeatedly over the three year period, indicating increased attacks on this species; and (3) if one takes into account the low numbers in 1985, statistics indicate that overall wounding rates from 1984-1986 have increased (e.g., 15.5% to 27.6%). This indicates that overall sea lamprey attacks have increased over the three year period.

4.4 Analysis of Sea Lamprey Wound Rates on Lake Trout and Chinook Salmon

In the next set of figures, data on wound rates was analyzed per 100 Lake Trout and Chinook Salmon taken from 235 Charter Boats in Lake Huron U.S. waters in districts MH1/MH6 for the period 1985.

In the spring, statistics reveal wounding percentages per 100 Lake Trout to range from 0% to 25%. District MH-6 recorded no wounds, and the highest percentage (25.0%) was recorded for district MH-5. In terms of number of fish caught, values range from 1 in district MH-6 to 1067 in district MH-3 (Figure 57).

During the summer, wounding rates on average, declined from the spring, ranging in value from 0% in MH-6 to 28.6% in district MH-5. The number of fish per district ranged from 2 (in MH-6) to 1137 occurring in district MH-3 (Figure 58).
FIGURE 57. NUMBER OF SEA LAMPEY WOUNDS PER 100 LAKE TROUT AND NUMBER OF FISH TAKEN BY 235 CHARTER BOATS IN LAKE HURON U.S. WATERS MH1/MH-6 SPRING 1985

PER SUM
1100
1000
900
800
700
600
500
400
300
200
100
0

SCAR  NON-WOUNDED  WOUNDED

Figure 58. Number of Sea Lamprey Wounds per 100 Lake Trout and Number of Fish Taken by 235 Charter Boats in Lake Huron U.S. Waters MH1/MH-6 Summer 1985

Source: Data from U.S. Fish and Wildlife Department 1986.
In fall, little data is provided on wounding rates for Lake Trout, since season closings occur in many districts of the Lake Huron basin after August 15 (U.S. Fish and Wildlife Service, 1985). Only two districts (MH-2 and MH-3) reported information on wounding rates for this period. Overall, 15 fish were caught of which no wounds were observed (Figure 59).

The next set of figures provides wounding rates per 100 Chinook Salmon captured by Charter Boats for the same period.

Spring statistics indicate wound rates ranged from 5.5% in MH-3 to a maximum of 13.1% in MH-4. Total fish caught per district ranged from 33 in MH-1 to 470 in MH-5 (Figure 60).

In summer, wounding rates increased on average for Chinook Salmon from spring, ranging in value from 10.6% in MH-1 to a maximum of 41.6% in MH-5. The total number of fish captured also increased since spring, with values ranging from 71 in district MH-6 to 392 in district MH-3 (Figure 61).

In the fall, wounding rates declined on average with values occurring from 11.6 in district MH-1 to a maximum of 34.0 in district MH-4. Total numbers of captured fish also declined since summer with values ranging from 16 in district MH-6 to 553 in district MH-3 (Figure 62).
FIGURE 59. NUMBER OF SEA LAMPREY WOUNDS PER 100 LAKE TROUT AND NUMBER OF FISH TAKEN BY 235 CHARTER BOATS IN LAKE HURON U.S. WATERS MH1/MH-6 FALL 1985

FIGURE 60. NUMBER OF SEA LAMPREY WOUNDS PER 100 CHINOOK SALMON AND NUMBER OF FISH TAKEN BY 235 CHARTER BOATS IN LAKE HURON U.S. WATERS MH1/MH-6 SPRING 1985

FIGURE 61. NUMBER OF SEA LAMPREY WOUNDS PER 100 CHINOOK SALMON AND NUMBER OF FISH TAKEN BY 235 CHARTER BOATS IN LAKE HURON U.S. WATERS MH1/MH-6 SUMMER 1985

FIGURE 62. NUMBER OF SEA LAMPREY WOUNDS PER 100 CHINOOK SALMON AND NUMBER OF FISH TAKEN BY 235 CHARTER BOATS IN LAKE HURON U.S. WATERS MH1/MH-6 FALL 1985

PER SUM
600

20.4

14.3 34.0 22.4

11.6

0 100 200 300 400 500

H H H H H H
1 2 3 4 5 6

REGION

SCAR NON-WOUN WOUNDED

In conclusion, by analyzing these overall statistics, several facts can be made. In terms of overall wounding rates for U.S. districts MH-1 - MH-6, Lake Trout appear to have a higher wounding rate in the spring (13.8%) than in summer (11.4%) or fall (0.0%). More fish were captured during summer (2,150) than in spring (1,495) or fall (15). Chinook Salmon wounding rates are highest during the summer (20.4%) than in spring (10.7%) or fall (18.6%). Also, the number of Chinook caught is greatest during the summer months (2,054) than during spring (1,226) or fall (1,020) (Figure 63).

In comparing the two species of fish, Lake Trout versus Chinook Salmon, other facts can also be made. On average, more lamprey wounds were found to occur on Chinook Salmon than on Lake Trout with averages of 6.7/100 versus 1.3/100 respectively. In spring, more wounds occurred on Lake Trout (13.8%) than for Chinook Salmon (10.7%). However, both summer and fall statistics reveal that Chinook wound rates were higher in summer (20.4/100 versus 11.4/100). In fall, lack of statistics inhibits any kind of comparison between the species (Figure 63).
FIGURE 63. NUMBER OF SEA LAMREY WOUNDS PER 100 LAKE TROUT/SALMON AND NUMBER OF FISH TAKEN BY 235 CHARTER BOATS IN LAKE HURON ALL DISTRICTS COMBINED MH-1/MH-6 1985

4.5 Analysis of Sea Lamprey Wound Rates on Lake Whitefish

The next set of figures illustrate wound rates per 100 Whitefish captured by commercial fishermen in Canadian waters of Lake Huron for the period 1977-1985. Statistics for total fish catchings and percent wounded are indicated for each district.

The first set of figures represent data collected in the spring for the period.

In district OH-1, wounding rates remained below 2.0% with values extending from 0.29% in 1981 to a maximum of 1.80% in 1984. In terms of total whitefish catches, values ranged from 155 in 1979, to 1546 in 1982. Overall, 1984-1985 show increased wounding rates since 1981, however 1985 rates are lower than in 1985 (Figure 64).

District OH-2 statistics indicate wounding rates to vary from 0.30% in 1982 to a peak of 2.0% in 1985. Whitefish numbers ranged from a low of 198 in 1985 to 816 in 1978. Therefore, wounding rates rose to 2.0% in 1985 indicating increased lamprey attacks in this district (Figure 65).

In district OH-3, wound rates range from 0.48% in 1977 to 3.0% in 1984, marking the highest wounding rate in the district. Whitefish numbers varied from 200 in 1984 to a maximum of 1690 in 1978. Overall, highest wound rates occurred in the district in 1984, but declined by more than one-half this rate in 1985 (Figure 66).
FIGURE 64. LAMPREY WOUNDING RATES PER 100 LAKE WHITEFISH AND NUMBER OF FISH TAKEN FROM CANADIAN WATERS IN LAKE HURON DISTRICT OH-1 SPRING 1977-1985

FIGURE 65. LAMPEY WOUNDING RATES PER 100 LAKE WHITEFISH AND NUMBER OF FISH TAKEN FROM CANADIAN WATERS IN LAKE HURON DISTRICT OH-2 SPRING 1977-1985

Figure 66. Lamprey wounding rates per 100 Lake Whitefish and number of fish taken from Canadian waters in Lake Huron District OH-3 Spring 1977-1985

Source: Data from Ministry of Natural Resources Unit Owen Sound 1986.
District OH-4 recorded wound rates from 0.20% in 1983 to a high of 1.73% in 1979. Whitefish numbers ranged from 131 in 1980 to 3201 in 1984. Generally, from 1980 to 1985 wound rates remain very low for the district, coupled with increased catches of whitefish which is variable (Figure 67).

In district OH-5 only one year of data has been recorded for 1981 of which 435 fish were taken with a 0.23% wounding rate. District GB-3 also recorded one year of data in 1983 with no wounds indicated on 158 whitefish. No comparative analysis statistically can be made since the data is incomplete.

In district GB-4 wound rates remain low from 1982-1985 with values ranging from 0.0% to 0.40%. In district GB-4, wound rates were highest in 1982 with 0.40%, which declined to 0.0% in 1983-1984. The number of captured whitefish varied over the period from a low of 419 in 1984 to a high of 776 in 1982 (Figure 68).

District NC-1 indicates an area of high lamprey wounds on whitefish numbers. Values ranged from 0.36% in 1979 to a peak of 3.50% in 1985. Since 1980, wound rates increased significantly from 0.70% to 3.50% suggesting a present problem of high wounding rates in this district. Whitefish numbers ranged from 408 in 1983 to 739 in 1985 suggesting higher whitefish numbers (Figure 69).
Figure 67. Lamprey wounding rates per 100 Lake Whitefish and number of fish taken from Canadian waters in Lake Huron District OH-4 spring 1977-1985.

Source: Data from Ministry of Natural Resources Unit Owen Sound 1986.
FIGURE 68. LAMPREY WOUNDING RATES PER 100 LAKE WHITEFISH AND NUMBER OF FISH TAKEN FROM CANADIAN WATERS IN LAKE HURON DISTRICT GB-4 SPRING 1977-1985

Source: Data from Ministry of Natural Resources Unit Owen Sound 1986.
FIGURE 69. LAMPREY WOUNDING RATES PER 100 LAKE WHITEFISH AND NUMBER OF FISH TAKEN FROM CANADIAN WATERS IN LAKE HURON DISTRICT NC-1 SPRING 1977-1985.

Source Data from Ministry of Natural Resources Unit Owen Sound 1986.
District NC-2 has insufficient data collected for the period. However, data compiled for 1985 indicates a wounding rate of 4.30% from 233 whitefish. Despite incomplete data, 1985 displays a high wounding rate for this period.

The next series of figures illustrates whitefish wounding rates for the summer period from 1977-1985.

In district OH-1, wounding rates range from 0.20% in 1981 to 1.40% in 1984. However, this rate declines below 0.5% in 1985. Whitefish numbers varied from 234 in 1982 to 2472 in 1985, indicating increased catchings of whitefish. In comparing spring and fall statistics, it is indicated that per average, wounding rates remain lower in summer. Also, whitefish catchings were greater in summer than fall (Figure 70).

District OH-2 reveals wounding rates ranging from 0.0% from 1982-1984 to 0.60% in 1985, suggesting low wound rates for the district. Numbers of whitefish captured varied from 147 in 1984 to 1696 in 1985, indicating higher whitefish counts for the latest period, 1985. Based on comparisons for spring and summer statistics, it is indicated that per average wounding rates are lower in summer (Figure 71).

In district OH-3, wounding rates ranged from 0.0% in 1982 and 1984 to 2.40% in 1983. However, rates remain low during 1985 with 0.90%. Whitefish catchings ranged from 50 in 1984 to 409 in 1983. Comparing spring and summer statistics indicates that on average, wound rates are lower in summer
FIGURE 70. LAMPREY WOUNDING RATES PER 100 LAKE WHITEFISH AND NUMBER OF FISH TAKEN FROM CANADIAN WATERS IN LAKE HURON DISTRICT OH-1 SUMMER 1977-1985

SOURCE DATA FROM MINISTRY OF NATURAL RESOURCES UNIT OWEN SOUND 1986.
FIGURE 71. LAMPREY WOUNDING RATES PER 100 LAKE WHITEFISH AND NUMBER OF FISH TAKEN FROM CANADIAN WATERS IN LAKE HURON DISTRICT OH-2 SUMMER 1977-1985

than in spring, with lower catchings of whitefish recorded for the summer period (Figure 72).

District OH-4 recorded wound rates ranging from 0.0% in 1981 to 0.40% in 1984, indicating low rates of lamprey attackings on whitefish for the period. Whitefish numbers varied from 17 in 1981 to 3333 in 1984. When comparing spring and summer statistics, it is found that wounding rates are lower in summer, and whitefish catchings are higher for the period 1983-1985 (Figure 73).

Statistics are only recorded for district GB-5 in the summer period. Overall, no wounds were found on whitefish catchings from 1982-1984, which ranged in number from 106 in 1983 to 959 in 1984 (Figure 74).

In district NC-1, wound rates ranged from 0.43% in 1981 to 6.30% in 1984. The wound rate declined significantly in 1985 from 6.3% to 1.6% signifying a reduction in lamprey attacks. Whitefish numbers ranged in value from 361 in 1983 to 3693 in 1985, indicating high whitefish counts for the latest period, 1984-1985. Comparing statistics for spring and summer indicates that wound rates are lower in summer, coupled with higher catchings of whitefish from 1984-1985 (Figure 75).

Only two years of data are present for district NC-2, indicating wound rates from 2.0% in 1985 to 10.10% in 1984, representing the highest wound rate for the entire period of the study. It should be noted however, that the wound rate
FIGURE 72, LAMPREY WOUNDING RATES PER 100
LAKE WHITEFISH AND NUMBER OF FISH TAKEN
FROM CANADIAN WATERS IN LAKE HURON
DISTRICT OH-3 SUMMER 1977-1985

PER SUM
500
400
300
200
100
0

YEAR
1977
1978
1979
1980
1981

SCAR
NON-WOUNDED
WOUNDED

FIGURE 73. LAMPREY WOUNDING RATES PER 100 LAKE WHITEFISH AND NUMBER OF FISH TAKEN FROM CANADIAN WATERS IN LAKE HURON DISTRICT OH-4 SUMMER 1977-1985

PER 100

PER SUM

4000

3000

2000

1000

0

FISH

SCAR

XXX NON-WOUNDED

WOUNDED

FIGURE 74. LAMPREY WOUNDING RATES PER 100
LAKE WHITEFISH AND NUMBER OF FISH TAKEN
FROM CANADIAN WATERS IN LAKE HURON
DISTRICT GB-5 SUMMER 1977-1985

FIGURE 75: LAMPREY WOUNDING RATES PER 100
LAKE WHITEFISH AND NUMBER OF FISH TAKEN
FROM CANADIAN WATERS IN LAKE HURON
DISTRICT NC-1 SUMMER 1977-1985

SOURCE DATA FROM MINISTRY OF NATURAL RESOURCES UNIT OWEN SOUND 1986.
significantly declined in 1985 from 10.10% to 2.0%. The number of whitefish caught varied from 168 in 1984 to 1192 in 1985, indicating increased catches. Lack of data prohibits comparisons between spring and summer data, however 1985 statistics show reduced wounding rates in summer coupled with increased whitefish catches (Figure 76).

The final set of figures illustrate wound rates for the fall period of 1977-1985.

District OH-1 wound rates range from 0.0% in 1981 to 2.0% in 1984, suggesting increased wound rates. Whitefish counts varied from 143 in 1980 to 1130 in 1978. In comparison, fall wound rates on average were higher than summer and spring periods. Whitefish catchings were lower than summer and spring statistics (Figure 77).

District OH-2 wounding rates varied from 0.0% in 1980 to 2.77% in 1978. The 1985 catchings jumped from 0.0% in 1984 to 2.1% in 1985. Number of whitefish captured ranged from 101 in 1984 to 736 in 1979, with lower catches occurring in the latest years, 1984-1985. Based on comparisons for all three seasons, fall wound rates on average, are higher than spring and summer, while whitefish catchings remain lower than spring and summer (Figure 78).

District OH-3 wound rates range from 0.0% in 1984 to 1.90% in 1983. Whitefish catches varied from 100 in 1984 to 1107 in 1979. Comparing all seasonal data suggests fall wounding rates per average, are lower than spring and sum-
FIGURE 76. LAMPIEY WOUNDING RATES PER 100 LAKE WHITEFISH AND NUMBER OF FISH TAKEN FROM CANADIAN WATERS IN LAKE HURON DISTRICT NC-2 SUMMER 1977-1985

SOURCE DATA FROM MINISTRY OF NATURAL RESOURCES UNIT OWEN SOUND 1986.
FIGURE 77. LAMPREY WOUNDING RATES PER 100 LAKE WHITEFISH AND NUMBER OF FISH TAKEN FROM CANADIAN WATERS IN LAKE HURON DISTRICT OH-1 FALL 1977-1985

SOURCES: DATA FROM MINISTRY OF NATURAL RESOURCES UNIT OWEN SOUND 1286.
FIGURE 78. LAMPREY WOUNDING RATES PER 100 LAKE WHITEFISH AND NUMBER OF FISH TAKEN FROM CANADIAN WATERS IN LAKE HURON DISTRICT OH-2 FALL 1977-1985

mer, and whitefish catches are higher than summer and lower than spring statistics (Figure 79).

In district OH-4, wound rates varied from 0.92% in 1977, to 0.0% from 1980-1985, with the exception of 1984 (0.40%). Overall, wound rates are low for the entire period. Whitefish catches ranged from 6 in 1981 to 990 in 1979. Comparing all seasonal data indicates that average fall wound rates were slightly higher than summer and lower than spring rates (Figure 80).

In district GB-4 no wounds were found on whitefish captured from 1982-1985, with catches ranging from 191 to 509. In comparison, wounding rates in the fall are lower than spring, coupled with lower catches of fish (Figure 81).

District NC-1 wound rates varied from 0.0% in 1984-1985 to 0.53% in 1978 suggesting low wounding percentages. Whitefish catches progressively decline from 374 in 1978 to 11 in 1985. In comparison, fall wound rates remain lower than spring or fall, coupled with lower whitefish numbers (Figure 82).

In conclusion, several facts can be drawn from the seasonal data on whitefish wounding rates for the period 1977-1985. Generally, wounding rates remain below the 2.0% level suggesting no significant problem with lamprey wounding. However, in spring, districts OH-2 (1985), OH-3 (1984), NC-1 (1983-1985), and NC-2 indicate wounding rates at or above the 2% level. Districts NC-1 and NC-2 projected highest rates on record. During the summer, districts OH-3
FIGURE 79. LAMPREY WOUNDING RATES PER 100 LAKE WHITEFISH AND NUMBER OF FISH TAKEN FROM CANADIAN WATERS IN LAKE HURON DISTRICT OH-3 FALL 1977-1985

PER SUM

<table>
<thead>
<tr>
<th>YEAR</th>
<th>SCAR</th>
<th>NON-SCAR</th>
<th>WOUNDED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>30</td>
<td>18</td>
<td>1.08</td>
</tr>
<tr>
<td>1978</td>
<td>0</td>
<td>11</td>
<td>0.12</td>
</tr>
<tr>
<td>1979</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1980</td>
<td>0</td>
<td>11</td>
<td>0.11</td>
</tr>
<tr>
<td>1981</td>
<td>0</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>1982</td>
<td>1</td>
<td>11</td>
<td>0</td>
</tr>
</tbody>
</table>

FIGURE 80. LAMPREY WOUNDING RATES PER 100
LAKE WHITEFISH AND NUMBER OF FISH TAKEN
FROM CANADIAN WATERS IN LAKE HURON
DISTRICT OH-4 FALL 1977-1985

PER SUM
1000
900
800
700
600
500
400
300
200
100
0

YEAR

SCAR  XXXX NON-WOUNDED  XXX WOUNDED

FIGURE 81. LAMPREY WOUNDING RATES PER 100 LAKE WHITEFISH AND NUMBER OF FISH TAKEN FROM CANADIAN WATERS IN LAKE HURON DISTRICT GB-4 FALL 1977-1985

FIGURE 82, LAMPREY WOUNDING RATES PER 100
LAKE WHITEFISH AND NUMBER OF FISH TAKEN
FROM CANADIAN WATERS IN LAKE HURON
DISTRICT NC-1 FALL 1977-1985

SOURCE DATA FROM MINISTRY OF NATURAL RESOURCES UNIT OWEN SOUND 1986.
[1983], NC-1 (1984), and NC-2 (1984-1985) recorded wound rates above or at the 2% level. Again, districts NC-1/NC-2 remain as a problem for high wound rates. In fall, districts OH-1 (1984), and OH-2 (1977-1979, and 1985), indicate 2% plus rates of wounded whitefish. Overall, statistics show districts OH-1, OH-2, NC-1 and NC-2 remain as areas of highest wounding rates. Throughout Lake Huron overall, the general pattern has been one of increasing whitefish abundance since the 1970's (Sea Lamprey Control Centre, 1986).

4.6 Analysis of Adult Spawning Sea Lamprey Biological Data

The next series of figures provides data on number of sea lamprey caught/sampled, percent male/female, mean length (cm), and mean weight (gm). This data extends for the period 1973-1985.

In district NC-1, numbers of lamprey captured ranged from 92 in 1982 to 12977 in 1985, indicating a large increase in lamprey caught from 1983-1985. Sampled lamprey varied in number from 213 to 3105, which increased over all years in the period. Generally, the data displays a large increase in lamprey numbers for the district, particularly from 1983-1985.

In terms of percent male/female, no set pattern can be found, with varied rates occurring throughout the period. Overall, percentages ranged from 42.8% to 57.2%, with an equal ratio of male/female lamprey utilized for the period.
Mean length (cm) of male/females varied from 45.4 to 51.5 cm. Females and males were found to be very close in length throughout the period, however, females were slightly larger for most of the period.

The mean weight of male/females varied from 203 gm to 263 gm. From 1973-1980 both male and females varied in weight, however, from 1981-1985 females were heavier than males throughout the period (Figure 33, Figure 34, Figure 85, and Figure 86).

In district OH-1 the number of captured lamprey varied throughout the period from a low of 20 in 1978 to 102 in 1981, indicating low numbers of lamprey. The number of sampled sea lamprey ranged from 19 in 1978 to 102 in 1981.

The percent male/female ranged from 32.0% to 71.0% with females dominating the gender category throughout the period, except for 1984.

In terms of the mean length of male/females, values ranged for both sexes from 42 to 50 cm, with the male bracket accounting for the longer lengths over most of the period, or equalling the females, in 1979, and 1981.

The mean weight of male/females was found to vary from 192 gm to 264 gm, with no one set dominating in weight for the period (Figure 37, Figure 88, Figure 99, and Figure 90).

District OH-3 recorded 32 captured sea lamprey of which 30 lamprey were sampled. The percentage of male/female varied from 45% to 55%, with the dominant sex being female.
Figure 83: Spawning-Phase Adult Sea Lamprey Biological Data (Number Caught/Number Sampled) by Evaluation Units in Canadian Tributaries of Lake Huron District NC-1 1977-1985

<table>
<thead>
<tr>
<th>YEAR</th>
<th>SAMPLED</th>
<th>NOT SAMPLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1978</td>
<td>212</td>
<td>234</td>
</tr>
<tr>
<td>1979</td>
<td>807</td>
<td>842</td>
</tr>
<tr>
<td>1980</td>
<td>555</td>
<td>556</td>
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<tr>
<td>1981</td>
<td>402</td>
<td>405</td>
</tr>
<tr>
<td>1982</td>
<td>909</td>
<td>927</td>
</tr>
<tr>
<td>1983</td>
<td>2495</td>
<td>3313</td>
</tr>
<tr>
<td>1984</td>
<td>3105</td>
<td>5359</td>
</tr>
<tr>
<td>1985</td>
<td>4752</td>
<td>12977</td>
</tr>
</tbody>
</table>

Source: Data from the Sea Lamprey Control Center Sault St. Marie Ont.
FIGURE 84. SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA (\%MALE / \%FEMALE) COLLECTED BY EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON DISTRICT NC-1 1978-1985

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE ONT.
FIGURE 85. SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA (MEAN LENGTH (cm) OF MALE/FEMALES) COLLECTED BY EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON DISTRICT NC-1 1978-1985

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE ON
FIGURE 86: SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA (MEAN WEIGHT (gm.) OF MALE/FEMALE) COLLECTED BY EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON DISTRICT NC-1 1978-1985

SOURCE DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE ONT.
FIGURE 8: SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA (NUMBER CAUGHT/NUMBER SAMPLED) BY EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON DISTRICT OH-1 1977-1985

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE ONT.
FIGURE 88. SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA (♂ MALE / ♀ FEMALE) COLLECTED BY EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON DISTRICT OH-1 1978-1985

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE ONT.
FIGURE 89. SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA (MEAN LENGTH (cm) OF MALE/FEMALES) COLLECTED BY EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON DISTRICT OH-1 1978-1985

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE ONT.
FIGURE 90. SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA (MEAN WEIGHT (g) OF MALE/FEMALE) COLLECTED BY EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON DISTRICT OH-1 1978-1985

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE, ONT.
In terms of mean length, female sea lamprey overall, were found to be larger from 1978-1981, with values ranging from 41 cm to 32 cm. However, both sexes were very close in weight.

The mean weight of male/females ranged in value from 151 gm to 304 gm, with females recorded as the heaviest of the genders for the period (Figure 91, Figure 92, Figure 93, and Figure 94).

In district GB-3, only 1 recorded year of data was compiled in 1978, of which 12/13 sea lamprey were sampled. Females accounted for more of the percent sampled, of which 58% were female, and 42% were male. Male sea lamprey were found to be both longer and heavier, with values of 51 cm/50 gm and 269 gm/261 gm respectively.

District GB-4 recorded 2 years of data for 1980/1981, of which 25/28 sea lamprey were sampled. Based on male/female, 70% were female and 30% male. Female length and weight were greater than males with values ranging from 22 cm/48 cm and 83.5 gm/237 gm respectively (Figure 95, Figure 96, Figure 97, Figure 99).

The final figures provide a summary of all compiled data for all districts combined from 1978-1985. Based on captured sea lamprey numbers, values ranged from 298 to 12977, and the number sampled ranged from 272 to 4752.

In terms of percent male/female, values varied from 37% to 65%, with the dominant sex being female for the period
FIGURE 91. SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA (NUMBER CAUGHT/NUMBER SAMPLED) BY EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON DISTRICT OH-3 1977-1985

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE ONT.
FIGURE 92. SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA (\%MALE / \%FEMALE) COLLECTED BY EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON DISTRICT OH-3 1978-1985

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE ONT.
FIGURE 93. SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA
(MEAN LENGTH (cm) OF MALE/FEMALES) COLLECTED BY
EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON
DISTRICT OH-3 1978-1985

LENGTH  FEMALE-L  MALE-LEN

YEAR

1 1 1 1
9 9 9 9
7 7 8 8
8 9 0 1

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE ONT.
FIGURE 94. SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA (MEAN WEIGHT (gm) OF MALE/FEMALE) COLLECTED BY EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON DISTRICT OH-3 1978-1985

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER Sault St. Marie ONT.
Figure 95. Spawning-phase adult sea lamprey biological data (number caught/number sampled) by evaluation units in Canadian tributaries of Lake Huron District GB-4 1977-1985

Source: Data from the sea lamprey control center Sault St. Marie Ont.
FIGURE 96. SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA (\%MALE / \%FEMALE) COLLECTED BY EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON DISTRICT GB-4 1978-1985

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE ONT.
FIGURE 97. SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA (MEAN LENGTH (cm) OF MALE/FEMALES) COLLECTED BY EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON DISTRICT GB-4 1978-1985

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE ONT.
FIGURE 88. SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA (MEAN WEIGHT (g) OF MALE/FEMALE) COLLECTED BY EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON DISTRICT GB-4 1978-1985

HEIGHT

1980 1981
YEAR

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE ONT.
1978-1982. However, males were found to be the dominant sex for 1984-1985. The mean length of sea lamprey varied over the period from 46 cm to 49 cm, of which females equalled or exceeded male size from 1979-1985.

The mean weight of male/females ranged from 199 gm to 255 gm, of which females exceeded male weight from 1979-1985, with the exception of 1978 (Figure 99, Figure 100, Figure 101, Figure 102).

In summary, several facts can be made from the biological data on spawning-phase adult sea lamprey, (all districts combined), for the period 1978-1985. These facts are: (1) statistics indicate a significant increase in the number of captured sea lamprey over this period, with the greatest increase occurring from 1982-1985. It should also be noted that the most infested district found was NC-1, as opposed to much lower numbers reported in all other districts (e.g., GB-4, 1-27; OH-3, 2-32; OH-1, 20-103); (2) the majority of sea lamprey caught were females from 1978-1982, which reversed to male lamprey for 1983-1985. All districts conform to this pattern except for district NC-1 in which more males were caught in 1978-1979; (3) based on mean length statistics, females either equalled or exceeded male lengths for most of the period 1979-1985, with the exception being 1978. This pattern is also supported by each district; (4) female lamprey also recorded greater weights for the period 1979-1985 with the exception being 1978. When examining
FIGURE 99. SPAWNING-PHASE ADULT SEA LAMPIEY BIOLOGICAL DATA (NUMBER CAUGHT/NUMBER Sampled) BY EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON ALL CANADIAN DISTRICTS 1977-1985

YEAR | Sampled | Not Sampled
--- | --- | ---
1978 | 272 | 298
1979 | 901 | 930
1980 | 651 | 653
1981 | 530 | 537
1982 | 909 | 937
1983 | 2495 | 3313
1984 | 3173 | 5430
1985 | 4752 | 12977

SOURCE: DATA FROM THE SEA LAMPIEY CONTROL CENTER SAULT ST. MARIE ONT.
FIGURE 100 SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA (%MALE / %FEMALE) COLLECTED BY EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON ALL CANADIAN DISTRICTS 1978-1985

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE ONT.
FIGURE 101. SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA
(MEAN LENGTH (cm) OF MALE/FEMALES) COLLECTED BY
EVALUATION UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON
ALL CANADIAN DISTRICTS 1978-1985

LENGTH

FEMALE-L

MALE-LEN

YEAR

177

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE ONT.
FIGURE 102. SPAWNING-PHASE ADULT SEA LAMPREY BIOLOGICAL DATA
(MEAN WEIGHT (gm) OF MALE/FEMALE) COLLECTED BY
EVALUATION UNITS IN CANADIAN TRIBUTARIES OF
LAKE HURON ALL CANADIAN DISTRICTS 1978-1985

SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE ONT.
each district, males were found to be heavier in districts OH-3 (1979), OH-1 (1978, 1980), and district NC-1 (1978, 1980).

4.7 Correlation Between Lamprey Numbers and Fish Production

The next set of figures deals with the correlation analysis of sea lamprey numbers with fish production for the period 1944-1986 inclusive. It should be noted that total fish production statistics were filtered by removing unwanted species which would not be a good indicator for sea lamprey wound rates. Furthermore, three different correlations were run on the data, which included the Canadian side of Lake Huron, the U.S. side of Lake Huron, and both U.S./Canada combined to reflect the overall spatial nature of the system.

The first correlation was performed on the Canadian data which indicates a moderate positive relationship of $R = 0.42$ (Table 1). This is illustrated by Figure 103, displaying both fish production versus sea lamprey numbers. Generally, from 1944-1957 both sets of data show similar configurations of peaks and troughs, as well as from 1961-1970, which lags behind each set of data by 5 years. From 1979-1986, again both sets of data illustrate similar patterns. Overall, the figures display a moderate correlation between both sets of data.
TABLE 1
CORRELATION COEFFICIENTS OF LAMPREY NUMBERS AND FISH PRODUCTION FOR THE PERIOD 1944-1986

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<thead>
<tr>
<th></th>
<th>X1</th>
<th>X2</th>
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<th>X4</th>
<th>X5</th>
<th>X6</th>
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<td>.409</td>
<td>.450</td>
<td>.759</td>
<td>.750</td>
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</tr>
</tbody>
</table>

WHERE
X1 = CANADIAN LAMPREY NUMBERS
X2 = CANADIAN FISH PRODUCTION
X3 = U.S. LAMPREY NUMBERS
X4 = U.S. FISH PRODUCTION
X5 = CAN./U.S. LAMPREY NUMBERS
X6 = CAN./U.S. FISH PRODUCTION
FIGURE 103 COMPARISON BETWEEN FISH PRODUCTION AND LAMPREY NUMBERS IN CANADIAN LAKE HURON WATERS ALL DISTRICTS COMBINED FOR THE PERIOD 1944-1986

If past and present ratios are analyzed, one finds, for example, that in 1953, for every 319,334 kg of fish, 1 sea lamprey was caught. In 1984, for every 335,664 kg of fish, 1 sea lamprey was captured. Therefore, conditions have improved in Canadian waters since the early 1950's, which is reflected by statistics indicating that more fish are caught without encountering a lamprey.

The second correlation was done on the U.S. data, indicating a weak relationship of $R = 0.11$ (Table 1). In Figure 104, it is evident that there are little comparisons to be made on both sets of data. Generally, from 1948-1961, sea lamprey and fish production numbers provide a similar pattern in terms of peaks and troughs, with a small similarity occurring from 1983-1984. Ratios of past and present statistics were then analyzed. For example, in 1948, for every 493,970 kg of fish caught, 1 lamprey was captured. In 1984, for every 44,906 kg of fish, 1 sea lamprey was captured. This indicates an increase in sea lamprey numbers on the U.S. side of Lake Huron, which is indicated by less catches of fish in recent years to encounter a lamprey.

Based on the comparison of the graphs between the Canadian and U.S. sides of Lake Huron, one important question arises. Why does the U.S. side indicate more lamprey numbers at present, and not the Canadian side?

One possible explanation is the limited amount of monitoring and data collection performed throughout the Canadian
FIGURE 104. COMPARISON BETWEEN FISH PRODUCTION AND LAMPREY NUMBERS IN U.S. LAKE HURON WATERS ALL DISTRICTS COMBINED FOR THE PERIOD 1944-1986

side of Lake Huron. Financial constraints limit the amount of manpower, monitoring, data collection, and control centers distributed in Lake Huron waters. Therefore, limited data accounting for only a fraction of the study area (e.g., North Channel, Georgian Bay) will not account for the true representation of sea lamprey populations in the Huron Basin.

A second possible explanation to account for this discrepancy is that the Canadian management control programs are more effective in maintaining sea lamprey populations. However, since similar programs are utilized in an international joint effort, this explanation is very improbable. Thus, incomplete data seems to provide the best explanation.

The final correlation represents both U.S. and Canadian statistics combined to present the overall spatial picture of the Lake Huron basin. In Figure 105, a moderate relationship of $R = 0.45$ is indicated (Table 1). Basically, from the mid 1940's through the early 1960's similar patterns are found between these two data sets. Also, from the late 1960's through 1984, the pattern is very similar, as supported by a correlation coefficient of 0.45.

Ratios of the data were then analyzed. For example, in 1958, for every 424,116 kg of fish caught, 1 lamprey was captured. However, in 1984, for every 105,688 kg of fish caught, 1 sea lamprey was captured. Therefore, the Lake Huron basin indicates that in the past, more fish per kg
FIGURE 105. COMPARISON BETWEEN FISH PRODUCTION AND LAMPREY NUMBERS IN BOTH U.S./CAN. WATERS OF LAKE HURON ALL DISTRICTS COMBINED FOR THE PERIOD 1944-1986

were caught without capturing lamprey than in the present. Thus, sea lamprey populations are found to be increasing over the past few years.

4.9 Distribution Analysis

Given the fact that in life science and population studies, it is worthwhile to determine the theoretical distribution of sampled data, then it is also justifiable to determine the theoretical distributions of sea lamprey counts and fish harvest data.

From a management perspective, if the theoretical distribution is known for sea lamprey counts and fish harvest data, then valid conclusions can be made as to whether the behaviour of sea lamprey populations and fish reproduction rates conform to those observed in the other Great Lakes.

In order to determine whether a) sea lamprey counts or b) commercial fish production fit any of the accepted theoretical distributions presented by life scientists, it was necessary to use a (GOODNESS-OF-FIT) distribution program.

A modified distribution fitting program previously written by Phillips (1972), was utilized to check whether a) sea lamprey counts or b) commercial fish production conform to either the lognormal, normal, exponential, or Rayleigh distributions.

Before the execution of the FORTRAN IV distribution program, it was necessary to specify the level of significance,
test statistic and the number of cells. These procedures are necessary in order to obtain the values for the Kolmogorov-Smirnov test statistic. A level of significance with regard to the Type I error of \( \alpha = 0.10 \) was chosen beforehand, and the number of cells was specified at 15.

There are several reasons why the Kolmogorov-Smirnov test is used, and these are: (1) this test allows for more discriminate cell classification; 2) a smaller sample size can be used; and 3) the data set used in this program was too small for utilization of the Chi-square test. Table 2 shows the results obtained from the program (using Canadian sea lamprey count data). At \( \alpha = 0.10 \), the critical value of the Kolmogorov-Smirnov test for 15 degrees of freedom is 0.304. Overall it is determined that the null hypothesis can be accepted that the data best fits the lognormal distribution.

The lognormal distribution is positively skewed, and is associated with bursts and quiet periods. There is no wide variance, and the shape of the distribution is described by the variance and standard deviation (note Figure 106). The lognormal distribution deals with non-negative random variables, and is continuous in nature. Many life scientists have applied this distribution to explain phenomena including to show the abundance of species of animals (for which this data applies).
(TABLE 2)
K.S. TEST RESULTS OF THE DISTRIBUTION ANALYSIS
(CANADIAN SEA LAMPREY DATA)

<table>
<thead>
<tr>
<th>DISTRIBUTION</th>
<th>K.S. OBS</th>
<th>K.S. CRIT</th>
<th>OBS.&lt;CRIT.</th>
<th>OBS.&gt;CRIT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOGNORMAL</td>
<td>0.015</td>
<td>0.304</td>
<td>*(.289)+</td>
<td></td>
</tr>
<tr>
<td>NORMAL</td>
<td>0.193</td>
<td>0.304</td>
<td>*(.111)</td>
<td></td>
</tr>
<tr>
<td>EXPONENTIAL</td>
<td>0.121</td>
<td>0.304</td>
<td>*(.183)</td>
<td></td>
</tr>
<tr>
<td>RAYLEIGH</td>
<td>0.289</td>
<td>0.304</td>
<td>*(.015)</td>
<td></td>
</tr>
</tbody>
</table>

* SPECIFIES WHETHER THE NULL WAS ACCEPTED OR REJECTED;
( ) SPECIFIES THE VALUE BETWEEN THE OBS. AND CRIT. VALUE;
+ INDICATES THE BEST FIT DISTRIBUTION TO THE DATA;
FIGURE 106. THE LOGNORMAL DISTRIBUTION

\[ f(x) \]

\( \xi = 0 \)
\( \xi = 1 \)
\( \xi = 2 \)
\( \xi = 3 \)

\( x \in [0, 20] \)

Under a management perspective, the lognormal distribution is not a good indicator that present control strategies are controlling sea lamprey numbers since this distribution is associated with peaks and troughs. The ideal managerial goal is to show sea lamprey numbers conform to a uniform (constant) distribution or a flat table-top distribution. A distribution of this type is indicative of the fact that lamprey populations are effectively being controlled.

Based on the results presented in Table 3, the decision was made to accept the null hypothesis that the U.S. sea lamprey count data best conforms to an exponential distribution (Figure 107). At \( \alpha = 0.10 \), the critical value of the Kolmogorov-Smirnov test for 15 degrees of freedom is 0.304.

The exponential distribution is continuous in nature, and deals with non-negative random variables. To date, exponential models are widely utilized by life scientists to express changes of phenomena over time, when constant rates of growth or decline are assumed (Derman et al., 1973).

Unfortunately, the U.S. sea lamprey data indicates constant rates of growth, suggesting that present management strategies are failing to control lamprey numbers. As earlier stated, the ideal management goal is to show lamprey populations conforming to a uniform distribution, representing constant lamprey numbers over time.

In Table 4, (illustrating combined statistics for U.S. and Canada sea lamprey counts) the results obtained from the
(TABLE 3)
K.S.TEST RESULTS OF THE DISTRIBUTION ANALYSIS
(U.S. SEA LAMIPREY DATA)

<table>
<thead>
<tr>
<th>DISTRIBUTION</th>
<th>K.S. OBS</th>
<th>K.S. CRIT</th>
<th>OBS.&lt;CRIT.</th>
<th>OBS.&gt;CRIT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOGNORMAL</td>
<td>0.072</td>
<td>0.304</td>
<td>*(.232)</td>
<td></td>
</tr>
<tr>
<td>NORMAL</td>
<td>0.156</td>
<td>0.304</td>
<td>*(.148)</td>
<td></td>
</tr>
<tr>
<td>EXPONENTIAL</td>
<td>0.070</td>
<td>0.304</td>
<td>*(.234)+</td>
<td></td>
</tr>
<tr>
<td>RAYLEIGH</td>
<td>0.254</td>
<td>0.304</td>
<td>*(.050)</td>
<td></td>
</tr>
</tbody>
</table>

* SPECIFIES WHETHER THE NULL WAS ACCEPTED OR REJECTED;
( ) SPECIFIES THE VALUE BETWEEN THE OBS. AND CRIT. VALUE;
+ INDICATES THE BEST FIT DISTRIBUTION TO THE DATA;
FIGURE 107. THE EXPONENTIAL DISTRIBUTION

\[ f(x) \]

\[ \theta = 2.0 \]
\[ \theta = 1.0 \]
\[ \theta = 0.5 \]
\[ \theta = 0.1 \]

(TABLE 4)

K.S. TEST RESULTS OF THE DISTRIBUTION ANALYSIS
(CAN./U.S. SEA LAMPREY DATA)

<table>
<thead>
<tr>
<th>DISTRIBUTION</th>
<th>K.S. OBS.</th>
<th>K.S. CRIT.</th>
<th>OBS.&lt;CRIT.</th>
<th>OBS.&gt;CRIT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOGNORMAL</td>
<td>0.078</td>
<td>0.304</td>
<td>*(.226)</td>
<td></td>
</tr>
<tr>
<td>NORMAL</td>
<td>0.174</td>
<td>0.304</td>
<td>*(.130)</td>
<td></td>
</tr>
<tr>
<td>EXPONENTIAL</td>
<td>0.057</td>
<td>0.304</td>
<td>*(.247)+</td>
<td></td>
</tr>
<tr>
<td>RAYLEIGH</td>
<td>0.194</td>
<td>0.304</td>
<td>*(.110)</td>
<td></td>
</tr>
</tbody>
</table>

* SPECIFIES WHETHER THE NULL WAS ACCEPTED OR REJECTED;
( ) SPECIFIES THE VALUE BETWEEN THE OBS. AND CRIT. VALUE;
+ INDICATES THE BEST FIT DISTRIBUTION TO THE DATA;
program indicates at \( = 0.10 \), the critical value of the Kolmogorov-Smirnov test for 15 degrees of freedom is 0.304. It was then decided that the null hypothesis can be accepted that the data best conforms to the exponential distribution (Figure 21).

If sea lamprey numbers were declining, then this distribution would be acceptable to management. However, sea lamprey populations throughout Lake Huron are increasing, reflecting poor management control in reducing sea lamprey numbers.

Based on the results illustrated in Table 5, the decision was made to accept the null hypothesis that the Canadian fish production data best fits the lognormal distribution. At \( = 0.10 \), the critical value of the Kolmogorov-Smirnov test for 15 degrees of freedom is 0.304. The lognormal distribution is not a good distribution for fish populations, because it is associated with bursts and quiet periods, indicating an unstable situation.

Based on a management perspective, the ideal managerial goal is for fish populations to be increasing in an exponential fashion. Thus, the exponential distribution would be the best choice, and would illustrate that present managerial strategies of fish farming, stocking programs and hatcheries are effectively increasing fish populations in Lake Huron.
(Table 5)

K.S. Test Results of the Distribution Analysis
(Canadian Fish Production Data)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lognormal</td>
<td>0.072</td>
<td>0.304</td>
<td><em>(.232)</em></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>0.161</td>
<td>0.304</td>
<td><em>(.143)</em></td>
<td></td>
</tr>
<tr>
<td>Exponential</td>
<td>0.224</td>
<td>0.304</td>
<td><em>(.080)</em></td>
<td></td>
</tr>
<tr>
<td>Rayleigh</td>
<td>0.117</td>
<td>0.304</td>
<td><em>(.187)</em></td>
<td></td>
</tr>
</tbody>
</table>

* Specifies whether the null was accepted or rejected;
( ) Specifies the value between the Obs. and Crit. value;
+ Indicates the best fit distribution to the data;
In Table 6, the results obtained from the program (using U.S. fish production data) indicates at $\alpha = 0.10$, the critical value of the Kolmogorov-Smirnov test for 15 degrees of freedom is 0.304. It was then determined that the null hypothesis can be accepted that the data best fits the lognormal distribution.

As discussed earlier, from a management perspective, the lognormal distribution is not a good indicator that present control strategies are effectively controlling sea lamprey numbers (bursts and quiet periods). The ideal conditions for management is to have fish populations increasing over time, and would be represented best from the exponential distribution.

The results in Table 7, led to the decision to accept the null hypothesis that fish production throughout U.S./Canadian waters of Lake Huron best fits the Rayleigh distribution (Figure 109). At $\alpha = 0.10$, the critical value of the Kolmogorov-Smirnov test for 15 degrees of freedom is 0.304.

The Rayleigh distribution is a narrow band-width distribution that is concentrated around a certain mean. Also, this distribution describes phase-shifts over time (e.g., sound waves). From a management perspective if there is little variance of values such that everything is concentrated around a specified mean, this distribution is a poor indicator that management strategies have increased fish
(Table 6)
K.S. Test Results of the Distribution Analysis
(U.S. Fish Production Data)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lognormal</td>
<td>0.113</td>
<td>0.304</td>
<td>*(.191)+</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>0.242</td>
<td>0.304</td>
<td>*(.062)</td>
<td></td>
</tr>
<tr>
<td>Exponential</td>
<td>0.114</td>
<td>0.304</td>
<td>*(.019)</td>
<td></td>
</tr>
<tr>
<td>Rayleigh</td>
<td>0.251</td>
<td>0.304</td>
<td>*(.053)</td>
<td></td>
</tr>
</tbody>
</table>

* Specifies whether the null was accepted or rejected;
( ) Specifies the value between the obs. and crit. value;
+ Indicates the best fit distribution to the data;
(TABLE 7)
K.S.TEST RESULTS OF THE DISTRIBUTION ANALYSIS
(CAN./U.S. FISH PRODUCTION DATA)

<table>
<thead>
<tr>
<th>DISTRIBUTION</th>
<th>K.S. OBS.</th>
<th>K.S. CRIT.</th>
<th>OBS.&lt;CRIT.</th>
<th>OBS.&gt;CRIT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOGNORMAL</td>
<td>0.101</td>
<td>0.304</td>
<td>*(.203)</td>
<td></td>
</tr>
<tr>
<td>NORMAL</td>
<td>0.102</td>
<td>0.304</td>
<td>*(.202)</td>
<td></td>
</tr>
<tr>
<td>EXPONENTIAL</td>
<td>0.218</td>
<td>0.304</td>
<td>*(.086)</td>
<td></td>
</tr>
<tr>
<td>RAYLEIGH</td>
<td>0.059</td>
<td>0.304</td>
<td>*(.245)+</td>
<td></td>
</tr>
</tbody>
</table>

* SPECIFIES WHETHER THE NULL WAS ACCEPTED OR REJECTED;
( ) SPECIFIES THE VALUE BETWEEN THE OBS. AND CRIT. VALUE;
+ INDICATES THE BEST FIT DISTRIBUTION TO THE DATA;
FIGURE 108  THE RAYLEIGH DISTRIBUTION

\[ F(x) = \left\{ \begin{array}{ll}
\frac{1}{a^2} & 0 \leq x \leq a \\
\frac{1}{2a^2} & a < x \\
0 & x > 2a
\end{array} \right. \]

populations through their various strategies. Therefore, the best distribution to indicate effective management strategies would be the increasing exponential situation.

4.9 Choropleth Maps

Data pertaining to adult spawning-phase sea lamprey for U.S., Canadian, and U.S./Canada districts combined were used to produce choropleth maps for the 1986 period.

On the Canadian side of Lake Huron, district NC-1 was the only area assessed for the period. A total of 7833 spawning-phase lamprey were captured in tributaries. However, it should be noted that all areas were not assessed, and the presented statistics are not representative of the whole area under study. However, the presented figures reveal the general trend in sea lamprey numbers, thus, NC-1 presently remains an area of concern with high rates of spawning-phase lamprey being captured (Figure 109).

Along the U.S. side of Lake Huron, district MH-1 recorded the highest rate of spawning lamprey of 18407, representing the highest capture rate for the entire Lake Huron basin for the 1986 period. District MH-4 ranked second with 441 caught, and MH-3 and MH-2 ranked last with low numbers of captured spawning lamprey of 20 and 3 respectively (Figure 110). Again, these figures are not representative of the district as a whole because not all tributaries were assessed during the 1986 period. However, the presented figures do indicate the general trend.
FIGURE 109. 1986 ASSESSMENT OF ADULT SPAWNING-PHASE SEA LAMPREY COUNTS IN CANADIAN DISTRICTS OF LAKE HURON

Source: U.S. Fish and Wildlife Department, Marquette Michigan, 1986.
1986 ASSESSMENT OF ADULT SPAWNING-PHASE SEA LAMPEY COUNTS IN U.S. DISTRICTS OF LAKE HURON

Source: U.S. Fish and Wildlife Department, Marquette Michigan, 1986.
Both U.S. and Canadian districts were combined to illustrate the overall spatial picture for 1986 sea lamprey captures throughout the Lake Huron basin. Generally, Figure 111 indicates that the northern districts of Michigan and Ontario remain the areas of heaviest concentrations of spawning-phase sea lamprey. Furthermore, the remaining districts of the lake (districts assessed) indicate much lower rates of captured lamprey, reflecting a lesser problem with spawning-phase sea lamprey numbers.

In conclusion, several points can be drawn from the produced maps which are: (1) the northern sections of Lake Huron (e.g., MH-1/NC-1) remain areas of concern for harbouring high numbers of spawning-phase sea lamprey in tributary waters; (2) the more southern districts which were assessed for lamprey numbers indicate much lower rates of captured lamprey, reflecting much less of a problem in these districts regarding lamprey numbers; (3) as indicated by the maps, several of the districts in both U.S.A. and Canada reported an absence of data for the 1986 period. This has arisen because of both political and financial constraints. In Canada, much of the northern areas of Lake Huron districts are within Indian reserves which makes assessment close to impossible without the aid of these indigenous people. To date, authorities have been working with the Indians under a program to collect the needed data. However, present conditions have terminated this joint effort, and the termination of data collection.
FIGURE 111. 1986 ASSESSMENT OF ADULT SPAWNING-PHASE SEA LAMPREY COUNTS IN BOTH CAN./U.S. DISTRICTS COMBINED LAKE HURON

Source: U.S. Fish and Wildlife Department, Marquette Michigan, 1986.
Furthermore, there are vast numbers of rivers, tributaries and streams which must be assessed in Canadian and U.S. waters, and financial constraints limit the amount of assessment provided, as reflected by the limited amount of data provided for the 1986 period.

The authoritative bodies involved in the decision processes of program development, implementation, and assessment are faced with a severe problem of incomplete data for the entire spatial area of Lake Huron. This reduces the effectiveness of present/future program formulation because of limited knowledge of spawning-phase sea lamprey distributions throughout Lake Huron.
Chapter V

MANAGERIAL STRATEGIES

5.1 Factors Contributing to Present Program Failures

Despite ongoing efforts to control sea lamprey populations by authorities, it has become evident that present control strategies have failed to effectively regulate their numbers. This is indicated through the statistical results reported in the study, signifying increased lamprey populations over the past five years (1982-1986). There are several factors which have contributed to the present control program's failure, which are outlined in the next section.

One of the key factors responsible for the shortfall of present control programs is financial constraints. Insufficient funding by higher levels of government (e.g., federal, provincial) prohibits the full implementation of program procedures, coupled with all linked processes within the program. Unfortunately, funding provides the main driving force behind these operations, and lack of funds creates a vicious circle for all integrated components bound within the program.

Lack of manpower stems from the constraint of insufficient funding. As a result, there are too many operative
procedures for too little workforce. As a consequence, trade-offs occur between manpower and program implementation which reflects in the overall performance of the program when assessed.

Many of the present controls bound within the program are limited in effectiveness due to their limited applicability in the field. Present problems that must be overcome through experiment/development of control strategies are: 1) the existence of sea lamprey ammocoetes in areas where controls can't be used, or are ineffective; 2) ammocoetes found in mouths of tributaries, estuaries, ox-low lakes, beaver flows, and streambed spawning areas sometimes survive treatments of lampricides due to dilution, or poor circulation; and 3) a need for more effective monitoring programs for sea lamprey populations. Since control application and development is very expensive, financial constraint presents trade-offs in regards to control use, resulting in insufficient application in the study area, and ineffective sea lamprey control strategies.

In conjunction with present control constraints, present research and experimental facilities are limited by improper funding. Present and future control strategies will only become more efficient and effective in sea lamprey management through research and development. Thus, financial constraints must be alleviated.
A critical component to authoritative bodies in present and future decision-making, and creation of new strategies is the collection of data through monitoring/assessment operations. Unfortunately, present monitoring stations coupled with assessment operations are limited to certain designated areas in the study area (upper Lake Huron). This prohibits the means of obtaining a more complete spatial outlook with Lake Huron. Also, questions arise as to which districts are potential threats to present or future sea lamprey resurgence. Data dealing with the morphological, biological, and characteristics of sea lamprey provides vital information to authorities regarding the study area. Lack of monitoring results in infrequent sampling, which limits the quantity and quality of compiled data. As a direct consequence, this constraint distorts the complete spatial outlook of the study area in terms of decision-making and evaluation by authorities.

A lack of communication between all levels of government, authoritative bodies in charge of the programs, interest groups, fishing clubs, and the public is a critical factor contributing to the downfall of the operation. Input by all levels of the groups is essential for a more effective sea lamprey control program. Often these groups can provide valuable information about sea lamprey problems (e.g., increased attacks on fish, scarring, etc.) in districts of the study area which is overlooked because of communication breaks in the system.
If present and future sea lamprey operations are going to be effective in the future, some modifications must be made to reduce this communication gap, and allow input into the system by all parties concerned.

5.2 Alternative Management Strategies

As indicated through the statistical results, present management programs have failed to control sea lamprey populations within the Lake Huron basin. Therefore, it is essential to re-evaluate present managerial practices and procedures involved in the evaluation, decision-making, assessment and monitoring processes in sea lamprey control.

The following section provides an in-depth review of several managerial strategies which could be adopted in the formulation stage of new managerial programs. These include: Environment Impact Assessment (EIA); Adaptive Environmental Assessment and Management Scheme (AEAM); Aquatic Biomonitoring; Environmental Effects Monitoring (EEM); and Multicriteria Evaluation Methods (MEM).

5.2.1 Environmental Impact Assessment (EIA)

Today, there are unlimited procedures for conducting environmental impact assessments (EIA's), which vary worldwide. However, Rosenberg et al. (1980), outline an ideal EIA which consists of the following elements: 1) definition of scientific objectives; 2) background preparation; 3) identification of the main impacts; 4) prediction of the
effects; 5) formulation of usable recommendations; 6) monitoring and assessment; 7) sufficient lead time (which is time allocated to implement procedures); 8) public participation; 9) adequate funding; and 10) evidence indicating the recommendations were utilized.

Several EIA's were selected and compared to the ideal EIA which involved aquatic resources (e.g., power plants, fossil fuels, recreation, reservoirs, wastewater treatment, forestry, dredging, and water diversion in estuaries). These EIA's were then reviewed and scored on a 0-5 scale based on the ideal elements proposed (Rosenberg et al., 1980).

Results indicated that mean scores for criteria that could be assessed (numbers 1-8) showed that the quality of the best EIA's did not exceed the defined average of the ideal EIA, which improved with the removal of legal documents (Rosenberg, 1980). Lowest mean scores for criteria under scientists control were identified for numbers 4 to 5.

Generally, overall mean scores based on the 0-5 scale for scoring created three basic groupings. One, above average quality EIAs were identified as wastewater treatment and recreation. Two, average quality EIAs were forestry (Rosenberg et al., 1980). Three, below average EIAs were the remainder.

The above average EIAs provided various successes which included increased environmental awareness resulting from public participation in the EIA, some protection within the
environment, increase in knowledge on research problems. Despite these successes, the following failures existed which are: 1) Tokenism, which is defined as a show of accommodation to a demand, principle, etc. (Webster's Dictionary 1984). According to Rosenberg (1980), various degrees of tokenism were present in the EIA's including: A) assessments that had no role in the YES/NO decision stage for a project (despite regulations requiring input) but were mitigative in nature; B) assessments which were used as justifications for existing engineering designs or management decisions; and C) assessments regarded as necessary legal steps before project is begun; (2) unrealistic time constraints were common such that insufficient lead time resulted, and inadequate time for monitoring and assessment which seriously jeopardized the EIA's efficiency; (3) uncertainty of program or development schedules, such that industry development strategies are rarely available to individuals initiating the EIA's, which reduces the accuracy of the whole practice; (4) difficulty was found in accessing EIA literature, that is attributed to literature not readily available without key source individuals/librarians on hand; (5) questionable ethics were raised in regards to reports not available to public access due to confidentiality, thus making the information restrictive in distribution; (6) lack of co-ordination among studies existed because the EIA's are not developed into a broad environmental framework. Often
jurisdictional constraints over intra/international borders result in incomplete or sectioned EIA efforts; and (7) failures also are the result of factors under the control of the scientist, including a poor research design, poorly stated objectives, lack of hypothesis testing, superficial research, inadequate use of predictive techniques, a poor statistical design, poor impact analysis, and poor organization of reports (Rosenberg et al., 1980).

5.2.1.1 Application to Sea Lamprey Management

Therefore, it is imperative that all future sea lamprey managerial procedures involving local, national, and international authoritative bodies in stages of decision-making, project formulation, etc. Both past and present failures of the selected EIA's can be used to upgrade sea lamprey management schemes in the following ways: 1) improved access to EIA literature; 2) increased accountability for EIA's and the bodies responsible for them; 3) improvement of public input into project decisions, designs, etc.; 4) improved organization and presentation of EIA reports (Rosenberg et al., 1980); 5) adequate funding for operation of all management programs and procedures; and 6) adequate monitoring and data collection. Based on the scientific/research level of EIA strategies, Rosenberg et al., (1980), proposed various improvements which can also be applied readily to sea lamprey management such as: 1) the development of methods to define and quanti-
fy the relationships between the biological, esthetic, and economic impacts; 2) support for the independent biological inventory programs; 3) adequate time frames; 4) improvements in the design of research; 5) the adoption of monitoring and assessment in all EIA's; 6) studies to include the cumulative impacts on a regional/national scale; and 7) to improve the overall communications between scientists and planners.

5.2.2 Adaptive Environmental Assessment and Management (AEAM)

Another alternative was devised through Environment Canada by two ecologists in the early 1970's (C.S. Holling and C.J. Walters) in redesigning the basic EIA into what they define as the adaptive environmental assessment and management scheme (AEAM). All the AEAM procedures and concepts are derived from the ideas of uncertainty and communication (Jones and Greig, 1985).

According to Maclaren and Whitney (1985), most natural systems are highly dynamic and variable in space and time, which may be the norm (e.g., aquatic systems), where some components may vary by order of magnitude under natural conditions. Therefore, variability coupled with complex interactions within/between ecosystems makes it all but impossible to develop total complete control strategies. Thus, the AEAM theme is defined as a collection of concepts and approaches designed to "recognize uncertainty", and "expect the unexpected". The goal of AEAM is that both environmen-
tal assessment and management must be designed with uncertainty in mind, and to do something about it by: 1) reducing uncertainty for the future; and 2) designing developments or management programs to be capable of dealing with unexpected events, leaving more options open under these circumstances (Jones and Greig, 1985).

Dealing with surprise entails the process of developing schemes in such a way to reduce the consequences to a minimal level of unexpected events. Therefore, a trade-off situation arises between minimizing the risks of failing (fail-safe policies), and minimizing the consequences (safe-fail policies) (Jones and Greig, 1985). This allows for a more open-minded approach for options in the developmental stages. A key element under the safe-fail approach is the idea of avoiding the use of options. However, if surprises are evident, as is indicated under the AEAM, then it is essential to all for the adaptation of unexpected events in the design stages for development (Jones and Greig, 1985).

The AEAM's position of uncertainty is philosophical in nature, and concerns personal views of how we think of environmental systems. Therefore, rational decision-making on the part of the AEAM position is the need to take uncertainty into account, and inevitability of unexpected events to occur in any design process (Jones and Greig, 1985).

In terms of communication, EIAs are multidisciplinary, and affect all levels of interest in society (e.g.,
government, authoritative agencies, specialist groups (fish clubs), and the general public). The downfalls of past E.I.A.'s were much a result of the lack of communication between all interested parties. The AEAM alleviates this problem by devising a series of workshops geared towards gathering all parties concerned to discuss project terms, objectives, etc.

At the decision-making level, authorities should ensure the relevance of studies by stating the required information. At the technical level phase, experts should react to these needs by ensuring that these needs are realistic goals. Also, the research should be at an interdisciplinary level, so one discipline's activities can be checked by other disciplines, and be defined by the information needs of others. Therefore, the main aim methodologically in the AEAM procedures are directed towards addressing issues on a coordinated, analytical basis, maintaining a high level of communication among both specialists and decision-makers (Jones and Greig, 1985).

5.2.2.1 Application to Sea Lamprey Management
The procedures under the AEAM scheme can be a valuable tool when applied under the sea lamprey management strategies. As indicated previously, aquatic systems are highly dynamic in nature, such that variability, coupled with complex interactions within/between ecosystems, makes development of complete control strategies all but impossible. Since no
complete sea lamprey control program can be devised, future development of strategies should incorporate the ideas of uncertainty and expect the unexpected. Furthermore, the AEAM approach is designed for in-depth communication between decision-makers, scientists, specialists, and the public. Since a major downfall with past/present EIA's results for lack of communication, adopting this approach could be valuable.

5.2.3 Aquatic Biomonitoring

According to McCart (1982), detailed aquatic biomonitoring programs in conjunction with developmental projects are essential to serve as a basis for assessing the potential impacts of other similar future projects. The continent is in the initial phase of vast industrial development (e.g., west and north arctic) which is geared toward energy-related industries of oil sands, coal mines, oil and gas, among others. Thus, many of these future development projects will be on a world class scale, necessitating the need for a detailed biomonitoring program. Other developments which can be applied are nuclear power plants, hydro plants, harbours, management control programs, etc. (McCart, 1982).

Many proposals of development projects include plans of future environmental and aquatic monitoring, however, many of these promises turn out to be a smoke screen for the sole purpose of obtaining a developmental permit. Often, the result is underfunding towards biomonitoring which leads to
ineffective monitoring, and limitations to short-term impact assessment only, failing to shed predictive insight towards future E.I.A.'s. Underfunding may also be a scheme to prohibit unwanted results of environmental disturbances to developers which would eventually go to governmental officials. Failure to provide a detailed biomonitoring program denies the chance of upgrading the ability to predict impacts in the environment more effectively (McCart, 1982).

As a result, predictions in impact assessments tend to be qualitative in nature, not quantitative, and are based on the individual components of the aquatic community, rather than the ecosystem as a whole. According to McCart (1982), it is difficult to take anything but a qualitative approach with E.I.A.'s, since the lack of full knowledge based on the interactions among aquatic species in the ecosystem, their response to disturbances, and the difficulty in predicting how the environment will be disturbed.

Much of the E.I.A. can be viewed a pseudo-science, since predictions and estimates of possible severity to the ecosystem are stated, but not tested (McCart, 1982). Therefore, a detailed biomonitoring program would allow for predictions to be tested, indicate whether the predictions are true/false, and improve the ability to make accurate predictions in the future (McCart, 1982).
5.2.3.1 Application to Sea Lamprey Management

However, AEAM's are limited in their applicability because they are based on qualitative rather than quantitative assessment. As a result, certain species are only analyzed and not species as a whole in the ecosystem. Predictive powers are also limited because of the lack of knowledge of interacting species within the ecosystem, in response to disturbances, and predicting how the environment will be disturbed.

Thus, applying a detailed biomonitoring program to areas under the control programs, would allow for more accurate predictive powers in terms of overall sea lamprey management, as well as to assess the programs' potential impacts or disturbances to surrounding aquatic life.

5.2.4 A Detailed Design for Aquatic Monitoring

Skalski and Mckenzie (1982) formulated a design for aquatic monitoring programs for nuclear power plants, however, certain aspects of this design could be modified into a design for sea lamprey management. Ecological assessments are procedures for estimating biological costs of a possible impact on an ecosystem. The Nuclear Regulatory Commission (NRC) requires an E.I.A. for nuclear plants before construction and licensing are issued. The purpose for the monitoring program is to identify area flora and fauna in the proposed plant site, and to provide a basis for assessing possible changes to the aquatic life resulting from plant construction and operation (Skalski and Mckenzie, 1982).
The prime objectives of ecological monitoring at N.P.P. are: 1) to detect any impacts, if occurred; and 2) to estimate the magnitude of an impact (Skalski et al., 1981).

The environment monitoring program (EMP) at NPP's were reviewed, and were found that EMP's were not designed for statistical analysis or detecting aquatic (biotic) changes. The major criteria when developing a EMP is to create an experimental design capable of identifying changes which are directly attributed to power plant operations (Skalski and Mckenzie, 1982).

Since populations of organisms vary both temporarily/spatially, a monitoring design should be able to differentiate the effects of this natural variability from those population changes resulting from the impact. It was then proposed that the ratio of population abundance between non-impact/control, and impact/treatment sites be used to quantify the impact. An impact in this case is referred to as a change in the ratio of abundance between pre-operational and operational phases of a NPP. The purpose of the control-treatment pairing (CTP) monitoring program design is to quantify changes in organism abundance that might occur as a result of NPP operations (Skalski and Mckenzie, 1982).

The nature and extent of a monitoring program depends on various constraining factors such as: 1) the site specific environmental characteristics at the NPP; 2) the quantitative objectives of the monitoring program; 3) experimental
error; 4) limitation of time/effort for concluding the monitoring program (Skalski and McKenzie, 1982).

The CTP design has three distinct advantages over the traditional unpaired designs frequently utilized in monitoring studies. One, the ability to relate changes in biota to the operation of NPP's; 2) allows repeated observations of a control-treatment combination between years to be designated as replications; and 3) reduces experimental error associated with monitoring, when favourable control-treatment station pairings are achieved (Skalski and McKenzie, 1982).

The identification of differences in biota between control-treatment stations or between pre-operational/operational phases is not sufficient evidence alone for assessment of impact in NPP operations. However, the CTP design in comparing proportional abundance of organisms at control-treatment stations and between pre-operational/operational periods can establish a relationship between biota changes and NPP operations (Skalski and McKenzie, 1982).

5.2.4.1 Application to Sea Lamprey Management

Generally, this type of biomonitoring program can be modified and implemented into the sea lamprey management procedures. The concepts of comparing non-impact/control, and impact/treatment sites as well as pre-operational/operational periods of sea lamprey management can provide
valuable assessments of possible impacts of program implementation and how the ecosystem responds prior to, and after treatments. Biomonitoring programs can provide a relationship between changes in aquatic life (e.g., fish populations, sea lamprey numbers, plants, etc.) before and after sea lamprey program operations. A cost in implementing this alternative would be the funding required to operate these procedures, which is a major constraint under present budget of the sea lamprey management operations.

5.2.5 Environmental Effects Monitoring (EEM)

Another aspect involved in an EIA is the environmental effects monitoring program (EEM). In the past however, EEM's have been utilized minimally when dealt with in the guidelines for environmental impact statements (EIS). But, recent guidelines issued by the Environmental Assessment and Review Process (EARP) in Canada has given more importance to the EEM, coupled with increased emphasis on sound monitoring principles in the EIA (Duinker, 1985). Furthermore, various groups have pushed for the modification of procedures to incorporate EEM's formally into the EIA process.

Various views across Canada have been expressed in regards to the limited application of EEM's in EIA procedures. According to Duinker (1985) "the current lack of adequate pre/post construction of data is the single greatest obstacle in advancing the state of the art in environmental impact prediction" and Duinker (1985) concludes that
"we must have some degree of ecological investigation during construction, operation, and abandonment phases of development projects if we are to improve our capabilities in impact prediction and assessment."

Generally, the definition of EEM is the repeated measurement of environmental variables to detect changes covered by external influences (Duinker, 1985). The broad goal of EEM is revealing whether a change has occurred in an environmental variable, such as in the EIA. The changes investigated are presumably linked to the development projects or activity being assessed (Duinker, 1985).

Overall, several scientific objectives can be stated in the EEM which are:

1. To test impact predictions and expand environmental knowledge, and improve predictive abilities.
2. Check the effectiveness of mitigation measures.
3. Provide early warning of undesirable change so that corrective measures can be implemented.
4. Provide evidence to refute or support claims for damage compensations, (Duinker, 1985).

Based on the definition provided for an EEM, the following implications can be stated. One, an accurate design to test for effects of an intervention should include both before and after intervention measurements in both the undisturbed (control) and disturbed sites (Duinker, 1985). Failure to provide pre/post measurements produces a much weaker study when lacking temporal/spatial controls.
Thus, an EEM within an EIA is not only a procedure for a time series if measurement of important variables in a disturbed area following disturbances, but also provides for adequate pre-disturbance measurements and measurements in areas not disturbed (Duinker, 1985).

The second implication refers to the timing of monitoring programs with respect to the timing of an EIS with that of construction, operation, and development of a project. The EEM should precede a disturbance for the length of time needed to establish the natural variability of the phenomena under study (Duinker, 1985).

EIA's are activities which provide important environmental information for project/program decision-making, therefore, EIA's can also be used for predicting effects. EEM's are not used in predictive procedures since predictions must come before disturbance. However, an EEM can still provide input into the decision-making process such as: (1) project operation and elements of project design that can be altered after implementation; and (2) future developments expected to result in similar effects (Duinker, 1985).

The procedures of an EIA have been performed in the U.S.A. for more than 10 years, and in Canada for less than 10 years, therefore, documentation is readily available dealing with EIA implementations. However, EEM application provides more of a problem as part of EIA procedures such as: (1) traditional monitoring procedures were geared for
post-EIS investigation; and 2) in most government EIA procedures, formal public reviews of EIA's are usually deleted once an EIS has been reviewed and decisions made on project approvals. Thus, documentation is available for EIA's on pre-EIS studies and impact predictions, but only proposals for EEM programs. Therefore, in order to gain information about EEM procedures, enquiries must be made to individuals related with the project matters in question (Duinker, 1985).

Overall, very little effort has been made with EEM procedures in Canada coupled with EIA's, which is similar in the U.S.A. Explanations defending lack of EEM utilization include: (1) non-implementation of EEM procedures due to weak requirements of the National Environmental Policy Act (NEPA); (2) too much time, money is required from other programs to be diverted; and (3) lack of institutional coordination mechanisms for inter-governmental monitoring programs (Duinker, 1985).

A great deal of conflict arises today over who must pay for the review, implementation of EIA studies. Initially, all parties involved in pre-approval EIA's are delegated responsibilities through government guidelines, however considerable conflict lies over responsibility of post-approved EEM studies. Generally, both government and agency involved would stand to benefit from conclusive results on specific effects of developments. This information will prove useful
in future/present developments of a similar nature (Duinker, 1985).

Two possible solutions for post-approved EEM studies are:
(1) cooperative agreements between industry and government to share costs of EEM studies; and (2) cooperative efforts between industries involved in such studies (Duinker, 1985).

5.2.5.1 Application to Sea Lamprey Management

The EEM scheme has valuable components which could be applied to sea lamprey management operations such as: (1) it would generate additional knowledge related to the aquatic system about possible effects of implemented controls; and (2) an EEM would operate as an early warning system in the event that any applied control in the treated area creates undesirable change to surrounding flora and fauna before and after program implementation (similar to biomonitoring strategies.

However, utilizing this type of system would generate certain problems such as: (1) the costs of funding such operations, and the allocation of responsible parties who must pay for such operations; (2) the procedures are time consuming, and entail increased manpower; (3) policies must be created by government authorities to enforce the mandatory EEM operation within all EIA's, and (4) there is a major problem as to the lack of communication and coordination among governments, authoritative groups, scientists, and the public.
5.2.6 Multicriteria Evaluation Method

Another aspect involved in managerial strategies involves the analysis of alternatives in an EIA process. Thus, multicriteria evaluation methods (MEM) provide for the evaluation of alternatives which often are marked by many conflicting criteria (Maclaren and Whitney, 1985). Some of these criteria would include effects of controls generated, economic costs of a project, etc. These criteria can be measured on different scales and levels as well as be measured in terms of importance of one criterion to another (Maclaren and Whitney, 1985).

Two conflicting problems arise within the methodological portion of multicriteria evaluation which are: (1) criteria measured are often in unmeasurable units; and (2) criteria are also varied in terms of qualitative/quantitative measurement of which, qualitative criteria are more complex to deal with (Maclaren and Whitney, 1985). These two problems make MEM decisions a very complex process. An alternative to this measurement problem is to aggregate all criteria levels into one common measure or score, which involves some sort of transformation onto an initial scale (Maclaren and Whitney, 1985). Other problems arise such as qualitative data (nominal/ordinal scaled data) that cannot be aggregated in a mathematical form. A problem arises because qualitative information must be modified into quantitative information, since criteria weights are mostly utilized on qualita-
tive data. Therefore, creating quantitative weights is time consuming and difficult. However, this modification alleviates the mathematical validity of qualitative measurement (MacLaren and Whitney, 1985).

One final problem exists with aggregation of criteria such that weights are assumed as independent of each other, which is not the case in many events.

Overall, there is no quick solution to these problems encountered with EIA data, but many methods exist which vary in strength and weakness.

5.2.7 Dominance Analysis

Dominance analysis involves the simple reduction in the number of alternatives. Certain alternatives are more dominant than other alternatives. This process involves the reduction in the number of alternatives which must all be considered without more complex techniques requiring more information by the decision-maker about criteria weights and levels. Essentially, alternatives are eliminated by comparing them to other alternatives of equal or greater criteria levels, of which higher level criteria are more desirable. Overall, dominance analysis may not eliminate alternatives, but acts as a screening device before more complex methods are utilized, and can be considered a first step in multi-criteria evaluation (MacLaren and Whitney, 1985).
5.2.7.1 Application to Sea Lamprey Management

Under the MEM operations Dominance analysis requires the least amount of information in a simple comparison of alternatives. Therefore, applying this method to sea lamprey management can be beneficial for analyzing alternatives. However, reducing alternatives through comparison results in tradeoffs which can be undesirable in management operations.

5.2.8 Concordance Analysis

Concordance analysis can be applied to both quantitative and qualitative data, and has stochastic, deterministic properties. However, the present description is based on quantitative deterministic concordance analysis (Maclaren and Whitney, 1985).

The first step involves paired comparisons between alternatives and a concordance set for each alternative pair derived. Thus, for each pair of alternatives, alternative 1 dominates in terms of a criteria level that is equal or preferred to the criteria for alternative 2 (Maclaren and Whitney, 1985).

Step two is the creation of a complementary set or discordance set. In this case of each pair of alternatives, all criteria are included which alternative 1 is worse than alternative 2 (Maclaren and Whitney, 1985).

The third step is to create a concordance and discordance index. In the concordance index, the criterion weights of each criterion in the set are modified into a standard scale.
and summed. Thus, one number specifies the amount of importance in paired comparisons in the index for one alternative to another. No magnitude of importance is indicated in this step.

In the discordance index, magnitude of importance is considered. All criteria are modified to a common scale, then the maximum difference between weighted criteria levels for alternative 1 to alternative 2 are found (Maclaren and Whitney, 1985).

The last step, is the determination of a threshold value for both concordance/discordance indexes. If values fall below the threshold an alternative is considered to be dominated by the alternative it is compared to. An alternative with a high concordance index is preferred over a low index, therefore all other alternatives below this can be eliminated. The same can be applied to the discordance index. Overall, the perfect situation is the elimination of all alternatives by these threshold values until one alternative remains (Maclaren and Whitney, 1985).

The problem of the concordance analysis is that in practice, threshold values may not be obtainable for either concordance/discordance indexes, thereby just reducing the number of alternatives instead of arriving at a single alternative.

Advantages of the concordance method are: (1) it produces two evaluation sets of indexes to measure two equally
important characteristics of a set of alternatives; and (2) the advantage of the number of variations and flexibility offered in applying the method to other multicriteria evaluation problems. However, this is confronted by the problem of the mathematical complexity which reduces understanding of this method coupled with the assumption of independent weights of each other and of each criterion level (Maclaren and Whitney, 1985).

5.2.8.1 Application to Sea Lamprey Management

Given both advantages and disadvantages of the concordance analysis, this method could be applied on a general basis in sea lamprey management. Concordance analysis is complex, but offers a more in-depth comparison between managerial alternatives that lead to a preferred alternative. However, this method requires more information that may not be available to the manager, coupled with the complexity of mathematical output, and unattainable threshold values.

5.2.9 Saaty Method

The Saaty method is used to transform qualitative data to quantitative data by a series of paired comparisons of alternatives or criteria (Maclaren and Whitney, 1985). If one is dealing with quantitative criteria weights to be estimated, then the decision-maker compares each pair of criteria and assigns the criteria a value based on a 9 point scale. If the criteria are equal in importance, a score of
If one criterion exceeds the other in importance, then it is given a score of 9, and the other a 1/9 score. The remaining 9 point scores of the scale indicate the degree of importance between the extremes 1 and 9 of one criterion over another (Maclaren and Whitney, 1985).

If qualitative data is being used to estimate criteria levels, the decision-maker compares criteria levels for each pair of alternatives. The criteria levels are assigned scores on the same 9 point scale as quantitative data for the criteria weights (Maclaren and Whitney, 1985).

The next stage involves the comparison of the scaled values for both criteria level or weight to form a matrix. From the matrix, a vector is created to approximate an interval scale and indicates the degree of distance between criteria weights and levels. For criteria weights, vectors represent a quantitative estimate of the decision-maker's value trade-offs, and for criteria levels represent a quantitative estimate of range of levels of a criterion for each alternative. The goal of this method is to determine the best alternative by selecting the one which maximizes the weighted sum of criteria values (Maclaren and Whitney, 1985).

The Saaty method does not demand trade-offs between criteria or alternatives for decision-making, but for simple paired comparisons. However, the resultant mathematical
output dealing with vectors of criteria weight/levels are difficult to understand. Another problem with this method involves deriving weights because under normal conditions, they are independent of criteria levels in a particular set of alternatives. Therefore, these weights can only be utilized under the assumption that no interdependencies exist among criteria and each criterion weight is linear (Maclaren and Whitney, 1985).

5.2.9.1 Application to Sea Lamprey Management

The Saaty method offers an effective approach in comparing alternatives and criteria which can prove valuable in sea lamprey management. This method offers an orderly scheme of evaluating both quantitative and qualitative data under a 9 point scale. Furthermore, this method does not entail tradeoffs between alternatives and criteria, but only a simple paired comparison. However, the resultant mathematical output is very complex, and analysis of this data can be confusing and time consuming to the manager.

5.2.10 TOPSIS Method

The TOPSIS method refers to the Order Preference by Similarity to Ideal Solution (TOPSIS), in which the alternative is selected that lies closest to some ideal solution. This method also accounts for the distance of an alternative from the negative or worst possible solution (Maclaren and Whitney, 1985). The overall best position is composed of the
best values for each criterion from all the alternatives, and the same applies for the negative ideal, which is composed of all the worst criteria values. The best alternative is located at the minimal distance from the ideal point, and at a maximum from the negative ideal (Maclaren and Whitney, 1985). The criteria are weighted and transformed to a common scale, and this method assumes the criteria weights are measured on a quantitative scale (Maclaren and Whitney, 1985).

The problem of using the TOPSIS method is that it requires quantitative data, which can be partially resolved utilizing the Saaty method for transformation, however, the Saaty method is not a good approach as earlier indicated (Maclaren and Whitney, 1985).

5.2.10.1 Application to Sea Lamprey Management

The TOPSIS method is designed to choose the best alternative closest to the ideal solution. This method can be valuable in sea lamprey management in attaining a group of best alternatives towards an ideal goal.

5.2.11 Interactive Multicriteria Models

Interactive multicriteria models are methods which recognize that the selected alternative is the best chosen on the basis of a priori criteria trade-off information given by the decision-maker which may not be the best solution (Maclaren and Whitney, 1985).
This may result from several areas such as: (1) the decision-maker is uncertain about their true preference for criteria value trade-offs prior to the evaluation; (2) the question of mathematical validity of the evaluation methods; (3) incorrect assumptions about the independence of criteria weights from one another; and (4) the decision-maker may fail to provide a priori information about the criteria weights (Maclaren and Whitney, 1985).

Generally, the interactive methods deal with the evaluation process as an orderly learning process such that the decision-maker can increase his/her understanding of criteria trade-offs in decision-making (Maclaren and Whitney, 1985). In this process, the decision-maker can check the criterion levels in the alternative. If satisfied, the process terminates, otherwise, new alternatives are selected until the decision-maker is satisfied.

This process is effective in dealing with many alternatives, but is limited when dealing with few alternatives. A second problem is that cooperation is required by the decision-maker that is time-consuming (Maclaren and Whitney, 1985).

5.2.11.1 Application to Sea Lamprey Management

Interactive multicriteria models can be valuable if applied to sea lamprey management since the procedures follow an orderly step-by-step process in evaluating decision-making and tradeoffs.
Overall, this procedure could increase one's knowledge and understanding of criteria levels and alternatives. The major flaw in utilizing this procedure is the requirement of many alternatives. Therefore, if few alternatives are available, this method could be ineffective.

5.2.12 Stochastic Multicriteria Methods

5.2.12.1 Stochastic Concordance Analysis

Stochastic multicriteria methods are scarcely found in the literature, however, Nijkamps stochastic concordance analysis assumes the criteria levels in the project matrix and weights are randomly generated. Furthermore, assumptions are made on the shape of the probability distribution of random variables utilizing a random number generator to choose values from the probability distribution. In this situation, one can analyze the changes of the dominant alternative from several runs. Overall, the result is a probability statement of the dominant alternative distribution. This accounts for uncertainty in the outcomes in multicriteria evaluation, but can only be applied when adequate information is provided for estimating the probability distribution shape (Maclaren and Whitney, 1985).

Several approaches are available to solve multicriteria problems in which multiple decision-makers can be invoked. In these approaches, the assumptions are: (1) it is possible to identify which decision-makers or affected groups are
significant in the evaluation problems; and (2) the results of these approaches assume the multicriteria evaluation should be a single alternative representing the best possible compromise among all decision-makers (Maclaren and Whitney, 1985).

5.2.12.2 HLAAW Method (A Higher Level Authority Assigns Weights)

In the next approach (a higher level authority assigns weights), the existence of a higher-level authority develops political weights to the decision-makers. Then, all opinions of decision-makers are aggregated to develop a single weight vector for the criteria. Generally, this approach provides equal weights to all decision-makers. It is stated that this approach is not realistic, however it is better than allowing higher level authorities to make quantitative decisions for which other groups/decision-makers are more effective (Maclaren and Whitney, 1985).

5.2.12.3 Application to Sea Lamprey Management

The stochastic multicriteria methods are devised to solve multicriteria problems by decision-makers. Some of the general concepts can be used in sea lamprey management, however, care should be taken in selecting the type of method since various requirements and assumptions are inferred for each.
5.2.13 Dominance Approaches

5.2.13.1 Paretian Method

Under the dominance approaches, the paretian analysis identifies a set of efficient outcomes that can only be improved for some decision-makers at the expense of another decision-maker (Maclaren and Whitney, 1985). Therefore, alternatives which meet this condition dominate others which do not. The outcome of this approach is a set of one or more non-dominated alternatives, which will be smaller than the original set of alternatives, and less of a multicriteria problem (Maclaren and Whitney, 1985).

5.2.13.2 Control Resolution Procedures

In the conflict resolution procedures, the methods are applied in situations whereby all decision-makers are agreed on a conflict resolution procedure coupled with abiding to the outcome of the procedures. This approach is best utilized under a flexible mediation structure in EIA procedures rather than structural frameworks (Maclaren and Whitney, 1985).

5.2.13.3 Interactive Majority Voting Procedure

Under an interactive majority voting procedure, the pre-voting elimination procedure is joined to eliminate dominated alternatives from future evaluation (Maclaren and Whitney, 1985).
Under a step-by-step process method, a decision-maker which differs in opinion to the majority of other decision-makers compromises his/her position. These conflicts are measured by one of three conflict indices. Overall, the compromise/concession process proceeds until total agreement is reached by all decision-makers. It is possible that conflicts result in deadlock situation because no decision-makers are willing to modify their view, which weakens the procedural process (MacClaren and Whitney, 1985).

5.2.13.4 Delphi Approach

In the Delphi approach, the goal is to obtain expert opinion in a systematic fashion for useful results. Generally, this involves an iterative procedure involving questionnaires or surveys distributed to a decision-makers. In the next stage, an analyst summarizes all responses and gives all decision-makers a chance to modify their opinions, considering group opinions. This procedure continues until an overall group consensus of all decision-makers is reached (MacClaren and Whitney, 1985).

5.2.14 Conflict Resolution Procedures

5.2.14.1 Compensation and Game Theory

The final set of approaches deal with conflict resolution procedures. Compensation and game theory concepts can be utilized in conflict situations of which decision-makers are expected to form groups for/against a certain position. One solution to minimize conflict of any group is to offer com-
pensation incentives to those originally withholding to join (MacIaren and Whitney, 1985).

5.2.14.2 Bargaining Theory

Under the bargaining theory, the decision-makers have cooperative but conflicting interests. This produces a situation such that failure to reach an agreement forces decision-makers to lose (e.g., long court cases, etc.). Also, to reach an agreement entails concessions by all sides based on their conflicting demands (MacIaren and Whitney, 1985).

5.2.14.3 Application to Sea Lamprey Management

In conclusion, the decision-makers within the authoritative bodies (e.g., government, special commissions, etc.) must carefully analyze and re-evaluate present procedures in formulating management strategies. Presently, it is found the present strategies have failed to effectively control lamprey numbers, thus authorities in charge must adopt a new approach in management procedures. The above array of management schemes, methods, and models can aid in this restructuring process, which also depends on the type of data encountered, the number of alternatives and criteria, and the number of decision-makers involved.
5.2.15 Conclusion

If I were under a management role, the best choice under these strategies would be the Adaptive Environmental Assessment and Management scheme (AEAM). Since total sea lamprey control cannot be initiated, it is imperative that future development of programs "recognize uncertainty" and "expect the unexpected." This is due to the fact that variability in aquatic systems coupled with complex interacting ecosystems makes it all but impossible to develop total control strategies. Also, dealing with uncertainty/surprise allows for the development of programs in a way to reduce the consequences to a minimal level of unexpected events. This allows for a more open-minded approach for options in the developmental stages of program formulation. Key factors which are valuable for present/future strategy development are: (1) AEAM's are multi-disciplinary, and include input from all levels of government and society (e.g., fish clubs, public); (2) AEAM's provide a series of workshops geared towards getting all parties concerned together to discuss problems, project objectives, etc.; and (3) the main aim of AEAM procedures are directed towards addressing issues on a coordinated, analytical basis, maintaining a high level of communication among specialists, scientists, decision-makers and the public.
Chapter VI

RECOMMENDATIONS

As indicated through the statistical analysis of sea lamprey data, present management programs have failed to keep sea lamprey populations under control. Therefore, it is imperative that present management practices, coupled with program operations, be modified towards alleviating problems within the Lake Huron system, and to provide more effective, efficient measures in sea lamprey managerial strategies. The following recommendations have been formulated for sea lamprey management schemes.

6.1 Decentralization and Monitorization

A key modification to be made involves the decentralization of both U.S. and Canadian control centers and operations. Presently, the centers under control are located in Marquette, Michigan (run by the U.S. Fish and Wildlife Department), and in Sault Ste. Marie, Ontario, the Sea Lamprey Control Center (run by the provincial government).

These centers are responsible for implementing the control programs, monitoring, and assessment of all data throughout the Lake Huron basin, coupled with other locations in the other Great Lakes (Lakes Ontario, Superior, and
Michigan). Since Lake Huron contains many river systems and associated streams and tributaries, operations under these present authorities are very difficult to conduct. This is supported by the limited amount of collected data obtained under the present state of operations. For example, much of the data is found to be incomplete in terms of years, seasons, or per district area. Data pertaining to captured spawning-phase adult sea lamprey from 1944-1986 is incomplete for various years throughout the period. Furthermore, some of the districts were absent of data completely. Lamprey wound rate data for Lake Trout and Chinook Salmon for 1985 was missing data per season, as well as per district. Wound rate data for whitefish from the period 1977-1985 was incomplete per season, year and district. Spawning-phase biological data from 1978-1985 was incomplete in terms of districts and for certain years within this specified time period.

Therefore, decentralization of centers and operations to all districts throughout Lake Huron will alleviate these problems of infrequent monitoring, data collecting, and overburden of workloads. Also, by decentralization, a greater degree of management control is ensured for operations in all districts and will reflect a more complete data base over the entire system, as reflected by more efficient/effective management procedures, accuracy of monitoring, and regular intervals of data collection.
Under this new strategy, the existing control centers can modify their role as overseers of operations for the entire Lake Huron system, and serve as the focal points of operations. The key role will also be a site for compiling and assessing all data from Lake Huron districts.

This new structure of operations (Figure 112) allows for more efficient allocation of operations, and provides feedback into the system by all groups involved.
Figure 112. Decentralization and Monitoring

- Provincial State and Federal Government Authorities
- U.S. Fish & Wildlife Department
- Scientists
- Control Centers
  - MH-1, MH-2, MH-3, MH-4, MH-5, MH-6
  - NC-1, NC-2, NC-3, GB-1, GB-2, GB-3, GB-4, OH-1/5
- Monitoring → Evaluation → Documentation → Evaluation → Monitoring
- Independent Appraisers Monitoring Committees
- Compliance/Scientific

Source: Author
6.2 Financial Solutions

6.2.1 Funding
The Great Lakes Fishery Commission is responsible for sea lamprey control in all of the Great Lakes, and are given power by federal, provincial, and state governments in both U.S.A. and Canada. In terms of funding, the U.S. governments allocate 69% of all funds, and the Canadian counterparts, the remaining 31%.

The Great Lakes Fishery Commission allocates its work to two agents in U.S.A. and Canada. These agents are the U.S. Fish and Wildlife Department and the Canadian Department of Fisheries and Oceans, for which the Sea Lamprey Control Center applies.

A major constraint however in implementing such procedures is the source of funding to support such an operation. The following solutions are stated to provide the necessary funding. One, since decentralization of existing authorities is taking place, their present budget can be allocated partially towards the operation of these centers.

Two, under the new license act for 1987, a $10 fee is required by all residents of Ontario who fish. According to Bolton (1986), an extra $10 million a year is expected to be generated by this license fee coupled with $30 million spent annually on Ontario fisheries. This new license fee was endorsed by the Ontario Federation of Anglers and Hunters, the Northern Ontario Tourist Outfitters Association, the
Canadian Wildlife Federation, and the Ontario Federation of Naturalists (Bolton 1986).

Part of this revenue can be allocated to aid in operating the decentralization scheme, since sea lamprey management is directly related to fisheries. According to Bolton (1986), the revenue will go a long way towards improving the quality of the resource, and maintaining/increasing the economic and social benefits from the sport. The Ministry is stressing just how economically vital sport fishing is to Ontario, which generates $700 million annually to Ontario's economy (Bolton 1986). Therefore, allocating funds to sea lamprey management will help reinforce these goals.

According to Bolton (1986), more than one-quarter of Ontarians fish at least once a year, therefore, it is logical to impose such a fee, which is the general view from anglers who assume an increasing responsibility for Ontario fisheries.

In the U.S.A. license fees are already mandatory, and the funds should also be allocated for this scheme under the same reasons as previously stated.

A third source of revenue to fund the decentralization scheme is the proposition of an outdoor-user tax by Conservative MP Barry Turner, a biologist in the House of Commons (Hopkins 1986). A study done by the Canadian Wildlife Service 1985, indicated that 85% of the population uses or benefits from the country's wildlife resources, therefore, the
act should be passed to aid in research and preservation (Hopkins 1986).

Presently, this tax has been supported by groups of organized sportsmen, conservationists, naturalists, and other public figures across the country. It has been proposed that the tax be placed on items from sports equipment to wildlife feed which can generate $5 - 27 million annually (Hopkins 1986).

If accepted, the funds would be allocated towards protecting a wide range of essential habitats, endangered species, among other federal/provincial research projects (of which sea lamprey management assumes a role) which are areas that are rapidly being reduced in adequate funding (Hopkins 1986).

6.3 Volunteer Programs

The situation of infrequent monitoring and data collection can be resolved through a joint effort between authoritative bodies and special interest groups. Through increased participation, authorities could initiate a volunteer program with fishing clubs in each district to conduct regular monitoring and data collecting within area tributaries, fish derbies, etc. Authorities should allow for outside aid in maintaining sea lamprey populations. Since sportsmen are showing increased responsibility to maintain and improve fish stocks, the services should be utilized.
This strategy can provide critical sea lamprey data to authorities, which otherwise, would not be available. According to Maclaren and Whitney (1985), field research must be adopted on a regular basis over the entire study area (Lake Huron), which will reduce the inadequacies in detecting change. The primary factors responsible for inadequacies in sea lamprey management is due to infrequent testing, sampling, and limited control stations.

6.4 Extend Control Development/Experimentation

Laboratory experimentation and development of future controls should be expanded in the future. Presently, extensive research is being done in the fields of biology, genetics, and chemistry, which can provide added potency for future management strategies against sea lamprey resurgence.

One possible avenue for investigation towards the development of future controls deals with analyzing sea lamprey populations along the Atlantic seaboard. Since this location marks the point of origin of these parasites, investigations could be made into possible natural predators or other controlling agents within this salt water body. Possibly, these controls can be modified and integrated within present lamprey programs for more effective control.

Present management schemes are designed to control sea lamprey populations in their larval stage within the river systems. Since lamprey numbers continue to persist in high numbers, authorities should research further controls in
regulating adult parasitic lamprey in open water bodies. This strategy could work in conjunction with river controls, and would offer a more effective component integrated into present lamprey management operations.

6.5 Increased Participation

Increased participation and communication at all levels of government, authoritative bodies, special interest groups (e.g., fishing clubs), and the general public is a vital element in the decision-making stages and program formulation.

Many cases in the past have created serious confrontations between government and societal groups dealing with the right to provide input (e.g., vital information). Often, public participation can result in further pertinent information to authorities which can determine a program's failure or success when applied in the field.

6.6 Increase Manpower

Increased manpower will allow a more efficient run of operations to be under the required regulations, and to ensure that all procedures are carried out properly, efficiently, and accurately. Overall, expanded control units with increased manpower to run them will allow authoritative bodies to analyze the entire spatial area of Lake Huron, coupled with more accurate monitoring and data collection from which to base their decision-making policies.
6.7 Develop New Sampling Design/Procedures

Internationally, both U.S. and Canada operate under similar procedures in sea lamprey management (e.g., chemical, biological, mechanical) controls. However, despite these efforts, lamprey numbers continue to remain high. Sampling procedures are also carried out in a similar fashion (e.g., use of weirs, dams, traps, commercial/sport fisheries) to collect data pertaining to sea lamprey populations and biological characteristics, yet statistics indicate highly variable counts.

The main reason for this is that certain locations per district are monitored infrequently, and that many areas are infrequently and consistently monitored because of insufficient time, manpower, as well as funding. Therefore, there must be some kind of standard design introduced to ensure accuracy of implementing procedures and sampling, which will reflect a more complete data framework to analyze.

6.8 Introduce Minimal Accepted Level of Lamprey Populations

In examining previous sets of data for analysis on sea lamprey populations, no set guideline was indicated as to an minimally accepted lamprey number for sampling. This is indicated from the compiled data previously mentioned in the study. Therefore, there should be an introduction of stringent controls and regulations governing the minimal number of sea lamprey captured per sampling period.
6.9 Establish an Inspectorate

To avoid any possible bias in monitoring, monitoring should be performed by an independent inspectorate to alleviate any outside change from this occurring. Also, outside independent inspectorates will ensure that data collected will be properly assessed in terms of any significant problem which may arise within the study area, and avoid any type of tokenism. Outside independent inspectorates will also ensure that data collected will be properly assessed in terms of any significant problem which may arise within the study area, and avoid any type of tokenism.

6.10 Outside Consultants

In order to maintain the efficiency of present sea lamprey operations, outside consultants in related expertise should be allowed to assess the internal operations of the program. The result will be an unbiased account of program organization designed to create perturbations within the system. This will allow all procedures, operations, etc. to run under the required guidelines and in the most efficient, effective manner attainable.

6.11 Non-structured Strategies

Based on the assumption that funding is reduced drastically to the point that these recommendations cannot be implemented, the following non-structured strategies can be pursued such as: (1) the public awareness about the problem of sea lamprey in the Great Lakes can be increased by distributing low-budget advertisements (e.g., pamphlets, flyers) which
will also aid in spreading this information by word of mouth; (2) seminars can also be organized by educated people on the problem and presented to the general public, which will also increase the awareness/knowledge of the problem; (3) a movement can also be generated utilizing scare tactics to upgrade the level of public awareness on the subject. For example, it can be stated that sea lamprey populations can expand to the point whereby all sport fish species are destroyed by lamprey, and thereby, eliminating the recreational sportfishing industry for millions of U.S./Canadian anglers; (4) a movement can also be created towards the development of the "destroy the sea lamprey fund" whereby the public can input funds to the cause of continued sea lamprey management; and (5) public interest groups/organizations (e.g., fish clubs) could form volunteer groups to help operate sea lamprey strategies in all respective districts.
Chapter VII

CONCLUSIONS

The major objective of the study is to investigate whether sea lamprey numbers have increased in Lake Huron. As indicated from the statistical findings, high sea lamprey populations remain a problem in several districts of the Lake Huron watershed. The U.S. side of Lake Huron has experienced two surges in lamprey numbers, from 1949-1951 and 1974-1986, indicating a present problem with lamprey populations despite ongoing control programs. Furthermore, these findings describe the characteristics of a lognormal distribution with periods of quiescence and resurgence. The Canadian side has undergone similar periods of lamprey surges and quiescence with the most recent period 1983-1986 indicating present problems with lamprey populations despite present controls.

Therefore, the null hypothesis (1) can be rejected, accepting the alternative hypothesis (1) which states that there is a resurgence of sea lamprey (*Petromyzon marinus*) in Lake Huron waters. It can also be inferred that sea lamprey resurgence is the result of ineffective control strategies and associated operations which have failed to limit sea lamprey populations from increasing. It is, therefore, nec-
essay to initiate the re-evaluation of present management practices, and analyze possible new strategies for more effective sea lamprey control.

Fish production data for selected deep-water species was analyzed for the period 1944-1986. Fish production statistics alone, indicate that fish production has not declined but increased for both U.S. and Canadian sides of Lake Huron. However, in order to determine this expansion of fish production, the ratio between sea lamprey numbers and fish production must be analyzed.

In the Canadian districts of Lake Huron, ratios ranged from a minimum of 1 sea lamprey to 56.0 kg of fish to a maximum of 1 sea lamprey to 3362.4 kg of fish (Table 3). Periods of low ratio values indicate that small amounts of fish are required to capture a sea lamprey, which occurred in Canadian waters in the mid 1940's - late 1960's, and in 1984. High ratio values indicate that large amounts of fish are required to capture a sea lamprey, which occurred in Canadian waters during the late 1950's, early-mid 1970's, and the early 1980's. The mean of the ratios is 1:715.1, of which, 10 years ranked above this mean and 23 years below the mean.

Generally, the Canadian waters of Lake Huron have recorded lower ratios for the last 3 years of data (1982-1984), indicating that more lamprey are being caught in smaller catches of fish.
In U.S. waters of Lake Huron, ratios ranged from a minimum of 1 lamprey to 10.02 kg of fish, to a maximum of 1 lamprey to 985.3 kg of fish (Table 4). Periods of low ratios were found to extend from the late 1940’s, early 1960’s, early 1970’s through 1984. High ratios were found to occur from the mid to late 1940’s, early 1960’s to early 1970’s. The calculated mean of these ratios is 1:226.5 kg, of which, 14 years ranked above this mean, and 25 years below the mean.

Overall, the U.S. side of Lake Huron has experienced lower ratios for the past 10 years (1974-1984), indicating that more lamprey are being caught in smaller catches (per kg) of fish.

Both U.S./Canadian statistics were combined to illustrate sea lamprey numbers to fish production ratios over the whole spatial watershed of Lake Huron. Low ratios occurred for the periods of the mid 1940’s, late 1960’s, mid 1960’s, early 1970’s, and mid 1970’s to 1984. Periods marked by high ratios extend from the mid 1940’s, late 1950’s, mid 1960’s, and mid 1970’s. The mean for all ratios is 1:303.2, of which, 15 years ranked above the mean, and 26 years ranked below the mean.

Overall, Lake Huron has experienced low ratios for the past 9 years, indicating that more sea lamprey are being captured in smaller catches of fish per kilogram.
Analyzing the spatial distribution of sea lamprey populations indicates that numbers range almost evenly in both sides of Lake Huron. However, U.S. statistics reveal higher numbers of sea lamprey catches than the Canadian side. It is therefore evident that U.S. management operations are run in a more efficient, effective manner than their Canadian counterparts. Thus, Canadian management operations must be expanded and intensified on a more militant scale to improve the sampling statistics of sea lamprey numbers throughout the Canadian districts.

Statistics indicate that more lamprey are caught in smaller harvests of fish. However, actual fish production statistics suggest increased harvests coupled with increased lamprey numbers. Therefore, the alternate hypothesis (2) can be rejected, accepting the null hypothesis (2) which states that there is not a decline in fish stocks in Lake Huron resulting from an increase in sea lamprey populations.

It can be inferred that increased fish production, despite increased sea lamprey numbers, can be attributed to increased technology in fishery hatcheries, stocking programs, and farms over the past decade. This field of technology has significantly upgraded the commercial and sport fisheries in the Great Lakes.

To date no limit has been set by authorities as a minimal by acceptable tolerable limit of sea lamprey. However, this limit can be identified by the ratio of fish production to
sea lamprey numbers. The lowest ratio calculated in Lake Huron is 1:7412.7 or 1 sea lamprey for every 7412.7 kg. Given this level, it is evident that both U.S. and Canadian authorities rank well below this level. Therefore, managerial operations must be intensified to reduce sea lamprey populations, and gain further control.

Steps must also be made to resolve the continuing dilemma of incomplete data collections and infrequent monitoring. However, these constraints present a major barrier to managers and decision-makers when formulating sea lamprey programs, because of limited knowledge regarding sea lamprey populations, distributions, and biological characteristics. Consequently, limited data input could also jeopardize the effectiveness of present/future strategies in sea lamprey management.

Despite these ongoing problems, the acting authorities, e.g., the Ministry of Natural Resources (provincial government), the U.S. Fish and Wildlife Department, and the Department of Fisheries and Oceans Canada (federal government) are making a concerted effort to alleviate these problems, and to improve the overall management of fish resources for both commercial and recreational purposes.

The Great Lakes fisheries is an important element to U.S. and Canadian economies. Therefore, it is imperative to pursue ongoing research to develop more effective measures for management strategies is vital in the future to improve and
preserve the Great Lakes fisheries. The sea lamprey \(\textit{Pteroniscus marinus}\) will always exist as a potential threat to fish habitats, thus it is essential to continually monitor and investigate lamprey populations. Once sea lamprey can be controlled to the specified limit (1:7412.7 or other accepted uniform levels) can our commercial and sport fishing industries be a consistent contributor to Ontario's economy.
Appendix A

CFPS CHANTRY CHINOOK CLASSIC FORM

<table>
<thead>
<tr>
<th>STATION</th>
<th>DATE</th>
<th>NAME OF ATTENDANT</th>
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<table>
<thead>
<tr>
<th>TICKET NO.</th>
<th>ENTRANT'S NAME</th>
<th>AGE</th>
<th>HOME TOWN</th>
<th>PHONE NO.</th>
<th>TIME ENTERED</th>
<th>SPECIES</th>
<th>WEIGHT</th>
<th>LURE USED</th>
<th>DID WE KEEP FISH</th>
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Appendix B

CFPS CHANTY CHINOOK CLASSIC - CHEEL CENSUS FORM

NOTE: A DRAW WILL BE MADE DAILY FROM ALL NAMES ON THIS SHEET FOR $100 WORTH OF LURES. FILL IN THIS CENSUS TO QUALIFY, EVEN IF YOU DIDN'T FISH.

<table>
<thead>
<tr>
<th>NAME &amp; TICKET NUMBER</th>
<th>HOME TOWN</th>
<th>TIME SPENT</th>
<th>NUMBER OF FISH CAUGHT:</th>
<th>NUMBER OF LAWFREY MARKED:</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>RAINBOW</td>
<td>BROWN</td>
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Appendix C

FEEDBACK CONTROL BIOLOGICAL SYSTEMS MODEL
Source: MODEL SYMBOLISM AFTER Odum, 1983.
INTERACTING ECOSYSTEM
LAKE HURON

MONITORING STAGE

NO CONTROLS
- NO CONTROLS LEADS TO CONTINUED AND POSSIBLY INCREASED PREDATION ON FISH STOCKS
- LAMPREY POPULATIONS ARE THEREFORE ALLOWED TO FLOURISH AND INCREASE IN NUMBER
- SPORT & COMMERCIAL FISHERMEN
- BOTH SPORT AND COMMERCIAL INDUSTRIES REDUCE FISH STOCKS FROM HARVESTS, WHICH CAN IN TURN, REDUCE LAMPREY PREY THAT COULD REDUCE LAMPREY NUMBERS
- NO DIRECT CONTROL IS PLACED ON LAMPREY NUMBERS FROM THIS PRACTICE
- CONTROLS (MECHANICAL)
- LAMPREY BARRIERS ARE RELATIVELY EFFECTIVE IN BLOCKING SPawning LAMPREY FROM MIGRATING FURTHER UPSTREAM TO THEIR SPawning EEDS
- REDUCES LAMPREY NUMBERS AND REDUCES PREDATION ON FISH STOCKS
- ELECTRIFIED WEIRS ARE VARIABLE IN THEIR SUCCESS IN CONTROLLING LAMPREY NUMBERS
- KILLS SPawning LAMPREY AS THEY TRY TO MIGRATE UPSTREAM TO THEIR SPawning EEDS
- REDUCES LAMPREY POPULATIONS, AND LOWERS THE PREDATION ON FISH STOCKS
- ATTRACTANTS/REPELLENTS
- ARE VALUABLE WHEN APPLIED IN CONJUNCTION WITH OTHER CONTROLS
- HAVE PRODUCED SIGNIFICANT RESULTS IN REGULATING SEA LAMPREY NUMBERS
- BIOLOGICAL
- ARE STILL IN THE DEVELOPMENTAL STAGES
- EXPERIMENTS TO DATE HAVE PROVEN INEFFECTIVE IN LAMPREY CONTROL
- GENETIC
- ARE FOUND TO BE EFFECTIVE TO CONTROL LAMPREY POPULATIONS WHEN INTEGRATED WITH OTHER CONTROL STRATEGIES (eg. STERILIZATION AND RELEASE PROGRAMS)
- CHEMICAL
- PRESENTLY, CHEMICAL CONTROLS HAVE PROVEN TO BE THE MOST EFFECTIVE IN REDUCING SEA LAMPREY POPULATIONS
- STATISTICS REVEAL THE MOST SIGNIFICANT DECLINE IN LAMPREY NUMBERS OVER ANY OTHER SINGLE CONTROL

NO CONTROLS
- THE ABSENCE OF CONTROLS LEADS TO INCREASING DISORDER WITHIN THE ECOSYSTEM OR (ENTROPY)
- CREATES POSITIVE FEED BACK SITUATION
- THIS SITUATION MUST BE AVOIDED SINCE IT DEPRESSES THE PURPOSE ESTABLISHING A DYNAMIC EQUILIBRIUM WITHIN THE AQUATIC ECOSYSTEM
- SPORT & COMMERCIAL FISHERMEN
- SPORT AND COMMERCIAL INDUSTRIES MAY DECAY CERTAIN FISH SPECIES IN TURN, COULD REDUCE LAMPREY NUMBERS
- THIS CREATES A NEGATIVE FEED BACK SITUATION
- PISH CATCHINGS MAY ALSO CAUSE LAMPREY TO SELECT OTHER FISH SPECIES TO PREDATE UPON (e.g. SPECIFIC PREDATION)
- THIS CREATES A POSITIVE FEED BACK SITUATION
- MECHANICAL CONTROLS
- BARRIERS
- BLOCKS LAMPREY FROM MIGRATING UPSTREAM HOWEVER, IS LIMIT EFFECTIVELY CONTROLLING THE UPSTREAM MOVEMENT (ex.1) IF ALLOWS LAMPREY TO MOVE AROUND DAM; 2) LAMPREY LATCH ONTO ORDER TO PASS THROUGH THE TUNA Dams WERE GIVEN A MAJOR ROLE IN CONTROLLING THE SUCCESS RATE OF LAMPREY NUMBERS
- IN 1959, BARRIERS WERE GIVEN A MAJOR ROLE IN CONTROLLING THE SUCCESS RATE OF LAMPREY NUMBERS
- ELECTRIFIED WEIRS
- PROVIDES LIMITED SUCCESS IN LAMPREY NUMBERS
- PRESENTS A POTENTIAL HAZARDOUS AQUATIC LIFE
- WEIRS CANNOT BE PLACED ON LOCATIONS, RELECTING THEIR APPLICABILITY
- IS EFFECTIVE IN LAMPREY CONTROL APPLIED IN AN INTEGRATIVE APPROACH WITH OTHER CONTROL STRATEGIES
- THIS INTEGRATIVE APPROACH ESTABLISHMENT OF A NEGATIVE SITUATION
- IS VALUABLE WHEN APPLIED TO THE SUCCESS RATE OF OTHER
<table>
<thead>
<tr>
<th>ASSESSMENT STAGE</th>
<th>DECISION STAGE</th>
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<tbody>
<tr>
<td><strong>LEADS WITHIN</strong></td>
<td><strong>THE ACTING AUTHORITATIVE BODY</strong></td>
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<td><strong>AVOIDED</strong></td>
<td><strong>MUST FORMULATE A RATIONAL</strong></td>
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<tr>
<td><strong>IMPOSED OR STATE OF AQUATIC MANAGEMENT SCHEME BASED ON THE</strong></td>
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<tr>
<td><strong>INDUSTRIES SPECIFIC COULD BE</strong></td>
<td><strong>SYSTEMS INPUTS, OUTPUTS, etc.</strong></td>
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<tr>
<td><strong>FEEDBACK</strong></td>
<td><strong>THIS SELECTED MANAGEMENT STRATEGY</strong></td>
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<td><strong>CAUSE</strong></td>
<td><strong>SHOULD REFLECT AN INTEGRATIVE</strong></td>
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<td><strong>ON</strong></td>
<td><strong>APPROACH GEARED TOWARDS SEA</strong></td>
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<tr>
<td><strong>FEEDBACK</strong></td>
<td><strong>LAMPREY MANAGEMENT, AND ESTABLISHING A DYNAMIC STATE OF EQUILIBRIUM WITHIN THE AQUATIC ECOSYSTEM</strong></td>
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<tr>
<td><strong>GRATING LIMITED IN</strong></td>
<td><strong>- IS AN EFFECTIVE CONTROL WHEN APPLIED</strong></td>
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<tr>
<td><strong>THEIR</strong></td>
<td><strong>- IN CONJUNCTION WITH OTHER STRATEGIES</strong></td>
</tr>
<tr>
<td>1) <strong>FLOODING</strong></td>
<td><strong>- CREATES A NEGATIVE FEEDBACK SITUATION</strong></td>
</tr>
<tr>
<td>2) <strong>AROUND THE</strong></td>
<td><strong>- CAN BE APPLIED IN AREAS WHERE OTHER</strong></td>
</tr>
<tr>
<td>3) <strong>ONTO FISH IN</strong></td>
<td><strong>- CONTROLS CANNOT BE IMPLEMENTED</strong></td>
</tr>
<tr>
<td><strong>THE DAM SYSTEM</strong></td>
<td><strong>- EXPENSIVE</strong></td>
</tr>
<tr>
<td><strong>CONTROL ACTS</strong></td>
<td><strong>- EXTENSIVE WATER TESTING MUST BE INITIATED BEFORE THIS CONTROL IS APPLIED</strong></td>
</tr>
<tr>
<td><strong>IN A MANNER</strong></td>
<td><strong>(e.g., TESTING FOR PH, VELOCITY OF WATER, DEPTH, etc.) IN ORDER TO DEFINE THE</strong></td>
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<td>GIVEN A FURTHER**</td>
<td><strong>REQUIRED DOSAGE</strong></td>
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<td>WHICH IS TO BE OF OTHER**</td>
<td><strong>- POSSIBILITY OF EFFECTING THE SURROUNDING AQUATIC LIFE</strong></td>
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<tr>
<td><strong>FEEDBACK SITUATION</strong></td>
<td><strong>GENETIC</strong></td>
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<td><strong>ROUTE OF OTHER</strong></td>
<td><strong>- STERILIZATION AND RELEASE PROGRAMS IN</strong></td>
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<td><strong>...</strong></td>
<td><strong>CONJUNCTION WITH OTHER PROGRAMS IS VERY EFFECTIVE IN LAMPREY CONTROL</strong></td>
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<tr>
<td><strong>IN CONTROLLING</strong></td>
<td><strong>- STERIL MALES PREVENT FEMALES FROM PRODUCING 1000’s OF POTENTIAL LAMPREY LARVAE</strong></td>
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<td><strong>HAZARD TO OTHER</strong></td>
<td><strong>- CREATES A NEGATIVE FEEDBACK SITUATION</strong></td>
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<td><strong>ON ALL RIVERS</strong></td>
<td><strong>- EXPENSIVE AND VERY TIME CONSUMING IN APPLICATION</strong></td>
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<td><strong>THEIR LIMITED</strong></td>
<td><strong>- RELEASED STERIL MALES STILL FEED ON THE FISH STOCKS</strong></td>
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<td><strong>CONTROL WHEN</strong></td>
<td><strong>- THIS ALLOWS A POSITIVE FEEDBACK SITUATION TO OCCUR</strong></td>
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<td><strong>...</strong></td>
<td><strong>BILOGICAL</strong></td>
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<td><strong>...</strong></td>
<td><strong>- IS STILL IN THE DEVELOPMENTAL STAGES</strong></td>
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<td><strong>...</strong></td>
<td><strong>- ALL EXPERIMENTS TO date, have failed to EFFECTIVELY CONTROL LAMPREY POPULATIONS</strong></td>
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<td><strong>...</strong></td>
<td><strong>- EXPENSIVE AND TIME CONSUMING</strong></td>
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<td><strong>...</strong></td>
<td><strong>- DEMANDS EXTENSIVE FUNDING AND PLANNING FOR IMPLEMENTATION</strong></td>
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<td><strong>CHEMICAL</strong></td>
<td><strong>...</strong></td>
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<td><strong>...</strong></td>
<td><strong>- IS THE MOST EFFECTIVE LAMPREY CONTROL TO DATE</strong></td>
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<td><strong>...</strong></td>
<td><strong>- SINCE THE 1950's, LAMPREY NUMBERS HAVE DECLINED AS MUCH AS 80% IN MANY WATERS HOSTING THIS PARASITE</strong></td>
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<td><strong>...</strong></td>
<td><strong>- CREATES A NEGATIVE FEEDBACK SITUATION</strong></td>
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<td><strong>...</strong></td>
<td><strong>- PRESENTS MINIMAL DAMAGE TO THE SURROUNDING AQUATIC LIFE</strong></td>
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<td><strong>...</strong></td>
<td><strong>- VERY EXPENSIVE</strong></td>
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<td><strong>...</strong></td>
<td><strong>- REQUIRES EXTENSIVE WATER TESTING PROCEDURES (BIO-ESSAY) BEFORE THIS CONTROL MEASURE CAN BE IMPLEMENTED</strong></td>
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<tr>
<td><strong>...</strong></td>
<td><strong>- T.P.M. AND BAYER 73 ARE USED IN A RATIO TO REDUCE COSTS BY AS MUCH AS 50%</strong></td>
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Appendix D

DEFINING TERMS USED IN MODEL EXPLANATION

**Input** - Refers to anything that is placed into something (e.g., inputs of the model include fish stocks, sea lamprey, sport and commercial fishermen, and sea lamprey controls).

**Output** - Refers to the quantity of material put out (e.g., the results of input interaction within the ecosystem of the model).

**Loop** - Refers to wraparound one or more times (e.g., positive and negative feedbacks).

**Ecosystem** - Refers to an energy driven complex consisting of a community of organisms, and their controlling environment.

**System** - Is a collection of objects and attributes consisting of components and variables and their interrelationships.

**Control System** - Is a process-response system which is significantly controlled by some form of intelligence (e.g., humans).

**Positive Feedback** - Involves the situation where an externally produced variation sets up a series of changes which has the effect of accelerating the effects of the original variation in the direction of the original change. If unchecked, this can lead to self-destruction in the system.

**Negative Feedback** - Involves situations where an externally produced variation sets up a series of changes which has the effect of damping down or stabilizing the effects of the original external variation.

**Dip Net** - Are designed into various shapes and models from materials such as metal, wood, and nylon fabrics. These devices are submerged into water bodies to trap certain aquatic life.
Portable Assessment Trap - Are constructed from various materials (e.g. wood, metal, screening, etc.) which are used to trap aquatic life for observation and scientific study.

Entropy - Is a measure of randomness of a system's organization. The state of the system may be thought of as the values of the system variables exhibited at a particular point in time, and their relative stability.

Dynamic Equilibrium - Is a state where the system variables are adjusted to a given level of input, producing a given level of output equal to in magnitude to the input rate.
REM: THIS SAS PROGRAM PLOTS 3 STACKED HISTOGRAMS DEALING WITH 6 DIFFERENT VARIABLES. DATA IS ENTERED AFTER LINE 7 AND TITLES, FOOTNOTES, AND NOTES CAN BE ENTERED AFTER PROC GCHART CALL.

/* EXEC SASAPS */
/* SYSSIN DD */
/* 12FT145X */
DATA USTRY;
  INPUT YEAR GENDER & PHLOT LENGTH & IEN WEIGHT & WT;
  FORMAT YEAR 8.
  TITLE1 H=1 F=XSWISS C=BLACK;
  TITLE2 H=1 F=XSWISS C=BLACK;
  TITLE3 H=1 F=XSWISS C=BLACK;
  TITLE4 H=1 F=XSWISS C=BLACK;
  FOOTNOTE H=1 F=XSWISS C=BLACK;
  SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE CNT.
  PROC GCHART DATA=USTRY;
  TITLE1 H=1 F=XSWISS C=BLACK;
  TITLE2 H=1 F=XSWISS C=BLACK;
  TITLE3 H=1 F=XSWISS C=BLACK;
  TITLE4 H=1 F=XSWISS C=BLACK;
  FOOTNOTE H=1 F=XSWISS C=BLACK;
  SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE CNT.
  PROC GCHART DATA=USTRY;
  TITLE1 H=1 F=XSWISS C=BLACK;
  TITLE2 H=1 F=XSWISS C=BLACK;
  TITLE3 H=1 F=XSWISS C=BLACK;
  TITLE4 H=1 F=XSWISS C=BLACK;
  FOOTNOTE H=1 F=XSWISS C=BLACK;
  SOURCE: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE CNT.
/*
REM: THIS SAS PROGRAM CHARTS STACKED HISTOGRAMS FOR THE VARIABLES
OF GENDER, LENGTH, WEIGHT, AND LAMPEY. DATA IS ENTERED AFTER
LINE 7, AND TITLES, ETC. CAN BE PLACED AFTER EACH PROC GCHART
COMMAND.
//TEST1 JOB (G169, QLZ2, 5), 'AK', CLASS=A
//EXEC SAS989
//SYSIN DC *
%TEK4010
DATA USTRY;
INPUT YEAR GENDER & PGTOT LENGTH & LEN WEIGHT & WT;
CARDS;
* PATTERN 1 V=10 C=BLACK;
* PATTERN 2 V=12 C=BLACK;
* TITLE1 H=1.2 F=ITALICT C=BLACK 'TEST';
* TITLE2 H=1.2 F=ITALICT C=BLACK 'HISTO';
* PROC GCHART DATA=USTRY;
* YEAR YEAR / SUGROUP=GENDER
* SUGROUP=PGTOT
* DISCRETE
* SPACE=0
* CAXIS=BLACK
* CTEXT=BLACK;
* TITLE1 H=1.2 F=ITALICT C=BLACK 'TEST';
* TITLE2 H=1.2 F=ITALICT C=BLACK 'HISTO';
* PROC GCHART DATA=USTRY;
* YEAR YEAR / SUGROUP=LENGTH
* SUGROUP=LEN
* DISCRETE
* SPACE=0
* CAXIS=BLACK
* CTEXT=BLACK;
* TITLE1 H=1.2 F=ITALICT C=BLACK 'TEST';
* TITLE2 H=1.2 F=ITALICT C=BLACK 'HISTO';
* PROC GCHART DATA=USTRY;
* YEAR YEAR / SUGROUP=WT
* SUGROUP=WT
* DISCRETE
* SPACE=0
* CAXIS=BLACK
* CTEXT=BLACK;
RE: THE SAS PROGRAM PLOTS 6 DIFFERENT GRAPHS WITH 6 SEPARATE VARIABLES. DATA IS ENTERED AFTER LINE 8, AND ALL OPTIONAL TITLES, FOOTNOTES, ETC. ARE INCLUDED AFTER LINE 293.

//TEST JOB (G180, QD2, E9), 'AK', CLASS=A
// EXEC SAS=55
// SYSTIN DD *
NEXT1453X
GCP*ICNS VPOS=50, HPCS=140;
DATA CANRAM;
  INPUT YEAR $ X1;
CARDS;
  PATTERN1 V=X2 C=BLACK;
  PATTERN2 V=R2 C=BLACK;
PROC GGRAPH DATA=CANRAM;
  TITLE1 H=1 P=XSWISS C=BLACK
  'COMPARISON BETWEEN FISH PRODUCTION AND LAMPREY';
  TITLE2 H=1 P=XSWISS C=BLACK
  'NUMBERS IN CANADIAN LAKE HURON WATERS';
  TITLE3 H=1 P=XSWISS C=BLACK
  'ALL DISTRICTS COMBINED FOR THE PERIOD';
  TITLE4 H=1 P=XSWISS C=BLACK
  '1944-1986';
  FCOUNT1 H=.6 P=XSWISS C=BLACK
  'SOURCE1: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE, ONT. 1986.';
  FCOUNT2 H=.6 P=XSWISS C=BLACK
  'SOURCE2: DATA FROM THE GREAT LAKES FISHERY COMMISSION, ANN ARBOR MICH. 1986.';
  PLOT X1*YEAR;
    SYMBOL1 L=1 C=BLACK I=JCIN;
PROC GGRAPH DATA=CTAFRO;
  PLOT Y1*YEAR;
    SYMBOL2 L=2 C=BLACK I=JCIN;
PROC GGRAPH DATA=USAERO;
  PLOT X2*YEAR;
    SYMBOL1 L=1 C=BLACK I=JCIN;
PROC GGRAPH DATA=COPIAM;
  TITLE1 H=1 P=XSWISS C=BLACK
  'COMPARISON BETWEEN FISH PRODUCTION AND LAMPREY';
  TITLE2 H=1 P=XSWISS C=BLACK
  'NUMBERS IN BOTH U.S./CAN. WATERS OF LAKE HURON';
  TITLE3 H=1 P=XSWISS C=BLACK
  'ALL DISTRICTS COMBINED FOR THE PERIOD';
  TITLE4 H=1 P=XSWISS C=BLACK
  '1944-1986';
  FCOUNT1 H=.6 P=XSWISS C=BLACK
  'SOURCE1: DATA FROM THE SEA LAMPREY CONTROL CENTER SAULT ST. MARIE, ONT. 1986.';
  FCOUNT2 H=.6 P=XSWISS C=BLACK
  'SOURCE2: DATA FROM THE GREAT LAKES FISHERY COMMISSION, ANN ARBOR MICH. 1986.';
  PLOT X3*YEAR;
    SYMBOL1 L=1 C=BLACK I=JCIN;
PROC GGRAPH DATA=COMFRO;
  PLOT Y3*YEAR;
    SYMBOL2 L=2 C=BLACK I=JCIN;
REM: THIS SAS PROGRAM IS DESIGNED TO CORRELATE TWO GROUPS OF DATA, 
(SEA LAMPEEY NUMBERS AND FISH PRODUCTION) FOR THE PERIOD 1944-
1996 INCLUSIVE. THE GROUPS WERE SEPARATED TO COMPARE THE U.S.
SIDE, THE CANADIAN SIDE, AND BOTH U.S./CAN. COMBINED. THE DATA
IS ENTERED AFTER LINE 5.
//ROCKY JOb (G180,0DZ), 'CAWAL1A', CLASS=A
// EXEC SAS924, REGION=600K
DATA:
INPUT YR X1-X6;
CARDS:
PROC CORR;
VAR X1-X6;
//
REM: THIS IS A SAS PROGRAM THAT SELECTIVELY PLCTS HISTOGRAMS. THE DATA IS ENTERED AFTER LINE 9, AND TITLES CAN BE MODIFIED TO CORRESPOND TO THE DATA IN LINES 26 TO 28.
//TEST1 JOB 'G190, QL2), 'AK', CLASS=A
//EXEC SAS855
//SYST 1453X
DATA USTRY:
  INPUT YEAR $ TOTAL;
  CARDS:
  PATTERN1 V=R2 C=BLACK;
  PATTERN2 V=R2 C=BLACK;
  TITLE1 H=1.2 F=TITALIC C=BLACK 'PARASITIC-PHASE SEA LAMBEY COLLECTED';
  TITLE2 H=1.2 F=TITALIC C=BLACK 'FROM COMMERCIAL FISHERMEN IN LAKE HURON';
  TITLE3 H=1.2 F=TITALIC C=BLACK 'H-1 1967-1986';
PROC GCHART DATA=USTRY:
  VBAR YEAR / SUMVAR=TOTAL
  SPACE=0
  CAXIS=BLACK
  CTEXT=BLACK;
//
REM: THIS SAS PROGRAM PLOTS A REgression CURVE FOR A SET OF
DATA (Eg. LAMPEY NUMBERS). DATA IS ENTERED AFTER LINE 8,
AND TITLES, ETC. ARE PLACED AFTER LINE 26. ALSO, 95_5%
CONFIDENCE INTERVAL LINES ARE PLOTTED AS WELL WITH THE DATA.
//TEST1 JOB G180, QE2), 'AK', CLASS=A
// EXEC SAS855
// SYSSIN DD *
%ZET1453X
DATA USTRY;
  INPUT TIME NUMBERS;
  CARDS;
  SYMBOL1 V=R2 C=ELACK;
  SYMBOL2 V=R2 C=ELACK;
  SYMBOL3 V=STAR I=RCCLM95 C=ELACK;
  TITLE1 H=1 P=XSWISS C=BLACK
  'REGRESSION OF PARASITIC-PHASE SEA LAMPEYS COLLECTED';
  TITLE2 H=1 P=XSWISS C=BLACK 'BY COMMERCIAL FISHERMAN IN LAKE HERON';
  TITLE3 H=1 P=XSWISS C=BLACK 'CAN./U.S. COMBINED 1967-1986';
PROC GGRAPH DATA=USTRY;
  PLOT NUMBERS*TIME=3 /
  CAXIS=ELACK
  CTEXT=ELACK;
//
REM: THIS FORTRAN PROGRAM IS DESIGNED TO CONVERT A ENTERED DATA FILE
FOR SAS TO PRODUCE STACKED HISTOGRAMS FOR WOUNDED/NONMOUNDED
FISH. LOOPS ARE USED FOR INITIATING THE INPUT/OUTPUT STATEMENTS
IN LINES 10/11, 13/17, 20/21. CAN MOST SPECIFY THE NUMBER OF
REGIONS IN THE DATASET AND HOW MANY YEARS OF DATA ARE PRESENT
IN EACH REGION.
// WOUND JOB (G180,Q12,10,10), 'FRANK J KUZNICK', CIASS=A
// EXEC WATPIV, REGIONS=300K
$JOB WATPIV

CALCULATE THE NUMBER WOUNDED FISH FOR EACH DISTRICT
PROVIDE A DATA SET FOR SAS HISTOGRAMS
CHARACTER NAME*80, DISTRI*4
INTEGER I, J, M, N(25), C, YEAR
REAL TOT, PER, WOU, NWOU
READ (5,*) M
READ (5,*) (N(I), I=1, M)
DO 50 J=1, M
   READ (5,*) NAME
   WRITE (6,90) NAME
50   CONTINUE
CONTINUE STOP
END

ENTRY
ENTRY
//
REM: THIS SAS PROGRAM CHARTS STACKED HISTOGRAMS FOR WOUNDED/
NONWOUNDED FISH. DATA IS ENTERED AFTER LINE 7, AND TITLES,
ETC. ARE PLACED AFTER LINE 9.
//TEST1 JOB 'R130231', 'AK', CLASS=A
//EXEC SAS855
//*TEK4010
DATA USTRY;
  INPUT YEAR SCAR $ PER TOTAL;
CARDS:
PATTERN1 V=A2 C=BLACK;
PATTERN2 V=R2 C=BLACK;
TITLE1 H=1.2 F=ITALIC C=BLACK 'TEST';
TITLE2 H=1.2 F=ITALIC C=BLACK 'HISTO';
PROC GCHART DATA=USTRY;
  VLBAR YEAR / SUBGROUP=SCAR
  SUMVAR=PER
  DISCRETE
  SPACE=0
  AXIS=BLACK
  CTEXT=BLACK;
  //
REM: THIS FORTRAN PROGRAM IS DESIGNED TO CONVERT A ENTERED DATA FILE FOR SAS TO PRODUCE STACKED HISTOGRAMS FOR WOUNDED/NONMOUNDED FISH. LOCFS ARE USED FOR INITIATING THE INPUT/OUTPUT STATEMENTS IN LINES 10, 13, 17, 20/21. ONE MUST SPECIFY THE NUMBER OF REGIONS IN THE DATASET AND HOW MANY YEARS OF DATA ARE PRESENT IN EACH REGION.

//WOUND JOB (G190, G1, 10, 10), 'FJANF J KU2NTK', CLASS=A
// EXEC WATPIV, REGION=300K
3JOB WATPIV
C CALCULATE THE NUMBER WCUNDED FISH FCR EACH DISTRICT
C PROVIDE A DATA SET FCR SAS HISTOGRAMS
INTEGER I, J, M (25), G, YEAR
REAL TOT, PER, WOU, NWCU
READ (5, *) M
READ (5, *) (N (I), I = 1, M)
DO 50 J = 1, M
READ (5, *) NAME
WRITE (6, 80) NAME
30 FORMAT (1, A80)
C = N (J)
DO 100 I = 1, C
READ (5, *) YEAR, PER, TOT
WCU = TOT * PER / 100
WOU = TOT - WCU
WRITE (6, 90) YEAR, NWOU, TOT
90 FORMAT (1, I4, ' WCUNDED', F8.2, 3X, F5.0)
95 FORMAT (1, I4, ' WCUNDED', F8.2, 3X, F5.0)
100 CONTINUE
50 CONTINUE
$ENTRY
$IESYS
//
REM: THIS SAS PROGRAM CHARTS STACKED HISTOGRAMS FOR WOUNDED/ NONWOUNDED FISH. DATA IS ENTERED AFTER LINE 7, AND TITLES, ETC. ARE PLACED AFTER LINE 9.
//TEST JOB "G130, QE2), 'AK', CLASS=A
// EXEC SAS8585
//SYSIN DD *
TEK4010
DATA USTRY:
INPUT REGION $ SCAR $ PER TOTAL;
CARDS:
PATTERN1 V=X2 C=BLACK;
PATTERN2 V=R2 C=BLACK;
TITLE1 H=1.2 F=ITALIC C=BLACK 'TEST';
TITLE2 H=1.2 F=ITALIC C=BLACK 'HISTO';
PROC GCHART DATA=USTRY;
VBAR REGION / SUBGROUP=SCAR
SUMVAR=PER
DISCRETE
SPACE=0
CAxis=BLACK
CTEXT=BLACK;
//
REM: THIS FORTRAN PROGRAM IS DESIGNED TO CONVERT A ENTERED DATA FILE
FOR SAS TO PRODUCE STACKED HISTOGRAMS FOR THE NUMBER OF SEA LAMPREY SAMPLED/NOT SAMPLED. LOCPS ARE USED FOR INITIATING THE INPUT/OUTPUT STATEMENTS IN LINES 10, 12, 13, 17, AND 20/21.
ONE MUST SPECIFY THE NUMBER OF REGIONS 5 YEARS IN THE DATASET.
// WOULD JOB (G180, QC2, 10, 10), 'FRANK J KUZNIK', CLASS=A
EXEC WATFIV, BEGIN=300K
$JOB WATFIV

C
C CALCULATE THE NUMBER WOUNDED FISH FOR EACH DISTRICT
C PROVIDE A DATA SET FOR SAS HISTOGRAMS
CHARACTER NAME*90, DISTRIBUTION*4
INTEGER J, M, N(25), C, YEAR, CAU, SAM
REAL TOT, PER, WOD, NWOD, EM, EP, NML, FML, MMW, FMW
READ (5, *) (M(I), I=1, *)
READ (5, *) (NAME(I), I=1, *)
DO 50 3=1, M
READ (5, *) NAME(3)
WRITE (6, 90) NAME
FORMAT(2, A30)
C=0
DO 100 I=1, 10
READ (5, *) YEAR, CAU, SAM, EM, EP, NML, FML, MMW, FMW
WRITE (6, 95) YEAR, CAU, SAM
WRITE (90, 100) YEAR, SAM
FORMAT(14, F8.2) KOTSAMELE, PE-2)
FORMAT(14, F8.2) SAMPLED, '8.2)
CONTINUE
CONTINUE
STOP
END
ENTRY
7
6
8
$SYS
REM: THIS SAS PROGRAM IS DESIGNED TO PLOT A HISTOGRAM CONTAINING 2 SETS OF DATA (E.G., LAMPEY SAMPLED/NCT SAMPLED, AND NUMBER). DATA IS ENTERED AFTER LINE 7, AND TITLES CAN BE MODIFIED TO EXPRESS THE DATA IN LINES 10 TO 19.

// TEST1 JOB (G18O, QE2) , 'AK', CLASS=A
// EXEC SASS5
// SYSPRINT DDS *
%TEK4010 DATA USTRY:
  INPUT YEAR $ LAMPEY $ PER;
CARDS:
PATTERN1 V=X2 C=BLACK;
PATTERN2 V=R2 C=BLACK;
TITLE1 H=1 F=XSWISS C=BLACK 'SPAWNING-PHASE ADULT SFA LAMPEY BIOLOGICAL DATA';
TITLE2 H=1 F=XSWISS C=BLACK ' (NUMBER CAUGHT/NUMBER SAMELED) BY EVALUATION';
TITLE3 H=1 F=XSWISS C=BLACK 'UNITS IN CANADIAN TRIBUTARIES OF LAKE HURON';
TITLE4 H=1 F=XSWISS C=BLACK 'ALL CANADIAN DISTRICTS 1977-1985';
PROC GCHART DATA=USTRY;
PCTNOTE1 H=.8 F=XSWISS C=ELACK 'SOURCE: DATA FROM THE SEA LAMPEY CONTROL CENTER SAULT ST. MARIE INT.';
VAR YEAR / SUBGROUP=LAMPEY SUMVAR=PER DISCRETE SPACE=C CAXIS=ELACK CTEXT=ELACK;
//
REM: THIS FORTRAN PROGRAM IS DESIGNED TO CONVERT A ENTERED DATA FILE FOR SAS TO PRODUCE STACKED HISTOGRAMS FOR MALE/FEMALE, MALE/ FEMALE LENGTH, MALE/FEMALE WEIGHT. LCOPS ARE USED FOR INITIATING THE INPUT/OUTPUT STATEMENTS IN LINES 10/11, 13, 17, AND 26/27. THE USER MUST SPECIFY THE NUMBER OF REGIONS & YEARS IN THE DATASET. // WOUND JOB 'G190, QD2, 10, 10', 'FRANK J KUHNR', CLASS=A // EXEC WATPIV, REGION=300K $#JOB WATPIV C C CALCULATE THE NUMBER WOUNDED FISH FOR EACH DISTRICT C PROVIDE A DATA SET FOR SAS HISTOGRAMS C CHARACTER NAME*80, DISTRICT*4 C INTEGER I, J, M, N(25), C, YEAR, CAU, SAM C REAL TOT, BED, BOU, N46U, FM, PF, MM, F7L, MMW, PWM C READ (5,*) M C READ (5,*) (N(I), I=1,M) C DO 50 J=1, M C READ (5,*) NAME C WRITE (6,80) NAME FORMA'T('l',A80) C C(3,100) DO 100 I=1,0 C READ (5,*) YEAR, CAU, SAM, FM, PF, MM, FML, MMW, PWM C WRITE (6,95) YEAR, C, FM, FML, MMW, PWM C WRITE (6,90) YEAR, FM, FML, PWM C FORMAT (I,14) 'FEMALE', F8.2, 'FEMALE-LENGTH', F8.2, C FORMAT (I,14) 'MALE', F8.2, 'MALE-LENGTH', F8.2, C CONTINUE STOP END $ENTRY $IESYS
BIBLIOGRAPHY


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