

FOREWORD

Sea Lamprey Research: Balancing Basic and Applied Research, and Using Themes to Define Priorities

Charles C. Krueger^{1,*} and J. Ellen Marsden²

¹*Great Lakes Fishery Commission
2100 Commonwealth Boulevard, Suite 100
Ann Arbor, Michigan 48105*

²*Rubenstein School of Environment and Natural Resources
81 Carrigan Drive
University of Vermont
Burlington, Vermont 05405*

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INTRODUCTION

Sea lamprey (*Petromyzon marinus*) occupy a unique role in the ecology of the Great Lakes as a vertebrate parasite of other vertebrates. Because their favored prey in the Great Lakes is lake trout (*Salvelinus namaycush*) and other salmonids, sea lamprey are in direct competition with human uses of fisheries. The damage they caused to economically and ecologically important native fishes in the Great Lakes motivated ratification of an international Convention on Great Lakes Fisheries in 1954 and formation of the Great Lakes Fishery Commission (GLFC) in 1955 (Christie and Goddard 2003). The Commission was charged to “formulate and implement a comprehensive program” for the purpose of controlling sea lamprey populations in the Great Lakes. Initial control efforts focused on use of barriers and lamprey-specific piscicides that target sea lamprey at the larval stage. Within two decades, lamprey populations had significantly declined in each of the three upper Great Lakes (Superior, Michigan, Huron), and feral hatchery-origin lake trout were surviving to maturity. Two sea lamprey international symposia (SLIS I and II) were convened in 1979 and 2000 to review the state of sea lamprey science and management (Smith 1980, Jones *et al.* 2003). One of the more important con-

ceptual advances resulting from the first symposium was the adoption of integrated pest management strategies, originally developed for agricultural insect pest control, for sea lamprey management (Sawyer 1980, Davis *et al.* 1982). The symposium also yielded recommendations to improve chemical treatments, identify alternative methods of control, investigate impacts of lamprey predation on important fisheries, and conduct research to better understand the biology of sea lamprey. Advances in these areas, and progress in sea lamprey control in each of the lakes since 1979, were presented at SLIS II (Jones *et al.* 2003).

Much of the sea lamprey management program depends on a lampricide (TFM; 3-trifluoromethyl-4-nitrophenol) which targets lamprey ammocoetes in streams. An objective of the Commission, as described in their Strategic Vision (GLFC 2001), is to “accomplish at least 50% of sea lamprey suppression with alternative technologies while reducing TFM use by 20% through use of at least one new alternative-control method, and increased use of current methods such as sterile-male-release, trapping, and barrier deployment.” This objective has provided a broad statement of priority for the Commission’s research program, which supports research to improve current lamprey management strategies and to develop alternative control measures. In order to focus proposals on topical areas

*Corresponding author. E-mail: ckrueger@glfc.org

of research for the Commission's research program, five research theme papers were developed by members of the Sea Lamprey Research Board, committee, and task forces. Authors were requested by the Commission to write papers that provide a review of the status of knowledge about five research topics (assessment of sea lamprey populations, pheromones, barriers and traps, sterile-male release, and lampricides), and to pose critical questions and hypotheses important for the research program to address. This background work simplifies the investigators' task of writing research proposals because the extensive literature reviews and rationales normally required to establish the importance of hypotheses have been completed for these topic areas. Investigators simply need to cite and briefly summarize a theme paper in the background, rationale, and relevance sections of their research proposals. Additionally, theme papers help direct new researchers to focus their proposals onto specific important research questions within each theme area. Research projects outside the theme areas are also supported. Although most research supported by the Commission falls within one of the five theme-area topics, a significant percentage of the budget (~30%) is spent on other research topics.

This foreword provides a context for the theme papers by outlining the specific design elements of the Commission's research program, followed by a summary of the five research theme papers used to organize the program.

RESEARCH PROGRAM ELEMENTS

Research Linkages to Lamprey Management

Ensuring relevancy of the Sea Lamprey Research Program to the sea lamprey management (control) program is a priority of the Commission. Tensions often exist between research and management programs within an agency. Competition for funds can occur when perceptions exist that funds spent on research could be better used by management. Research programs can become irrelevant to management when the information needs of management are not communicated to the research community effectively or if research programs ignore priorities identified by management. Promoting communication among all interests is essential to reduce the potential for such tensions. To address this issue in the Sea Lamprey Research Program, both researchers and managers advise the research program; this joint advising was deemed an essential element to achieve effective communication be-

tween the research program and the sea lamprey control program.

The Commission adopted a strategy whereby both scientists and managers participate in coordinating sea lamprey research and management programs. As a part of that strategy, a board was established to lead the research program; the board includes a majority of members (> 60%) who are cross-appointed to topically relevant management committees within the Commission's sea lamprey control program. Management program representation comes from two high-level agency representatives (from Department of Fisheries and Oceans – Canada and the U.S. Fish and Wildlife Service) who conduct sea lamprey control on behalf of the Commission and who are required by Commission policy to be members of the research board. Similarly, several scientists on the research board are also members of management task forces that provide advice about sea lamprey management. The high proportion of cross appointments is intended to enhance understanding and communication between the research and management programs.

Achieving Balance within the Applied to Basic Research Continuum

The Commission's research program is intended to address the immediate information needs of the management program and also to develop the long-term science needed to operationalize new alternative measures for controlling sea lamprey. This dual purpose, however, can generate conflicts between researchers and managers. The long-term benefits of more "basic" research may not be balanced against the immediate benefits of "applied" research. For example, managers may only view immediately applicable research as relevant. A lack of recognition that long-term research has the potential to make great gains in promoting novel means to control sea lampreys exacerbates tensions within the "basic" and "applied" research conflict. Willingness to support long-term research requires acceptance that such research may only pay off in the long term and may have a higher risk of failure (i.e., results contain no operationally useful information). Alternatively, "pure science" researchers may view with disdain all forms of immediately applicable research, claim that applied research is "not science," and support only long-term basic science. Understanding the need for support of research that answers important near-term management questions is required if the research program is to fulfill its goals of meeting near-term research needs and en-

uring long-term success. Although discussion about the applied vs. basic research conflict often imply two discrete categories, the terms “basic” and “applied” really represent two ends of a research continuum.

Potential conflicts surrounding basic and applied research were addressed in part by the cross-appointment strategy (described earlier) used to promote communication. However, in addition the Commission has explicitly adopted a portfolio approach to meet near-term research needs, ensure long-term success, and balance risk elements. The research program was designed to support immediate, short-range, and long-range research projects, all three of which are managed together as a blended portfolio.

Immediate application research is regarded as low-risk research where results will clearly be applicable to the management program within one to three years. This type of research typically represents 20–40% of the program in terms of number of projects and funds. Examples of such projects include improving design of portable assessment sea lamprey traps and determining the mode of toxicity of lampricides.

Short-term application research is defined as medium risk in terms of the probability of providing valuable information to the Commission’s sea lamprey control program. Application of the research results from these projects is expected to occur in a 3 to 8-year time frame. Typically, these research projects make up the largest percentage (40–60%) of the Commission’s research program in terms of project numbers and cost. Research projects focused on understanding sea lamprey movement behavior and pheromone communication are examples of these short-term application research.

Long-term application research projects are those for which direct application to the management program may not be conceptualized at the time when the research is undertaken. Because the ultimate application of these projects is not always clear at their conception, long-term application research is inherently more risky in terms of the likelihood of providing useful information to the Commission’s sea lamprey control program. The time frame to application to the management program extends beyond eight years to 20 years or more. These projects are generally the fewest in number (10–20%) and yet can be significant in total percentage of the research program budget (20–40%). These research projects tend to be more expensive per project than the other two categories because

cutting-edge technologies are typically involved. Recent areas of focus have been investigations into the sea lamprey genome, neural mechanisms of pheromone communication, and steroidal control of sea lamprey reproduction.

The five papers that follow in this issue comprise the five research theme areas developed by the Sea Lamprey Research Board. Common to all of the theme papers is the task to “know thy enemy”—a belief that a better understanding of the basic biology of sea lamprey will enhance barrier design and trap success, improve assessment efficiency, and guide development of new lampricides or improved methods of lampricide application, and may lead to novel physiological or genetic manipulation technologies.

Members of the research board and individuals directly related to the control and assessment portions of the sea lamprey program developed the theme papers. One or two lead authors volunteered for each topic. The lead authors were free to secure additional co-authors as needed. Early drafts of the theme papers were presented to the research board; the board then discussed and provided comments to the authors, and authors then used this feedback to make their next revision. This process was completed over a 5-year period.

The papers suggest approaches and technology to use to investigate lampreys within each of the theme subject areas. For example, recent developments in underwater video equipment, radio-telemetry, and passive integrated transponder technologies have greatly improved the ability to track and observe lamprey movements in relation to stream flow, barriers, traps, and in the presence of pheromones. Below are short descriptions of each of the theme paper topics.

RESEARCH THEME PAPER TOPICS

Larval and Spawning Assessment

Efficient, effective use of all control technologies requires reliable information about larval and spawning populations of sea lamprey. For example, streams are prioritized for lampricide treatment based on assessment of larval densities and predicted metamorphosis of larvae. Methods for quantitative assessment of larval lamprey populations have been the focus of considerable development in recent years. The current standard protocol involves estimation of larval habitat area, larval densities at randomly selected plots, and size distribution of larvae (Slade *et al.* 2003). The point estimates of these

parameters yield considerable uncertainty, as measured by coefficients of variation in abundance estimates (Steeves *et al.* 2003, Hansen *et al.* 2003, Jones 2007). This has pointed to the need for methods for selecting streams for lampricide treatment that are robust to these uncertainties. In addition, better information is needed about larval substrate preferences (including lentic habitat in stream deltas), larval movements within streams, and variables that trigger metamorphosis. Post-treatment assessments, including mark-recapture, could provide valuable data on larval densities as well as success of treatments. Of particular importance to predicting metamorphosis is development of a reliable, validated method for assigning ages to larval sea lamprey. Parasitic (juvenile) phase lamprey living in the lakes are assessed through mark-recapture of recently metamorphosed larvae and parasitic life stages, observations by commercial fishermen, and inferences made about relative population abundance using wounding data from prey (e.g., wounds per 100 lake trout). Research is needed on post-attack mortality of host fish, differences in survival of parasites having different stream origins, and differences in damage potential among lamprey-producing streams. Assessment and interpretation of wounding data also need refinement. Whole-lake and individual stream estimates of spawning-run size are achieved using traps and mark-recapture techniques combined with regression modeling (Mullett *et al.* 2003). These estimates could be improved by expansion of these methods to more streams. Finally, a better understanding of mating systems, spawning habitat, sex ratios, and variables that affect recruitment would improve models used to assess efficacy of alternative control strategies such as sterile male releases (Bergstedt and Twohey 2007) and trapping (McLaughlin *et al.* 2007).

Pheromones

Pheromones have been used in insect pest management since the late 1800s (Howse *et al.* 1998), and their presence in lamprey (*Lampetra* and *Petromyzon*) was recognized as early as 1930 (Kleerekoper 1982, Fontain 1938). Two pheromones offer promise for use in sea lamprey control: a migratory pheromone produced by larvae that cues maturing lamprey to select streams suitable for larval rearing (Moore and Schleen 1980, Teeter 1980), and a sex pheromone produced by spermiating males that attracts females (Teeter 1980, Li *et al.* 2007). Both pheromones could potentially be

used to enhance trapping or distract migrating or spawning lamprey away from areas that are either difficult to treat with lampricides or offer poor egg or larval habitat (Li *et al.* 2007). Potential also exists to confuse adult lamprey by altering pheromone reception or creating a camouflage, antagonist, or disruptor. Field trials have recently confirmed that both pheromones can be used successfully to alter behavior of sea lamprey (Johnson *et al.* 2005, Siefkes *et al.* 2005, Wagner *et al.* 2006). Protocols have been developed to extract pheromones from water in which larvae or mature males are held. Subsequently, several of the active compounds that constitute each pheromone signal have been isolated and, in part, chemically characterized. Although progress has been made toward synthesizing both pheromones, development of an inexpensive method for synthesis remains a priority. Considerable work remains to characterize physiological and behavioral responses to pheromones, including ascertaining their ultimate role(s) in the sea lamprey mating system. Further understanding of the biosynthesis of pheromones may improve methods for extraction and suggest routes to alter or block pheromone release. Development of assays to measure pheromones in the field is critical for field trials and eventual application to control.

Progress in use of pheromones will benefit from further work on trapping, behavior, physiology, neurophysiology, and possibly genomics. In turn, trapping and the release of sterile males will be enhanced by use of pheromones.

Barriers and Traps

Barriers and traps were the first methods used to combat sea lamprey (McLaughlin *et al.* 2007). Barriers block access to spawning areas, and traps reduce the number of spawning sea lamprey that turn away from a barrier and seek alternate streams in which to spawn. Once lampricides were developed and applied widely, the use of traps was confined to assessing abundance of spawning-phase sea lamprey and providing males for the sterile-male release program. Barriers, however, still offer an alternative to the use of lampricides by reducing the area of streams available for lamprey spawning and larval rearing, and thereby reducing the area that must be chemically treated. While the concept of blocking streams is not new, sea lamprey barriers have evolved through several designs. Important research priorities for barriers include improving the efficiency of blocking, minimizing effects on non-

target fishes, and ensuring human safety. Important research priorities for traps include maximizing the attraction and retention of sea lampreys. Both control methods have motivated research into basic understanding of sea lamprey movement and behavior (McLaughlin *et al.* 2007).

Sterile-Male-Release and Genetic Alteration Techniques

The sterile-male-release program (SMRT), initiated in 1971, is based on theories associated with the use of sterilization in insect control (Knipling 1965). Spawning phase male sea lamprey are captured in stream traps, injected with the chemosterilant bisazir in a specialized facility, and released into a stream where they compete for females. Field trials began in Lake Superior in 1991, and were switched to the St. Marys River (a river virtually untreatable with chemical lampricides due to its size) in 1997. In combination with trapping of female lamprey, the overall percent reduction in reproduction potential achieved by SMRT averaged 81% (range = 71–92%) during 1999–2001 (Bergstedt and Twohey 2007). Nine criteria were established that would need to be met in order for the SMRT program to be considered successful; evaluation of progress toward meeting these criteria is still underway (Bergstedt and Twohey 2007). The method continues to be refined; optimal dosages and more efficient synthesis of bisazir, and a better assay for sterility, are needed to reduce costs and improve efficiency. Bisazir is costly and highly toxic, so development of alternative sterilization methods is sought; genetic alteration offers some promise in this direction. Female sterilization may also be a useful control method, but more research is needed to understand the short- and long-term effects of biasing sex ratios. Development of pheromone-based control techniques (Li *et al.* 2007) may enable enhancement of male attractiveness, thus increasing the effect of sterile males. Finally, acquisition of males for sterilization is a critical need of the SMRT program; therefore, exploration into alternative sources of males (trapping, Atlantic coast sources, culture) or use of females should be done.

Lampricides

Chemical control of sea lamprey began in 1958 with the use of the selective larval lampricide 3-trifluoromethyl-4-nitrophenol (TFM) in tributaries to

Lake Superior; by the 1960s, use of TFM was supplemented with niclosamide (Bayluscide®; McDonald and Kolar 2007). Currently, as many as 173 tributaries are treated on average once every 4 years, and the lampricides have reduced populations of spawning adults by as much as 92% (Christie and Goddard 2003). By the early 1990s, concerns about chemical cost and non-target effects prompted actions to reduce use of lampricides. An approximately 36% reduction in TFM use since the early 1990s has been achieved by reducing the number of streams treated, use of synergists (niclosamide), and through more efficient applications using improved pH/alkalinity models to predict toxicity (McDonald and Kolar 2007). Further reductions require additional study of the toxic action of the two lampricides, methods to increase treatment efficiency, and development of new lampricides. These studies will also further the goal of reducing non-target effects.

CONCLUSION

Our understanding of sea lamprey biology and prospects for control has progressed significantly since the first Sea Lamprey International Symposium held in 1979 (Smith 1980). The papers contained in this special issue summarize the state of knowledge in five key areas that represent the primary topical foci of the Great Lakes Fishery Commission's Sea Lamprey Research Program. Gaps in our knowledge, and suggested areas of future research, are outlined for each theme area. By using the theme papers to guide research priorities, supporting a mix of applied and basic research projects, and ensuring connections between scientists and managers, the Commission promotes a research program to meet both its short and long-term information needs.

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