Journal of Great Lakes Research 47 (2021) S1–S10

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/ijglr

Commentary

Foreword: Control and Conservation of Lampreys Beyond 2020 - Proceedings from the 3rd Sea Lamprey International Symposium (SLIS III) ☆

Robert McLaughlin [a,*], Jean V. Adams [b], Pedro R. Almeida [c,d], Jessica Barber [e], Dale P. Burkett [f], Margaret F. Docker [g], Nicholas S. Johnson [h], Mary L. Moser [i], Andrew M. Muir [f], Donald L. Pereira [j], Michael J. Siefkes [f], Todd B. Steeves [k], Michael P. Wilkie [l]

[a] Department of Integrative Biology, University of Guelph, Guelph, ON N1G 2W1, Canada
[b] US Geological Survey - Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI 48105, USA
[c] University of Évora, School of Sciences and Technology, Department of Biology, Largo dos Colegiais 2, 7004-516 Évora, Portugal
[d] MARE - Marine and Environmental Sciences Centre, Largo dos Colegiais 2, 7004-516 Évora, Portugal
[e] U.S. Fish and Wildlife Service, Marquette Biological Station, 1095 Cornerstone Drive, Marquette, MI 49855, USA
[f] Great Lakes Fishery Commission, 2200 Commonwealth Blvd., Suite 100, Ann Arbor, MI 48105, USA
[g] Department of Biological Sciences, University of Manitoba, Winnipeg, MB R3T 2N2, Canada
[h] U.S. Geological Survey, Great Lakes Science Center, Hammond Bay Biological Station, 11188 Ray Road, Millersburg, MI 49759, USA
[i] Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Boulevard East, Seattle WA 98112, USA
[j] 15318 Afton Hills Ct. S., Afton, MN 55001 USA
[k] Department of Fisheries and Oceans, 1219 Queen Street East, Sault Ste Marie, ON P6A 2E5 Canada
[l] Department of Biology and Laurier Institute for Water Science, Wilfrid Laurier University, Waterloo, Ontario N2L 3C5, Canada

Introduction

The extensive and varied ways that human actions are changing environments and altering biodiversity are heightening the need to review natural resource management programs to demonstrate that intended benefits are being achieved and to identify program improvements. Such reviews can be challenging for at least three reasons. First, management programs can be complex, implementing multiple management actions and involving multiple agencies, or divisions and participants within agencies. Second, management programs need to adapt to the environmental, social, and political changes that can present new challenges and to the scientific, technological, and operational changes that can offer new solutions to these challenges. Third, a program's success, continued relevance, and directions for improvement can be evaluated and documented in a variety of ways. Identifying which methods to use for a specific program and implementing them are daunting tasks.

The program controlling invasive sea lamprey (*Petromyzon marinus* L.) in the Laurentian Great Lakes is one of the most ambitious, intensive, and spatially extensive efforts ever attempted to control an invasive vertebrate. The program is overseen by the Great Lakes Fishery Commission (Commission), implemented by Fisheries and Oceans Canada and the U.S. Fish and Wildlife Service, with consultation and participation with other provincial and state agencies, and Indigenous rights holders throughout the Great Lakes basin. For over 60 years, the control program has relied on in-stream barriers to restrict the number and extent of tributary kilometers of spawning habitat where sea lamprey can reproduce and on recurrent application of chemical lampricides to kill larval sea lamprey in the tributary stretches accessible to sea lamprey. However, the control program has also been dynamic as the Commission strives to deliver a program that is scientifically and economically defensible and socially acceptable. Ongoing efforts aim to improve barrier designs (McLaughlin et al., 2007; Zielinski et al., 2019) and lampricide use (McDonald and Kolar, 2007; Wilkie et al., 2019) to maintain effective sea lamprey control while minimizing costs and unwanted effects on non-target species, and to develop and implement new control tools, such as trapping (Miehls et al., 2019). The control program has been highly successful, but challenges remain with research indicating that sea lamprey abundances are approaching (but still above) economic injury levels, justifying higher levels of control (Adams et al., 2021-a; Treska et al., 2021; Irwin et al., 2012). The program's success is obvious when the current abundances of sea lamprey in the basin and

☆ *Given their roles as Guest Editors, Rob McLaughlin, Jean Adams, Jessica Barber, Margaret Docker, Nicholas Johnson, Todd Steeves, and Michael Wilkie had no involvement in the peer-review of this article and have no access to information regarding its peer-review. Full responsibility for the editorial process for this article was delegated to Robert Hecky.*

This article is published as part of a supplement sponsored by the Great Lakes Fishery Commission.

* Corresponding author.
E-mail address: rlmclaug@uoguelph.ca (R. McLaughlin).

https://doi.org/10.1016/j.jglr.2021.11.001

the numbers of sea lamprey wounds on large prey fishes are compared to sea lamprey abundances and wounding rates prior to implementation of the control program (Brant, 2019; Robinson et al., 2021), but quantifying the incremental effects of contemporary changes to the program is much harder. Facets of the control program are under continual review during semi-annual meetings of several task forces, the Sea Lamprey Control Board, and its commissioners (see Gaden et al., 2021-a for a discussion of the management structure). The purpose of the Sea Lamprey Control Board is to assist the Commission in developing and implementing strategies and policies related to control of sea lamprey for management of Great Lakes fish communities. The Lampricide Control Task Force aims to maximize the number of sea lampreys killed, while minimizing costs and impacts on aquatic ecosystems; the Larval Assessment Task Force ranks streams for sea lamprey control options and evaluates the success of lampricide treatments; the Barrier Task Force coordinates efforts to construct, operate, and maintain sea lamprey barriers; and the Trapping Task Force seeks to optimize trapping techniques for assessing and removing adult and transforming sea lampreys from spawning and feeding populations. In the late 1970s, the Commission extended its methods of review to include an international symposium to undertake a reflective, multi-decade horizon scan to document changing demands, adaptations in practise and their success or failure, and emerging issues and new ways to improve.

This special issue summarizes outcomes from the 3rd Sea Lamprey International Symposium (SLIS III; Fig. 1) held 28 July – 2 August 2019 at Wayne State University in Detroit, Michigan, U.S.A. The first two symposia (SLIS I and SLIS II) were held 30 July – 8 August 1979 at Northern Michigan University in Marquette, Michigan and 14–18 August 2000 at Lake Superior State University in Sault Ste. Marie, Michigan, respectively. The published volumes from these symposia in 1980 (Canadian Journal of Fisheries and Aquatic Sciences, Volume 37, Issue 11) and 2003 (Journal of Great Lakes Research Volume 29, Supplement 1) have been invaluable references for the broader scientific community and for management agencies around the Laurentian Great Lakes; cited over 4800 and 3300 times, respectively. SLIS III was attended by over 150 scientists, biologists, resource managers, graduate students, and Commission advisors, including participants from Australia, Canada, China, Japan, New Zealand, Portugal, Spain, the United Kingdom, and the United States (Fig. 2). Similar to SLIS I and SLIS II, the goals of SLIS III were to provide a forum to (i) update and publish information on sea lamprey control and research on lampreys since SLIS II, (ii) exchange knowledge and ideas to bring practitioners to a common plateau of understanding, and (iii) develop innovative initiatives and stimulate new vigor in efforts to control sea lamprey in the Great Lakes and to conserve lampreys in their native ranges. The emphasis on conservation of lampreys is unique to SLIS III and reflects a heightened international recognition that scientific and management advances supporting sea lamprey control in the Great Lakes can benefit the global effort to conserve native lampreys and vice versa.

SLIS III consisted of two main parts: the symposium and the supporting written products compiled herein. The symposium was planned as an "unconferencing" style of meeting to foster engagement and conversation needed to achieve the goal of active information exchange and elicitation and generation of new ideas. The symposium was organized as half-day themes focused on pressing issues for sea lamprey control and lamprey conservation, with free time for discussion interspersed between the themes. Each theme consisted of four or five short synopsis talks to frame the issue of the theme, followed by smaller group break-out discussions on how to address the issues, and synthesis sessions where the break-out groups reconvened to report on their progress. The themes addressed were: (i) balancing the tension between aquatic connectivity and sea lamprey control; (ii) how will human-induced environmental change affect the predator–prey interactions of sea lamprey in the lakes?; (iii) can we develop control strategies targeting recently metamorphosed, juvenile, and adult sea lamprey?; (iv) what are the feasibility, delivery, and expectations of genetic control?; (v) how can control program funds be allocated to provide the greatest benefit?; and (vi) can we eliminate sea lamprey from the Great Lakes in the next 50 years?

The compiled papers in this special issue consist of a combination of syntheses requested in advance of the symposium and perspectives that emerged from the symposium break-out discussions. These written contributions address the symposium goals of updating our understanding of sea lamprey control and research on lampreys since SLIS II and of exploring new ideas and posing new methods for controlling sea lamprey in the Great Lakes while supporting conservation of lampreys in their native ranges. The papers are organized into five topics identified prior to the symposium and spanning the symposium goals above. The topics are (i) history of sea lamprey control and Sea Lamprey International Symposia, (ii) comparative lamprey biology: conservation and management, (iii) advances in sea lamprey control in the Great Lakes, (iv) advances in sea lamprey biology; and (v) emerging opportunities – from advances to conservation and control.

Symposium highlights

SLIS III was successful by many measures. Below we underscore some of the main highlights from the symposium and SLIS III proceedings that distinguish the symposium from the earlier SLIS symposia and help chart the course for continued program evolution and success by expanding the scope of the program, encouraging reciprocal learning between the lamprey conservation and control communities, and broadening perspectives from beyond the typical participants. These highlights are intended to inspire action and represent a call to the Commission and its partners to

Fig. 1. The SLIS III logo featuring a stylized depiction of a sea lamprey oral disc. Produced by Q Ltd. for the Great Lakes Fishery Commission.

Fig. 2. Sea Lamprey International Symposium (SLIS) III participants. a) 1, Aaron Jubar; 2, Tonia Van Kempen; 3, Michael Hansen; 4, Scott Miehls; 5, Ralph Lampman; 6, Lisa O'Connor; 7, Mikaela Hanson; 8, Hiroaki Arakawa (a novel lamprey host); 9, John Hume; 10, Aliana Hellmuth; 11, Kenneth Merckel; 12, Seiji Yanai; 13, Sergio Silva Bautista; 14, Ronald Thresher; 15, Haley Fellows; 16, Benson Solomon; 17, Eric Smyth; 18, Leah Gerweck; 19, Chris Freiburger; 20, Bill Taylor; 21, Bob Lambe; 22, Brian Anderson; 23, Chris Eilers; 24, McLean Smith; 25, Sean Lewandoski; 26, Richard Manzon; 27, Jeff Tyson; 28, Carrie Kozel (nee Kozel); 29, Michael Jones; 30, Scott Grunder; 31, Gavin Christie; 32, Thomas Evans; 33, Heather Dawson; 34, Jeff Bernardy; 35, Jeramiah Smith; 36, Julie Hinderer; 37, Chris Gagnon; 38, Benjamin Clemens; 39, Sasha Bozimowski; 40, David McCauley; 41, Michael Fraidenburg; 42, Ross Shaw; 43, Matthew Symbal; 44, Tyler Firkus; 45, Tom Stewart. b) 46, Alex Maguffee; 47, Dale Burkett; 48, Kelly Robinson; 49, Travis Brenden; 50, Cory Goldsworthy; 51, Jane Kitson; 52, Jesse Lepak; 53, Jill Wingfield; 54, Lindsay Chadderton; 55, Thomas Pratt; 56, Robert Frank; 57, Kim Fredricks; 58, Christina Wang; 59, Gale Bravener; 60, Erin Dunlop; 61, Michael Siefkes; 62, Kevin Mann; 63, Lisa Walter; 64, Titus Seilheimer; 65, Nathan Barton; 66, Patrick Carilli; 67, Taylor Haas; 68, Ted Treska; 69, Jean Adams; 70, Rob McLaughlin; 71, Michael Boogaard; 72, Michael Wagner; 73, Cheryl Kaye; 74, Nicholas Schloesser; 75, Pete Hrodey; 76, Charles Bronte; 77, Cory Brant; 78, Bill Mattes; 79, Kandace Griffin; 80, Darin Simpkins; 81, Rebecca Philipps; 82, Terrance Hubert; 83, Jess Barber; 84, Shawn Nowicki; 85, Jim Luoma, c) 86, John Epifanio; 87, Lori Criger; 88, Cheryl Murphy; 89, Bhuwani Paudel; 90, Emily Mensch; 91, Tyler Buchinger; 92, Zhe Zhang; 93, Oana Birceanu; 94, Ashley Moerke; 95, Belinda Huerta; 96, Michael (Mike) Wilkie; 97, Pedro Almeida; 98, Jonathan Wilson; 99, Jessica Ives; 100, Connor Buckley; 101, Diogo Ferreira Martins; 102, Jim McKane; 103, Margaret Docker; 104, Charles Madenjian; 105, Mike Steeves; 106, Rachel Holub; 107, Paul Sullivan; 108, Theodore Castro-Santos; 109, Inês Oliveira; 110, Andrew Muir; 111, Esmeralda Pereira; 112, Daniel Zielinski; 113, Martyn Lucas; 114, Carl Platz; 115, Jackson Champer; 116, Barbara Zielinski; 117, Catarina Mateus; 118, Mary Moser; 119, Christopher Holbrook; 120, Stephen McCormick; 121, Cindy Baker; 122, Bernardo Quintella; 123, Marc Gaden; 124, Chris Wilson; 125, Brian Locke; 126, Fraser Neave; 127, Nicholas Johnson, Not in picture: David Browne; Doug Buhler; Yongsheng Cao; Mark Christie; John Dettmers; Skye Fissette; Thomas Gorenflo; Stephanie Guildford; Robert Hecky; Courtney Higgins-Weier; Thomas Lauer; Shaowu Li; Weiming Li; Matt Lipps; Thomas Loch; Nicholas Mandrak; Ellen Marsden; Amy McGovern; Bruce Morrison; Kurt Newman; Don Pereira; Anne Scott; Maria Sepulveda; Jenna Tews; Gary Whelan Image by C. Brant, Great Lakes Fishery Commission.

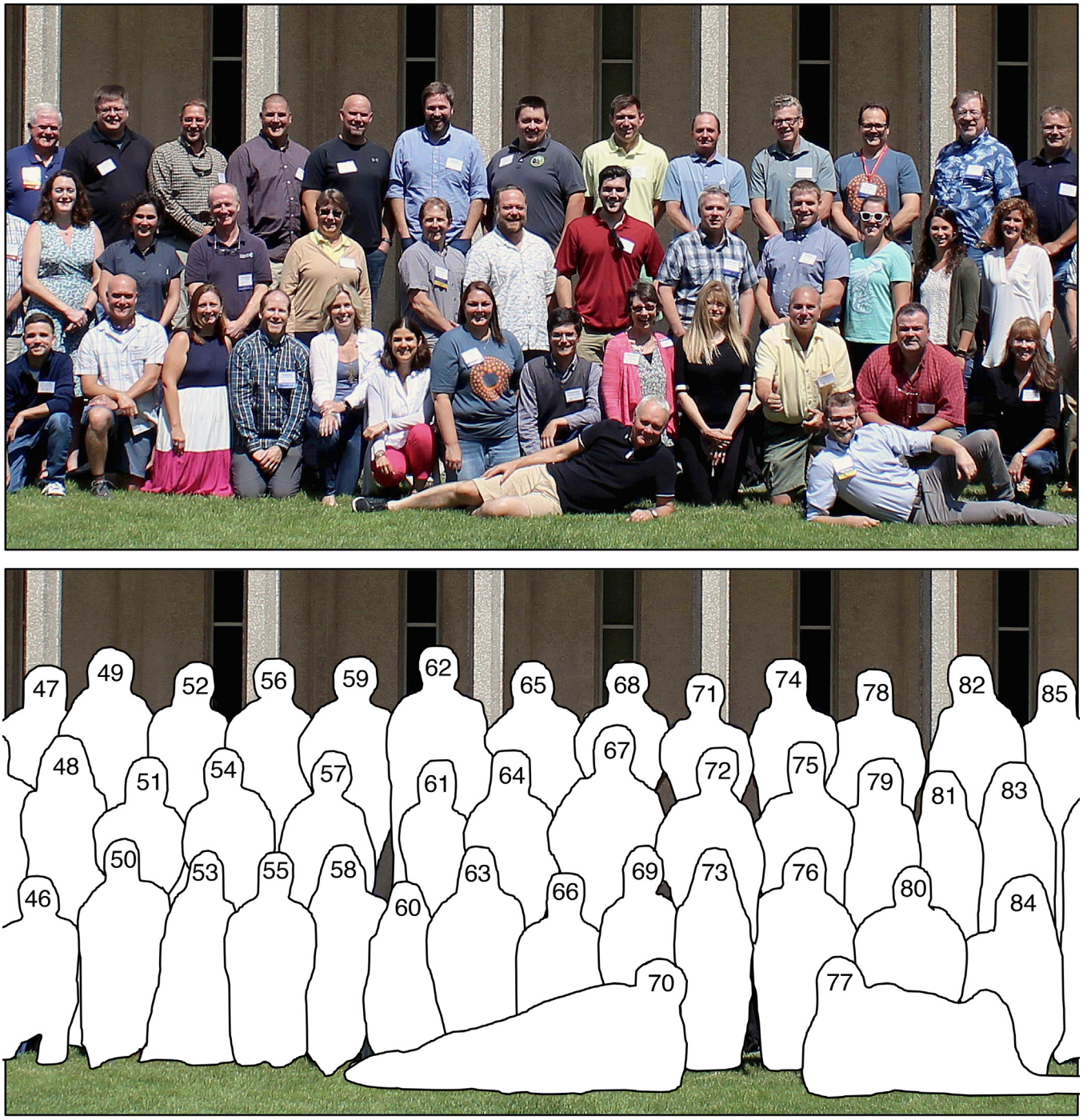

Fig. 2 (*continued*)

embrace the present challenges, strategically plan for the future, and maintain the commitment to one of the most successful vertebrate control programs globally.

Greater synthesis and integration to support lamprey control and conservation

SLIS and SLIS II featured strong engagement between scientists and members of the control program, the introduction of expertise from outside the Great Lakes basin, and data syntheses of control efforts. SLIS III continued these areas of emphasis, but surpassed SLIS and SLIS II in terms of topical coverage, geographic scope of authorship, and integration of authors with scientific and management backgrounds. Twelve papers considered the conservation or general biology of lampreys both outside and inside of the Great Lakes basin. Examples include Neave et al. (2021) and Lucas et al. (2021), which evaluated changes in native lamprey populations in the Great Lakes since the onset of sea lamprey control and emerging conservation initiatives for lampreys throughout the world, respectively. Further, 13 papers were co-written by authors from multiple continents, emphasizing the strong collaboration evident within the global lamprey community. Examples here include Lucas et al. (2021), Clemens et al. (2021), and Almeida et al. (2021), with authors on each paper hailing from 7

Fig. 2 (*continued*)

to 10 countries and 4 to 5 continents. Finally, 32 papers were jointly authored by scientists from academia or government and members of agencies responsible for delivering control or conservation programs. This level of collaboration and co-production allowed authors to consider lamprey biology more broadly and thoroughly and opened up new channels of thought. We encourage SLIS IV organizers to continue the trend towards inclusivity and broadening of the perspectives represented. The diversity of participants and ideas will strengthen and improve control and conservation programs.

A greater role for Indigenous participation in sea lamprey control

Indigenous participation in sea lamprey control was a valuable highlight that emerged organically from symposium discussions. Those discussions began on the first day of the symposium with a talk addressing Indigenous perspectives on the use of in-stream barriers to control sea lamprey and the damage the barriers cause to native fishes versus the removal of barriers to enhance connectivity between lakes and rivers for native fishes. Mattes and Kitson (2021) provided the first ever SLIS paper offering an Indigenous perspective on sea lamprey control in the Great Lakes. Their paper is noteworthy because some Indigenous nations have been managing the basin's resources since time immemorial. Following the colonization of North America, however, opportunities for Indigenous participation in the management of Great Lakes fisheries have been limited. Indigenous groups from the U.S. side of the basin were invited to sign The Joint Strategic Plan for Management of Great Lakes Fisheries (GLFC, 2007), but similar invitations and partnerships with Indigenous nations in Canada need to be added. Mattes and Kitson (2021) noted that the many Indigenous communities around the basin may differ in their viewpoints on sea lamprey control. Mattes and Kitson further emphasized the value of creating ethical space and respect for multiple ways of knowing

and offer advice on how to work hand-in-hand with Indigenous communities and build trust. In addition, these authors insightfully cautioned that opposition to sea lamprey control can arise from a perceived lack of respect given to sea lamprey, non-target species, and the land and water. Expanded Indigenous participation in the sea lamprey control program in the future and greater presence at SLIS IV would be beneficial.

Adapting to shifting baselines and changing attitudes

Shifting baselines was one of the greatest concerns to emerge from the symposium discussions. When the sea lamprey control program began, impacts of sea lamprey were obvious to commercial and recreational fishers, management agencies (Brant, 2019), and the general public (Anonymous, 1947, 1955). Wounds and scars of sea lamprey attacks were common, and populations of important recreation fish were clearly declining in abundance (Hile, 1949; Hile et al., 1951a,b). Sixty years later, the control program has been so successful that some members of a new generation of public stakeholders, and even of management agencies, no longer view sea lamprey as a major threat to the Great Lakes fishery, despite the fact that the sea lamprey control program must be operated annually to keep sea lamprey suppressed. As the past is forgotten, concerns about non-target effects of in-stream barriers and chemical lampricides used for sea lamprey control are being weighed more heavily (Johnson et al., 2021-b; Kaye, 2021; Pratt et al., 2021; Walter et al., 2021; Zielinski and Freiburger, 2021). Gaden et al. (2021-b) explored how such shifting baselines could affect society's approval of the control program, i.e., the program's social license to operate, including the continued use of in-stream barriers and lampricides, as well as the introduction of new control tools, such as genetic control methods. Gaden et al. (2021-b) identified research projects that could further public understanding of shifting baselines and the social license to operate and improve communication between management agencies and the public. In keeping with this objective, SLIS III included a museum-quality display of the history of the control program. The history captured in this display, which took up an entire conference room, has been documented by Brant (2019). The display served as a resource for authors and as an opportunity for symposium participants to video-record their experiences with sea lamprey research and the control program. In a companion paper, Gaden et al. (2021-a) expanded on Fetterolf's (1980) SLIS paper "Why a Great Lakes Fishery Commission?" and summarized the decades of challenging, multi-jurisdictional deliberation leading to the creation of the Commission and its mandate via the Convention on Great Lakes Fisheries between Canada and the United States (U.S. Department of State 1956).

The need for stronger partnerships between inland and lake managers

Current sea lamprey control efforts and their non-target effects occur in specific tributaries to the Great Lakes, while populations of native and desirable non-native fishes that benefit from sea lamprey control occur in the lakes or spend significant parts of their life history in the lakes. This spatial disconnect creates conflict among stakeholders, managers, and landowners with different interests and value judgments of riverine habitat and species that can be negatively affected by control actions versus lake habitat and species benefiting from control. These value judgments are a major source of tension in discussions regarding the non-target effects of lampricide treatments (Kaye, 2021) and managing connectivity through the maintenance or removal of in-stream barriers (Hrodey et al., 2021; Walter et al., 2021). Stronger partnerships and better communication between inland and Great Lakes managers, stakeholders, and rightsholders could help resolve these tensions and select the management options that best meet shared ecological, economic, and recreational objectives for native fishes at watershed- and lake-wide spatial scales.

Striving to demonstrate incremental program success

Since SLIS II, the managers of the control program have relied on two types of information to gauge program success: estimates of adult sea lamprey abundances migrating from the lakes into spawning tributaries and sea lamprey wounds on lake trout (*Salvelinus namaycush* (Walbaum, 1792)) as an indicator of the mortality caused by sea lamprey attacks. Robinson et al. (2021) provided new lake-wide estimates of adult sea lamprey abundances prior to the start of the control program based on trap catches and environmental and lampricide treatment predictor variables during 1953–1976. These estimates reinforce how effective the control program has been long-term. In addition, Adams et al. (2021-a) reviewed recent changes to create a more defensible index of contemporary adult abundances for each lake, including the rationale for switching from predicting adult run sizes for tributaries across each lake basin using a regression model (Mullett et al., 2003) to estimating run sizes for a lesser number of index streams directly using mark-recapture methods. The case study by Johnson et al. (2021-a) further capitalized on long-term data from Lake Superior to demonstrate how abundance estimates are influenced by biotic and abiotic factors, revealing the need for caution when trying to link abundance estimates to control actions. Another series of papers, described next, documented and advanced our understanding of sea lamprey-induced wounding rates on lake trout. The control program strives to reduce wounding rates to justifiable levels (targets identified by the lake managers) for each lake. Treska et al. (2021) documented the development and adjustments made to these targets over the past two decades. Firkus et al. (2021) tested assumptions regarding the accuracy of identifying and classifying wounds into different types based on external features (e.g., piercing the skin), as well as the agreement between individuals scoring the wounds. Adams et al. (2021-c) used simulation modeling to demonstrate that, under certain assumptions about the rates of piercing and lethality, different types of wounds can provide good indices of lake trout mortality caused by sea lamprey. Two other papers examined wounding rates on other salmonines (Simpkins et al., 2021) and explored how host switching could complicate the use of wounding rates on lake trout to gauge program success (Adams and Jones, 2021). Despite the efforts documented herein, the control program continues to face an ongoing dilemma. The Commission can convincingly demonstrate long-term success suppressing sea lamprey abundance and reducing wounding rates on lake trout, but demonstrating the efficacy of more recent programmatic changes remains challenging either because the refined metrics remain too blunt, or because there remain important blind spots in our understanding of sea lamprey biology.

The enduring pursuit of control methods to supplement or replace barriers and lampricides

At SLIS I, Sawyer (1980) introduced the sea lamprey control program to the concepts of integrated pest management. In the ensuing 40 years, the program has excelled at delivering sea lamprey control that is ecologically, economically, and socially sound (Hubert et al., 2019). Recent improvements to the sea lamprey control program include refinements in the application of lampricides (Hlina et al., 2021; Sullivan et al., 2021; Symbal et al., 2021) and advances in understanding lampricide toxicity (Wilkie et al., 2021; Borowiec et al., 2021). Correspondingly, abundances of sea lamprey across the Great Lakes are at near record lows (Adams

et al., 2021-a). However, the desired development of new, widely applicable control tools to supplement or replace barriers or lampricides (Lamsa et al., 1980) has yet to be realized (e.g., Fissette et al., 2021). Siefkes et al. (2021) reinforced the philosophy that new tools can be useful if they supplement barriers and lampricides, for example by delaying the frequency of treatments within a tributary or the number of larvae surviving a treatment. Lewandoski et al. (2021) built on this philosophy in a proposed adaptive management framework for implementing supplemental controls, while the case study by Tews et al. (2021) contrasted how the lack of an adaptive management plan contributed to the decommissioning of a seasonally operated electrical barrier. Efforts to develop control tools targeting juvenile and adult sea lamprey continue. Evans et al. (2021) reviewed possible approaches and critical uncertainties for control methods targeting outmigrating juveniles. A management strategy evaluation by Miehls et al. (2021) identified the types of tributaries where suppressing reproduction could reduce the frequency of lampricide treatments and lake-wide abundances of sea lamprey. The development of supplemental control tools remains important for addressing tributary-specific concerns regarding non-target effects of in-stream barriers and lampricide treatments and could also aid in further suppressing lake-wide abundances of sea lamprey.

The promise of genetic controls: Will we be ready?

The prospect for new genetic controls was a dominant source of qualified enthusiasm and discussion at SLIS III (Ferreira-Martins et al., 2021). York et al. (2021) provided an up-to-date review of how rapidly evolving functional genetic, transcriptomic, and gene editing tools are being applied to the study of lamprey development and discussed the potential for genetic manipulations to be exploited for sea lamprey control or even eradication. The most recent of these is CRISPR genome editing, a technology being explored in efforts to suppress or eliminate mosquitos that transmit malaria and rodents that have invaded islands and wreaked havoc on native wildlife (Scudellari, 2019). Ferreira-Martins et al. (2021) presented an overview of different genetic control options that could be considered for sea lamprey control, describing the technical aspects, challenges (including preventing the possibility for "genetic contamination" of the native Atlantic sea lamprey population), and potential application of each method. Ferreira-Martins et al.'s synthesis focused on gene drives, a fast-evolving research area that was only a distant possibility for sea lamprey control until recently. Technological developments are happening quickly, stimulating excitement for their potential, but also raising questions about how well they will work in real-world applications, possible unwanted effects, who will decide where and when to apply them, and how to communicate all of this to the public (Gaden et al., 2021-b). The need to build international public understanding of new technologies is widely recognized and could be a focal issue for SLIS IV.

Is eradication on the horizon?

Eradication of sea lamprey from the Great Lakes has been considered impractical and cost prohibitive. Most successes with eradication have been made with small, island populations - nothing like the Great Lakes in terms of geographic extent. The Great Lakes Sea Lamprey Committee from the 1940s, which petitioned for the creation of the Commission, considered eradication to be a "pipe dream" (Brant, 2019). While eradication was written into the Commission's mandate, it has been viewed as unattainable at any cost due to diminishing returns of control tools as sea lamprey abundance declines (Christie and Goddard, 2003). However, major and rapid scientific advances in the past two decades are revealing potential new pathways to eradication (see genetic control above) making reconsideration of this option timely and worthwhile. Jones and Adams (2021) used data analyses and simulation modeling to conclude that the conditions necessary for successful eradication of sea lamprey in the Great Lakes are achievable. In a companion paper, Adams et al. (2021-b) considered the trade-offs between suppression and eradication of sea lamprey in the Great Lakes. Unlike past perspectives, the greatest challenge to eradication may come down to the social, political, legal, and institutional willingness to take that step. Adams et al. (2021-b) stressed the importance of being prepared for changing social perspectives on suppression versus eradication.

Post symposium reflections

Planning SLIS III was a major challenge and some program achievements and challenges were considered more thoroughly than others at the symposium and in this volume, owing to the design of the symposium, planning and paper writing deadlines, and additional delays and demands created by the Covid-19 pandemic. Below we reflect on some key topics that: (i) did not make it into the proceedings due to time constraints, but which could be addressed in SLIS III products published elsewhere in the near future, (ii) were recognized as important, but not considered more extensively in SLIS III because they were recently addressed elsewhere, or (iii) in hindsight, we would have liked to emphasize more. Our intention is to recognize the importance of these topics to the control program and stress that further exploration of them is needed and, in some cases, impending.

Sea lamprey control in a management mosaic

Shifting baselines and the social license to operate are just two of the social challenges the sea lamprey control program is facing. The control program is also carried out in a complex, basin-wide social landscape involving the collective effort of federal, state, provincial, and Indigenous resource managers responsible for fisheries, water and environmental quality, and conservation of listed species (a management mosaic; Epanchin-Niell et al., 2010). Furthermore, the benefits of sea lamprey control are realized basin-wide, while the specific control actions are primarily implemented in specific, local tributaries. As a result, unexpected policy, administrative, or operational changes by a partner, or inconsistencies among partners, that affect the operations of the control program (e.g., removal of a dam, preventing a chemical treatment) can hamper how and where sea lamprey control is carried out, potentially increase the cost of control, and even erode the enthusiasm for control in the other partner agencies (sensu Epanchin-Niell et al., 2010). Coordination among partners is crucial, but it is becoming more complex as attitudes toward dam removals, introduction of chemicals into the environment, and protecting species of conservation concern change regionally, and within agencies. Delivering an effective, lake-wide control program and communicating its success in an increasingly complex, changing social landscape are primed to become major topics for SLIS IV.

Broader appreciation of Indigenous perspectives on lampreys

Mattes and Kitson (2021) provided a welcome and needed Indigenous perspective on sea lamprey control in the Great Lakes, but this captured only part of the rich discussion that ensued during the symposium. There is much more to be learned from the perspectives that other Indigenous nations within the Great Lakes basin have on sea lamprey and sea lamprey control, as well as from the viewpoints of Indigenous peoples regarding lampreys inhabit-

ing their native (distributional) ranges. We hope Mattes and Kitson's paper stimulates this broader exploration, as well as how Indigenous knowledge can benefit sea lamprey control and the conservation of native lampreys.

Aquatic restoration and climate change can shift sea lamprey habitat

Participants at the original SLIS in 1979 hypothesized that improvements to stream water quality could result in increased sea lamprey production, because tributary stretches where water quality is improved, contaminated sediments are removed, and degraded physical habitat is restored could create new habitat for spawning and embryo and larval rearing of sea lamprey. In a presentation at SLIS III, Tom Pratt (Fisheries and Oceans Canada) revisited this hypothesis by reviewing if increases in larval and adult sea lamprey, and requirements for lampricide treatment, coincided with restoration efforts in Great Lakes Areas of Concern. While current data are limited, sea lamprey have become established in nine areas of concern, seven of which now require treatment, and two others that are expected to require treatment in the future. More extensive, quantitative assessments of sea lamprey abundance are needed now, prior to restoration, for prospective restoration areas to strengthen comparisons of abundance before and after restoration and to increase the number of restoration areas examined.

A changing climate must also be considered when assessing the effects of restoration on sea lamprey habitat. Lennox et al. (2020) reviewed how climate change could influence the physiology, behavior, and demography of sea lamprey and suggested that Great Lakes sea lamprey could benefit from climate change with longer growing seasons, more rapid growth, and greater access to spawning habitat, but noted that uncertainties remain about the future availability and suitability of larval habitats. Lennox et al. (2020) also explored implications of these changes that should be considered by the Commission's control program.

These habitat shifts warrant greater attention. Persistent, incremental changes in habitat quality and their cumulative consequences against a background of climate change could become a large and lasting challenge for the control program between now and SLIS IV.

Predicting the production potential of sea lamprey and native fishes following dam removal

The inability to reliably predict how the production of sea lamprey and native fishes will change following dam removal is a pressing source of uncertainty and tension in discussions of dam removal, particularly removal of the dams located closest to the lake in tributaries where sea lamprey reproduce. Often, the reliability of projections is weak and hampered by simplistic and potentially incorrect assumptions, such as populations being limited by spawning habitat (Minns et al., 1996), and, for many species, by limited knowledge of key life history and demographic traits, as well as habitat supply above the dam. Stronger hypotheses, better data, and more rigorous population and ecosystem modeling could help managers decide which management action (dam removal or retaining the dam with or without fish passage) offers the greatest benefit to native fish species, and which species benefit the most. We could see additional SLIS III products, which were not ready in time for the publication deadline of this special issue, addressing this topic in the near future.

Uncertainty surrounding sources of parasitic lamprey production

It is unclear if all of the potential sources of juvenile sea lamprey within the Laurentian Great Lakes basin are known. In Lake Erie, lampricide treatments of all tributaries with larval sea lamprey were conducted in two consecutive years, 2008 and 2009 (Grunder et al., 2021). This back-to-back strategy was expected to reduce adult abundance to target levels and delay recruitment in sea lamprey producing tributaries. The strategy proved unsuccessful and raised questions about unidentified sources of juvenile lamprey production. Attention focused on the St. Clair River as a potential source of sea lamprey in Lake Erie, but the outcome raised broader questions about the precision of abundance estimates for sea lamprey, our ability to assess control actions, and possible overlooked sources of sea lamprey throughout the Great Lakes basin, such as sea lamprey spawning and rearing in lentic areas. To avoid blind spots, this topic could be explored more deeply and greater effort could be devoted to how uncertainty in sources of production can be reduced.

The evolution of resistance to lampricides

The evolution of resistance to lampricides is becoming one of the most alarming threats to the control program. There is accumulating evidence demonstrating that the evolution of resistance is possible despite the relatively small number of sea lamprey generations that have been exposed to control via lampricides (e.g., Christie et al., 2019; Dunlop et al., 2018; Yin et al., 2021). The symposium proceedings have only one paper addressing this topic (Dunlop et al., 2021), but that is only because a separate workshop devoted to lampricide resistance and the development of next-generation lampricides was held in 2015 and products from that workshop have recently been published (e.g., Dunlop et al., 2018; Lantz et al., in press). Given the importance of lampricides to the success of the control program, this topic could be the focus of much greater and ongoing attention including in SLIS IV.

Closing thoughts

This special issue demonstrated that SLIS III succeeded in achieving its goals. The numerous synthesis papers document the advances in sea lamprey control and research on lampreys since SLIS II. The synthesis and perspective papers collectively show that participants from different geographic regions and with different career experiences (research, management, conservation) and different interests (control and eradication of invasive species, lamprey conservation and management, broader lamprey biology) were able to achieve a shared understanding of topics crucial to the biology and management of lampreys and to generate new ideas for controlling sea lamprey in the Great Lakes and conserving lampreys in their native ranges. The symposium furthers the Commission's longstanding commitment to evaluating the sea lamprey control program and improving program delivery by reflecting on recent changes, gauging their success, and capitalizing on advice and perspectives solicited from outside of the program. The symposium papers on lamprey conservation and on greater Indigenous participation in sea lamprey control exemplify this commitment. Further, in the issue's final paper Burkett et al. (2021) integrate findings and ideas from many of the SLIS III papers to chart a course for sea lamprey control over the next 20 years.

This special issue does not represent the culmination of SLIS III. The symposium's success will further depend on the transfer of ideas and products from SLIS III to the scientific and management communities and the broader public. This further work includes the transfer of ideas and recommendations to the Commission's sea lamprey control program, the priorities of its research boards, and the Commission's strategic vision. It also includes transfer to heighten the awareness, and, where appropriate, influence the policy and management of partner agencies and the attitudes of the

broader public engaged with sea lamprey control in the Great Lakes basin, as well as of agencies responsible for lamprey conservation across the globe. This special issue is a key step in this transfer and its impact can be gauged using analyses of citations, downloads, and activity on social media. Transfer to the management agencies and the broader public will be harder to achieve and assess. Discussions with the Commission's Science Transfer Board began during spring 2021 to actively plan and facilitate the dissemination of SLIS III outputs to these important stakeholder groups. We look forward to seeing the advances in lamprey biology, conservation of lampreys in their native ranges, and in sea lamprey control in the Great Lakes over the next 20 years.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Several authors are heavily involved with the Great Lakes Fishery Commission and the sea Lamprey control program, including being on salary with the commission. However, the paper largely synthesizes a Commission funded symposium and the highlights and recommendations arising from that symposium and the papers written for it.

Acknowledgements

Thanks to Charles Madenjian and Heather Dawson for suggestions that improved the manuscript. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

Adams, J.V, Barber, J.M., Bravener, G.A., Lewandoski, S.A., 2021-a. Quantifying Great Lakes sea lamprey populations using an index of adults. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.04.009.

Sullivan, W.P., Wingfield, J., 2021-b. Trade-offs between suppression and eradication of sea lampreys from the Great Lakes. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.04.005.

Adams, J.V, Jones, M.L., 2021. Evidence of host switching: Sea lampreys disproportionately attack Chinook salmon when lake trout abundance is low in Lake Ontario. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2020.03.003.

Adams, J. V, Jones, M.L., Bence, J.R., 2021-c. Using simulation to understand annual sea lamprey marking rates on lake trout. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2020.08.008.

Almeida, P.R., Arakawa, H., Aronsuu, K., Baker, C., Blair, S-R, Beaulaton, L., Belo, A.F., Kitson, J., Kucheryavyy, A., Kynard, B., Lucas, M.C., Moser, M., Potaka, B., Romakkaniemi, A., Staponkus, R., Tamarapa, S., Yanai, S., Yang, G., Zhang, T., Zhuang, P., (2021). Lamprey fisheries: history, trends and management. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.06.006.

Anonymous, 1947. Sea lamprey menace. Life 23, 97–98.

Anonymous, 1955. Death for baby lampreys. TIME Mag. 66, 84–85.

Borowiec, B.G., Docker, M.F., Johnson, N.S., Moser, M.L., Zielinski, B., Wilkie, M.L., 2021. Exploiting the physiology of sea lampreys to refine methods of control and conservation. J. Great Lakes Res. (2021).

Brant, C.O., 2019. Great Lakes Sea Lamprey: The 70 Year War on a Biological Invader. University of Michigan Press, Ann Arbor.

Burkett, D.P., Barber, J.M., Steeves, T.B., Siefkes, M.J., 2021. Sea lamprey control 2020 – 2040: charting a course through dynamic waters. J. Great Lakes Res. (2021).

Christie, G.C., Goddard, C.I., 2003. Sea Lamprey International Symposium (SLIS II): advances in the integrated management of sea lamprey in the Great Lakes. J. Great Lakes Res. 29, 1–14. https://doi.org/10.1016/S0380-1330(03)70474-2.

Christie, M.R., Sepúlveda, M.S., Dunlop, E.S., 2019. Rapid resistance to pesticide control is predicted to evolve in an invasive fish. Sci. Rep. 9, 18157.

Clemens, B.J., Arakawa, H., Baker, C., Coghlan, S., Kucheryavyy, A., Lampman, R., Lança, M.J., Mateus, C.S., Miller, A., Nazari, H., Pequeño, G., Sutton, T.M., Yanai, S., 2021. Management of anadromous lampreys: Common threats, different approaches. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2020.09.005.

Dunlop, E.S., McLaughlin, R., Adams, J.V., Jones, M., Birceanu, O., Christie, M.R., Criger, L.A., Hinderer, J.L.M., Hollingworth, R.M., Johnson, N.S., Lantz, S.R., Li, W., Miller, J., Morrison, B.J., Mota-Sanchez, D., Muir, A., Sepúlveda, M.S., Steeves, T., Walter, Westman, E., Wirgin, I., Wilkie, M.P., 2018. Rapid evolution meets invasive species control: the potential for pesticide resistance in sea lamprey. Can. J. Fish. Aquat. Sci. 75 (1), 152–168. https://doi.org/10.1139/cjfas-2017-0015.

Dunlop, E.S., Christie, M.R., McLaughlin, R., Steeves, T.B., 2021. Life history evolution of sea lamprey is predicted to reduce the effectiveness of pesticide control. J. Great Lakes Res. (2021).

Epanchin-Niell, R.S., Hufford, M.B., Aslan, C.E., Sexton, J.P., Port, J.D., Waring, T.M., 2010. Controlling invasive species in complex social landscapes. Front. Ecol. Environ. 8 (4), 210–216.

Evans, T.M., Wagner, C.M., Miehls, S.M., Johnson, N.S., Haas, T.F., Dunlop, E.S., Manzon, R.G., 2021. Before the first meal: The elusive pre-feeding juvenile stage of the sea lamprey. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.02.005.

Ferreira-Martins, D., Champer, J., McCauley, D.W., Zhang, Z., Docker, M.F., 2021. Genetic control of invasive sea lamprey in the Great Lakes. J. Great Lakes Res. (2021).

Fetterolf Jr., C.M., 1980. Why a Great Lakes Fishery Commission and why a Sea Lamprey International Symposium. Can. J. Fish. Aquat. Sci. 37, 1588–1593. https://doi.org/10.1139/f80-206.

Firkus, T.J., Murphy, C.A., Adams, J. V, Treska, T.J., Fischer, G., 2021. Assessing the assumptions of classification agreement, accuracy, and predictable healing time of sea lamprey wounds on lake trout. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2020.07.016.

Fissette, S.D., Buchinger, T.J., Wagner, C.M., Johnson, N.S., Scott, A.M., Li, W., (2021). Progress towards integrating an understanding of chemical ecology into sea lamprey control. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.02.008.

Gaden, M.E., Brant, C.O., Lambe, R., 2021-a. Why a Great Lakes Fishery Commission? The seven-decade pursuit of a Canada-U.S. fishery treaty. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.01.003.

Gaden, M.E., Brant, C.O., Stedman, R.C., Cooke, S.J., Young, N., Lauber, T.B., Nguyen, V. M., Connelly, N.A., Knuth, B., 2021-b. Shifting baselines and social license to operate: Challenges in communicating sea lamprey control. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.01.016.

GLFC, 2007. A joint strategic plan for management of Great Lakes fisheries (adopted in 1997 and supersedes 1981 original), Misc. Publ. 2007-01. Great Lakes Fishery Commission, Ann Arbor, MI.

Grunder, S.A., Markham, J.L., Sullivan, W.P., Eilers, C., Tallon, K., McGarry, D., 2021. A review of sea lamprey control in Lake Erie, 2000-2019. J. Great Lakes Res. (2021).

Hile, R.O., 1949. Trends in the lake trout fishery of Lake Huron through 1946. Trans. Am. Fish. Soc. 76, 121–147. https://doi.org/10.1577/1548-8659(1946)76[121:TITLTF]2.0.CO;2.

Hile, R.O., Eschmeyer, P.H., Lunger, G.F., 1951a. Decline of the lake trout fishery in Lake Michigan. Fish. Bull. 52, 77–95.

Hile, R.O., Eschmeyer, P.H., Lunger, G.F., 1951b. Status of the lake trout fishery in Lake Superior. Trans. Am. Fish. Soc. 80, 278–312. https://doi.org/10.1577/1548-8659(1950)80[278:SOTLTF]2.0.CO;2.

Hlina, B.L., Birceanu, O., Robinson, C.S., Dhiyebi, H., Wilkie, M.P., 2021. The relationship between thermal physiology and lampricide sensitivity in larval sea lamprey (*Petromyzon marinus*). J. Great Lakes Res. (2021).

Hrodey, P., Lewandoski, S.A., Sullivan, W.P., Barber, J.M., Mann, K.A., Paudel, B., Symbal, M.J., 2021. Evolution of the Sea Lamprey Control Barrier Program: the importance of lowermost barriers. J. Great Lakes Res. (2021).

Hubert, T.D., Miller, J., Burkett, D., 2019. A brief introduction to integrated pest management for aquatic systems. North Am. J. Fish. Manag. 41 (2), 264–275. https://doi.org/10.1002/nafm.10331.

Irwin, B.J., Liu, W., Bence, J.R., Jones, M.L., 2012. Defining economic injury levels for sea lamprey control in the Great Lakes basin. North Am. J. Fish. Manag. 32 (4), 760–771. https://doi.org/10.1080/02755947.2012.685140.

Johnson, N.S., Adams, J. V, Bravener, G.A., Barber, J.M., Treska, T.J., Siefkes, M.J., 2021-a. Winter severity, fish community, and availability to traps explain most of the variability in estimates of adult sea lamprey in Lake Superior. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2020.08.011.

Johnson, N.S., Snow, B., Bruning, T., Jubar, A., 2021-b. A seasonal electric barrier blocks invasive adult sea lamprey (*Petromyzon marinus*) and reduces production of larvae. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.09.008.

Jones, M.L., Adams, J.V., 2021. Eradication of sea lampreys from the Laurentian Great Lakes is possible. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2020.04.011.

Kaye, C.A., 2021. Addressing the risk of lampricide exposure to three federally listed species in U.S. streams. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.08.015.

Lamsa, A.K., Rovainen, C.M., Kolenosky, D.P., Hanson, L.H., 1980. Sea lamprey (Petromyzon marinus) control – Where to from here? Report of the SLIS Control Theory Task Force. Can. J. Fish. Aquat. Sci. 37 (11), 2175–2192. https://doi.org/10.1139/f80-260.

Lantz, S.R., Adair, R.A., Amberg, J.J., Bergstedt, R., Boogaard, M.A., Bussy, U., Docker, M.F., Dunlop, E.S., Gonzalez, A., Hubert, T.D., Siefkes, M.J., Sullivan, W.P., Whyard, S., Wilkie, M.P., Young, B., Muir, A., in press. Next generation lampricides: a three-stage process to develop improved control tools for invasive sea lamprey. Can. J. Fish. Aquat. Sci.

Lennox, R.J., Bravener, G.A., Lin, H.-Y., Madenjian, C.P., Muir, A.M., Remucal, C.K., Robinson, K.F., Rous, A.M., Siefkes, M.J., Wilkie, M.P., Zielinski, D.P., Cooke, S.J., 2020. Potential changes to the biology and challenges to the management of

invasive sea lamprey *Petromyzon marinus* in the Laurentian Great Lakes due to climate change. Glob. Chang. Biol. 26 (3), 1118–1137.
Lewandoski, S.A., Brenden, T.O., Siefkes, M.J., Johnson, N.S., 2021. An adaptive management implementation framework for evaluating supplemental sea lamprey (*Petromyzon marinus*) controls in the Laurentian Great Lakes. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.09.007.
Lucas, M.C., Hume, J.B., Almeida, P.R., Aronsuu, K., Habit, E., Silva, S., Wang, C.J., Zampatti, B., 2021. Emerging conservation initiatives for lampreys: Research challenges and opportunities. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2020.06.004.
Mattes, W.P., Kitson, J.C., 2021. Sea lamprey control in the Great Lakes: A Tribal/First Nations Representative's perspective. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.08.011.
McDonald, D.G., Kolar, C.S., 2007. Research to guide the use of lampricides for controlling sea lamprey. J. Great Lakes Res. 33 (sp2), 20–34.
McLaughlin, R.L., Hallett, A., Pratt, T.C., O'Connor, L.M., McDonald, D.G., 2007. Research to guide use of barriers, traps, and fishways to control sea lamprey. J. Great Lakes Res. 33 (sp2), 7–19.
Miehls, S., Sullivan, P., Twohey, M., Barber, J., McDonald, R., 2019. The future of barriers and trapping methods in the sea lamprey (*Petromyzon marinus*) control program in the Laurentian Great Lakes. Rev. Fish Biol. Fish. 30 (1), 1–24.
Miehls, S.M., Dawson, H.A., Maguffee, A.C., Johnson, N.S., Jones, M.L., Dobiesz, N., 2021. Where you trap matters: Implications for integrated sea lamprey management. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2020.06.023.
Minns, C.K., Randall, R.G., Moore, J.E., Cairns, V.W., 1996. A model simulating the impact of habitat supply limits on northern pike, *Esox lucius*, in Hamilton Harbour, Lake Ontario. Can. J. Fish. Aquat. Sci. 53 (Suppl. 1), 20–34.
Mullett, K.M., Heinrich, J.W., Adams, J.V., Young, R.J., Henson, M.P., McDonald, R.B., Fodale, M.F., 2003. Estimating lake-wide abundance of spawning-phase sea lampreys (*Petromyzon marinus*) in the Great Lakes: Extrapolating from sampled streams using regression models. J. Great Lakes Res. 29, 240–252. https://doi.org/10.1016/S0380-1330(03)70492-4.
Neave, F.B., Booth, R.M.W., Philipps, R.R., Keffer, D.A., Bravener, G.A., Coombs, N., 2021. Changes in native lamprey populations in the Great Lakes since the onset of sea lamprey (*Petromyzon marinus*) control. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2020.10.005.
Pratt, T.C., Morrison, B.J., Quinlan, H.R., Elliott, R.F., Grunder, S.A., Chiotti, J.A., Young, B.A., 2021. Implications of the sea lamprey control program for lake sturgeon conservation and rehabilitation efforts. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2020.06.014.
Robinson, K.F., Miehls, S.M., Siefkes, M.J., 2021. Understanding sea lamprey abundances in the Great Lakes prior to broad implementation of sea lamprey control. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.04.002.
Sawyer, A.J., 1980. Prospects for integrated pest management of the sea lamprey (*Petromyzon marinus*). Can. J. Fish. Aquat. Sci. 37 (11), 2081–2092. https://doi.org/10.1139/f80-249.
Scudellari, M., 2019. Self-destructing mosquitoes and sterilized rodents: the promise of gene drives. Nat. 571 (7764), 160–162. https://doi.org/10.1038/d41586-019-02087-5.
Siefkes, M.J., Johnson, N.S., Muir, A.M., 2021. A renewed philosophy about supplemental sea lamprey controls. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.03.013.
Simpkins, D.G., Kornis, M.S., Maguffee, A.C., Bence, J.R., Pankow, K.W., Bronte, C.R., 2021. Spatial and temporal variation in marking rates and severity of sea lamprey attacks on salmonines in Lakes Michigan and Huron. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.01.002.
Sullivan, W.P., Burkett, D.P., Boogaard, M.A., Criger, L.A., Freiburger, C.E., Hubert, T. D., Leistner, K.G., Morrison, B.J., Nowicki, S.M., Robertson, S.N.P., Rowlinson, A.K., Scotland, B.J., Sullivan, T.B., (2021). Advances in the use of lampricides to control sea lampreys in the Laurentian Great Lakes, 2000–2019. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.08.009.
Symbal, M.J., Neave, F.B., Jubar, A.K., Steeves, T.B., Nowicki, S.M., Frank, R.J., 2021. Targeted lampricide treatment strategies for sea lamprey suppression in the Great Lakes: 2008–2018. J. Great Lakes Res. (2021)
Tews, J.M., Adams, J. V, Mann, K.A., Koon, E.M., Heinrich, J.W., 2021. A review of an electric weir and fishway in a Great Lakes tributary from conception to termination. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2020.09.004.
Treska, T.J., Ebener, M.P., Christie, G.C., Adams, J.V, Siefkes, M.J., This issu). Setting and tracking suppression targets for sea lamprey in the Great Lakes. J. Great Lakes Res. (2021).
U.S. Department of State, 1956. Convention on Great Lakes Fisheries between the United States of America and Canada. TIAS 3326. In: United States treaties and other international agreements, Vol. 6, part 3, pp. 2836–2842. U.S. Government Printing Office, Washington. Available: http://www.glfc.org/pubs/conv.pdf.
Walter, L.M., Dettmers, J.M., Tyson, J.T., 2021. Considering aquatic connectivity trade-offs in Great Lakes barrier removal decisions. J. Great Lakes Res. (2021).
Wilkie, M.P., Hubert, T.D., Boogaard, M.A., Birceanu, O., 2019. Control of invasive sea lampreys using the piscicides TFM and niclosamide: Toxicology, successes & future prospects. Aquat. Toxicol. 211, 235–252.
Wilkie, M.P., Tessier, L.R., Boogaard, M., O'Connor, L., Birceanu, O., Steeves, T.B., Sullivan, W.P., 2021. Lampricide bioavailability and toxicity to invasive sea lamprey and non-target fishes: The importance of alkalinity, pH, and the gill microenvironment. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2021.09.005.
Yin, X., Martinez, A.S., Perkins, A., Sparks, M.M., Harder, A.M., Willoughby, J.R., Sepúlveda, M.S., Christie, M.R., 2021. Incipient resistance to an effective pesticide results from genetic adaptation and the canalization of gene expression. Evol. Appl. 14 (3), 847–859.
York, J.R., Thresher, R.E., McCauley, D.W., 2021. Applying functional genomics to the study of lamprey development and sea lamprey population control. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2020.03.010.
Zielinski, D.P., McLaughlin, R., Castro-Santos, T., Paudel, B., Hrodey, P., Muir, A., 2019. Alternative Sea Lamprey Barrier Technologies: History as a Control Tool. Rev. Fish. Sci. Aquacult. 27 (4), 438–457.
Zielinski, D.P., Freiburger, C., 2021. Advances in fish passage in the Great Lakes basin. J. Great Lakes Res. (2021) https://doi.org/10.1016/j.jglr.2020.03.008.

Update

Journal of Great Lakes Research

Volume 48, Issue 4, August 2022, Page 1128

DOI: https://doi.org/10.1016/j.jglr.2022.05.016

Journal of Great Lakes Research 48 (2022) 1128

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/ijglr

Corrigendum

Corrigendum to "Foreword: Control and Conservation of Lampreys Beyond 2020 – Proceedings from the 3rd Sea Lamprey International Symposium (SLIS III)" [J. Great Lakes Res. 47(S1) (2021) S1–S10]

Robert McLaughlin [a,*], Jean V. Adams [b], Pedro R. Almeida [c,d], Jessica Barber [e], Dale P. Burkett [f], Margaret F. Docker [g], Nicholas S. Johnson [h], Mary L. Moser [i], Andrew M. Muir [f], Donald L. Pereira [j], Michael J. Siefkes [f], Todd B. Steeves [k], Michael P. Wilkie [l]

[a] Department of Integrative Biology, University of Guelph, Guelph, ON N1G 2W1, Canada
[b] US Geological Survey - Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI 48105, USA
[c] University of Évora, School of Sciences and Technology, Department of Biology, Largo dos Colegiais 2, 7004-516 Évora, Portugal
[d] MARE - Marine and Environmental Sciences Centre, Largo dos Colegiais 2, 7004-516 Évora, Portugal
[e] U.S. Fish and Wildlife Service, Marquette Biological Station, 1095 Cornerstone Drive, Marquette, MI 49855, USA
[f] Great Lakes Fishery Commission, 2200 Commonwealth Blvd., Suite 100, Ann Arbor, MI 48105, USA
[g] Department of Biological Sciences, University of Manitoba, Winnipeg, MB R3T 2N2, Canada
[h] U.S. Geological Survey, Great Lakes Science Center, Hammond Bay Biological Station, 11188 Ray Road, Millersburg, MI 49759, USA
[i] Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Boulevard East, Seattle, WA 98112, USA
[j] 15318 Afton Hills Ct. S., Afton, MN 55001, USA
[k] Department of Fisheries and Oceans, 1219 Queen Street East, Sault Ste Marie, ON P6A 2E5, Canada
[l] Department of Biology and Laurier Institute for Water Science, Wilfrid Laurier University, Waterloo, Ontario N2L 3C5, Canada

The authors regret that in the originally published version of Fig. 2 the caption contained two errors. The correct identification of individual 23 in the photo is Matthew Lipps. The correct name of individual 28 in the photo is Carrie Baker (nee Kozel).

The authors apologise for any inconvenience caused.

DOI of original article: https://doi.org/10.1016/j.jglr.2021.11.001
* Corresponding author.
E-mail address: rlmclaug@uoguelph.ca (R. McLaughlin).

https://doi.org/10.1016/j.jglr.2022.05.016
0380-1330/