GREAT LAKES FISHERY COMMISSION

1993 Project Completion Report[1]

Metamorphosis: Biological Control for Sea Lampreys

by:

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Metamorphosis: Biological Control for Sea Lampreys

(Workshop sponsored by the Great Lakes Fishery Commission)

Principal's Residence
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Report to the Great Lakes Fishery Commission

by

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INTRODUCTION

The abundance of sea lampreys Petromyzon marinus in the Great Lakes has been partially controlled for over 30 years through the treatment of natal streams with selective toxicants. Although this program continues to be successful, there is increasing concern in the Great Lakes Fishery Commission (GLFC) at the near total reliance on toxicants. The GLFC and its control agents (U.S. Fish and Wildlife Service, Canada Department of Fisheries and Oceans) have been committed to a program of integrated pest management (IPM) since the 1970s (Smith and Tibbles 1980), and have added barrier dams to block adults on their upstream migration to spawn and the sterile-male-release technique to the control program. Until the effectiveness of these strategies can be measured, it is important to explore alternative approaches to controlling lamprey abundance in the Great Lakes.

The Control Theory Task Force at the Sea Lamprey International Symposium (SLIS), recognized more than a decade ago that a more thorough understanding of the environmental cues and hormonal controls of lamprey metamorphosis might be particularly relevant point of attack for providing new control methods (Lamsa et al. 1980). Since this report, there has been considerable progress in isolating and sequencing lamprey-specific hormones such as GnRH, insulin, somatostatin, and neuropeptide Y, and progress has been made in ascertaining the role of environmental factors, particularly temperature, in lamprey metamorphosis (e.g., Purvis 1980; Morman 1987; Youson et al. 1993). Recently, Holmes and Youson (1993) induced metamorphosis in sea lampreys using $KClO_4$, and anti-hyperthryroid drug.

The GLFC continues to search for other control methods that will be useful in an integrated pest management program to control sea lampreys in the Great Lakes. As part of this search, scientists from other disciplines are being encouraged to participate in workshops designed to develop fresh approaches and ideas. With this in mind, Prof. John Youson convened an evening workshop on metamorphosis in sea lampreys, bringing together 38 researchers and graduate students with expertise on metamorphosis or hormone regulation in marine invertebrates, insects, fishes, and amphibians, to discuss the latest information and techniques in their fields as it might be applied to lamprey control. The workshop was held at the Scarborough Campus of the University of Toronto, and was timed to take advantage of the fact that many of the researchers would be in Metropolitan Toronto to attend the XIIth International Congress of Comparative Endocrinology (ICCE), May 16-21, 1993, with some presenting papers at the ICCE Symposium on Metamorphosis.

Purpose and Organization of Workshop

The objectives of the workshop were threefold: (1) to determine what basic information on metamorphosis in lampreys is required; (2) to suggest relevant data and approaches to biological control of sea lampreys based on experiences with other organisms; and (3) to provide a list of priorities for future research on lamprey metamorphosis. The participants were introduced and asked to identify their particular area(s) of expertise as shown below.

Participants and Research Interests

1.	Ilya Adam Division of Life Sciences Scarborough Campus University of Toronto 1265 Military Trail Scarborough, Ontario M1C 1A4 Canada	Research: Blood serum proteins during lamprey metamorphosis.
2.	Dr. Burr G. Atkinson Molecular Genetics Unit Western Science Centre Department of Zoology University of Western Ontario London, Ontario N6A 5B7 Canada	Research: Thyroid hormones and amphibian metamorphosis; heat shock and heat shock genes.
3.	Dr. Eric Baehrecke Howard Hughes Medical Institute University of Utah Salt Lake City, Utah 84102 U.S.A.	Research: Steroid gene regulation in Drosophila as a model and other insects for comparative aspects; insect metamorphosis and development.
4.	Dr. Stefan Berking Zoologisches Institute Universitat Zu Koln Im Weyertal 119 5000 Koln 41 Germany	Research: Control of metamorphosis and pattern formation in Hydrozoa and some other animals.
5.	Dr. Dave Borst Department of Biological Sciences Illinois State University Normal, IL 61701 U.S.A.	Research: Hormone regulation of growth, development, and metamorphosis in arthropods, including crustaceans such as lobsters.
6.	Elizabeth Callery Department of Zoology University of Toronto Toronto, Ontario M5S 1A1 Canada	Research: Expression pattern of thyroid hormone receptor during development of Eleutherodactylus currui.

7. Sashko Damjanouski
Department of Zoology
University of Toronto
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Canada

Research: Role of extracellular matrix protein in Xenopus development.

8. Dr. Margaret Docker
Department of Fisheries and Oceans
Pacific Biological Station
Nanaimo, BC V9R 5K6
Canada

Research: Lamprey biology, particularly the role of environment in sex differentiation of larvae.

9. Dr. J.G. Eales
Department of Zoology
University of Manitoba
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Research: Fish thyroid; peripheral metabolism of thyroid hormones; T_3 regulation.

10. Dr. Rick Elinson
Department of Zoology
University of Toronto
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Canada

Research: Frog development without metamorphosis.

11. Dr. M.F. Filosa
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Research: Blood serum proteins in lampreys.

12. Dr. Martin Fitzpatrick
Department of Zoology
Oregon State University
Corvallis, OR 97331
U.S.A.

Research: Reproductive endocrinology of fish.

13. Dr. Valerie Anne Galton
Dartmouth Medical School
Department of Physiology
1 Medical Center Drive
Lebanon, NH 03756-0001
U.S.A.

Research: Mechanism of action of thyroid hormones in developing forms.

14. Dr. Aubrey Gorbman
Zoology Department NJ-15
University of Washington
Seattle, WA 98195
U.S.A.

Research: Metabolism of larval lampreys; subpharyngeal gland; distribution of GnRH in brain of lampreys; sex differentiation.

15. Dr. Tyrone B. Hayes
Department of Integrative Biology
University of California
Berkeley, CA 94720
U.S.A.

Research: Role of steroids in amphibian growth and development; growth, sex differentiation, and metamorphosis.

16. Julie Heinig
Division of Cardiovascular Research
Hospital for Sick Children
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Canada

Research: Role of pituitary hormones in lamprey metamorphosis.

17. Dr. John Holmes
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Research: Larval lamprey ecology; role of environmental factors in lamprey metamorphosis.

18. Dr. Yasuo Inui
National Research Institute of Aquaculture
Nansei
Watarai, Mie 516-01
Japan

Research: Endocrine control of flounder metamorphosis.

19. Dr. Jean Joss
School of Biological Sciences
MacQuarie University
Sydney, NSW 2109
Australia

Research: Pineal/pituitary involvement in lamprey metamorphosis.

20. Dr. Jane C. Kaltenback
Mount Holyoke College

Research: Amphibian metamorphosis; thyroid hormone, TRH, and controls of thyroid hormone.

21. Dr. Fred Keeley
Division of Cardiovascular Research
Research Institute
Hospital for Sick Children
Toronto, Ontario M5G 1X8
Canada

Research: Connective tissue biochemistry.

22. Dr. Hans Laufer
Department of Molecular and Cell Biology
University of Connecticut
75 North Eaglesville Road
Storrs, CT 06269-3125
U.S.A.

Research: Juvenile hormone in insects, crustaceans, and annelids.

23. Dr. John Leatherland
Department of Zoology
University of Guelph
Guelph, Ontario N1G 2W1
Canada

Research: Comparative endocrinology of growth, metabolism, and development of fish.

24. Bojan Lipicnik
Division of Life Sciences
Scarborough Campus
University of Toronto
1265 Military Trail
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Canada

Research: Serum thyroid hormone binding proteins in sea lampreys.

25. Luciano Marra
Department of Anatomy
University of Toronto
Toronto, Ontario M5S 1A1
Canada

Research: Corpuscles of Stannius in fish.

26. Dr. Maurice Ringuette
Department of Zoology
University of Toronto
Toronto, Ontario M5S 1A1
Canada

Research: Role of extracellular matrix protein in early embryonic development.

27. Paul Robson
Division of Cardovascular Research
Hospital for Sick Children
Toronto, Ontario M5G 1X8
Canada

Research: Gene expression for the cartilage protein lamprin during lamprey metamorphosis.

28. Dr. Carl B. Schreck
Oregon Cooperative Fishery Research Unit
U.S. Fish and Wildlife Service
104 J Nash Hall
Oregon State University
Corvallis, OR 97331-3803
U.S.A.

Research: Stress and reproductive endocrinology in fishes and juvenile development in salmonids.

29. Dr. Mark Sheridan
Department of Zoology
Regulatory Biosciences Center
North Dakota State University
Fargo, ND 58105-5517
U.S.A.

Research: Hormonal control of growth and metabolism in fish; endocrinology of salmonid smoltification and lamprey metamorphosis.

30. Dr. Stacia Sower
Department of Molecular Biology
University of New Hampshire
Durham, NH 03824
U.S.A.

Research: Neuroendocrinology and reproductive physiology of lampreys.

31. Dr. Jennifer Specker
Department of Zoology
University of Rhode Island
Kingston, RI 02881-0816
U.S.A.

Research: Early larval fish development, role of pituitary and thyroid glands.

32. Dr. Shintaro Suzuki
Department of Comparative Endocrinology
Institute of Endocrinology
Gunma University
Maebashi 371
Japan

Research: Endocrinology of fish metamorphosis, including lampreys.

33. Dr. Masatomo Tagawa
Department of Zoology
University of Rhode Island
Kingston, RI 02881-0816
U.S.A.

Research: Thyroid hormone in fish development, hormones in fish eggs.

34. Dr. James Truman
Department of Zoology
University of Washington
Seattle, WA 98195
U.S.A.

Research: Steroid control of insect metamorphosis.

35. Lori Wood
Division of Life Sciences
Scarborough Campus
University of Toronto
1265 Military Trail
Scarborough, Ontario M1C 1A4
Canada

Research: Role of heat shock proteins during metamorphosis in lampreys.

36. Dr. Glenda M. Wright
Atlantic Veterinary College
Department of Anatomy and Physiology
University of Prince Edward Island
Charlottetown, PEI C1A 4P3
Canada

Research: Cartilage development in lampreys.

37. Sister Mary L. Wright
Biology Department
Elms College
Chicopee, MA 01013
U.S.A.

Research: Amphibian developmental endocrinology and metamorphosis.

38. Dr. John Youson
Division of Life Sciences
Scarborough Campus
Unvirersity of Toronto
Scarborough, Ontario M1C 1A4
Canada

Research: Environmental and hormonal factors affecting lamprey metamorphosis; gene expression during metamorphosis.

The workshop was organized into three parts, consisting of two plenary sessions with discussions in working group between these sessions. In the first plenary session the invasion of the upper Great Lakes by sea lampreys, subsequent damage to fisheries, the life cycle, and current control techniques were briefly described by J. Youson and were followed by comments, questions and answers. With this basic information, the participants were divided into three groups, with a recorder, and asked to consider each of the workshop objectives. After about an hour of discussion, the groups were brought back for the final plenary session during which reports were presented outlining the discussion of each group. The plenary discussions are summarized in this report. The audio portion of these discussions were recorded and the tapes are available from J. Youson.

The three working groups, and the respective chairs (C) for each group are listed below.

V. Galton (C)	J. Eales (C)	J. Truman (C)
H. Laufer	M. Sheridan	Y. Inui
A. Gorbman	R. Elinson	J. Joss
G. Wright	S. Sower	M. Filosa
J. Leatherland	J. Specker	B. Atkinson
M. Tagawa	F. Keeley	S. Suzuki
M. Ringuette	M. Wright	J. Holmes
E. Baehrecke	J. Heinig	S. Berking
P. Robson	S. Damjanouski	L. Wood
B. Lipicnik	J. Kaltenback	E. Callery
T. Hayes		I. Adam
C. Schreck		M. Fitzpatrick

Background Information

At the present time sea lamprey abundance is out of control in northern Lake Huron. The problem relates to the presence of a large population in the St. Mary's River. This system is too large for effective control using current techniques, particularly lampricides. Because sea lampreys do not have a homing instinct, spawning animals have the potential to disperse widely from uncontrolled sources.

Sea lampreys probably entered the Great Lakes through the Hudson River system after the construction of the Erie Canal. Upstream movement from the Atlantic Ocean through the St. Lawrence River does not appear to have been a viable entry route. Construction of the Welland Canal provided access to the upper Great Lakes, with the first reports of lampreys in the upper Great Lakes appearring in 1938. Within a decade commercial fisheries were in serious trouble with drastic declines in catches of salmonines and coregonines in Lakes Huron, Michigan, and Superior. These declines were the result of lamprey predation, overfishing, and habitat destruction, particularly the loss of spawning habitat.

The sea lamprey life cycle consists of three phases: larval, parasitic, and adult. The larvae (ammocoetes) are blind, sedentary, filter-feeders. Ecologically, larval lampreys are not considered to be a problem in the Great Lakes ecosystem. At the end of the larval phase, which lasts 3 to 17 years in the Great Lakes, the animal undergoes a metamorphosis to the parasitic phase. During the parasitic phase the animals undergo tremendous growth as they are feeding primarily on the blood and body fluids of salmonines. After 12 to 18 months, sexual maturation begins, the animals migrate upstream, not necessarily their natal streams, spawn, and die.

Lampreys have one of two life history types: parasitic or non-parasitic. Paired species of parasitic and non-parasitic species exist for most genera of lampreys, except sea lampreys, for which there is no closely related non-parasitic species. The parasitic condition is believed to be more primitive than the paired non-parsitic life history type. Although paired parasitic and non-parasitic species are nearly indistinguishable morphologically and genetically, there are several important differences. Non-parasitic species are relatively small compared to parasitic species, they undergo minimal spawning migrations, they undergo sexual maturation by omitting the feeding period, and they are not perceived to be an ecological problem in the Great Lakes.

Three methods to control lamprey abundance were described.

1. Trapping. Adults are trapped at dams during their upstream migration to spawn. Some of the trapped animals are used in the sterile male release program (see below) and the rest are killed. This program is reasonably successful but highly labour-intensive.

2. Selective Toxicants. The application of two toxicants, TFM and Bayer 73, to natal streams to kill larval sea lampreys is the principal method of control. These chemicals are selective for larval lampreys but other fish species may be killed during a treatment if stressed because of high temperature, low oxygen, spawning, etc. Some reduction in invertebrate populations also occurs in treated streams but these declines are generally temporary due to reseeding from outside the stream and from untreated portions upstream. There is considerable pressure to reduce the amount of lampricide applied to streams. This in part is the reason underlying the search for alternate control techniques and this workshop.

3. Sterile Male Release Technique (SMRT). This program is relatively new, beginning about 2 years ago. Males captured in traps in streams known to have large spawning migrations are sterilized using the chemical bisazir. Bisazir is a mutagen of sperm, rendering them ineffective at fertilizing eggs. Sterilized males are released back into selected streams where they compete

with unsterilized males for females. Because the program is new, there is no documented evidence yet of its effects on population abundances in the target streams. Sterilization is a labour-intensive process, with most of the work occurring at the Hammond Bay Biological Station (HBBS). There are a large number of streams in the Great Lakes, not all of which can be treated with lampricide because they are too large, e.g., on the St. Mary's River. In these circumstances sterilization or alternate control methods can be used. Males are employed in the SMRT rather than femals because the male reproductive system is less complex than the female system, consequently it is a relatively simple process to sterilize males and make sure they go through their reproductive behavior. Also, males appear in streams before females, which aids in the collection of large numbers of animals for the SMRT. Applegate's (1950) studies indicated that one pair of sea lampreys spawn per nest but more recently multiple pairs have been observed in some nests in the Great Lakes region.

An example of one approach that may be useful to understanding metamorphosis in lampreys comes from work on the protein lamprin in F. Keeley's laboratory. Lamprin is a useful way to look at metamorphosis because (1) it comprises more than 50% by dry weight of the cartilage in the annular ring which supports the oral disk in parasitic phase animals, a structure crucial to the parasitic behavior of sea lampreys, and because (2) it appears to be unique to lampreys and is strongly upregulated at metmorphosis. The lamprin gene has been sequenced and work is underway on the regulatory sequences to determine which elements are involved in its upregulation at metamorphosis. These elements may be involved in initiating metamorphosis and so may provide a way of controlling lampreys.

With this background information, the participants were divided into three working groups and asked to address the objectives of the workshop. Participants were reminded that the goal of the GLFC is to produce an environmentally benign program to control sea lamprey abundance in the Great Lakes and that they should keep in mind the practicalities of new approaches.

Workshop Recommendations

The reports of each working group were discussed in the final plenary session of the evening. Most of the comments and recommendations addressed the first two objectives of the workshop. Since there was considerable consensus among the groups, we have summarized these deliberations below without specifically attributing comments to any particular group or individual.

1. Endocrine Profile. The entire endocrine profile of sea lampreys needs to be studied where it hasn't already been examined. In particular, more information on thyroxine metabolism (is the increase, decrease, or both components important to metamorphosis?), monoiodinase enzymes for converting T_4 to T_3, and thyroid receptors and their role in metamorphosis, is required. A better endocrine profile is needed before interference with metamorphosis can be considered in an alternative control scheme.

Two approaches that might provide information on the endocrine system were described.

(i) Compare streams in which there are considerable differences in the length of the larval period. The Big Garlic River was cited as a stream in which the larval period is particularly long. It was subsequently pointed out that the Big Garlic River does not represent a typical sea lamprey population in the Great Lakes. This was a unique experimental setup designed to determine, among other objectives, the age of metamorphosing animals. Some animals metamorphosed after five years whereas others metamorphosed much later (up to 18 years). Participants still felt this would be a good situation in which to investigate factors influencing the length of the larval period because of the great disparity observed.

(ii) Compare paired parasitic and non-parasitic species to determine why some species have the non-parasitic life history. This was a particularly uniform recommendation and created the most discussion. Morphologically and genetically paired parasitic and non-parasitic species are nearly identical, the main difference is in life history. There is a lamprey population on Vancouver Island, BC, Canada, that is predominately non-parasitic but occasionally gives rise to individuals that can feed parasitically, suggesting that there is little difference between the two life history types (Beamish 1987). Non-parasitic species mature sexually without feeding, suggesting that the appearance of sex hormones leads to degeneration of the gut. The workshop participants were pleased to hear that J. Youson, M. Docker, and S. Sower had recently began work on GnRH levels in the brain of non-parasitic lampreys. If this hormone is the stimulus that causes the gut to shrink, then it might provide a way of forcing sea lampreys to bypass feeding and be a useful control measure.

Using non-parasitic species as a model for sea lampreys has been discussed many times before this workshop. However, because there is no paired species for sea lampreys, the idea has not been followed up. Workshop participants felt strongly that, notwithstanding this difficulty, this comparative approach merits attention.

Some participants suggested that if the parasitic-non-parasitic comparison was useful, then a transgenic approach to control might be attempted. For example, sea lampreys in which the larval period was short and that passed through metamorphosis but do not feed parasitically could be bred and released. Hypothetically, these animals could outbreed normal animals because they would breed after a shorter period of time and they wouldn't be a problem in terms of parasitism of salmonines and coregonines. However, this scenario works best with r-selected species (fast growing, short lived) whereas lampreys are k-selected (relatively slow growing, long-lived). Consequently there was some doubt about the utility of this particular transgenic approach.

2. Condition Factor. Condition factor seems to be important for metamorphosis (see Youson et al. 1993) and relates to the deposition and mobilization of lipid reserves. More information on the hormones involved in lipid metabolism is important to understanding metamorphosis. There are interesting parallels with insects, in that many insect species have critical weights for metamorphosis. But the initiating stimulus for metamorphosis after an individual is at its proper size is not known.

3. Pituitary Hormones. Work on rats some years ago by Bakke in Seattle demonstrated that thyroid treatments of newborn rats disrupted the relationship of the hypothalamo-hypophyseal relationship in the young rats as they grew up. It might be worthwhile attacking lamprey metamorphosis at this point as well. Large numbers of eggs or embyros could be treated in the laboratory with substances suspected of altering the hypothalamo-hypophyseal relationship. If some active substance is found, rather than putting it in a stream, animals could be treated in the laboratory and released into the stream to compete with normal animals. Presumably these treated animals would be non-parasitic and stream-resident. The idea is to disrupt control of the pituitary gland by the hypothalamus.

4. Sterile Male Release Program. There is little information available so far concerning the effects of sterile male releases on progeny in a particular stream population. In particular, participants wanted to know if there is a 1:1 ratio or some multiplicative effect in terms of survival to spawning. Presumably it is higher than 1:1, that is more than one progeny from a particular spawner survives to spawn itself. Typically when sterile male releases are used to control insects the population is swamped with sterile males, probably 100:1 or more. This is clearly not being done with lampreys nor does it appear to be possible since the procedure is so labour-intensive. Consequently some concern was expressed about the efficacy of SMRT and it was suggested that a multiplicative factor was needed to have a real impact and that this could only be done through a female line in these circumstances.

5. Immune System. One of the main changes in teleosts and amphibians when they metamorphose occurs in the immune system. Although regulated by the endocrine system, some participants felt that the immune system may be more vital to allowing metamorphosis to proceed in an animal. Thus a comparative immunological approach might provide important information on metamorphosis in lampreys.

One suggestion raised by all groups was to develop consumer markets for lamprey products. For example, sea lampreys are protected in New Hampshire because one biological supply house nearly wiped the species out in its efforts to collect animals to supply anatomy laboratories. Lampreys are consumed locally in Japan. Most edible lampreys are species with long migration periods in which the adults become jaundiced and bile-pigment laden very slowly. In contrast, sea lampreys have a short migration period and build up extremely high levels of bilirubin and biliverdin in the skin and body tissues very quickly, rendering them unpalatable. If migrating animals were captured early in the run, then it might be a way to control abundance and be economically beneficial at the same time.

Due to the limited time for discussion (3 hours) and the fact that many individuals were learning about sea lampreys for the first time, few practical approaches that could be implemented immediately to control sea lampreys were suggested at the workshop. However, there was general agreement that metamorphosis was a good target period in the life cycle for alternate control methods. There are many ways to stop metamorphosis in other organisms but they all require putting substances into the water or injecting animals, both of which are highly labour-intensive. Until there is a more thorough understanding of all aspects of lamprey metamorphosis, the use of pheromones or some transgenic approach is only speculation.

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