BARRIER AND TRAPPING RESEARCH THEME UPDATE WORKSHOP PROCEEDINGS

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Prepared by the Barrier and Trapping Workshop Planning Committee:

Daniel Zielinski[1], Rob McLaughlin[2], Ted Treska[1], Carrie Baker[1], Scott Miehls[3], Matthew Symbal[4]

[1]Great Lakes Fishery Commission
[2]University of Guelph
[3]U.S. Geological Survey – Hammond Bay Biological Station
[4]U.S. Fish and Wildlife Service – Marquette Biological Station

T. Lawrence, GLFC

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Introduction

The Great Lakes Fishery Commission's sea lamprey (*Petromyzon marinus*) Barriers and Trapping research theme was formalized with a guiding document (McLaughlin et al., 2007) published in 2007 which highlighted thirteen research priorities and key information gaps. In June 2024, the Great Lakes Fishery Commission hosted a workshop to update the research priorities of the Sea Lamprey Barrier and Trapping Theme in Sault Ste. Marie, ON. Participants representing state, provincial, federal, and tribal managers, biologists, and researchers, along with experts from academia and industry, were invited to participate (Appendix A).

Workshop Goals and Desired Outcomes

The goals of the research theme update were to complete a progress review of the original research needs identified in McLaughlin et al. (2007) and to define barrier and trapping research needs to move the Sea Lamprey Control Program (SLCP) forward. Workshop discussions focused on what research needs must be addressed to truly advance the use of barriers and trapping in the SLCP and differentiating between overarching research needs and more specific priorities. Research needs were identified as broader themes that are not so narrow that the research program is contracting out the work (i.e., we want to bound the work, but not be too prescriptive). Research priorities are more specific and have more immediate requirements (i.e., we would like to see them addressed within the next 5 years). The result will be a Barrier and Trapping Theme synthesis paper that will guide research in the future.

Presentations

The two-day workshop began with a description of the workshop goals and presentations providing an overview of the research needs identified in the existing theme paper (McLaughlin et al. 2007), a review of metrics used to gauge success of barriers, traps, and fishways, and a synopsis of the past theme research at the basin and catchment scales. The sessions culminated in an assessment of the existing research needs and the development of recommendations for priorities to guide the Barrier and Trapping Theme into the future.

Review of 2007 barrier and trapping research theme – R. McLaughlin

The research strategy for the sea lamprey barrier and trapping theme identified in McLaughlin et al. (2007) was aimed at improving the effectiveness of barriers, traps, and fishways for controlling invasive sea lamprey populations, while simultaneously minimizing negative impacts on non-target fish species and ensuring human safety. The theme was intended to highlight the need for innovation and assessment in management options (e.g., fixed-crest, adjustable-crest, and electrical barriers, in addition to various fishway and trap designs), and linking them to desired outcomes like enhanced sea lamprey control, reduced non-target effects, and cost efficiency. The research theme identified 13 research needs including:

1. Prediction of the timing and magnitude of runs of sea lampreys and non-target species.
2. Assessment of the frequency and consequences of early- and late- season movements by sea lampreys.
3. Characterization of sea lamprey migration and dispersal behavior.
4. Determination of the passage needs for non-target fishes.
5. Behavior of sea lampreys and non-target species at barriers, traps, and fishways.
6. Hydraulic, hydrological, and biological criteria for effective sea lamprey barriers.
7. Attractors and distractors for sea lamprey and non-target species.
8. Novel funnel and trap configurations.
9. New and improved designs of barriers, traps, and fishways.
10. New spillway designs (block sea lamprey and improve safety).
11. Effectiveness of blocking and trapping sea lampreys.
12. Effectiveness of non-target fish passage.
13. Traditional/personal knowledge of sea lampreys and non-target fishes.

Brief review of metrics used to gauge success of barrier, traps, and fishways – M. Symbal, S. Miehls, & D. Zielinski

The second presentation provided an in-depth look at the use of barriers and traps to manage sea lamprey populations in the Great Lakes and the use of fishways to mitigate the impact of barriers on non-target species. The presentation also focused on the metrics used to gauge the success of these interventions. Overall, the SLCP metrics for success are based on the adult sea lamprey life stage and the damage they have done to lake trout (*Salvelinus namaycush*) populations in the Great Lakes. The key metrics include indices of Great Lakes adult sea lamprey populations, sea lamprey wounding rates on lake trout, and trends in lake trout populations. The metrics represent the "report card" used for all sea lamprey control activities in the Great Lakes.

Barriers remain the backbone of sea lamprey control throughout the Great Lakes by limiting infestation to a manageable area for lampricide treatment and preventing spawning sea lamprey access to difficult to treat head-water reaches. Barrier effectiveness is gauged by the presence or absence of sea lamprey recruitment (larvae) upstream and the ability of a barrier to withstand major flood events (20-25-year events) while maintaining the required 18-inch drop necessary to stop sea lamprey. Currently, the SLCP manages a network of over 460 barriers throughout the Great Lakes (Hrodey et al., 2021). The barriers are comprised of 77 structures built or modified specifically for sea lamprey control, while the remaining structures were all built for other purposes (e.g., flood control, hydropower, recreation, road crossings) but also assist with sea lamprey control (Zielinski et al., 2019).

Traps serve a dual purpose in the SLCP: 1) assessment of adult sea lamprey populations; and 2) control through capture and removal of pre-spawn adults (Miehls et al., 2020). Trapping effectiveness may be determined by trap efficiency (i.e., proportion of captured sea lamprey relative to the overall population estimate) and whether it provides a reliable population estimate or by the overall total catch and impact on the adult lamprey run in a given stream. Sea lamprey traps are typically installed at barriers to aid in maintenance and operation of the trap using existing infrastructure, as well as taking advantage of the natural congregation of sea lamprey downstream of barriers. Over the years, the SLCP has made efforts to integrate sea lamprey traps within fishways to exploit the sea lamprey's migration instincts. In certain cases, larval sea lamprey pedigree analysis (notably in streams where supplemental control methods,

such as the Supplementary Control, or SUPCON, program led by Nick Johnson), are being applied to determine the effectiveness of sea lamprey trapping.

Fishways, though not a control measure, provide a critical function in reducing the impact of sea lamprey barriers on native fish populations as the ultimate goal of sea lamprey control efforts is the enhancement of native Great Lakes fish populations. There are a wide variety of fishway designs used throughout the Great Lakes including (percent of all fishways): pool-and-weir systems (44%), vertical slot designs (19%), Denil structures (13%), nature-like passages (13%), and others such as eel ladders and fish lifts (11%) (Zielinski & Freiburger, 2021). The effectiveness of a fishway is typically defined by total fish passages over time. While a limited number of close examinations of fishway efficacies have uncovered a wide array of attraction (21-96%) and passage efficiency (0-88%) (Zielinski & Freiburger, 2021); the effectiveness of most fishways is not monitored systematically.

Overall, barriers, traps, and fishways need to be adapted to a diverse condition of streams. Targeted approaches will be necessary to improve the overall effectiveness of these tools, improve sea lamprey control, support the health of native fish populations, and maintain the ecological integrity of the Great Lakes.

Synopsis of past theme research, basin and tributary wide – R. McLaughlin

The barrier and trapping research theme, based on McLaughlin et al. (2007), aimed to link management options with specific outcomes which must balance controlling invasive sea lamprey populations while safeguarding the movement and sustainability of native fish species. The research theme sought to evaluate, improve, and implement various control tools including barriers, traps, and fishways.

Barriers are categorized into fixed, adjustable/seasonal, and electrical types, with each offering distinct advantages and challenges based on factors like cost, impact on non-target species, and overall effectiveness. Fishways, including pool-and-weir systems and those equipped with selective sorting mechanisms, are designed to allow native fish passage while impeding sea lampreys.

Trapping methods have also evolved since 2007, incorporating innovative approaches like pheromone-baited traps (Johnson et al., 2015) and push-pull techniques to enhance sea lamprey capture rates (Hume et al. 2020). For example, targeted trapping in the St. Marys River has been a focal area, illustrating the importance of location-specific strategies in achieving control objectives. Decision analysis frameworks have also been employed to optimize outcomes by balancing the effectiveness of blocking sea lampreys against the passage of non-target fish, alongside other considerations such as costs and habitat connectivity (Lewandoski et al., 2025).

A key takeaway from these efforts is the need for integrated management strategies that combine physical barriers, trapping systems, and chemical methods like TFM (lampricide) application. An integrated approach ensures that management goals, such as selective fish passage and improved productivity above barriers, are achievable. Lessons learned emphasize the importance of clearer management goals, the potential for productive collaboration among Rightsholders and shareholders, and the role of advanced technologies in refining and improving sea lamprey control measures. These efforts underscore the ongoing evolution of ecosystem management strategies to meet both environmental and biodiversity objectives.

Summary of status of 2007 research needs

Research addressing the 13 priorities over the past 20-years has been accomplished through a competitive funding program with research needs highlighted annually through the request for proposals announcements. Progress towards each research need at the pre-proposal, proposal, and publication levels has been unevenly distributed (**Figure 1**), with priorities #3, 5, 7, 9, and 11 receiving the most attention, while #2, 10, and 13 have received the least attention.

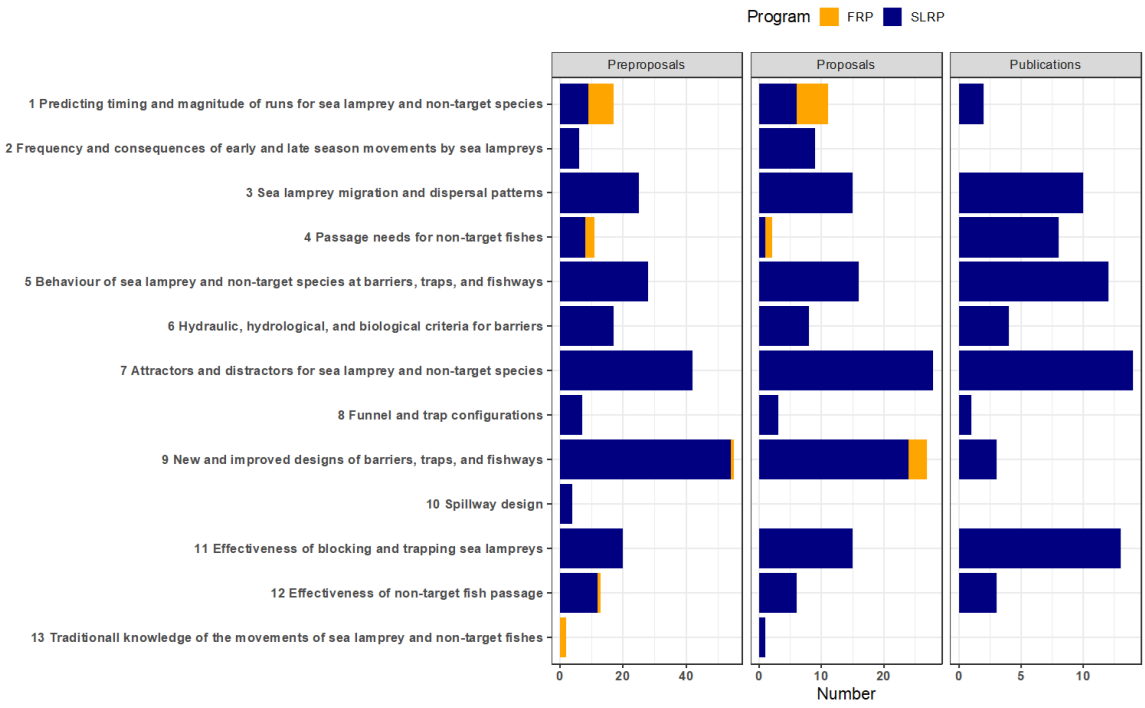

Figure 1. Summary of the number of pre-proposals, full proposals, and publications generated to address each barrier and trapping theme research needs between 2004-2024. A single pre-proposal, proposal, or publication can address more than one research need.

Facilitated Discussions

Topic 1 – Long-term success, basin wide

1.1: What does success look like over the next 20 years?

Overall, effective management of sea lamprey populations and support for ecosystem health requires sustained sea lamprey control efforts at or above current levels. The transition from research to practical implementation can be slow, possibly making the 20-year time frame for progress overly ambitious. A more incremental approach may be necessary to achieve realistic goals for sea lamprey control and the management of non-target species. Basin-wide success for the use of barriers and traps in the SLCP over the next 20 years will require emphasis on:

1. continued maintenance of critical barriers;
2. alignment of management objectives with changing values and improved understanding of sea lamprey and non-target fishes population dynamics; and
3. adaptive barrier and trapping designs that consider environmental changes, increase focus on sea lamprey and non-target fishes life-history, and are co-developed by managers and scientists.

Maintaining the ~500 most critical lower most barriers is crucial to sea lamprey control over the next two decades. This effort will require the inevitable removal of certain barriers and consistent engagement with Rightsholders, landowners, and multiple shareholders throughout the life of each barrier. It will be important to refurbish, maintain, or replace these critical barriers to ensure their effectiveness. Engaging with Rightsholders, barrier owners, and shareholders is key to maintaining the relevance of sea lamprey control and ensuring successful stream restoration. This involves fostering communication and including appropriate parties in the design phase of infrastructure projects. Additionally, enhancing decision-making tools and understanding the social and ecological contexts in which they are applied will improve their acceptance and effectiveness.

Management strategies must adapt to changing values and goals among agencies and the public. Improved communication and collaboration between Great Lakes and inland water managers will help align management goals. Specifically, a deeper understanding of stock-recruitment curves and lake-wide abundances of sea lamprey and non-target fishes will help identify potential production trade-offs. Better metrics for assessing lake-wide populations of sea lampreys and non-target species, as well as a basin-wide integration and assessment of supplemental controls, will help apply successful strategies more broadly. Finally, acknowledging and building upon successful partnerships will strengthen ongoing efforts and support effective management.

Adapting barriers and trapping designs and methods to be more flexible and responsive to changing environmental conditions and sea lamprey life cycle vulnerabilities is important. Collaboration between agents and researchers is vital for co-creating and refining tools and methods from inception to implementation. Future barrier designs must consider climate change and aim for solutions that can adapt to increased storm severity and other evolving conditions.

1.2: How should we measure our progress on meeting this vision? What are the ideal performance metrics?

Measuring the progress to achieve the updated vision of the barrier and trapping theme and the SLCP requires a comprehensive set of metrics that evaluate both individual barrier/trap/fishway performance and the broader impact on populations of sea lamprey and non-target species affected by sea lamprey

control. In addition to the existing set of metrics listed in the Presentations, several additional measures of progress and metrics, where possible, were identified for sea lamprey barriers, traps, and fishways.

Barriers – Effective barrier management for sea lamprey control requires a holistic approach that integrates biological, environmental, and operational considerations. One critical metric is the assessment of propagule pressure risk, which quantifies the number and reproductive potential of sea lamprey attempting to pass each barrier. Barrier effectiveness must also be measured by tracking escapement rates (i.e., sea lamprey which get past a barrier) and correlating these with larval densities upstream of the barrier to determine how well barriers are preventing reproduction. The frequency of lampricide treatments in streams could also serve as an indirect indicator of barrier performance, with more frequent treatments suggesting higher rates of sea lamprey passage or reproduction upstream. In addition to these direct control metrics, it will be important to monitor the health and genetic diversity of non-target fish species both above and below barriers to ensure that control efforts do not inadvertently harm native ecosystems. Economic efficiency is another key consideration, requiring the development of realistic long-term cost models to evaluate the sustainability of various control strategies. At a broader scale, lake-wide estimates of larval and adult sea lamprey populations help assess the cumulative impact of barriers and/or barrier removal on overall sea lamprey abundance.

To support strategic planning, an inventory of barriers is needed. The barrier inventory should be prioritized based on metrics that capture barrier vulnerability to climate change, flood risk, geomorphological stability, and ownership complexity. Integrating these metrics into a unified framework enables data-driven, adaptive management that balances ecological integrity, economic feasibility, and long-term effectiveness in controlling sea lamprey populations using barriers.

Traps – To enhance the role of trapping within the SLCP, a comprehensive understanding of trap effectiveness—defined by both opportunity and efficacy—is essential. Trapping opportunity involves more than just tracking the number of operational versus non-operational days; it also requires a detailed understanding of the spatial and temporal overlap between sea lamprey migration patterns and trapping operations. This includes documenting reasons for trap downtime and analyzing sea lamprey behavior and timing to ensure that traps are deployed when and where they are most likely to be effective. Quantifying the trapping process itself is equally important. Metrics such as approach, entry, and retention rates provide insight into why some traps perform better than others and help establish realistic efficiency targets. However, current population estimates based on adult lamprey trapping lack an independent means of verification. This gap limits the program's ability to determine whether adult trapping accurately reflects lake-wide parasitic abundance, a critical measure for evaluating control success. Spatial representation of trap data also needs improvement. Certain regions, such as the northern coast of Lake Superior, remain underrepresented in trapping efforts, introducing potential bias and uncertainty into population estimates. Addressing these spatial gaps could improve the reliability and comprehensiveness of trapping data.

Another significant limitation of the current program is the lack of focus on juvenile sea lampreys. Although this life stage is closest to the parasitic phase—the stage of greatest concern for fishery damage—it is not currently targeted for control or assessment. Incorporating juvenile trapping into the program could allow for earlier removal of sea lampreys, potentially reducing their impact before they reach the damaging parasitic stage.

Trapping has long been a foundational component of the sea lamprey control program, particularly for assessment purposes. However, it has lacked clearly defined management targets for efficacy and specific decision points for when trapping should be used as a control method. Establishing these targets and decision thresholds will enable managers to more effectively integrate trapping into the broader control strategy, ensuring that it contributes meaningfully to long-term population suppression and ecosystem protection.

Fishways – To improve management of non-target fishes, it is essential to understand what constitutes significant fish passage from biological, social, cultural, and genetic perspectives. Current knowledge regarding attraction and passage of non-target fishes is limited, with only anecdotal evidence from a few fishways. The health of populations both upstream and downstream, along with genetic introductions and reproductive contributions, must be considered beyond simple fish passage metrics (i.e., number of fishes passed). Evaluating functional and taxonomic diversity, and the genetic structure of populations above and below barriers, is crucial. Success in selectively sorting sea lampreys from non-target species should be measured, and the viability (e.g., stress and survival) of fish that pass barriers needs to be assessed. Clear documentation of agency goals and trade-offs between objectives such as improved fish passage, disease control, and invasive species management, is necessary. Downstream passage also requires effective metrics, and exploring the potential job creation (e.g., manual trap and sort) and economic benefits from alternative methods like trapping or fishways, as well as the social and investment aspects, should be part of the strategy.

1.3: What research is needed for us to identify, measure, integrate, and interpret these performance metrics?

Effective sea lamprey management requires the integration of human dimensions into the strategy. This includes understanding the values of Rightsholders and shareholders, evaluating engagement outcomes, and improving science communication between researchers and decision-makers. Implementing human dimensions metrics and enhancing communication about implementation metrics are crucial steps.

Understanding the biological dynamics of systems where barriers might be maintained, installed, or removed will be critical for evaluation and interpretation of existing metrics. For systems with barriers, assessment of post-passage fate of fish, both up- and down-stream, is essential for fish passage assessment, as passing through a barrier does not guarantee that the habitat can support them. Modernized fishway designs and evaluation approaches (i.e., time-to-event analysis) from sources outside the Great Lakes basin could be adopted. When installing barriers, quantifying sea lamprey and non-target distributions and movement will be critical to help identify ideal barrier locations to maximize control while minimizing negative effects. In scenarios involving dam removals and fishways, it will be important to better characterize the newly accessible habitat and the resulting productivity. Overall, decisions at the management scale should consider how much passage is needed to meet management goals and whether fish passage is needed everywhere or only at strategic points.

The impacts of climate change, particularly on geomorphology and flood frequency needs to be studied as it pertains to sea lamprey control and fish passage needs. In the context of climate change, barrier requirements may need re-evaluation to deal with more frequent high flow events. This involves assessing whether existing metrics, such as crest height and flood return intervals, are still appropriate and exploring supplemental tactics for barriers affected by seasonal flooding. Collaboration with partners to understand and communicate the impacts of different barrier designs, and improving stream mitigation strategies, are also important.

Research is needed to help prioritize the ~500 barriers critical to sea lamprey control based on factors like accessible habitat, barrier structural integrity, fish community and passage needs. Specifically, better understanding fish communities above and below barriers will allow quantification of propagule pressure (i.e., abundance of sea lamprey and non-targets alike attempting to pass a barrier) that will aid with prioritization. Further, barrier-specific strategies and value of various fish species should be evaluated using tools such as structured decision-making to better understand possible management decisions. Evaluating biases in current assessment methods and understanding tributary specific trapping efficiency can help prioritize and improve barrier management.

To improve trapping as a tool within the sea lamprey control program, a holistic approach considering the entire transition from lake to spawning redds for adults and from larval stream habitat to lake environment for juveniles is necessary. An independent means to gauge parasitic or adult sea lamprey populations at the lake level would reduce uncertainty around current abundance indices and may shed light on disconnects among the current metrics of program success. Program wide review of current logistic constraints (e.g., seasonal timing of operations), and new technologies would provide understanding of where and how the biggest improvements might be made. Further, better understanding of sea lamprey reproductive success relative to seasonal timing would inform operational influences. A cost-benefit analysis for targeting different life stages should be conducted including benefits currently not realized such as use of captured lamprey to inform natal origins, development of new economic models, or assessing the adequacy of lake trout marking rates as program success indicator.

1.4: What additional capacities are needed?

To advance sea lamprey management and research, it will be crucial to bring in new expertise and better define the process of moving from research results to practical implementation. The inclusion of experts in the social sciences, engineers with hydrologic and structural backgrounds, economists, and those with structured decision-making (SDM) expertise would be beneficial. Strategic discussions among partners should focus on transitioning from research to implementation, with a commitment to long-term resource allocation and funding. The process may need to start with an acknowledgement of the potential risks and learning opportunities involved with new tools. Addressing the process of implementing new tools may require larger budget initiatives to programs like Science Transfer or Technical Assistance Programs and multi-institutional teams. Exploring alternative funding models, such as bounty systems for improved sea lamprey capture or blockage, could bridge the gap between research and application. The GLFC may need to examine current barriers to technology development / implementation such as alternatives to the current research proposal documents (i.e., too hypothesis driven for design). For example, the outcome of a design proposal would be a field testable product and not a published manuscript. Additionally, the GLFC will need to examine potential exit strategies for long running (both successful and unsuccessful) research or product development projects. Knowing when and how to suspend or exit research programs that have received significant investments will be critical for resource allocation and future research prioritizations.

Investing in equipment for data collection, including hydrologic, climate, and fish species monitoring, is necessary for building better predictive models. USGS stream gauges are an ideal area for potential partnerships (i.e., could the GLFC be a cooperator) to secure long-term hydrologic data collection at sites with a risk of decommissioning. Improved infrastructure, maintenance, and data management through a centralized database would also support research efforts. Additionally, developing technologies that

could be implemented at different times of the year, and managing expectations regarding the time needed for results are important aspects of the strategy.

The GLFC could help foster new ideas / research and enhance program efficacy through enhanced knowledge exchange through cross-disciplinary training programs or rotating work details among control agents from different stations. Expanded outreach and communications plans could help build acceptance of non-traditional deliverables (e.g., products vs. scientific discovery) and program expectations. The plans should highlight research opportunities at the new GLFC facilities (e.g., USGS - Hammond Bay Biological Station, FishPass) to help broaden the network of researchers aware of GLFC research priorities. Leveraging local communities, including First Nation and tribal groups, to improve human resource capacity will be a vital component to program longevity. Employee recruitment and retention could be improved through more localized work (i.e., minimize distance to sites through development of a Lower Lakes Stations).

Additional capabilities to consider for the future include dedicated permit liaisons or specialists to stay ahead of permitting issues related to pheromones and other semiochemicals to ensure capacity is maintained, and developing lab capabilities for analyzing eDNA and storing genetic information. There is also a substantial amount of institutional knowledge on predictive modelling that could be tapped to improve beyond simple correlation of environmental factors. For example, improved modelling could help direct juvenile trapping strategies or timing of seasonal operation of barriers and traps. Finally, improving lentic sampling and lentic treatment options will support more comprehensive sea lamprey management.

Topic 2 – Improving success at the tributary scale to support long-term program success

2.1: What key uncertainties /challenges are currently limiting our ability to improve the blocking (barriers) and removal (trapping) of Sea Lamprey prior to reproduction, while minimizing impact on desirable fishes (fishways, physical sorting), at the tributary scale?

The transition from research to broader field testing presents significant challenges in sea lamprey management. Research conducted in controlled environments often faces difficulties when applied to variable field conditions. Furthermore, we must acknowledge that rivers are not replicates and techniques specific to one tributary may not necessarily be universally applicable. The urgency to apply research findings can also conflict with the natural inclination towards risk aversion, complicating the transition to practical use. These issues also relate to the delayed implementation of commercially developed solutions. Automatic sorting solutions, primarily relying on image recognition techniques, have become more prevalent in the commercial sector. An additional challenge for implementing such tools is a tendency for technology companies to over-sell on operational efficiency and efficacy. To address these challenges, leveraging outside resources and driving technological innovation, as seen with Great Lakes Acoustic Telemetry Observation System (GLATOS), is essential.

Implementing large field-scale research like SupCon or the bi-directional selective fish passage (FishPass) project presents numerous logistical challenges and spatial constraints. Permitting requirements can add a layer of complexity that may become more of a significant challenge than the inherent uncertainty of the research itself. Another major difficulty is the allocation of resources and coordination of efforts when field sites are located far from research stations. There has been a historical reluctance to undertake labor-intensive projects and engineered solutions. This reluctance often stems from the difficulty of forcing solutions that may require significant time, effort, and resources. Despite these challenges, significant learning has already taken place through the application of the control program and numerous

laboratory studies, and the next steps in research are likely to involve large field-scale projects that must be carefully managed to overcome the logistical and practical hurdles involved.

Assumptions about sea lamprey and non-target fish behavior pose significant challenges to controlling invasive sea lamprey populations. The uncertainty associated with these assumptions, particularly regarding movement and behavior at both barriers and traps, can hinder the effectiveness of current control methods. Currently, there is likely a misalignment between trap placement and areas of high sea lamprey activity, as barrier integrated traps are placed in areas opportunistic for staff access and but not for sea lamprey capture. Based on the wide spatial scale of the control program and limited time of trapping opportunities, the number of sea lamprey that never encounter a trap in the first place needs to be understood more thoroughly. Thus, future barriers should be specifically designed to create fishable areas tailored to sea lamprey, rather than relying on generalized designs. Even with improved placement and design, multiple traps will likely be required to meet any yet-to-be-determined trapping efficiency targets. Monitoring escapement past barriers in real time, including understanding the movement and environmental conditions at the time of escapement, is crucial for refining these strategies. Furthermore, differences between anadromous sea lamprey and lake-run populations raise questions about how transferable knowledge and technology are between these distinct populations, requiring population-specific approaches. Identifying where to focus efforts, such as targeting exploitable life stages, remains a key consideration to improve control measures.

The implementation of Artificial Intelligence (AI) and machine learning in sea lamprey control offers promising opportunities, but also requires a thoughtful approach to when and how these technologies are applied. One key consideration is understanding water levels, as AI and machine learning can analyze large datasets to identify patterns and predict optimal conditions for control measures. However, determining the appropriate contexts for their use remains crucial. The technology involved in automation can help streamline processes and improve efficiency, but leveraging AI also presents an opportunity to integrate new technology with existing infrastructure within the sea lamprey control program. This integration could enhance the overall effectiveness of control efforts, but it would require an initial investment in both infrastructure and skilled personnel to ensure successful implementation.

Understanding how climate change may impact sea lamprey control is critical for developing effective long-term management strategies. There is currently a lack of clarity about how shifting climate conditions will affect sea lamprey populations. Climate-related changes in land use and water quality could further complicate control efforts, making it harder to predict when and where to trap effectively. Specifically, understanding stream conditions that trigger juvenile sea lamprey to migrate downstream and predicting spawning run timing are essential for the operation of seasonal or adjustable barriers and traps. Shifts in migration timing becomes even more complex in the context of a changing climate, which could affect both early and late run lamprey, as discussed in the current theme paper. Addressing these uncertainties remains a key challenge in improving sea lamprey control in the face of climate change.

Increasing costs of dam maintenance present significant challenges for sea lamprey control efforts, particularly as ownership of these structures becomes more complex and maintenance becomes less consistent. The risk of dam failure increases if routine maintenance is deferred due to rising costs, which could undermine the effectiveness of barriers designed to control sea lamprey populations. Additionally, more stringent permitting requirements complicate the ability to maintain or upgrade these dams. Many dams lack a comprehensive Operation and Maintenance Plan, leaving them vulnerable to deterioration over time. Specifications used for barrier design, which were established under previous conditions, may

no longer be viable given the uncertainties of modern environmental changes, raising the question of whether barrier designs need to be revisited. Currently, there is an opportunity to address some of these challenges with new infrastructure funding, but this will require advanced planning and a substantial redesign of existing structures, which goes beyond simple adjustments or minor tinkering.

Finally, the last major uncertainty that could limit our ability to improve the blocking and removal of sea lamprey is the potential for shifts in the social license afforded to the GLFC for sea lamprey control. Relationships with other agencies add to this uncertainty, as there may be differing values regarding which species are prioritized. Understanding if and how the social license is changing will have a great impact on the acceptability of continuing current control practices as well as implementation of new technology or large-scale testing. Alternatively, changes to the social license may accelerate the development of new tactics that support approaches like automatic sorting to reduce handling time and stress on non-target fishes. Renewed efforts to strengthen inter-agency relationships may help to identify how compromises could be reached when there are differences in values.

2.2: Which of these uncertainties, if resolved, offers the greatest opportunity for improvement in Sea Lamprey control?

Climate Change – Seasonal changes, including variations in rainfall and water levels, significantly influence chances of upstream reproduction, trap placement, and the timing of out-migrating animals. Rising temperatures are altering treatment schedules and may affect the abundance, reproduction, and distribution of species, with some systems no longer producing sea lamprey while others start to support populations. This leads to questions surrounding the consistency of index streams as reliable indicators and broader demographic effects. Land use changes and anthropogenic stressors are leading to increased variability of in-stream conditions and possibly reshaping our understanding of barrier performance. While adjustable height barriers may accommodate changing hydraulic conditions, design criteria for any future barrier may need to be adapted to a changing climate. The potential resurgence of hydropower and other green technologies also poses implications for fisheries, including changes in species diversity and migration patterns. Economic research is needed to evaluate the cost-benefit of operating controls under these evolving conditions.

Barrier design and fishing – Uncertainties surrounding the spatial distribution and movement behavior of sea lamprey are highlighted by the need for improved trap designs and placement that are both publicly acceptable and more efficient. By studying successful traps and barrier designs, we could replicate effective features across different systems. The possibility of designing removable barriers that trap out-migrating sea lamprey could reduce the reliance on barriers blocking upstream migration. Additionally, there is a need for barriers that are easier to maintain, especially in remote locations, and strategically located to optimize sea lamprey control while supporting native fish spawning and social acceptance.

Movement near barriers and traps – To effectively manage sea lamprey, it is crucial to clearly characterize environmental conditions across the entire barrier portfolio, including a comprehensive barrier inventory with detailed mapping of streams and substrates. The program will need to identify areas for collaboration as some work on barrier and stream characterization is already underway. Understanding sea lamprey and non-target species behavior and timing in relation to traps is essential, since fish may not respond to navigational cues near barriers and traps as they would in open water or unrestricted stretches of a river. Reducing uncertainty around trap encounter probability and trap retention will be

critical to future trap designs and placement. Greater understanding of fish behavior could help identify possible negative feedbacks such as decreased movement due to manipulations or the impact of marking studies on behavior. There is potential to leverage commercial and recreational fishing technologies (i.e., sonar systems), though challenges like acoustic interference from dams exist. The potential for variations in movement behavior based on the maturity stage, or other covariates like those linked to climate change, should also be explored. Finally, ensuring that steps towards improving human safety at barriers and traps do not negatively impact non-target species or impair sea lamprey control efforts will benefit the longevity and acceptance of the program.

Research to field applications – The first uncertainty that should be addressed is to critically examine and characterize what, if any, real or perceived hurdles exist that hinder the transition between laboratory research to field-scale deployments. Adopting rapid development approaches analogous to those used in the technology sector could accelerate prototype development and implementation of field-scale experiments. The GLFC research boards may need to adapt programs for management-level experiments, balancing the controlled conditions of lab studies with the complexities of fieldwork. Effective communication and collaboration with the right researchers and agents are critical, as is acknowledging that there may not be a single solution to the challenges faced. Overcoming systemic barriers in academia, like the "publish or perish" mindset, and increasing risk tolerance among decision-makers could foster innovation. Success could be redefined to include incremental progress, with transparency in decision-making processes and a thoughtful approach to team composition for large-scale projects. Integrating AI and diversifying expertise in fields like computer science and machine learning could be transformative, envisioning new technologies like telemetry-based monitoring systems, aerial drones, and GIS tech for site mapping; however, hurdles such as funding, training, and management support need to be addressed. Effective data management, like the GLATOS model, and expert guidance on when and how to use technology are also crucial. The SupCon project highlights the importance of strategic implementation, suggesting that success in large-scale fieldwork requires a unique skill set, careful team selection, and the flexibility to adapt over the long term.

2.3: What looming uncertainties (habitat, climate, and social changes), could limit the effectiveness of barriers, traps, and fishways at the tributary level?

The challenges of managing sea lamprey control are multifaceted, with possible funding cuts and shifting public support complicating efforts. Political changes, emerging invasive species, and new fish health concerns further strain resources. These challenges are exacerbated by the loss of site access, staffing shortages, and reduced acceptance of application of lampricides, which may increase reliance on barriers and trapping. Additionally, there is a growing concern that current control techniques could drive evolutionary resistance in sea lamprey. While potentially beneficial, new technologies like AI and green energy initiatives, could be disruptive to the sea lamprey control program in currently unknown ways and require careful planning to ensure fish passage and control mechanisms remain effective. Social and ecological factors also play significant roles. Changes in public perception, shifting demographics, and the rapid spread of disinformation could impact support for current control measures. Issues like animal welfare and Indigenous values challenge the ethics of current practices, while the potential re-invasion from the Atlantic side and new pollutants threaten to undermine progress. The need for transparency, effective communication, and adaptive management is critical as the program navigates these complex and evolving challenges.

Status of 2007 research theme

Attendees were asked to vote (Red, Yellow, Green) on whether current research topics are relevant for the next 20 years (**Table 1**). Where modifications or questions were raised, the specific notes were recorded.

Table 1. Summary of attendee votes on relevance of current research needs. Green indicates high relevance, Red indicates low relevance, and Yellow indicates indecision or need for modification.

Research Topic	Score	Notes
1. Prediction of the timing and magnitude of runs of sea lampreys and non-target species	Green	NA
2. Assessment of the frequency and consequences of early and late season movements by sea lampreys	Green	NA
3. Characterization of sea lamprey migration and dispersal behavior	Green	NA
4. Determination of the passage needs for non-target fishes	Green	Is the SLCP responsible for this?
5. Behavior of sea lamprey and non-targets at barriers, traps, and fishways	Green	NA
6. Hydraulic, hydrological and biological criteria for effective barriers	Green	Modification: add trapping, add characteristics of good traps, and fishways
7. Attractors and distractors for sea lamprey and non-target species	Yellow	Why so much research with little change to management? What about transfer to application? Combinations are baked into FishPass and SupCon Do not want to discount new ideas This is still related to trap encounter rates which is still a key need
8. Novel funnel and trap configurations	Green	NA
9. New and improved designs of barriers, traps and fishways	Green	Combine with #6 Need to distinguish between barrier integrated traps and other traps
10. New spillway designs (block sea lamprey and improve safety)	Green	Combine with ##6 & #9 This is a design criterion for barriers.
11. Effectiveness of blocking and trapping sea lamprey	Green	Include population level impacts

		Could be at the individual tributary level up to whole lake level Evaluation of how things work
12. Effectiveness of non-target fish passage	Yellow	See #4
13. Traditional/personal knowledge of sea lamprey and non-target fishes	Yellow	Did not previously include Indigenous knowledge Traditional fishing knowledge of lamprey in native regions Why wouldn't this be inherently incorporated into the other research needs? This is a need for developing a process for documenting tinkering internally. This is an SOP not a research proposal. Shift focus to Indigenous knowledge and traditional fishing knowledge rather than the programmatic (this was not agreed upon in the group). Remove as is.

Reflections / Parking Lot

1.1. What does success look like over the next 20 years?

- Finding new vulnerabilities (life-stages?) for control efforts
- Identify natal origin adult of sea lamprey
- At least 1 "invisible" barrier on a major river on each lake that selectively passes important non-targets

1.2. How should we measure progress towards success?

- Genetics to detect escapement
  - Pedigree analysis
  - Understand population
- Need metric for social science components for all these (barriers/traps/fishways)
  - i.e. improving acceptability of programs

1.3. What research is needed for us to identify/measure/integrate or interpret performance metrics?

- Seeding traps with caged sea lamprey to see if having sea lamprey already in the trap will be more attractive
- Linkages between recreation benefits and economic valuation
  - Economic valuation of ecosystem services
  - To help inform trade offs
- Gene drives
  - E.g. sex chromosome destruction = single sex population
  - turn off smell so adults don't optimize migration
- Mussels
  - Better understanding the implications of barrier/no barrier to freshwater mussel and host fish populations

1.4. Additional capacities needed to support research

- Logistics training and expertise
  - "military-level" capacity to quickly adapt, flex, and deploy resources
- Transfer of knowledge from those experienced people leaving sea lamprey control
  - Interviews and documenting experience of control
- Commitment to increased outreach and education
  - improved social license
- Remote sensing loggers for temperature, water level and other parameters
- Extending seasonal employment to retain people
- Building and maintaining collaboration/relationships with tribes and First Nations
  - Will/can lead to productive research relationships?

Next Steps

A research theme synthesis paper summarizing the progress made since the 2007 barrier and trapping research theme and highlighting research areas to prioritize for the future will be developed. A draft list of updated research priorities will be distributed to the workshop participants in 2025, and later submitted to the Sea Lamprey Control Board to formally accept.

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Appendix A: Attendees list (Affiliation)

Fraser Neave (DFO)
Tonia Van Kempen (DFO)
Pete Hrodey (FWS)
Jeff Jolley (MIDNR)
Michael Wagner (MSU)
Anne Scott (MSU)
Carrie Baker (GLFC)
Ted Treska (GLFC)
Heather Dawson (UM-Flint)
Dan Zielinski (GLFC)
Kevin Mann (FWS)
Scott Miehls (USGS)
Hannah Bashore (USACE)
Kevin Meyer (USACE)
Carrie Link (UMESC)
Candace Griffin (MSU)
Sam Hultberg (FWS)
Nick Johnson (USGS)
Ryan Booth (DFO)
Kevin Letsin (FWS)
Mike Siefkes (GLFC)
Jess Barber (FWS)
Bruce Morrision (DFO)
Dave Gonder (OMNRF)
Jess Ives (GLFC)
Gale Bravener (DFO)
Matt Symbal (FWS)
Greg Allen (Verdantas – Alden Lab)
Deven Nicholson (U. of Guelph)
Alex Duncan (UBC)
Juliana Pantea (U. of Guelph)
Rob McLaughlin (U. of Guelph)