CARING FOR SEA LAMPREY: RISK MANAGEMENT, BIOTECHNOLOGY, AND ERADICATION IN THE GREAT LAKES

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Abstract

CRISPR genome-editing technology offers great potential and considerable uncertainties for the future management of invasive sea lamprey (*Petromyzon marinus*) in the Laurentian Great Lakes. However, without the integration of CRISPR, the future of sea lamprey management is likely to mirror the past 70 years, characterized by significant maintenance and operational costs, ongoing chemical treatments in the water, and the continued use of barriers that block important migratory passages. This research examines the perspectives and potential of using CRISPR technology to control or eradicate sea lamprey in the Great Lakes, using the Great Lakes Fishery Commission's (GLFC) new genetic control theme as a case study. Fieldwork interviews in the Great Lakes region and virtual semi-structured interviews were conducted (n=16) with senior leadership from the GLFC, Indigenous Knowledge Holders and an Indian in Transition, First Nation Fishery Professionals, and scientists. A focus group (n=3) was also conducted with senior officials from the Government of Canada. The findings reveal that the use of CRISPR to control or eradicate sea lamprey in the Great Lakes is polarized, with significant opposition to applying CRISPR technology on host species. Additionally, the research identified that the current GLFC governance framework could be insufficient in meaningfully involving First Nations in the CRISPR decision-making process, which could potentially undermine Canadian law and community sovereignty. This research serves as a starting point for acknowledging the ethical conundrums associated with using CRISPR technology to control sea lamprey in the Great Lakes.

Key Words: CRISPR, sea lamprey, eradication, decision-making, sovereignty, technology

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Positionality Statement

As a curious thinker with experience spanning the arts and sciences, I approach this work with a commitment to fostering bridges and building consensus across academic disciplines.

As a descendant of European settlers, I extend my deepest gratitude to the First Nations, Inuit, and Métis Peoples, who have respectfully cared for these lands since time immemorial. I am profoundly thankful to the First Nations who have generously shared their knowledge with me and fostered meaningful, lasting relationships throughout and beyond this research journey. This research was conducted in partnership with the larger research project titled Sea Lamprey Research & Management – Indigenous Input and Inclusion (3I Project).

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Chapter One: Introduction

Research Overview

Regularly Interspaced Short Palindromic Repeats (CRISPR) technology grew in popularity in 2013 when scientists demonstrated its ability to edit genomes in organisms, a breakthrough that has since contributed to a growing interest in environmental applications (Lander, 2016; Henderson et al., 2024). One promising application of CRISPR technology is the use of gene editing in invasive species, where it could be applied to modify or control invasive populations, thereby lowering the damage they cause and supporting the recovery of ecosystems (Henderson et al., 2024). However, applying CRISPR technology for invasive species control presents significant ethical, ecological, and technical challenges, resulting in the need for careful consideration of potential risks and long-term consequences (Brokowski & Adli, 2019). To address these challenges, it is important to fully understand the contexts where CRISPR technology could be implemented and to acknowledge the perspective of rightsholders to ensure its responsible use (Rath, 2017).

Described as one of the greatest ecological disasters of the 20th century, the invasion of sea lamprey (*Petromyzon marinus*) in the Great Lakes contributed to the collapse of native trout populations and continues to threaten native fish today (Adams et al., 2021). Albeit research has investigated the use of CRISPR technology to control sea lamprey, and the GLFC has initiated a genetic control theme, there remains sparse literature recognizing rightsholders' perspectives on the technology's development and implementation (Thresher et al., 2019a; Ferreira-Martins et al., 2021). Specifically, no research to date has directly engaged Indigenous Peoples on the research topic, despite their extensive relationship to the Great Lakes. This research serves as a starting point for

acknowledging the ethical challenges associated with using CRISPR technology to control sea lamprey in the Great Lakes and the diverse perspectives that exist. Information has been gathered from various rightsholders to contextualize CRISPR technology and its potential use in controlling sea lamprey, aiming to support a more inclusive and informed decision-making environment.

Research Context

Since time immemorial, the Great Lakes region has been central to the livelihoods and cultural traditions of Indigenous Peoples (Johnston, 2006; Chiblow, 2023). Millions of Indigenous Peoples have inhabited the Great Lakes region, and robust governance frameworks upheld the continued health of the environment (Ettawageshik & Norman, 2020; Chiblow, 2023). The Dish with One Spoon is an example of an agreement used by Indigenous Peoples in the Great Lakes and St. Lawrence Valley, symbolizing the shared hunting grounds between neighbouring nations (Lytwyn, 1997). However, since the colonization of Canada by European settlers, the Great Lakes have depreciated in health and quality (McGregor et al., 2023). The Great Lakes have suffered a significant environmental decline from polluting industries like automotive and mining, but they are also among the most invaded aquatic systems globally, with 188 non-native species documented as of 2023 (Hartig et al., 2020; Lower et al., 2024). The ongoing challenges facing the Great Lakes call into question the effectiveness of current government organizations and environmental programs in addressing the region's complex environmental issues.

Amidst growing ecological pressures on the Great Lakes, the GLFC is frequently recognized for running one of the most successful aquatic pest management programs in the world (Hrodey et al., 2021). The Sea Lamprey Control Program (SLCP) has been implemented in the Great Lakes since the

1950s, with the GLFC overseeing the deployment of field agents from the United States Fish and Wildlife Service and the Department of Fisheries and Oceans Canada (Hrodey et al., 2021). The centralized management authority granted by the Convention on Great Lakes Fisheries between The United States of America and Canada, hereafter dubbed "the Convention," addressed the "divided governance" issues that existed prior to the GLFC's formation, leading to more established working arrangements and strengthened collaboration on fisheries management between the two nations (Gaden et al., 2021a). Today, the SLCP has contributed to a 90% reduction in sea lamprey populations from pre-control levels, supporting the health of the ecosystem, fish communities, and related economies (Burkett et al., 2021; Hrodey et al., 2021).

Given the success of the SLCP, a study by Gaden et al. (2021b) brought attention to the SLCP from the angle of the "shifting baseline syndrome," a concept that highlights the loss of generational knowledge and historical perspective in defining a healthy environment. Gaden et al. (2021b) argue that "shifting baseline syndrome" undermines societal support for the SLCP, posing challenges to the program's "social license to operate" in the Great Lakes. While Gaden et al. (2021b) attribute the declining social license to operate the SLCP to a fading historical memory of sea lamprey impacts, McGregor et al. (2023) argue that Indigenous Peoples in Canada are largely excluded from Great Lakes governance, and Burkett et al. (2021) explain several operational limitations of current control techniques. While the erosion of knowledge may contribute to a declining social license to operate, factors such as the exclusion of Indigenous Peoples and operational challenges appear to be more significant drivers of the SLCP's diminishing social acceptance. After all, if rightsholders are consistently

excluded from governance, it is neither fair nor acceptable to expect the preservation of knowledge over time.

Moving beyond the shifting baseline syndrome, the SLCP has suppressed sea lamprey to 90% of their peak density through two primary suppression methods: lampricides and barriers (Burkett et al., 2021; Hrodey et al., 2021). While these methods have lessened the impact of lamprey predation, each has significant challenges for sustained use. Barriers, including natural structures like falls and rapids, and human-made dams, have played a crucial role in reducing sea lamprey populations by limiting the reach of the species (Miehls et al., 2020). Despite their benefits, barriers pose considerable challenges to river ecosystems, including impeding the movement of native fish species, reduced aquatic connectivity, and increased maintenance costs because of aging infrastructure and degradation over time (Miehls et al., 2020; Burkett et al., 2021). Chemical lampricides, notably 3-trifluoromethyl-4-nitrophenol (TFM), emerged in 1958 as a vital tool in managing sea lamprey populations within the Great Lakes ecosystem (Sullivan et al., 2021; McDonald & Kolar, 2007; Great Lakes Fishery Commission, 2024a). By targeting sea lamprey larvae in their nursery habitats, lampricides can contribute to protecting sensitive species like lake trout (*Salvelinus namaycush*) and lake sturgeon (*Acipenser fulvescens*), which helps in achieving ecosystem health and conservation goals (Sullivan et al., 2021; Adams et al., 2021). However, drawbacks exist with the use of lampricides. Concerns persist regarding their potential impact on non-target species, such as native lampreys, necessitating ongoing research and monitoring to assess and mitigate ecological harm (McDonald & Kolar, 2007; Sullivan et al., 2021). Additionally, rising societal apprehensions regarding chemical use in water pose an additional hurdle to the sustained use of lampricides as a sea lamprey control method (Sullivan et al.,

2021). The social and environmental risks associated with current suppression methods used to control invasive sea lamprey are growing, and the sustainability of the SLCP is being put into question.

The declining social license to operate has resulted in the GLFC needing to evaluate its science and future pathway for the SLCP (Burkett et al., 2021). Consequently, the GLFC is now leveraging its current position to explore the development of CRISPR technology through its newly created genetic control theme. With CRISPR technology, scientists can make specific genetic alterations that disrupt invasive species' survival, growth, or reproduction, thereby mitigating their environmental and economic impact (Dana et al., 2014). CRISPR technology operates primarily through two mechanisms: knock-in, involving the insertion of genetic material into an organism's DNA, and knock-out, aimed at disabling or removing a specific gene from an organism (Johnson et al., 2016 & Yang et al., 2022). By precisely targeting key genes associated with invasive traits, such as rapid reproduction or competitive advantages, CRISPR technology provides the potential to disrupt the biological mechanisms underpinning invasiveness (Oye et al., 2014; Dana et al., 2014). The precision of CRISPR technology allows for the selective species-specific modification of genes critical to invasive species' survival, raising the prospect of not only controlling but potentially eradicating entire invasive populations (Webber et al., 2015). Such capabilities signify a paradigm shift in invasive species management, offering a new technique to approach environmental management. CRISPR technology applications in managing sea lamprey populations within the Great Lakes region is braided in scientific innovation and yet-to-be-explored socio-political dynamics. Recent explanations, such as those outlined in Thresher et al. (2019a) and Ferreira-Martins et al. (2021), provide comprehensive insights into the diverse array of genetic

control options available for sea lamprey control. The new GLFC genetic control theme holds both promise and uncertainty; on the one hand, it could offer a more sustainable control program and even lead to eradication, but on the other, it raises numerous new questions about the governance and management of invasive species.

As environmental change and technological advancements accelerate, pre-existing governance frameworks can be evaluated to determine whether they effectively address new contexts. The GLFC is a centralized umbrella organization for an incredibly complex multijurisdictional and multilevel governance arrangement (Mulvaney et al., 2015). The emergence of CRISPR technology and the diminishing social licence to operate the SLCP presents a unique opportunity to assess the effectiveness and inclusivity of GLFC governance frameworks. The Convention, the Joint Strategic Plan for Management of Great Lakes Fisheries, hereafter dubbed "the Joint Strategic Plan," the Council of Lake Committees, and the Lake Committees must be critically assessed to determine whether they can effectively and meaningfully include rightsholders in decisions as transformative as the potential use of CRISPR technology to eradicate sea lamprey. This issue is particularly significant because First Nations are not included on lake committees, which means they have no direct influence in crafting the objectives that shape GLFC decisions, goals, and actions across their territories (Nonkes et al., 2023).

This research is timely, as it marks the first study to critically evaluate the GLFC governance frameworks and rightsholder perspectives surrounding the application of CRISPR technology for sea lamprey control. As concern for declining public support and pressures for sustainable solutions grow, genetic control introduction offers promise and uncertainty (Thresher et al., 2019b; Burkett et al., 2021; Gaden et al., 2021b). While it is foreseeable that tensions will arise

when approving the use of genetic control with the present GLFC multijurisdictional and multilevel governance framework, this research nonetheless opens a beginning to thinking about the challenges and gaps that may exist with Indigenous exclusion.

Gaps in Consensus and Knowledge

Given the recent advancements in CRISPR technology, many gaps across discipline boundaries are not fully understood (Moro et al., 2018). Critical knowledge gaps in the genetic modification of sea lamprey include challenges in border biosecurity, uncertainties about potential consequences, regulatory complexity, risks to public and environmental health, technological feasibility, and the need for meaningful Indigenous inclusion (Ferreira-Martins et al., 2018; Moro et al., 2018; Sharpe, 2014). While existing research has examined public opinions on using genetic control to manage sea lamprey in the Great Lakes, a significant gap exists in understanding how Indigenous Peoples perceive these advancements (Thresher et al., 2019b). For instance, Sharpe (2014) conducted eight focus groups, including 61 participants between 2009 and 2010, to develop a general understanding of people's knowledge, attitudes, and concerns about the genetic control of invasive species in the American Great Lakes region. Sharpe (2014) found that research participants were generally supportive of genetic control, however participants set high standards in terms of deciding whether to use the technology in the environment. A notable limitation of Sharpe (2014) is that only 3% of participants identified as belonging to a tribal group, resulting in an inadequate representation of Indigenous perspectives on the topic.

Another study, supported by a grant from the GLFC, explored whether a 'social license' could exist to develop and use genetic biotechnology in the Great Lakes. Thresher et al. (2019b) highlighted the importance of both a social license

to operate and informed decision-making in the development and use of genetic biocontrol to manage invasive species in the Great Lakes. Findings from Thresher et al. (2019b) showed that roughly 90% of 144 respondents support researching and using a form of genetic control to manage sea lamprey. Similar to Sharpe (2014), Thresher et al. (2019b) lacked meaningful engagement with Indigenous Peoples, as the study included only tribal biologists and did not involve Indigenous Peoples more broadly. First Nations from Canada are frequently underrepresented in studies like Sharpe (2014) and Thresher et al. (2019b), despite these studies addressing issues that are connected to their lands. The lack of First Nation engagement in the GLFC genetic control theme highlights a critical gap in current management, emphasizing the importance of incorporating First Nation perspectives to ensure the equitable and culturally sensitive implementation and development of a new control method in the Great Lakes region.

Finally, sparse research has explored the importance of First Nations in representing their interests as members of the GLFC lake committees. Nonkes et al. (2023) discussed the significance of GLFC lake committees and the current exclusion of First Nations from the decision-making process, a gap that could prove highly detrimental as advancements like CRISPR technology move forward.

Research Participants

Recognizing the interdisciplinary nature of this research, participants (n=19) were carefully selected to represent a range of disciplines, expertise, and lived experiences, which ensured a comprehensive understanding of perspectives. Participants were recruited from five different backgrounds: GLFC, Scientific Community, First Nation Fishery Professionals, Indigenous Knowledge Holders from First Nations and an Indian in Transition, and the Government of Canada. The phrase “Indian in Transition” has ties to Canadian First Nations artist Daphne

Odjig and her 1978 painting "The Indian in Transition" that was motivated by the rebirth of Indian consciousness (Odjig et al., 2001; Campbell, 2014). Participants were given the option to remain anonymous, with their contributions linked to a numerical coding system, or to identify themselves and their contributions. Table 1 lists all research participants along with their backgrounds.

Table 1

Research Participants

Category	**Name/Code**	**Title**	**Organization/Special Notes**
Great Lakes Fishery Commission (GLFC)			
	Marc Gaden	Executive Secretary	GLFC
	Andrew Muir	Director, Science	GLFC
	Gregory McClinchey	Director, Policy and Legislative Affairs	GLFC
	Ted Treska	Programs Manager, Sea Lamprey Control	GLFC
Scientific Community			
	Margaret Docker	Professor	University of Manitoba Leader, GLFC Genetic Control Theme
	Melinda Kliegman	Director, Public Impact	Innovative Genomics Institute
	Tyler Square	Assistant Professor	University of Florida
	Interview Participant 1	Anonymous	

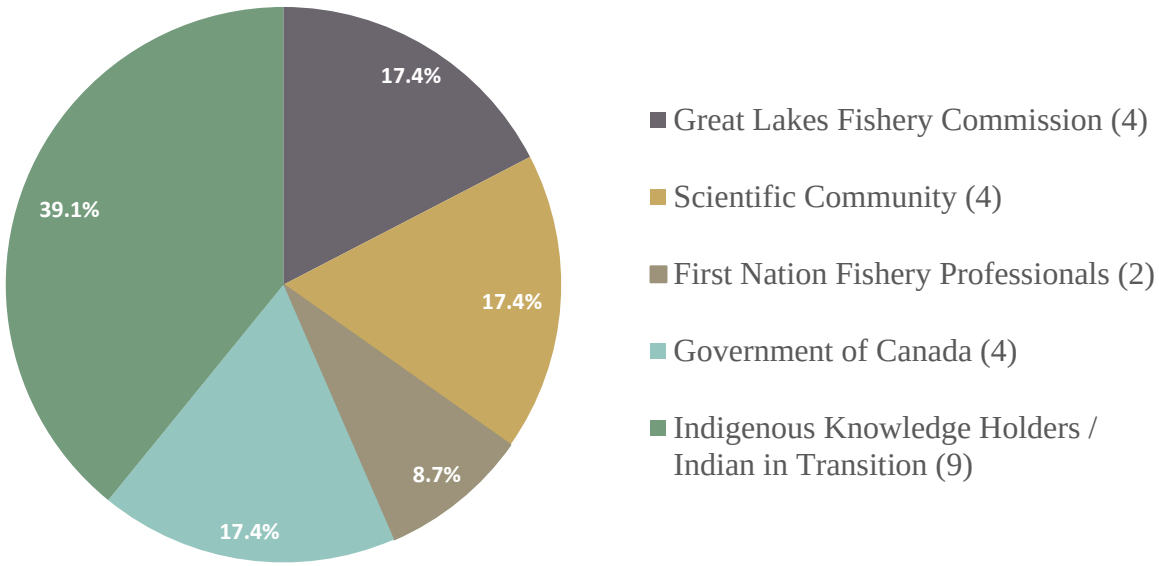
First Nation Fishery Professionals			
	Interview Participant 2	Anonymous	
	Interview Participant 3	Anonymous	
Indigenous Knowledge Holders			
	Noah LeSage		Indigenous Advisor
	Interview Participant 4	Anonymous	
	Interview Participant 5	Anonymous	
	Interview Participant 6	Anonymous	
	Interview Participant 7	Anonymous	
Indian in Transition	Joseph Corbiere		This research participant self-described and requested to be recognized as an "Indian in Transition"
Government of Canada (GC)			
	Interview Participant 8	Anonymous	GC
	Interview Participant 9	Anonymous	GC
	Interview Participant 10	Anonymous	GC

Note. This table shows participants grouped by background.

Some research participants fit clearly into a single thematic category, while others could be placed into more than one category due to their intersectional backgrounds. Figure 1 highlights the intersectional backgrounds, acknowledging participant involvement across multiple categories.

Figure 1

Intersectional Participant Representation



Note. Some participants could be identified in more than one category, and this pie chart places some people in multiple categories.

The research participants in this study provide a comprehensive overview of current perspectives on using CRISPR technology in the Great Lakes. In contrast to Sharpe (2014) and Thresher et al. (2019b), this research focuses exclusively on First Nation perspectives from Canada, marking a significant step toward meaningfully incorporating Indigenous Peoples and their contributions into sea

lamprey genetic control research. The research also benefits from the participation of Margaret Docker, leader of the GLFC genetic control theme, and Marc Gaden, Executive Secretary of the GLFC, who provide essential insights into the status and future direction of genetic control efforts in the Great Lakes.

Geographic Location

This research is based in the Great Lakes region, see Figure 2. The Great Lakes form the largest freshwater lake system on Earth, accounting for nearly 18% of the world's freshwater supply (Waples et al., 2008). The Lakes themselves include Lake Superior, Michigan, Huron, Erie, and Ontario, stretching 16,000km of coastline (Waples et al., 2008).

Figure 2

The Laurentian Great Lakes

Note. Image from September 16, 2002. Left to right: Lakes Superior, Michigan, Huron, Erie, and Ontario (Descloitres, 2002).

Sociologically, the Great Lakes are complex. Nearly 10% of the American population and 32% of the Canadian population reside in the Great Lakes region, which includes roughly 40 million people (Sterner et al., 2017). Economically, the Great Lakes are valued at more than $7 billion annually and support more than 75,000 jobs, resulting in being a powerhouse for economic productivity in the region (Great Lakes Fishery Commission, 2024b; Great Lakes Fishery Commission, 2024c). Ecologically, the Great Lakes support 177 fish species, including 139 native species like walleye, bass, and brook trout, along with 34 non-native species, while 61 are classified as threatened or endangered (Great Lakes Fishery Commission, 2024d). Collectively, the Great Lakes are valued and cared for in diverse ways, reflecting the varied priorities of the millions who depend on them, from environmental conversation to economic development and cultural preservation. This range of perspectives on how people value and care for the Great Lakes highlights the complexity of managing such a vital and shared resource.

Research Questions

The overarching aim of this research is to investigate if and to what extent First Nations near the Great Lakes support the control of sea lamprey using CRISPR technology. To determine whether the use of CRISPR technology in the Great Lakes can be justified within an acceptable social and political context, this research is framed by three key questions:

1. Among First Nation Indigenous Peoples, what perspectives exist on using CRISPR technology on sea lamprey?
2. How do scientists contextualize the use of CRISPR technology on sea lamprey?

3. Do current regulatory and policy frameworks adequately include First Nation Indigenous Peoples in decision-making about developing and implementing CRISPR technology in the Great Lakes?

Research Objectives

Given the complex nature of implementing CRISPR technology in the Great Lakes, this research is structured around three key objectives, each addressing a distinct theme. The first objective is focused on gaining a deeper understanding of the perspectives that exist on the recent GLFC genetic control theme and the use of CRISPR technology for sea lamprey control. The second objective aims to explore the benefits and drawbacks of CRISPR technology by engaging with scientists in relevant fields while also developing an understanding of how the technology operates. The third objective involves critically analyzing the current governance and policy frameworks that guide decision-making regarding the use and development of CRISPR technology in the Great Lakes. The following are the specific objectives of this research:

1. Develop a comprehensive characterization of First Nation Indigenous Peoples' perspectives and recommendations on the use of CRISPR technology for sea lamprey control in the Great Lakes.
2. Evaluate the benefits and challenges of using CRISPR technology for sea lamprey control in the Great Lakes and examine its operational implementation.
3. Examine the current policy and governance framework for decision-making regarding CRISPR technology in the Great Lakes and assess the level of inclusion of First Nations in these processes.

Thesis Structure

The research is divided into 7 chapters. Chapter 1 opens with an introduction to this research, providing information about the research context, geographical region, and research objectives. Chapter 2 is a literature review that provides depth and breadth to the core research objectives, expanding on the GLFC governance structure and the use of CRISPR technology on sea lamprey in the Great Lakes. Chapter 3 presents the methodology and study design, including the theoretical framework, timeline, and approach. Chapter 4 is a repository of perspectives that were collected on the GLFC genetic control theme and the potential use of CRISPR technology for sea lamprey control in the Great Lakes. Chapter 5 provides a comprehensive contextualization of the benefits and drawbacks of CRISPR technology for sea lamprey control, including a critical section on key recommendations from rightsholders regarding the future of the GLFC genetic control theme. Chapter 6 is a reflection on the research design, strengths, and limitations. Chapter 7 offers a summary of the research context and key findings, and it recommends the next steps for further research in the field.

Chapter 2: Literature Review

Sea Lamprey Control in the Great Lakes

The invasive nature of sea lamprey, characterized by their high reproductive capacity and excessive feeding traits, has posed significant challenges to the Great Lakes ecosystem since the early 1900s (Brant, 2019; Adams et al., 2021). The cumulative effects of both high reproductive features and excessive feeding traits exemplify the invasive properties of sea lamprey. Sea lamprey invasion spurred concerted efforts to control their populations, driven by the drastic depletion of native fish stocks in the 1940s and 1950s, igniting what Brant (2019) calls a chemical and infrastructural war against the species (Great Lakes Fishery Commission, 2024e; Brant, 2019). The control of invasive sea lamprey through chemical and infrastructural suppression methods has led to a 90% reduction in sea lamprey numbers but has also posed challenges such as long-term costs, non-target mortality in native species, and a shifting baseline of support from Indigenous Peoples (Ferreira-Martins et al., 2021; Gaden et al., 2021b). Suppression methods have led to a resurgence of native biodiversity; however, each presents significant problems, such as decaying and growing pressure to remove infrastructure and the potential resistance to current chemical applications (Burkett et al., 2021).

Barriers, including natural structures like falls and rapids, and human-made dams, have played a crucial role in reducing sea lamprey populations by limiting the reach of the species (Miehls et al., 2020). Roughly 1000 barriers impede sea lamprey migration in streams feeding into the Great Lakes, shielding over 300,000 kilometres of habitat from potential sea lamprey infestation. Barriers have also improved the effectiveness and reduced costs of lampricide treatments by confining sea lamprey to specific areas (Miehls et al., 2020). Walter et al. (2021) explain, “stream fragmentation can protect fish population from competition with

non-native species or contaminants and it can restrict non-native species from accessing spawning and rearing habitat" (Walter et al., 2021). While barriers have been instrumental in mitigating sea lamprey populations in the Great Lakes, their efficacy comes with significant ecological drawbacks. Despite their benefits, they pose considerable challenges to river ecosystems, including impeding the movement of native fish species, reduced aquatic connectivity, and increased maintenance costs because of aging infrastructure and degradation over time (Miehls et al., 2020; Burkett et al., 2021).

Chemical lampricides, notably 3-trifluoromethyl-4nitrophenol (TFM), emerged in 1958 as a vital tool in managing lamprey populations within the Great Lakes ecosystem – though it should be mentioned not all sea lamprey are vulnerable to lampricides (Sullivan et al., 2021; McDonald & Kolar, 2007; Great Lakes Fishery Commission, 2024f; Adams et al., 2021). The selective toxicity of TFM towards larval lampreys has led to reductions in their populations, which aids the recovery of native fish species and enhances overall biodiversity (McDonald & Kolar, 2007). By targeting sea lamprey larvae in their nursery habitats, lampricides can contribute to protecting sensitive species, such as lake trout (*Salvelinus namaycush*) and lake sturgeon (*Acipenser fulvescens*), which helps in achieving conservation goals, but also requires ongoing financial investment (Sullivan et al., 2021; Adams et al., 2021). However, challenges accompany the use of lampricides. Concerns persist regarding their potential impact on non-target species, such as native lampreys, resulting in ongoing research and monitoring (Sullivan et al., 2021; McDonald & Kolar, 2007). Furthermore, rising societal apprehensions regarding pesticide use and increasing advocacy for barrier removal and enhanced stream connectivity pose additional hurdles to the sustained use of lampricides as a sea lamprey control method (Sullivan et al., 2021).

In 2018, the Sea Lamprey Control Leadership Team was formed, bringing together senior leadership from the GLFC, Fisheries and Oceans Canada (DFO), U.S. Fish & Wildlife Service, and U.S. Geological Survey, all experts in the management and regulation of sea lamprey control (Burkett et al., 2021). The Sea Lamprey Control Leadership Team allows for better planning and delivery of the program, and this was shown at the third Sea Lamprey International Symposium in 2019, where the team generated a list of program strengths and weaknesses. The recorded strengths and weaknesses of the SLCP were assessed in the context of developing a better path toward 2040, with the goal of offering valuable insight for future management (Burkett et al., 2021). See Tables 2 and 3 for the strengths and weaknesses of the SLCP.

Table 2

Strengths of the Sea Lamprey Control Program

Control an aquatic species on a watershed scale
90% reduction of sea lamprey populations from pre-control levels
Supports restoration of the ecosystem, fish community and related economy
Commitment to minimize effects on non-target species
Use of relatively selective lampricides that degrade rapidly after application
Strong cooperation with management and regulatory agencies
Strong and expanding science base
Close integration of science with control actions
Large network of effective barriers not owned or maintained by the GLFC
Nearly six decades of program delivery experience
Lifelong career investments at field, supervisory, and policy levels

Wide public support because lamprey are ugly and unique – people want them to be controlled

Note. The Sea Lamprey Control Program Leadership Team identified the strengths of the SLCP from the third Sea Lamprey International Symposium (Burkett et al., 2021).

Table 3

Weaknesses of the Sea Lamprey Control Program

Dependence on lake trout marking rates as an indicator of sea lamprey control effectiveness
Inability to consistently link sea lamprey abundance with lake trout abundance and marking rates
Barriers to infestation, followed by lampricides, remain the only effective methods of control
Effective barriers disrupt aquatic habitat connectivity
Although highly selective, lampricides do yield non-target mortality in some species
Use of barriers and lampricides can conflict with people's relationship with water
Lampricide application permit restrictions can result in marginally effective control
Outdoor enthusiasts are declining in number and demographics and attitudes are shifting
Funding limitations reduce larval and adult assessment efforts in favour of barriers and lampricides
Expectations for adult and juvenile control tactics as alternatives to barriers and lampricides were unreasonably high at the outset
No intuitive way to compare cost-effectiveness of new versus existing control tools results in inertia favoring the status quo
The scientific process and academic review systems do not reward risk taking that may lead to revelations and new control tools

Note. The Sea Lamprey Control Program Leadership Team identified weaknesses of the SLCP from the third Sea Lamprey International Symposium (Burkett et al., 2021).

The control of sea lamprey in the Great Lakes is highly successful from the perspective of reducing population numbers. However, the current SLCP is not achieving the full target set by the Convention, which aims for the potential eradication of invasive sea lamprey (Great Lakes Fishery Commission, 2024g). Although Article IV of the Convention specifies that the GLFC should "formulate and implement a comprehensive program to eradicate or reduce the sea lamprey population in the Convention area," the SLCP has thus far focused on the latter rather than the former. Adams et al. (2021) express that the eradication of sea lamprey is an extreme goal, especially in the current context of suppression methods. However, Adams et al. (2021) and Jones and Adams (2021) explained that the successful eradication of sea lamprey is possible, especially considering a cost-effective method to control them with genetic control could be discovered within the next ten to twenty years.

The Divided Governance Problem

For much of history, Canada and the United States shared the Great Lakes without meaningful cross-border collaboration on the fishery, leading to severe ecological, social, and economic consequences (Gaden et al., 2021a; Gaden et al., 2022). Before the sea lamprey invasion, the Great Lakes were already severely degraded, with the region's most economically valuable and iconic species, such as Lake Trout (*Salvelinus namaycush*) and Lake Whitefish (*Coregonus clupeaformis*), facing near-extirpation due to overexploitation (Gaden et al., 2022). In 1954, widespread government mismanagement of fish stocks, inconsistent scientific practices, and economic downturns prompted the establishment of the Convention (Gaden et al., 2022). Article II of the Convention established the GLFC.

> "The Contracting Parties agree to establish and maintain a joint commission, to be known as the Great Lakes Fishery Commission, hereinafter referred to as "the Commission," and to be composed of two national sections, a Canadian Section and a United States Section. Each Section shall be composed of not more than three members appointed by the respective Contracting Parties (Article II, Great Lakes Fishery Commission, 2024g)."

The Convention reduced the challenge of the divided governance problem by establishing a permanent centralized body dedicated to sustaining the vitality of fish stocks shared between the two nations (Gaden et al., 2022). The new powers of the GLFC included the ability to formulate and coordinate research programs, recommend management measures, implement control strategies for sea lamprey, and publish scientific findings. Although the GLFC is praised for running the most successful aquatic pest management program in the world, the issue of divided governance has not been fully resolved (Hrodey et al., 2021; Burkett et al., 2021; Gaben et al., 2021a).

The GLFC's current consolidation and centralization of powers have effectively strengthened its ability to manage lake-wide interests but have also diminished the influence of local control (Hall & Houston, 2014). Centralizing management and power is significant to acknowledge, as in this case, it heavily restricts the ability of Indigenous Peoples to oversee and manage the fishery (Hall & Houston, 2014; McGregor et al., 2023). McGregor et al. (2023) identified the longevity of Indigenous governance in the Great Lakes region and explained, "for thousands of years, the Great Lakes ecosystem was governed through Indigenous inter-national (between nations through treaties), regional (e.g., confederacies), and local (through clan systems) relations. The GLFC's centralization through the

Convention effectively represents the international colonization of the Great Lakes, creating significant barriers to involvement and institutionalizing a colonial approach to governance.

To establish a more adaptable and responsive governance system, the GLFC introduced the 1997 Joint Strategic Plan, which aimed to implement a more coordinated and structured framework for fisheries management. A critical component of the Joint Strategic Plan was the establishment of a lake committee for each lake, creating a platform for jurisdictions to:

a) consider issues pertinent to, or referred by, the GLFC;
b) address issues and problems of common concerns to member agencies;
c) develop and coordinate joint programs and research projects;
d) serve as a forum for state, provincial, tribal, and federal agencies; and
e) respond to requests made by any of the lake committees (Great Lakes Fishery Commission, 2024h; Nonkes et al., 2023).

As Nonkes (2023) noted, American tribes were included in the lake committee process in the mid-1980s. However, to date, First Nations in Canada have been entirely excluded from the decision-making power of the lake committees. This exclusion has resulted in their non-involvement in setting objectives, establishing goals, and identifying concerns within the GLFC's governance framework and sea lamprey program conducted across their territories (Nonkes et al., 2023).

First Nations from Canada are excluded from formal representation in the lake committee process due to colonial power dynamics maintained between the Federal Government of Canada and the Province of Ontario (Gaden et al., 2022; Nonkes et al., 2023; Gaden et al., 2012). The British North America Act (BNA Act), which defines federalism in Canada, designates freshwater fishery

management and conservation as a federal responsibility under Article VI. Gaden et al. (2012) describe how the federal government's powers under the BNA Act are exercised through the Fisheries Act, granting jurisdiction over areas such as fish habitat protection, law enforcement, and licensing (Gaden et al., 2012). The federal government possesses significant powers over fishery management; however, Ontario yields greater authority (Gaden et al., 2012). Gaden et al. (2012) explain why Ontario's role in fisheries management is more significant than that of the federal government.

> "Much of Ontario's authority derives from the fact that the provinces own the natural resources, such as fish, within their boundaries. BNA Act Article VIII, S 109 and S 117 grant to the provinces ownership of, and the rights to royalties from, 'all lands, mines, [and] minerals'. Article VI, S 92 enumerates provincial powers, giving them the right to legislate property issues and manage provincial lands. Provinces are also given meaningful powers to raise revenues and manage commerce" (Gaden et al., 2012).

Given the immense powers granted to the province of Ontario and its ownership of the lakebeds and the fish within those waters, it has effectively colonized the full Canadian representation for the GLFC lake committee process (Gaden et al., 2012). The consolidation and centralization of power in the province of Ontario exacerbates the divided governance problem in the Great Lakes by not meaningfully including First Nation representation.

Although the centralization of power within the GLFC is seldom debated, the authority granted by the Convention should also be understood within the broader context of the lake committee and GLFC process (Hall & Huston, 2014). Given that lake committees play a significant role in shaping objectives, issues,

and programs, they have a direct impact on the deliverables and operations of the GLFC (Great Lakes Fishery Commission, 2024h; Nonkes et al., 2023). The GLFC's duties are protected by Article X of the Convention on Great Lakes Fisheries.

> "Nothing in this Convention shall be construed as preventing any of the States of the United States of America bordering on the Great Lakes or, subject to their constitutional arrangements, Canada or the Province of Ontario from making or enforcing laws or regulations within their respective jurisdictions relative to the fisheries of the Great Lakes so far as such laws or regulations do not preclude the carrying out of the Commission's duties" (Great Lakes Fishery Commission, 2024g).

Article X of the Convention confirms and reinforces the Canadian colonial state, entirely omitting any recognition of Indigenous Peoples' inherent rights and jurisdiction over their traditional territories and waters (United Nations Declaration on the Rights of Indigenous Peoples Act, CRC, c. 14.). Article X showcases the continued injustice that Indigenous Peoples face, as the clause prioritizes the Commission's duties, which ignores Indigenous jurisdiction and the principles enshrined in the 2021 United Nations Declaration on the Rights of Indigenous Peoples Act (UN Declaration Act).

The UN Declaration Act is a relatively new piece of Canadian legislation that affirms the rights of Indigenous Peoples and stems from the international United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP). Specifically, the UN Declaration Act aims to create space for transformative change and ensure the full realization of Indigenous rights in Canada, fostering reconciliation, healing, justice, and the promotion of good governance (Department of Justice, 2023). The UN Declaration Act has numerous articles

which could impact the GLFC in carrying out its duties to protect Indigenous sovereignty and rights:

> *Article 5*: Indigenous Peoples have the right to maintain and strengthen their distinct political, legal, economic, social and cultural institutions, while retaining their right to participate fully, if they so choose, in the political, economic, social and cultural life of the State.
>
> *Article 18*: Indigenous Peoples have the right to participate in decision-making in matters which would affect their rights, through representatives chosen by themselves in accordance with their own procedures, as well as to maintain and develop their own Indigenous decision-making institutions.
>
> *Article 19*: States shall consult and cooperate in good faith with the Indigenous Peoples concerned through their own representative institutions in order to obtain their free, prior and informed consent before adopting and implementing legislative or administrative measures that may affect them.
>
> *Article 29*: Indigenous Peoples have the right to the conservation and protection of the environment and the productive capacity of their lands or territories and resources. States shall establish and implement assistance programmes for Indigenous Peoples for such conservation and protection, without discrimination.
>
> *Article 38*: States in consultation and cooperation with Indigenous Peoples, shall take the appropriate measures, including legislative measures, to achieve the ends of this Declaration (United Nations Declaration on the Rights of Indigenous Peoples Act, CRC, c. 14.).

The UN Declaration Acts emphasis on reconciliation and Indigenous rights can potentially challenge Article X of the Convention, which prioritizes the Commission's ability to carry out its duties without obstruction, raising questions about how the UN Declaration Act will align with GLFC governance. The emergence of the GLFC's genetic control theme prompts a crucial question: Given the ongoing divided governance issues in the Great Lakes and the potential sidelining of key Canadian legislation like the UN Declaration Act, is pursuing CRISPR technology to control sea lamprey appropriate? It is essential to include First Nations in GLFC lake committees, not only to align with Canadian law but also to ensure that progress addresses their needs and priorities (Nonkes et al., 2023).

CRISPR Technology

Genetic genome-editing as a form of biocontrol is a relatively new field yielding interdisciplinary expertise, and modified organisms are intended for release into complex socio-ecological environments (Dana et al., 2014). The methods used to suppress sea lamprey have reduced their predation on other species but have neither eliminated the threat their presence and reproduction pose to the Great Lakes nor reduced the cost of their management (Ferreira-Martins et al., 2021). The GLFC highlighted their vision for the future by acknowledging the significant progress achieved in sequencing the sea lamprey genome.

> "The sea lamprey genome has been sequenced, providing an understanding of the genes that determine the animal's behaviour and physiology, such as migration, mating, and responses to danger and environmental stressors. This monumental achievement will allow scientists, for years to come, to perhaps customize control techniques to exploit points of weakness that interrupt the sea lamprey's life cycle. No

> other aquatic pest control program has this advantage, and the commission is intent on using genomic knowledge to develop innovative tools and tactics for suppressing sea lamprey populations" (Great Lakes Fishery Commission, 2024i).

Ferreira-Martines et al. (2021) suggest that the evolution of gene editing is making it a viable tool for precisely editing natural genomes, which could potentially be applied to control and even eradicate sea lamprey populations (Ferreira-Martins et al., 2021).

Deoxyribonucleic acid (DNA) acts as the blueprint for all living organisms, governing their reproduction, growth, and survival. Animals and plants frequently encounter germs, which include bacteria, viruses, archaea, and some fungi, all of which can cause illness. For example, *Streptococcus*, a type of bacteria, causes strep throat (Henderson et al., 2024b). Although humans are often exposed to harmful germs, we typically stay healthy because organisms, even single-celled ones like bacteria, have their own immune systems. Immune systems are critical because they effectively identify and neutralize harmful germs, distinguishing between those that are dangerous and those that are harmless. When a virus, in this case, a bacteriophage "phages," enters into a bacteria, it replicates and eventually ruptures, spreading the phages to other bacteria cells (Henderson et al., 2024b). CRISPR is a special immune system that some bacteria use to fight viruses; through this system, bacteria capture and store short pieces of viral DNA (spacers) within their genome, which is the entire DNA sequence of an organism. When the phage returns again, the CRISPR immune system and Cas proteins, which are enzymes that act like molecular scissors, cut up and destroy the phage (Hochstrasser et al., 2022). This happens because the

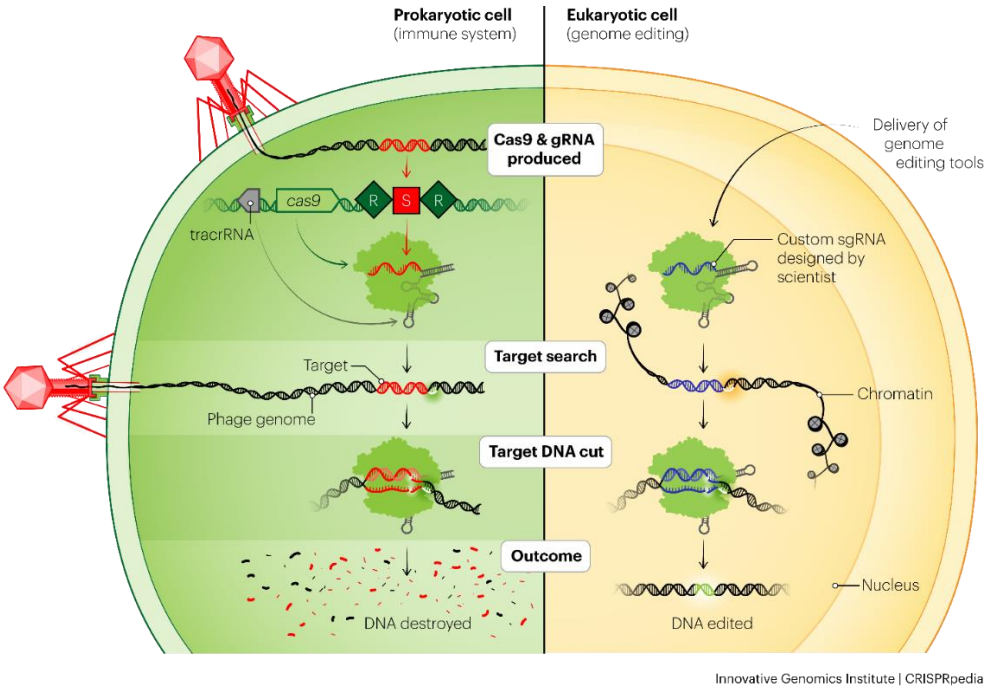
CRISPR immune system has recorded the phage in its memory, also called the CRISPR array (Hochstrasser et al., 2022). The critically important part of the CRISPR immune system and Cas proteins are that they work together to remember, target, and defend phages when they attack. The natural function of CRISPR immune systems in bacteria is a straightforward biological process, so why has CRISPR become recognized today as an incredibly powerful tool capable of eradicating species like sea lamprey?

CRISPR-Cas9 technology is a tool used in genetic research for genome editing. The CRISPR immune process found in bacteria has been adapted by scientists for this purpose. In nature, Cas9 is guided by ribonucleic acid (RNA) derived from stored phage DNA to cut specific DNA sequences. However, scientists have developed a synthetic CRISPR-Cas9 system that use custom synthetically designed RNA, allowing them to target DNA sequences with Cas9 without relying on phage-derived material (Hochstrasser et al., 2022). Since Cas9 is not naturally present in the cells of plants and animals (eukaryote organisms), scientists must introduce the system into these organisms to enable genome editing, which requires overcoming cellular barriers. In nature, Cas9 is guided by two RNA molecules: tracrRNA and crRNA. The tracrRNA helps Cas9 find the crRNA, which specifically targets and guides the Cas9 enzyme to the DNA sequence to cut it. Scientists simplified this process by combining both RNA molecules into one single-guide RNA (sgRNA) (Hochstrasser et al., 2022). This sgRNA molecule allows them to target and edit a specific DNA sequence. To make this work, scientists took advantage of a feature in the natural system: protospacer adjacent motifs (PAMs). PAMs are small DNA sequences that help Cas9 find the target DNA by acting as recognition sites, ensuring the enzyme makes

precise cuts – they allow Cas9 to accurately target specific sequences without damaging the entire organism (Hochstrasser et al., 2022). Once the PAM is identified, the sgRNA guides Cas9 to the correct location. By understanding how PAMs work in bacteria, scientists were able to design the sgRNA to target the right part of the DNA, making it possible to edit genes in more complex organisms like plants and animals. See Figure 3 for a diagram of natural vs lab CRISPR-Cas insertion.

Figure 3

Natural vs Lab CRISPR-Cas9 Insertion

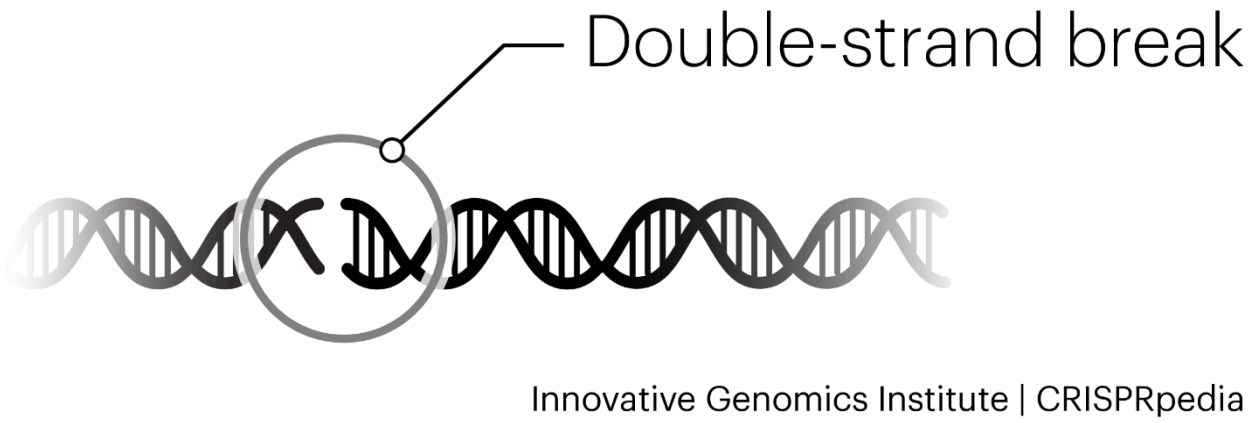


Note. In nature (green, left), CRISPR-Cas9 protects the bacteria from a virus. In the lab (yellow, right), scientists use CRISPR-Cas9 to edit DNA (Hochstrasser et al., 2022). (CC BY-NC-SA 4.0)

Currently, CRISPR-Cas9 technology has been described as a “plug and play” process for genome editing. Scientists first need to develop a sgRNA in the lab, to which they will program the Cas9 enzyme to their sgRNA. Using various techniques, such as chemical simulation, electroporation, viral delivery, microinjecting, or transforming plasmids, scientists will then apply the lab-developed sgRNA and the programmed Cas9 to the organism’s entire genome, which will eventually result in the Cas9 finding its PAM region and a double-strand break will be made to both strands of the DNA at the target site. See Figure 4 for a double-strand break (Hochstrasser et al., 2022).

Figure 4

Double-Stand Break of a DNA Strand



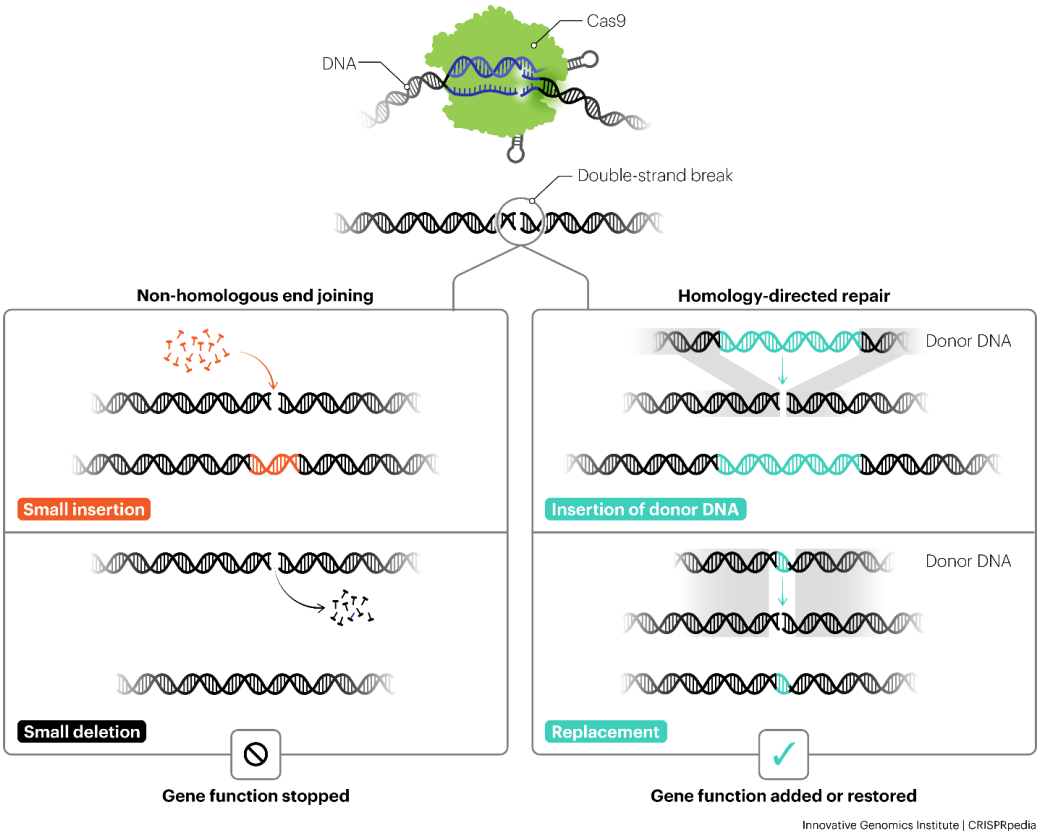
Note. The critical step during a genome edit, where the Cas9 enzyme breaks a DNA sequence (Hochstrasser et al., 2022). (CC BY-NC-SA 4.0)

In a general sense, sgRNA and Cas9 are important for identifying target sites to make deletions and other genome edits. The sgRNA binds to the target DNA, and Cas9 recognizes PAM sequences to ensure the correct

site is cut, allowing for precise edits like deletions or insertions (Hochstrasser et al., 2022).

Figure 5

Non-Homologous End Joining vs Homology-Directed Repair



Note. The non-homologous end joining pathway (NHEJ, left) leads to small insertions or deletions. The homology-directed repair pathway (HDR, right) can insert a sequence of DNA created by scientists (Hochstrasser et al., 2022). (CC BY-NC-SA 4.0)

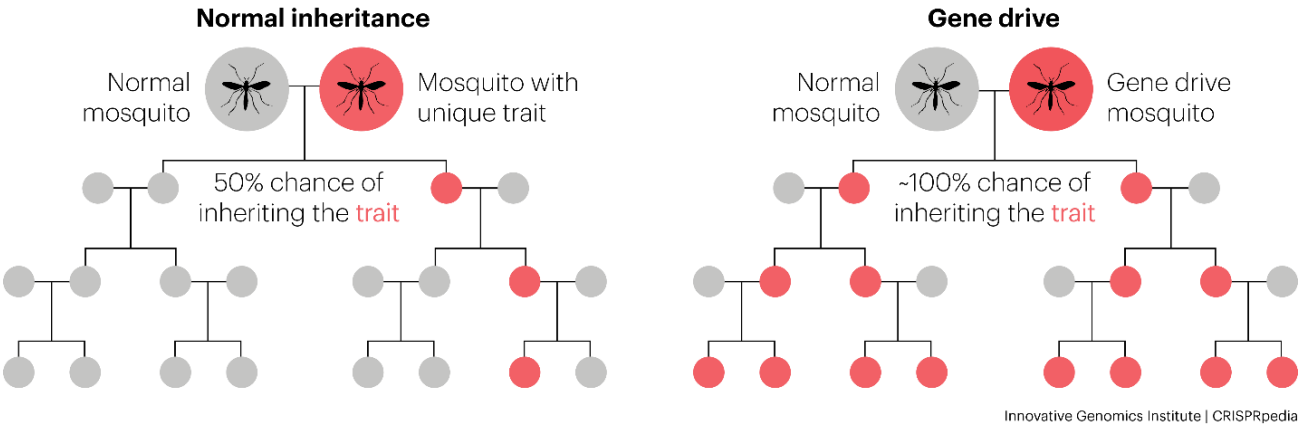
The double-strand break is incredibly important since it creates a gap between the free ends of the DNA. The first part of this CRISPR technology

section discussed the evolution of CRISPR methodology from bacteria immune systems and the synthetic hijacking of such process through programmed Cas9 and lab-designed sgRNA. The second part is controlling how the DNA repairs the double-strand break. Figure 5 shows the two options that exist for repairing a double-strand break, either the non-homologous end joining (NHEJ), which often causes insertions or deletions, or homology-directed repair (HDR), which can be used to introduce specific changes or insert new DNA (Hochstrasser et al., 2022). With NHEJ, cells are damaged from a double-strand break, the cell repair system goes into action to fix the break, resulting in either the deletion or insertion of new small sequences at the repair site. However, HDR is a more technical and specific approach to genome editing where scientists can use a template or donor DNA which contains sequences matching the broken ends of the double-strand break, which can precisely repair the break (Hochstrasser et al., 2022). Scientists can use either method as a scoping exercise to understand how their double-strand breaks are impacting the functions of the organisms. See Figure 5 for an example of NHEJ and HDR.

Both NHEJ and HDR are forms of CRISPR technology that can show the results of insertions or deletions in organisms, but the ability for organisms to pass on the edited trait is not guaranteed entirely (Hochstrasser et al., 2022). The use of gene drives ensures that traits are passed on 100% of the time.

Figure 6

Normal Inheritance vs Gene Drive

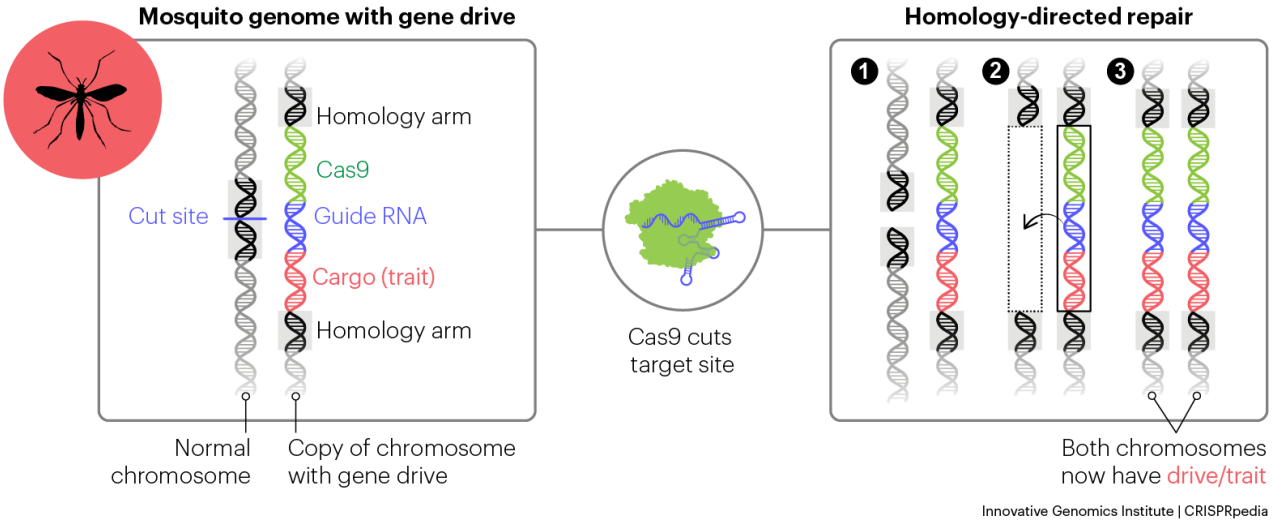


Note. Representation of normal inheritance vs a skewed gene driven inheritance (Hochstrasser et al., 2022). (CC BY-NC-SA 4.0)

Gene drives include a Cas9 enzyme, a guide sgRNA, and a cargo gene. The cargo gene can either be an edited version of an existing gene in the organism, or it can be a foreign gene. Once the organisms have received the gene drive from researchers, they let the organisms breed with unmodified organisms, and usually, the full gene drive will be passed on from one organism to another (Hochstrasser et al., 2022). This process uses HDR since it uses homologous arms to insert precisely into a target location. See Figure 6 for a diagram on natural vs gene driven inheritance.

Figure 7

Gene Drive Process



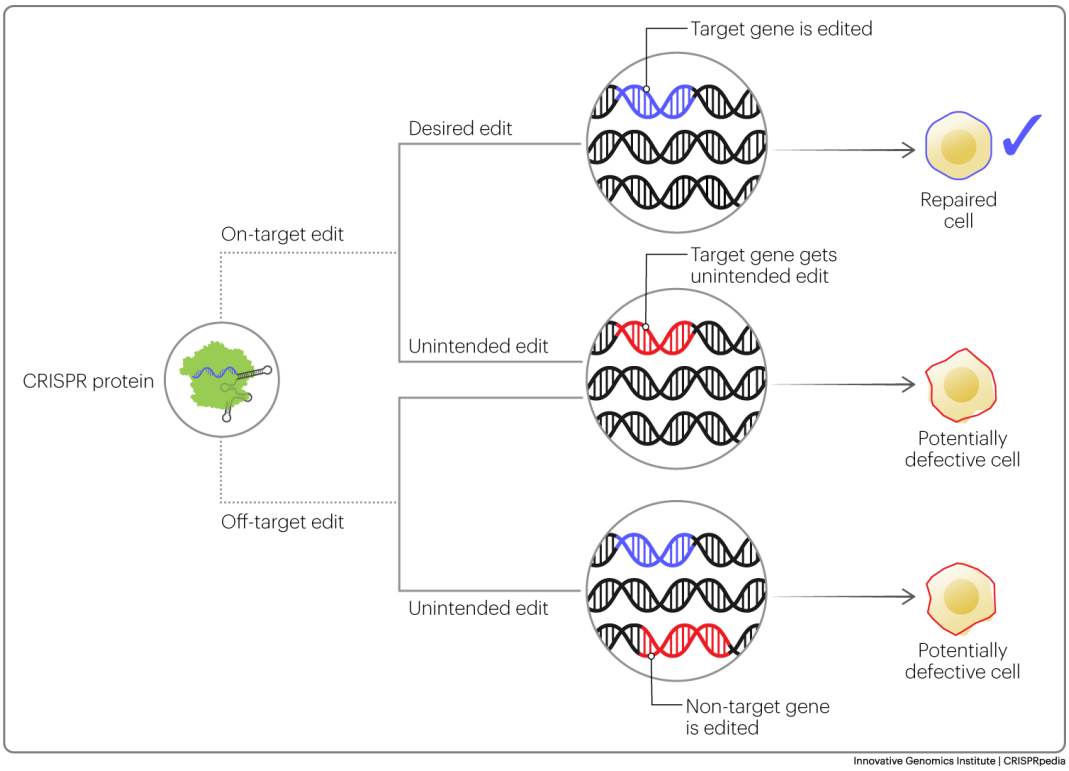
Note. The process of introducing a lab created gene drive to a complex organism (Hochstrasser et al., 2022). (CC BY-NC-SA 4.0)

The use of gene drives can be valuable since genes can be edited for specific goals. Through using HDR and gene drive specifically, CRISPR-Cas9 holds significant promise for addressing a wide array of invasive species across both terrestrial and aquatic ecosystems. The precision of CRISPR-Cas9 allows for the selective and species specific modifications of genes critical to invasive species' survival, raising the prospect of not only controlling but potentially eradicating entire invasive populations (Dana et al., 2014; Harvey-Samuel et al., 2017; Adams et al., 2021). However, gene drives do have some drawbacks. Firstly, gene drives can only be used in sexually reproducing organisms, and second, from a practical stance, gene drives are most useful for fast reproducing organisms with short lifespans so the edited gene can spread quickly. Moreover, the ability for off-target effects

and on-target effects in the genome is also possible, where unintended effects happen on a molecular level because changes are happening in a location other than the one directed in the sgRNA (Henderson, et al., 2024). See Figure 7 for an example of the gene drive process.

Figure 8

On-Target vs Off-Target Edits



Note. The potential results of an on or off-target genome edit (Henderson et al., 2024). (CC BY-NC-SA 4.0)

There have been no field trials of using a gene-driven HDR to control an invasive species population (Thresher et al., 2019b). However, scientists are driving considerable momentum to progress CRISPR technology, considering the

widespread failure of current conservation efforts globally and the ongoing threat that new invasive species bring to ecosystems (Thresher et al., 2019b). See Figure 8 for the possible results from a genome edit.

Risk Management, Care, and Erasure

Who and what are at risk? The big idea concerning environmental risk management is to balance the identified risks, costs, and benefits and to ensure that all rightsholders understand and appreciate the new sustainable development objective (Calow, 1998). Historically, science has been used as the leading form of knowledge and method of demonstrating sound environmental risk assessments – yet "science now finds itself routinely operating in an arena of apparently irreducible uncertainties and irresolvable value conflicts" (Failing et al., 2007). The current challenges surrounding environmental risk management call for democratizing expertise, yet such calls raise vital unanswered questions about how to value and integrate diverse knowledge, such as scientific expertise and traditional knowledge, into environmental risk management decisions (Failing et al., 2007). Nonkes et al. (2023) explain, "bridging knowledge systems is a potential means of equitably and collaboratively working towards improved conservation and management of aquatic ecosystems, such as the management of invasive species." *Etuaptmumk* (Two-Eyed Seeing) is a conceptual framework that could be integrated into risk assessment and is described as "learning to see from one eye with the strengths of Indigenous knowledge and ways of knowing, and from the other eye with the strengths of Western knowledge and ways of knowing, and to use both these eyes together, for the benefit of all" (Bartlett et al., 2012). Bridging knowledge using Two-Eyed Seeing can be particularly fruitful in the assessment and evaluation of risk in environmental programming like the SLCP (Nonkes et al., 2023).

Two-eyed seeing and risk management become particularly important when discussing the prospect of eradicating entire species or using environmentally altering technologies like CRISPR. As shown in Figure 8, the ability to do on or off target editing can raise multiple questions about the risk and uncertainty of outcomes when using CRISPR technology. Given the extensiveness of removing entire species from ecosystems, researchers have identified criteria for guiding the whole process of species removal (Nonkes et al., 2023; Adams et al., 2021). See Table 4 for the guiding criteria for species removal.

Table 4

Eradication Guiding Criteria

The pest population can be forced to decline from one generation to the next, irrespective of its density
Every pest individual must be at risk of control at some stage of its development
Pest individuals can be detected at low population densities
Success is favored by small spatial extent of the population
Immigration and emigration can be prevented
Environmental impacts of the program are acceptable
Benefit-cost analysis favours eradication over control
Suitable social, political, legal, and institutional environment
Program is effectively managed, and its status is reliably monitored and accurately recorded

Note. Critical considerations when developing and implementing a species removal program (Phillips et al., 2018; Adams et al., 2021).

CRISPR technology offers the potential eradication of sea lamprey from the Great Lakes, envisioning a future free from invasive sea lamprey and promising the potential for ecological balance in the region (Harvey-Samuel et al., 2017; Adams et al., 2021). However, alongside this promise is uncertainty. Questions regarding the long-term ecological impacts, unforeseen consequences of genome editing, and the potential migration of modified organisms cast doubt over the widespread adoption of CRISPR technology (Sharpe, 2014). Additionally, recognizing the paramount importance of free, prior, and informed consent from Indigenous Peoples adds a crucial layer of ethical scrutiny, underscoring the imperative for scientists and governments to engage in respected and mutually beneficial partnerships with Indigenous communities.

Two-Eyed Seeing offers an excellent approach to developing a genealogy of 'care' in the Great Lakes. Scholarship from the social sciences has recently identified that care is both a productive and destructive term, with the most compelling illustration coming from the Galapagos Islands (Bocci, 2017). Paolo Bocci (2017) nuances the modalities of environmental care by examining the relationality of rightsholders to the conservation objectives. Ecologically, invasive goats became a problem in the Golápagos Islands because of their domination of eating the vegetation that Golápagos tortoises depend on for survival – a native species that aids the Islands tourism industry. In an effort to reverse the looming extinction of Golápagos tortoises, a multi-institutional effort using guns, helicopters, and hunting dogs to eradicate invasive goats resulted in the slaughter of nearly 99% of the entire goat population (Bocci, 2017).

The killing of invasive goats in the Golápagos Islands led to conflict and protest from local farmers and fishermen who rejected the mass killings. Locals identified that caring for tortoises and taking care of goats benefited travel

agencies while reducing the historical relationalities of human-goat connections on the Islands (Bocci, 2017). Central to Bocci's (2017) research is the idea of "exploring consequences of care – and, indeed, forms of care – that are uncomfortable" (Bocci, 2017, p. 440). As such, Bocci (2017) explains, "recent work in animal studies has argued that conservation measures aimed at protecting endangered species are not always as irenic and uncontroversial as we have imagined – they can be ambiguous, coercive, and even violent" (p. 440). Viewing the potential eradication of invasive sea lamprey through care and the lens of Two-Eyed Seeing can allow for developing a constellation of care in the Great Lakes.

Chapter 3: Methodology

Research Design

Given the diverse range of participants who participated in this research, a mixed-methods approach was used to provide greater adaptability to gain information from different rightsholder groups. The research methodology can be understood through its core use across three main research themes: Indigenous engagement, scientific community engagement, and governance engagement. The flexible approach of the research recognized that different approaches to gain data will be required to effectively and meaningfully engage diverse rightsholders in the Great Lakes region. Each form of engagement was designed differently to ensure that the approach would be appropriate for the context of the research engagement. The research used three main forms of data collection: semi-structured interviews conducted via the Internet, fieldwork that included semi-structured interviews, and a focus group. Research participants had the opportunity, outlined in the research consent form, to review their transcriptions and modify them by removing, revising, or adding information to ensure accuracy and validity. The mixed-methods approach resulted in a holistic and collective understanding of existing perspectives on the use of CRISPR technology in the Great Lakes, including recommendations for the future use and development of the technology.

This research sought to decolonize the research process. Central to the research is the idea of embracing other ways of knowing and working with people of different lived experiences to the norm (Thambinathan & Kinsella, 2021). The research embraced the idea of uncertainty and the notion of multiple competing knowledge to represent the depth and breadth of existing perspectives on CRISPR technology use in the Great Lakes region (Thambinathan & Kinsella, 2021). The

research benefited from the cultural guidance of Noah LeSage. In the Indigenous Advisory role, LeSage offered a decolonizing perspective and helped to ensure proper protocols were followed when engaging with Indigenous Peoples in the Great Lakes region. The research was also guided from the perspective of respect for self-determination and reciprocity. As Thambinathan and Kinsella (2021) argue, in order to fully conduct research with decolonial values, respect for self-determination and reciprocity requires the act of listening. As such, using both eyes and ears is not enough, the heart and mind must also be open with a commitment to accountability and a commitment to being transformed (Thambinathan & Kinsella, 2021).

A purposive, intentional sampling strategy was used in this research, as it focused on a specific case that required specialized expertise and experience in a particular geographic region. Participants were identified based on their proximity to the GLFC genetic control theme, including expertise in the subject matter. Targeted participants included senior leadership from the Government of Canada and the GLFC, Indigenous Knowledge Holders from First Nations and an Indian in Transition, First Nation Fishery Professionals, and scientists in relevant fields. LeSage used a snowball sampling technique to identify Indigenous Knowledge Holders who were interested in participating in the research. The total number of participants was 19 (n=19), with eight semi-structured fieldwork interviews, eight online semi-structured interviews, and one focus group with three participants. Table 1 outlines the categories of research participants, including those who chose to have their names disclosed, along with their positions and affiliated organizations. Participants were contacted by official communication forms, such as telephone or email. Interested participants were given a scheduled interview time that was convenient for them and signed a consent form prior to the interview

taking place. LeSage was chosen based on his previous relationship with Noah Gauthier and received an honorarium for his contribution and time spent during the research. All self-identifying Indigenous participants received a token honorarium for their contributions and time spent during the research.

This research followed the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2) and OCAP principles and received ethics approval from the University of Ottawa.

Indigenous Engagement

Indigenous Engagement took place through one week of fieldwork in the Great Lakes region. Indigenous engagement started with the selection of an Indigenous Advisor, whose role was to provide guidance on decolonizing the methodological approach and to provide assistance in identifying Indigenous Knowledge Holders who actively engage with the Great Lakes and expressed interest in participating in the study. LeSage attended all meetings with Indigenous Peoples and actively participated in discussions to help guide conversations. LeSage also participated in the entire one-week fieldwork in the Great Lakes region.

Initially, it was planned that there would be a fishing session with Indigenous Knowledge Holders, some of whom are Great Lakes practitioners; however, because of scheduling conflicts during the week of fieldwork, individual semi-structured interviews occurred instead. Semi-structured interviews with Indigenous Knowledge Holders and an Indian in Transition were conducted throughout the one-week fieldwork timeline, resulting in six completed interviews. The interviews resulted in the collection of information about natural resource management, the genetic control of sea lamprey, recommendations for the GLFC genetic control theme, and the cultural and social importance of the Great Lakes.

In some cases, semi-structured interviews with Indigenous Knowledge Holders took place while fishing the Great Lakes.

Semi-structured interviews with First Nation Fishery Professionals were conducted during the one-week fieldwork timeline, resulting in two completed interviews. First Nation Fishery Professionals is inclusive of both Indigenous and non-Indigenous individuals who have broad knowledge and understanding of how fisheries are connected to First Nations. These interviews, lasting three hours each, gathered insights on fisheries management and governance, the genetic control of sea lamprey, the cultural importance of the Great Lakes, and recommendations for the GLFC genetic control theme.

Figure 9

Ceremonial Tabacco Leaves

Participants involved in this theme were offered traditional ceremonial tobacco as part of the protocol for inviting them to participate in the research. See Figure 9 and 10 for the ceremonial tobacco that was offered. Additionally, homemade maple syrup prepared by Noah Gauthier was given to First Nation Fishery Professionals as a gesture of gratitude for their contributions to the research. See Figure 11 for the maple syrup that was provided as a kind gesture.

Figure 10

Ceremonial Tabacco Offering

The Indigenous engagement and methodology utilized in this research offered unique insights; however, they do not represent the perspectives of all Indigenous Peoples in the Great Lakes region.

Figure 11

Homemade Maple Syrup

Scientific Engagement

Semi-structured interviews with scientists in related or adjacent fields to genetics were conducted via Internet over a three-month period. The interviews resulted in an understanding of CRISPR technology and its current status, the benefits and drawbacks of the technology, and their general full characterization of the technology.

Government Engagement

Although the GLFC is not a government body but a binational treaty organization, it is included in this section due to its close connections to the Canadian and American governance structures. Semi-structured online interviews with GLFC senior leadership took place over a three-month period. The interviews captured a variety of perspectives within the organization, spanning roles such as

the executive secretary, science director, policy director, and program manager for the SLCP. The interviews provided a comprehensive understanding of the GLFC's direction regarding the genetic control theme, as well as the current challenges and successes associated with the ongoing operations of the SLCP.

A focus group was held with senior officials from the Government of Canada. The focus group included three participants and lasted one hour and thirty minutes. The focus group provided a forum to discuss the policy conundrum that currently exists with the exclusion of First Nations from formal GLFC decision-making bodies. Participants were asked a series of questions about the historical relationship between Canada and Indigenous Peoples and spoke one at a time, ensuring each participant had equal contributions. The focus group contributed to the development of recommendations aimed at enhancing Indigenous inclusion within the GLFC's genetic control theme while also providing insights into Indigenous governance in Canada.

Theoretical Framework

Philosophically, this research mobilizes care as a frame to understand the varying ways humans care about the environment and the multiple contact zones where care is enacted. The concept of contact zones is defined as "zones of encounters and contact" that shape relationships between "distant and near actors" in a process where "human and animal lives biologically, culturally and politically intertwine" (Haraway, 2008; Aisher & Damodaran, 2016). This idea is important since the politics of care brings attention to new understandings of conservation practices for two reasons. The first reason is anthropological: "conservation comes face-to-face with landscapes that are always products of variable human and nonhuman histories, with multiple pathways that are sensitive to human intervention" (Haraway, 2008). The second reason is political: "sociotechnical

practices and institutions may have political origins, implications, or effects, and thus be political, without necessarily being a mode, site or object of politics" (Brown, 2015). Recent development like the genetic control theme has thus far been directed in a genealogy of care that favours scientific, political, and economic agendas with little support given towards other forms of human-animal care.

While Two-Eyed Seeing offers a valuable approach to bridging knowledge systems, its broad conceptual scope carries the risk of being misinterpreted or misapplied, potentially steering analysis and use in an uncoordinated direction. The research adopted Two-Eyed Seeing as an interpretive lens to investigate the forms of care that exist with the genetic control of sea lamprey. Two-Eyed Seeing is especially fruitful when interpreting controversial management options, not least because conservation activities often present an "illusion of certainty" and are based on a Eurocentric paradigm (Reid et al., 2021).

Timeline

The research timeline unfolded throughout 2024 and was not linear across themes. Approval from the Research Ethics Board of the University of Ottawa was received on February 5th, 2024, with invitations to participate sent shortly thereafter. Online semi-structured interviews were conducted from early June to late July 2024, and the one week of fieldwork was during the last week of July. The focus group took place in August. After completing the interviews and the focus group, transcripts were reviewed, and data analysis took place from August to September. A thematic analysis was conducted using inductive coding. Each participant's transcript was coded line by line to identify general themes. Participants were grouped into five categories: GLFC, Indigenous Knowledge Holders from First Nations and an Indian in Transition, First Nation Fishery Professionals, Scientific Community, and the Government of Canada. Categories

were analyzed to identify linkages and draw general conclusions. The thesis was written from September to December 2024.

Chapter 4: The Genetic Control of Sea Lamprey in the Great Lakes

This chapter presents a collection of perspectives on the development and application of CRISPR technology in the Great Lakes. It opens by highlighting the varied forms of care participants hold for the lakes, followed by an exploration of their perspectives on using CRISPR technology to manage sea lamprey populations. The chapter concludes with participant reflections on the governance and management of the Great Lakes. Together, this chapter offers a comprehensive overview of diverse perspectives and viewpoints that exist on the potential genetic control of sea lamprey in the Great Lakes.

Care in the Great Lakes

Understanding care can highlight points of alignment or divergence, aiding decision-makers in making informed choices that consider the interests of multiple rightsholders. In this context, participants were asked why they or their organizations care about the Great Lakes, fostering an understanding of their relational connection to these waters. One insight from an Indigenous Knowledge Holder said:

> "I've grown up on these lakes. My family has been on these lakes for generations—my son learned to swim in these waters. The water is our biggest provider, without the Great Lakes we wouldn't be here or sustain ourselves without them. They bring our community together; our pow-wows are called the Gathering at the Rapids. The Great Lakes need to be protected at all costs" (Interview Participant 5).

The idea of using the Great Lakes as a form of subsistence was expressed by multiple Indigenous Knowledge Holders who identified the importance of the Lakes as a source of food:

> "It's the largest body of water in North America, and that's a pretty big deal to take care of, and a lot of First Nations here and in the United States use the Great Lakes to support themselves and their communities—they rely on fishing and hunting more so than going to a supermarket" (Interview Participant 4).

For some Indigenous Knowledge Holders, care extended beyond economic prosperity to encompass the deep social connections and sense of community that the lakes foster:

> "I care about the Great Lakes because I care about water. Fishing is part of who I am—that's how many people survive. My fondest memories are when I learned how to clean the fish, what to look for, and how to show them respect. It's not just economic, it's ingrained in how a lot of stories are told by elders. During the salmon season, I would meet cousins or people that I knew from my community, and they would show me new techniques and the good spots" (Noah LeSage).

A First Nations Fishery Professional emphasized the Great Lakes central role in Indigenous livelihoods while also explaining their ongoing decline and environmental degradation:

> "We owe our absolute livelihoods to the Great Lakes, they are such a big provider of food and culture to us, it's all connected. It's sad to see that there's been so much damage caused to the lakes around us from industrial pollution and invasive species" (Interview Participant 2).

When Marc Gaden, the Executive Secretary for the GLFC was asked about how the organization cares for the Great Lakes, his response focused less on community connections or subsistence and more on the institutional frameworks of the organization:

> "Well, the GLFC has to because it's obviously set up to protect the Great Lakes and, more specifically, its fishery. It's kind of axiomatic that the Fishery Commission has to care about it because of the Treaty. It's our whole reason for existing. So that's why, but if you read the Treaty, it is a very broad type of agreement about looking after the Great Lakes fishery, but also the things that affect the fishery" (Marc Gaden).

Gaden's response identified the vested power of the GLFC by identifying that the organization cares for the Great Lakes because of the existence of the Convention. However, when asked about how the GLFC cares for sea lamprey, Gaden provided a more reflective response:

> "If you don't care about sea lamprey, the best analogy is that if you stop caring about your garden, you're going to have nothing but weeds and invasive plants in there. Whereas if you pay some attention to it, maybe put up a little chicken wire to keep the rabbits from eating your carrots, you're going to be approaching it from a stewardship perspective that's reflective of trying to maintain its natural state" (Marc Gaden).

When asked the same question, Andrew Muir, the Science Director at the GLFC provided a more authoritative response by identifying the harsh reality of sea lamprey invasion in the Great Lakes. Muir identified several elements:

> "They care about it in the sense that they need to get rid of it. They're a top down predator, and they may play a critical role in their ecosystem,

> but they just aren't in their native ecosystem in the Great Lakes, so they're particularly damaging. A lot of what we do with respect to control helps to inform the restoration of lampreys on both the Pacific Coast and the Atlantic Coast, where they're imperilled. So I think there's a dichotomy in the science we do; it's to control the Great Lakes, but it also is to help conserve and restore them in places that need that" (Andrew Muir).

Margaret Docker, the leader of the GLFC genetic control theme and a professor in the Department of Biological Sciences at the University of Manitoba, reflects on the importance of understanding why people care about certain things. She offers a multi-faceted explanation in response:

> "These are great questions because they are things I haven't explicitly thought about and growing up near the Great Lakes, sometimes we take them for granted. From a human use perspective regarding the economy and their use for water, transportation, and fish, they are immense, and we have a duty not to take them for granted but to care for them" (Margaret Docker).

While similarities were evident among research participants, using care as a starting point for this research revealed the unique perspectives that knowledge holders bring to the discussion. Indigenous Knowledge Holders and First Nations Fishery Professionals provided responses that emphasized the central role of the Great Lakes to their lives and communities while GLFC leadership and scientists offered a more institutionalized response.

Perspectives on Genetic Control in the Great Lakes

A key objective of this research was to gather perspectives from various participants on the genetic control of sea lamprey, and particularly Indigenous Peoples. This section provides a comprehensive range of various perspectives in the Great Lakes. Through these varied perspectives, the research identifies the diverse opinions and concerns of participants regarding the use of genetic control for invasive sea lamprey in the Great Lakes. Docker begins this section by articulating the genetic control theme:

> "It's one of the newest research themes for the GLFC. It was roughly five years ago, as a community, we started talking about the possibility of genetic control and trying to organize and promote research related to genetic control systematically. Research related to genetic control was being done before, but it was usually submitted as non-theme research, so this theme was one way to raise the profile a little bit more. The GLFC does not do the research itself, but it manages a portfolio of research where it solicits research from the community. One of the main goals of the genetic control theme was to make it much more visible as a priority for the GLFC in the coming years. There's a brief description on the GLFC website and the opportunity to talk with people one-on-one through emails or at conferences. We are trying to identify key areas where research can inform genetic control to fill some gaps and technical aspects in identifying target genes" (Margaret Docker).

When asked explicitly what the goals and objectives of the GLFC genetic control theme are, Docker responded:

> "In a broad sense, there are three main goals. One is to identify possible targets for modification. The sea lamprey genome was sequenced in

2013, but that dosen't mean we have a list of genes we can go in and modify; there's still a lot of basic biology that needs to be done to identify what those sequences are, what they do, and what happens when you knock them down. So, there are some groups, including collaborators of mine, that are doing a gene-by-gene study to try and identify the function of genes and possible targets for modification. Reproduction—is there some way to impair reproduction?—it's the holy grail if you can manipulate sex ratio, so you're producing heavily biased male populations, effectively breeding females out of existence. Others could be genes involved in immunity that could make sea lamprey more susceptible to illness or death. So, the first goal is more about characterizing genes that could be the target for manipulation, and the second research goal is developing and optimizing gene editing tools, such as CRISPR-Cas9. It's already been demonstrated that it works in sea lamprey, so now the question is how can it be optimized in a tissue-specific manner. The third theme is better exploring the potential risks and how those risks can be mitigated" (Margaret Docker).

With a thorough understanding of the GLFC genetic control theme, Tyler Square, a developmental biologist, explains the benefits and drawbacks of controlling invasive sea lamprey through CRISPR-Cas9:

"I'll enter the potential benefits and then segue immediately into the potential downfalls or repercussions. I think it's quite obvious that humans have caused 99% of all instances of invasive introduction. Controlling with CRISPR, I mean that obviously has benefits if it works, such that we undid a bad thing that we did. We can start to try and restore the ecosystem, that's obviously what they're facing in the Great

> Lakes with sea lamprey. But moving onto the bad things—I just feel like you're trying to fight fire with fire. I'm not really sure, we could end up just irreversibly changing the genetic makeup of the whole species. What could happen if they get out from the Great Lakes and go somewhere else—that might happen, potentially without actually even achieving what we wanted to achieve in the first place" (Tyler Square).

Square goes on to explain that just knocking genes out and creating a mutant with a loss of function will not result in the widespread sharing of the trait to other species. Tyler Square goes on to explain the potential consequences of adding DNA to an organism through gene drive:

> "Almost every intervention of any kind of population control is adding DNA, and that is going to be much more complicated—so now you are trying to make transgenic animals, not just mutant animals. Those are two different things in regulatory speak. A mutant is just missing some of its DNA, such that a gene is broken. A transgenic animal has added DNA, and you are adding genes that do things. It's certainly possible that the DNA that we add might not act exactly how we think it's going to act, it might start doing other things. So, that's a really scary thing to me, Cas9 does have off target effects, it causes breaks in the genome elsewhere—even if you add your transgene to the place that you wanted in the genome, it could move around or go somewhere else, and then you're facing all kind of possibilities. I feel like you have committed a very bad act in that case, like to me that would absolutely stop me from ever being involved with anything like that—there's just no way I could put my name on anything like that—there's just no way I could put my name on anything that was going to modify an animal to be released with

added DNA with the intention of changing the genetics of a natural population, even if it is introduced. You could probably convince me to make a single mutant release—but I would never add DNA to an organism and release it, there's just no way I could do that, it's really unsettling to me" (Tyler Square).

Malinda Kliegman, Director of Public Impact at the Innovative Genomics Institute—an organization founded by Jennifer Doudna, the 2020 Nobel Prize winner in Chemistry—shared her insights on the potential drawbacks of using CRISPR technology to control invasive species:

"Obviously, something could go wrong. I feel like the world is littered with examples of invasive species management strategies that had unintended adverse effects and you end up with a situation where it is worse than it was before. The biggest concern is that it doesn't quite work the way that researchers predict and there is some unintended effect, there's a lot of hypotheticals, but I think it's just the question mark about what if there's something we didn't think about?" (Melinda Kliegman).

When asked what her thoughts are on the criticism of gene drives, Docker explained:

"Not all gene drives are the same, but my sort of understanding is that I don't think you'd be able to get successful genetic control without using a gene drive approach—I just don't think you'd be able to get the genetic modification into the entire population sufficiently. There are many types of gene drives, so you need to be careful about the type you use. The most efficient ones are where you can do it once and sit back, almost

> like that nuclear button, but there are different types of gene drives that are more dangerous than others. The GLFC is not at a point where they're advocating for genetic control or anything like that, but investing in the research to determine if it can be done, or if it were to be done, what are the risks? How do we mitigate risks? The GLFC is investing in this exploratory phase, that is still in the initial research and development stage" (Margaret Docker).

The scientists involved in this research have identified mixed perspectives towards the use of CRISPR technology to control invasive species in the Great Lakes. While scientists generally support the research of genome editing in the lab, transitioning to field trials raises more concern and anxiety about the unknowns which cannot be tested until released in the environment. During the discussion with LeSage, the idea of questioning the risk to benefit ratio was raised:

> "It doesn't seem like that big of a problem to go to this length. I think you're opening Pandora's box with that kind of mentality to use that research. I don't even think the general public would sign off if they knew it was being researched—it's just ridiculous that we need to go this far without a real demand for such a thing; it's a drastic measure" (Noah LeSage).

In a similar tone, Interview Participant 5 expressed how CRISPR technology and the genetic modification of sea lamprey is at odds with their teachings and perspectives:

> "I personally disagree with it because it's not natural. It's not what's mentioned in our teaching; there is no modification of anything, and that's the way it's supposed to be" (Interview Participant 5).

When asked about the modification of a host species, Interview Participant 5 explained:

> "I don't agree with that type of modification or any type of man-made threat because that's not the way we were brought up; it's not the way to follow the traditions. Everything from the earth is a gift—it is a blessing, everything from earth is sacred" (Interview Participant 5).

In a different light, Interview Participant 6 showed broad support for the use of CRISPR technology to control sea lamprey:

> "When it comes down to it, I personally worked in the fish trade myself, and whether we know it or not, we are eating genetically altered things every day without even knowing it. There are salmon sold in Canada that are bright orange because they are altered and fed specific things, and when it comes down to it, I don't think it's going to really change how people view what they're eating unless it's dramatic and changes the whole dynamic of things to a great degree" (Interview Participant 6).

However, when asked if Interview Participant 6 supported the use of CRISPR technology to genetically modify a host species, a less supportive answer was provided:

> "That's a harder one for me because it's easier to go out and say we're going to directly change sea lamprey. But, if you change another animal, I would say that opens room for error" (Interview Participant 6).

Similar to Interview Participant 6, Interview Participant 7 also supports the broad research of CRISPR technology and it's use on sea lamprey, but also identified the importance of engaging First Nations in the discussion:

> "As long as there are proper procedures for this technology and they are letting people know, especially the First Nations and the lakes they own, to ask permission before changing any fish" (Interview Participant 7).

Interview Participant 7 also expressed their disapproval of genetically modifying host species:

> "I feel like that's doing too much to the host fish. It's almost a slippery slope to the point where it's like, how far are we going to go until it's still considered salmon or whitefish?" (Interview Participant 7).

First Nation Fishery Professionals also showed general support to the idea of genetic control and expressed the current challenges of control methods with barriers and lampricides. Interview Participant 2 expressed they wanted to learn more about the negative repercussions but showed curiosity towards the new genetic control theme:

> "The initial thought is that it sounds like an interesting control method that I think should be explored. I think that it could potentially be something that could be really beneficial for sea lamprey control, however, I don't like the negative side effects. There needs to be some sort of education for Indigenous communities of what's going on, and I can see there being a lot of support from Indigenous communities for a program like this, although this is my personal opinion. The current suffering that sea lamprey go through and the labour involved with control, including the negative side effects from dams and barriers, these could potentially be a lot more negative than doing gene editing.

> Sea lamprey are one of the most destructive invasive species in the Great Lakes, and if we are going to have more invasive species in the future and we can manage them in a more humane way than dumping chemicals in our water, than I think that's a really cool idea with the caveat that I don't know what the negative repercussions are—I would be interested in learning more about the potential negatives. I know in Europe they're an endangered species, so as an Indigenous person out here on turtle island, I would want to make sure that we don't negatively affect some of our friends over in Europe" (Interview Participant 2).

Interview Participant 2 was then asked about their thoughts on genetically modifying a host species, and they responded by articulating the historical relationships that Indigenous People have had with fish:

> "We've had relationships with native species of fish for thousands of years and they are perfect the exact way the creator has made them—I don't think that they should be messed with—just leave them alone. You are targeting the thing you're supposed to protect, why do they want to alter the thing we want to keep natural?" (Interview Participant 2).

Echoing the perspective of Interview Participant 7, Interview Participant 3 highlighted the vitality of consultations and including First Nations as the genetic control theme progresses:

> "My first thought and worry is whether there is a possibility that a modified sea lamprey could somehow hybridize with native lamprey. If they are developing this technology, there would be a lot of societal

concern for sure, but then on the First Nation side of things, it can't be done without consultations—you need to have everyone's part in that decision. I don't think that one organization should be able to make such a sweeping decision without the proper decision-making process that supports those who need to be a part of the decision-making. I think it's really an ethical dilemma, and I don't think the GLFC has the moral authority suitable to start doing that" (Interview Participant 3).

The prospect of genetically modifying sea lamprey has created both optimism and critical reflection about the feasibility of such an approach. When asked about where the genetic control theme will be in five to ten years, Docker explained the importance of having at least one generation of lab-modified organisms and a greater understanding of gene function:

"Five to ten years is still relatively early days. I'm not sure if in five years, but definitely in 10 I would like to have seen at least one generation of genetically modified organisms and at least one-half generation in the lab; this could even be done with a non-parasitic organism. A lot of work so far has been looking at gene expression to sort of see what genes are up or down-regulated and under which conditions to sort of get a sense of what they might do—so getting a better sense of what they do and then the second part of that is knocking them down through various methods. I'd say if we could do that in 10 years, I think that would be considered a success, being able to have a much longer list of genes with known function and demonstrate the heritability of at least one gene construct" (Margaret Docker).

Leadership at the GLFC has identified the infancy of the genetic control theme and the importance of it as a technical scientific initiative. Andrew Muir confirmed that expenditures since 2021 associated with the genetic control theme is over $7 million, with nearly half going towards personnel and research projects and the other half going towards laboratory construction and set up. Muir also explained that some of the $7 million was expended on other projects like chemosensory communication. The collected perspectives reflect general support for researching the techniques and feasibility of genetically modifying sea lamprey. However, participants emphasized the critical importance of consulting First Nations on the issue, even if the GLFC does not intend to adopt the technology as a full control method. Moreover, participants identified their dissatisfaction and dissent towards using CRISPR technology to modify host species.

Governance and Management of Sea Lamprey

Given the relationship between science and governance can be directly tied to politics, not least considering the use of CRISPR technology, this section identifies the unique governance situation in the Great Lakes, with particular attention directed towards the current exclusion of First Nation communities from the GLFC lake committee process. In particular, comments from leadership in the GLFC, Government of Canada, and First Nation Fishery Professionals resulted in a characterization of the current governance of sea lamprey in the Great Lakes. This section begins by expressing the current state of the sea lamprey control program by Gaden:

> "I would describe it as a success beyond the wildest dreams of the people who wrote the convention, and I don't think that's hyperbole. I don't think they ever expected us to get to 95% control in large areas

> of the Great Lakes using a selective technique, I know this for a fact—because when they wrote the Treaty, the lamprey sites hadn't been identified and they were hoping that maybe some mechanical barriers would lessen the damage, but frankly the discovery of TFM and then the better use of barriers over time saved the Great Lakes fishery. There's nowhere else on the planet where you have a species this destructive and widespread, and this species is able to be controlled on a massive scale, at a level that is 90-95%. Results in 90% to 95% reduction in their pre-control levels made possible the recovery of native species, whether you like it or not, it saved commercial fishing operations and it protects subsistence fisheries, and its responsible for the huge growth in the recreational fishery. So you know I come from a biased position, but where anywhere on the planet have you seen this kind of success?" (Marc Gaden).

The success of managing sea lamprey was expressed by Gaden as going beyond the wildest dreams of the people who wrote the Convention, however the divided governance problem still remains. When explaining the exclusion of First Nations from the GLFC lake committee process, Gaden expressed the importance of being signatory to the Joint Strategic Plan:

> "First Nations might participate in technical committees, which are subordinate units to the lake committees, but those are open to anybody that has data or needs to be included on a technical level, but First Nations are not signatory themselves to the Joint Strategic Plan nor are they members of lake committees" (Marc Gaden).

The Lake Committee process is important since it provides a forum for signatories to the Joint Strategic Plan to discuss maters of importance to their

jurisdictions. Greg McClinchey explains the importance of GLFC lake committees:

> "Committees get to decide their own course. They come to the table, they bring their issues, they talk them through and they come up with collective solutions. It's a process that's intended to encourage solutions that are collaborative. When you're sitting across the table from someone, you're forced to put yourself in their position for a little bit" (Greg McClinchey).

The collaborative effort of the GLFC lake committees play a significant role in the successful management of sea lamprey across the jurisdictions. However, when asked why First Nations are not signatories or included on lake committees, Gaden pointed to Ontario's authority on the matter:

> "The difference is that the tribes can be on lake committees, and the First Nations can't until or unless Ontario were to say it's okay for that, that's the reality. Do I like that is the way? No, I wish it were different. I do think that there is a richness of perspective that we get from having a large number of participants in our collaborative process. I think that the more data we have, the better. The more eyes on the water and feet on the ground and biologist in the streams, the better. I think that being part of the process enhances the ability for there to be consensus, and not being part of the process hinders that" (Marc Gaden).

While the control of sea lamprey has been expressed as a wild success, one First Nations Fishery Professional identified the extensive challenges that

sea lamprey barriers pose to their community to provide food for themselves:

> "All of this sea lamprey management work has been going on since the 70s and 80s. Specifically, the dams are deteriorating infrastructure that they've had to continuously upgrade and update, but it's all based on super old infrastructure that is deteriorating. Lampricide is a very targeted chemical that has to be applied once every four to five years—a lamprey barrier dam is a permanent alteration of the aquatic environment that essentially colonized rivers. They are colonized rivers that only salmonids, the invasive species we don't like, are able to jump above. There are other native fish that can jump above, like speckled trout and rainbow trout. But sea lamprey barriers cannot meet our communities need to provide food for ourselves. We are going to make a demand to the DFO that we want to see that dam removed, because these are our waters for our people" (Interview Participant 2).

Interview Participant 2 continued by explaining how they are not opposed to the control of sea lamprey, but rather the use of damns and their impact on native fish populations:

> "When I was a kid, I never got to fish for walleye in a river, and that happened in my community because of the lack of consultation from the DFO and the entire barrier system. Since lampricides are so costly, they use permanent barriers, putting their cost saving as a greater benefit than my community being able to continue our traditions and feed ourselves—I think that's shocking. We're in a good place right now to make a demand to the DFO, to say we support the sea lamprey

> program, but we do not want this dam in our river—that's something that's going to happen sooner than later. It's also not just telling the DFO to get lost, we want to say let's work together to come up with a plan to figure out how we can remove this dam without causing negative effects downstream and upstream. We have a very small population of spawning walleye that happens below the dam—my thoughts is once we take the dam out, they already have a spawning population there, they'll be able to go up further with more spawning habitat to create more. We want to see sea lamprey management happen, we don't agree with how it happened in the past, and we want to rectify that. We can change what we do today and what we can do is remove this dam and be able to increase the walleye population, that will allow me to work with my community to rehabilitate the historic lake sturgeon spawning ground that has been completely extirpated from this entire river system. We can introduce lake sturgeon to an old river system where they used to live" (Interview Participant 2).

Unexpectedly, Interview Participant 2 identified a critical finding which questions the effectiveness of sea lamprey barriers across certain rivers:

> "One additional thing, this is the first summer that the DFO put sea lamprey treatment upstream of the dam. Since there was so much sea lamprey larvae sediment, it justified doing sea lamprey treatment application upstream, meaning the dam doesn't work—the dam is not functional, it doesn't work for this specific river. When sea lamprey attach to the fish, they go where the fish goes. They attach to salmon, the salmon jumps above the dam, and now the sea lamprey are able to get above the dam, it makes no sense. The dam doesn't work for sea

> lamprey management—the only thing that it works for is restricting walleye and sturgeon to be able to spawn in that river. We have a unique history and I've never seen anything like what we're trying to do in the literature. We want to continue to stand up for ourselves and show others what Indigenous communities are capable of. We are in a very good position, a powerful position where we control the narrative on this story and being able to control the story has a lot of influence to our community because for the longest time it's been the DFO and the GLFC that have been telling the story for sea lamprey, and now it's our turn to tell the story of what damages this has caused our community. It's going to happen regardless of it the DFO supports us or does not support us" (Interview Participant 2).

The inclusion of American tribes and the exclusion of First Nations from lake committees raises pivotal questions about the historical relationship between Canada and Indigenous Peoples. Interview Participant 8 begins by characterizing the relationship between Canada and Indigenous Peoples:

> "Historically, abusive in a sense—a lot of unequal power dynamics, a lot of misunderstanding, and today I still think there's a lack of trust from Indigenous communities where they only see them as something to access, or they're looking for a trauma story so they can fund a program—it's really gross, but at the same time it's what the government designed. There needs to be an actual cultural shift in the Government of Canada" (Interview Participant 8).

One First Nations Fishery Professional explained the necessity of involving First Nations on GLFC lake committees:

> "I think that the legal and ethical landscape should require consideration that First Nations ought to be involved in these lake committees and decision-making. I would ask the GLFC and Ontario government to reconsider their opinion that there are too many First Nations that would require too much of a headache from a logistical standpoint to have First Nations involved. There are good organizations out there, like the Chiefs of Ontario, that could be helpful in organizing First Nations inclusion" (Interview Participant 3).

Although the GLFC considers the SLCP a significant success, others are beginning to raise concerns about their exclusion from management decisions related to sea lamprey control. Specifically, First Nation Fishery Professionals have identified continued challenges in the fisheries because of SLCP measures and have argued for greater involvement in the decision-making process. Moreover, GLFC leadership has also recognized that there remains a gap by not including First Nations in the lake committee process. Although the Government of Ontario was contacted, no response was received.

Chapter 5: Discussion and Recommendations

The overarching aim of this research was to determine if and to what extent Indigenous Peoples near the Great Lakes support the control of sea lamprey through CRISPR technology. The research findings suggest that at its current state, there would be little support for the use of CRISPR technology to control sea lamprey because of the lack of engagement that First Nations have received from the GLFC on the topic. Findings also revealed that modifying a host species is completely at odds with most non-GLFC participants in the research. Another key finding of the research is the complete absence of decision-making power for First Nations regarding the use of CRISPR technology on sea lamprey, stemming from their exclusion from the GLFC lake committee process. The findings are significant as they offer valuable depth and breadth to the GLFC's genetic control theme, an area that has, to date, provided limited publicly available data. The first section of this chapter will provide a critical discussion regarding the collected information and the overarching topic of the research. The second section will provide a list of recommendations that were collected from Indigenous participants and First Nation Fishery Professionals that can help guide the GLFC in better engaging Indigenous Peoples in Canada.

Discussion

The invasive nature of sea lamprey has posed a significant threat to the Great Lakes fishery (Brant, 2019; Adams et al., 2021). Although the decline of native fish in the Great Lakes justifiably resulted in the control of sea lamprey, the obstruction and continued rejection of First Nation participation in decision-making is unacceptable and should not continue. Since time immemorial, Indigenous Peoples have stewarded and governed the lands of Turtle Island, where they innovated and developed complex governance agreements like the Dish with

One Spoon Treaty (Crown-Indigenous Relations and Northern Affairs Canada, 2023; Lytwyn, 1997; Miller, 2004). Today, the divided governance problem in the Great Lakes has resulted in the benefit of central organizations like the GLFC who now have a significant consolidation of power (Hall & Huston, 2014).

Even though the consolidation of power in the GLFC has resulted in significant reductions of sea lamprey, the continued use of suppression tactics like lampricides and barriers are resulting in a diminishing social license to operate (Gaden et al., 2021b; McGregor et al., 2023; Burkett et al., 2021). A weakened social license to operate stems from the combined challenges of chemicals and barriers. Chemicals harm non-target species and come with high costs, while barriers disrupt fish movement, reduce aquatic connectivity, and require costly maintenance (McDonald & Kolar, 2007; Sullivan et al., 2021; Miehls et al., 2020; Burkett et al., 2021). Securing a valid social license to operate is essential for implementing an environmental program and understanding the diverse ways people care about the Great Lakes is crucial to ensuring that environmental alterations align with societal values. Using Two-Eyed Seeing through the lens of care made it apparent that people come to appreciate the Great Lakes for different reasons. The research found that some participants value the Great Lakes for the recreational opportunities they offer or the sense of community they provide, while others care for them due to institutional mandates. In either case, the complexity of the Great Lakes cannot be understated, and any modification to its ecology should be carefully considered to understand the full range of risks and benefits.

The development of CRISPR technology has prompted large organizations like the GLFC to invest significant amounts of money into the development of the technology, driven by the technology's potential to eradicate sea lamprey. CRISPR technology also offers the option to lower the fitness of sea lamprey, reducing their

invasiveness, but both full eradication and fitness reduction pose potential risks to the ecosystems. Genetic control presents additional advantages, such as the potential to restore ecosystem balance and its cost-effectiveness as a “set it and observe” approach (Harvey-Samuel et al., 2017; Adams et al., 2021). However, the complexity of CRISPR-Cas9 makes it difficult to fully grasp, and significant concerns remain about the escape of modified organisms into host regions and the extensive uncertainties surrounding the technology's use (Sharpe, 2014; York et al., 2021; Ferreira-Martins et al., 2021).

Perspectives from Indigenous Peoples and First Nation Fishery Professionals showed mixed reactions to the utilization of the technology. Some participants expressed that the technology conflicts with concepts of naturalness, while others indicated support for its use and development, provided that communities are involved in the decision-making process. The GLFC also identified the idea of administering a “host vaccination” to protect species from sea lamprey, an idea that was largely opposed by nearly all Indigenous Peoples and First Nation Fishery Professionals who participated in the research.

Perspectives from Indigenous participants and First Nation Fishery Professionals showed mixed reactions to the utilization of CRISPR in the Great Lakes. Interview Participant 6 identified the plethora of genetically modified foods that humans already eat each day, pointing out that the alteration of sea lamprey is not a big worry. Even though Interview Participant 6 is correct that humans regularly eat genetically modified foods, its also important to make the distinction that eating modified foods and eradicating species are entirely different scenarios. On a similar note, Interview Participant 7 explained his support for the use of the technology so long as First Nations are meaningfully included in the decision-making process. However, other participants did not support the utilization of the

technology and cited that it conflicts with concepts of naturalness. Interview Participant 5 explained that in all their teachings, there is no mention of modifications and that it is not how they were brought up. Despite mixed perspectives on the use of the technology, the GLFC genetic control theme leader expects to have at least one generation of genetically modified organisms within 10 years.

With mixed perspectives about utilizing CRISPR technology in the Great Lakes, the current governance structure in the Great Lakes is not designed to include the diverse perspectives of First Nations and is at odds with federal legislation like the UN Declaration Act. Leadership from the GLFC has consistently stated that they have never had to invoke Article X of the Convention, but this may be due to the fact that sea lamprey control has never faced such a potentially drastic shift in management that the introduction of CRISPR technology could bring. Although the GLFC's genetic control theme is still in its early stages, they have already fallen short in meaningfully engaging First Nations before developing new initiatives that could potentially impact their lands and waters. For genetic control to have any chance of gaining a social license to operate, the GLFC must immediately begin meaningful collaboration with First Nations and begin strategizing possible pathways for their inclusion in the lake committee process.

The idea of the knowledge-action gap recognizes that there is a disconnect between scientific knowledge and its application, which is consequential to not only program management but also risk assessment (Cooke et al., 2021). When there are gaps that exist in risk assessment or evaluation because of unknown information or potential challenges with acquiring certain knowledges, the outcomes could be detrimental. As Alijabali et al. (2024) rightly identify, "the

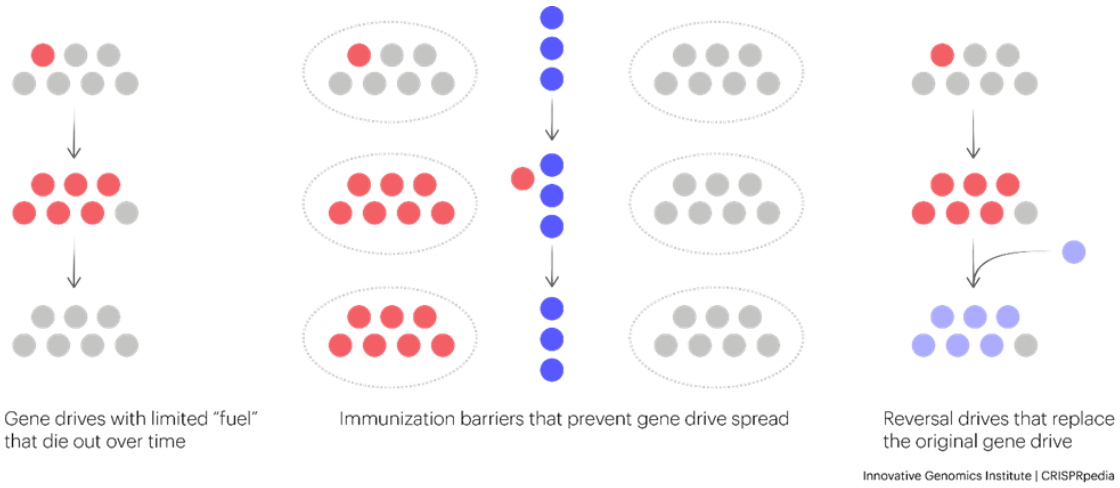
extraordinary potential unlocked by CRISPR-Cas9 technology gives rise to profound ethical considerations and regulator challenges. Manipulating the genetic code of living organisms raises fundamental questions concerning the boundaries of genetic manipulation and the potential ramifications of altering natural life processes" (Aljabali et al., 2024). As mentioned, CRISPR technology could result in unintended modifications or the chance a modified organism could escape to native range, which would result in devastating outcomes (Aljabali et al., 2024). Gene drives in particular heighten the risk of using CRISPR technology given heritability of the modified gene. Scientists have engineered three ways to reduce the risks of gene drive escape. First, scientists could use "limiting gene drive inheritance" which means genetic material would only be spread over a limited number of generations. The second option is "creating barriers to inheritance," which in the sea lamprey case could be the modification of an off switch if a genetically modified sea lamprey in fresh water was to reach salt water. The third option is "overriding one gene drive with another" which can be used as a reversal mechanisms if the original modification was to cause unanticipated issues (Hochstrasser et al., 2022). See Figure 12 for an illustration of the three risk reduction methods for gene drives.

Another option that scientists could use to lower the risk of gene drives is an edit that does not result in the full eradication of the species, but rather an edit that lowers the fitness of the species so its predation researches a sustainable threshold. While there are potential avenues for reducing the risk of gene drives, the unknown consequences or potential mutations still exist. The use of the "network of networks" risk framework could be used as a mitigating starting point to reduce the risk of CRISPR technology. Researchers explained the importance of ensuring that all rightsholders are included in the risk management process and that their

perspectives are included into a feedback system to ensure comprehensive governance (Bohua et al., 2023). The use of a network of networks framework to the governance of bio-risks recognizes the shared jurisdictional realities of risks and prioritizes the full inclusion and mutually beneficial outcomes before the integration of new initiatives (Bohua et al., 2023).

Figure 12

Gene Drive Risk Reduction



Note. Potential paths to reduce the risk that gene drives pose to nature (Hochstrasser et al., 2022). (CC BY-NC-SA 4.0)

Recommendations

The research has identified numerous areas where gaps currently exist within the GLFC genetic control theme. To better address these gaps, recommendations were gathered from the Indigenous engagement process in the hopes that they would illuminate concrete areas where the GLFC can improve its approach to the genetic control theme. See Table 5 for the provided

recommendations. While the recommendations would help the genetic control theme, the nature of each recommendation could benefit the entire SLCP.

Table 5

Recommendations for the GLFC

There needs to be an assessment process already developed to prevent any issues in the case something could unexpectedly happen
Open a dialogue with Indigenous communities and listen to them
Implement full transparency and speak to the Chiefs and Elders. They need to know that these lands and waters are sacred.
Do not sidestep around Indigenous communities, work with them, their ideas, knowledge, and views are beneficial
Implement institutional training for SLCP professionals that focuses on cultural competencies.
Prioritize hiring and retaining Indigenous talent.

Source: Author summary of recommendations provided by participants in semi-structured interviews during the Indigenous engagement process.

The GLFC needs to begin fully embracing traditional ecological knowledge (TEK) as equal to Western science. As McGregor et al. (2023) rightly identified, TEK often remains secondary to Western science, especially in decision-making scenarios (McGregor et al., 2023). Currently, TEK is entirely absent and ignored from the development and testing of genetic methods. When asked if we are at the point of using Two-Eyed Seeing, Gaden explained some of the institutional challenges:

> "I don't think we're there, in part I think the past five years have been enormous in moving the yardstick on that, but I don't think, even including myself, that the vast majority of people even know what we are talking about. Let's be frank, most of the people doing research and most of the money spent for it and decisions are all based on Western science, which means that there has to be a lot more work for those people to even understand what we're talking about when it comes to Indigenous science and what the Two-Eyed Seeing approach actually means" (Marc Gaden).

As McGregor et al. (2023) rightly identified, TEK often remains secondary to Western science, especially in decision-making scenarios (McGregor et al., 2023). Interview Participant 2 provided an excellent characterization of the difference between Western science and Traditional Knowledge:

> "There are different levels of formality—the basic core ideas of how Indigenous Knowledge is collected is very similar to Western science—it's just different in terms of peer review, educational institutions, and funding. Another difference from Western science and Indigenous Knowledge and Traditional Knowledge is about the challenges of finding information, where it is much easier for Western science. In Indigenous communities, you have to know the people that have that information, there is a significant difference in how that information is given and received. For example, if I have any questions about trapping for fur for cultural learning, I would go into the bush with my uncle, and he would physically show me—that's the difference from science, where you would likely read concepts and ideas out of a book to experience and collect that information" (Interview Participant 2).

The GLFC's current focus on Western science, largely for institutional convenience and to maintain the status quo, is eroding its relationship with

Indigenous Peoples. Gaden pointed to the reality of most large North American institutions: they are not currently designed for the easy integration of traditional ecological knowledge. It has been identified that a significant gap exists in the understanding of and engagement with Indigenous Knowledge Systems among technical experts and decision-makers. One way to begin addressing this issue is by targeting educational initiatives to build cultural competencies. To address the issue, it also means the thoughtful, meaningful, and mutually beneficial integration of Indigenous Knowledge Systems into any assessment, engagement, programs, or research the GLFC conducts. Without including Indigenous Knowledge Systems, the GLFC risks overlooking critical insights that could inform Great Lakes science, while perpetuating exclusionary practices that sustain colonial relationships. Another way to reduce Western conceptual frameworks and science is through the full inclusion and employment of Indigenous Peoples within these organizations.

Chapter 6: Reflection

Research Design

The research was structured around three groups of knowledge engagement: scientific community engagement, Indigenous engagement, and government engagement. The three groups of knowledge holders provided a comprehensive and full understanding of the perspectives that exist around the use of CRISPR technology in the Great Lakes. The use of semi-structured interviews also allowed for flexibility in questions when discussing with knowledge holders since conversations could be tailored to the unique experiences and profiles of participants. The flexibility of the semi-structured interviews and the three groups of knowledge holders afforded the collection of nuanced insights and diverse perspectives. The use of a focus group at the Government of Canada also created a unique opportunity to engage leaders in Canadian policy on the topic to discuss paths forward and historical contexts between the Government of Canada and Indigenous Peoples.

The purposive and intentional sampling strategy was a strategic targeted approach to ensure that all participants had prior knowledge on the topic. The targeted approach also ensured that the research had perspectives from each knowledge group, so findings were reflective of various positionalities. Having an Indigenous Advisor from the geographic region also significantly strengthened the work. LeSage provided numerous Indigenous Knowledge Holders who have insights into fisheries or governance and was instrumental in fostering trust and facilitating relationship building between the participants.

Finally, the conceptual framework was guided by Two-Eyed Seeing, which emphasized the importance of Indigenous and Western Knowledge and the lens of care that promoted the ethics of various worldviews and positionalities. Together,

this conceptual framework resulted in the valuing of diverse worldviews and an understanding of the relationality that knowledge holders bring to their perspectives.

Research Strengths

The research acknowledges the complexity of science and investigated the inherently political and interdisciplinary nature of environmental management. By acknowledging that diverse knowledge is needed to address environmental challenges, the research integrated perspectives across discipline boundaries. The interdisciplinary approach of the research is its strongest strength since it eloquently ties together diverse knowledge systems to understand complex science and its application in real-world contexts.

Recognizing that science does not exist in a vacuum but is influenced by sociopolitical dynamics and power structures, the research exposed the tensions and opportunities between the diverse perspectives shared. In doing so, the approach of including voices from varying positionalities revealed how scientific processes shape and are shaped by the broader political and cultural contexts in which they are produced.

Storytelling was also used as a powerful approach to understanding the complexity and politics of science. Through the ideas shared and expressed by participants, the research was able to bridge personal connections to the potential use of CRISPR technology in the Great Lakes. Additionally, the use of fieldwork added depth in terms of further developing relationships with participants and positioning the research within the larger scope to which it exists.

Finally, the research provided a new and unique case study to evaluate the continued exclusion of First Nations from GLFC lake committees. This

contribution is particularly important for rethinking the future direction of GLFC science and governance by recognizing that the current trajectory of the genetic control theme is at odds with the UN Declaration Act and is not representative of all jurisdictions.

Research Limitations

One limitation of the research was the duration of the fieldwork. Although the time spent in the field provided excellent insight, longer fieldwork would have enriched and deepened engagement with participants. Also, a longer time in the field could have led to more relationships, which could have aided in collecting more insights to inform the research questions. Moreover, while the research collected valuable insights from individual Indigenous Peoples and First Nation Fishery Professionals, the research did not specifically engage First Nation communities directly. If the research built stronger connections with communities, it could have provided a more holistic and reflective understanding of perspectives on the topic.

Finally, even though the 19 participants in this research provided evidence to answer the research questions, the research only serves as a starting point for further discussion and scholarly critique. Future studies should foster stronger relationships with Indigenous communities to provide a more holistic understanding of perspectives that exist on genetic control.

Chapter 7: Conclusion

The advancement of CRISPR-Cas9 technology and the sequenced genome of sea lamprey has provided the potential opportunity to fully eradicate the species from the Great Lakes. The depreciating social license to operate the SLCP in the Great Lakes because of the exclusion of First Nations in official decision-making positions and the continued environmental impacts of suppression control methods has resulted in over a $7 million contribution to the GLFC genetic control theme. The use of CRISPR technology to control sea lamprey is complex and includes numerous risks, such as mutations which could cause more substantial problems or the escape of a modified sea lamprey to its native range.

Despite the benefits and drawbacks of the technology, the exclusion of First Nations from GLFC lake committees shed light on the colonial structures that manage the Great Lakes. With current governance frameworks, First Nations do not have equal decision-making power, and the GLFC recognizes this issue. The drastic changes that the genetic control theme could make to the Great Lakes show the centralized and concentrated power that is vested in the GLFC. Currently, the use of Article X has never been invoked, but this research argues that is because there has not yet been a control option that has provided the possibility of complete eradication. While barriers and lampricides each present their own challenges, genetic control could potentially impact native populations or create an undesirable heritable mutation. Additionally, findings from this research suggest that there are mixed feelings towards the application of CRISPR technology, but there was nearly complete rejection for modifying a host species. Going forward, the GLFC needs to begin valuing the importance of Indigenous Knowledge Systems and formally include First Nations in the decision-making process.

Future research needs to continue valuing the importance of interdisciplinary research. There remain significant gaps in understanding not only the science of CRISPR technology, but also the socio-politics risks that exist with the utilization of this technology in the Great Lakes. Future research should build on this assessment by further understanding the socio-political risks of CRISPR-Cas9 by engaging and partnering directly with First Nation communities.

References

Adams, J. V., Birceanu, O., Chadderton, W. L., Jones, M. L., Lepak, J. M., Seilheimer, T. S., Steeves, T. B., Sullivan, W. P. & Wingfield, J. (2021). Trade-offs between suppression and eradication of sea lampreys from the Great Lakes. *Journal of Great Lakes Research. 47*, 782–795.

Aisher, A., & Damodaran, V. (2016). Introduction: human-nature interactions through a multispecies lens. *Conservation and Society, 14*(4), 293–304.

Aljabali, A. A. A., El-Tanani, M., & Tambuwala, M. M. (2024). Principles of CRISPR-Cas9 technology: Advancements in genome editing and emerging trends in drug delivery. *Journal of Drug Delivery Science and Technology, 92*, 105338-. https://doi.org/10.1016/j.jddst.2024.105338

Bartlett, C., Marshall, M., & Marshall, A. (2012). Two-eyed seeing andother lessons learned within a co-learning journey of bringing to-gether Indigenous and mainstream knowledges and ways of know-ing. Journal of Environmental Studies and Sciences, 2(4), 331–340

Bocci, P. (2017). Tangles of care: Killing goats to save tortoises on the galápagos islands. *Cultural Anthropology, 32*(3), 424–449. https://doi.org/10.14506/ca32.3.08

Bohua, L., Yuexin, W., Yakun, O., Kunlan, Z., Huan, L., & Ruipeng, L. (2023). Ethical framework on risk governance of synthetic biology. *Journal of Biosafety and Biosecurity, 5*(2), 45–56. https://doi.org/10.1016/j.jobb.2023.03.002

Brant, C. (2019). *Great lakes sea lamprey: The 70 year war on a biological invader*. University of Michigan Press, Ann Arbor, MI.

Brokowski, C., & Adli, M. (2019). CRISPR ethics: moral considerations for applications of a powerful tool. *Journal of Molecular Biology*, *431*(1), 88–101. https://doi.org/10.1016/j.jmb.2018.05.044

Brown, M. B. (2015). Politicizing science: Conceptions of politics in science and technology studies. *Social Studies of Science, 45*(1), 3–30. http://www.jstor.org/stable/43829010

Burkett, D. P., Barber, J. M., Steeves, T. B. & Siefkes, M. J. (2021). Sea lamprey control 2020 – 2040: Charting a course through dynamic waters. *Journal of Great Lakes Research. 47*, 809–814.

Calow, P. (1998). *Handbook of environmental risk assessment and management*. Blackwell Science.

Campbell, M. (2014). *We want the biggest damned painting you can do*. Macleans. https://macleans.ca/news/canada/daphne-odjig-on-creating-her-masterpiece/

Chiblow, S. (2023). Reconciling our relationships with the Great Lakes. *Journal of Great Lakes Research, 49*, 87–92.

Cooke, S. J., Nguyen, V. M., Chapman, J. M., Reid, A. J., Landsman, S. J., Young, N., Hinch, S. G., Schott, S., Mandrak, N. E., & Semeniuk, C. A. D. (2021). Knowledge co-production: A pathway to effective fisheries management, conservation, and governance. *Fisheries (Bethesda), 46*(2), 89–97. https://doi.org/10.1002/fsh.10512

Crown-Indigenous Relations and Northern Affairs Canada. (2023, May 11). *About national Indigenous history month*. Government of Canada. https://www.rcaanc-cirnac.gc.ca/eng/1683124800202/1683124846095

Dana, G. V., Cooper, A. M., Pennington, K. M., & Sharpe, L. S. (2014). Methodologies and special considerations for environmental risk analysis of genetically modified aquatic biocontrol organisms. *Biological Invasions, 16*, 1257–1272.

Department of Justice. (2023).United Nations Declaration on the Rights of Indigenous Peoples Act Action Plan. Government of Canada. https://www.justice.gc.ca/eng/declaration/ap-pa/ah/pdf/unda-action-plan-digital-eng.pdf

Descloitres, J. (2002). *The Great Lakes* [Photograph]. Nasa Visual Earth. https://www.visibleearth.nasa.gov/images/62288/the-great-lakes

Ettawageshik, F. & Norman, E. (2020). From "Stakeholder to Rights-Holder": Re-examining the Role of Indigenous Peoples in the International Joint Commission as the Third Sovereign. In *The First Century of the International Joint Commission* (1st ed., pp. 433-456). University of Calgary Press. https://doi.org/10.2307/j.ctvvb7kmv.20

Failing, L., Gregory, R., & Harstone, M. (2007). Integrating science and local knowledge in environmental risk management: A decision-focused approach. *Ecological Economics, 64*(1), 47–60. https://doi.org/10.1016/j.ecolecon.2007.03.010

Ferreira-Martins, D., Champer, J., McCauley, D. W., Zhang, Z. & Docker, M. F. (2021). Genetic control of invasive sea lamprey in the Great Lakes. *Journal of Great Lakes Research, 47,* 764–775.

Gaden, M., Brant, C., & Lambe, R. (2021a). Why a Great Lakes Fishery Commission? The seven-decade pursuit of a Canada-U.S. fishery treaty.

Journal of Great Lakes Research, 47, S11–S23. https://doi.org/10.1016/j.jglr.2021.01.003

Gaden, M., Brant, C., and Lambe, R. (2022). The history behind the Canada-U.S. convention on Great Lakes fisheries: a seven-decade effort. Journal of the Great Lakes Fishery Commission, 2022(1), 1-97.

Gaden, M., Brant, C., Stedman, R. C., Cooke, S. J., Young, N., Lauber, T. B., Nguyen, V. M., Connelly, N. A. & Knuth, B. (2021b). Shifting baselines and social license to operate: Challenges in communicating sea lamprey control. *Journal of Great Lakes Research*, *47*, 800–808.

Gaden, M., Goddard, C., Read, J. (2012). Multi-jurisdictional management of the shared great lakes fishery: transcending conflict and diffuse political authority, in W. Taylor, A. Lynch and N. Leonard (Eds.) *Great lakes fisheries policy & management*. Michigan State University Press, East Lansing, 305-337.

Great Lakes Fishery Commission. (2024a). Ann Arbor: Great Lakes Fishery Commission; [accessed 2024 August 28].

Great Lakes Fishery Commission. (2024b). Fishery management. http://www.glfc.org/fishery-management.php

Great Lakes Fishery Commission. (2024c). Joint strategic plan committees https://www.glfc.org/joint-strategic-plan-committees.php

Great Lakes Fishery Commission. (2024d). The fishery. https://www.glfc.org/the-fishery.php

Great Lakes Fishery Commission. (2024e). Sea lamprey. https://www.glfc.org/sea-lamprey.php

Great Lakes Fishery Commission. (2024f). TFM and sea lamprey control. https://www.glfc.org/pubs/FACT_4.pdf

Great Lakes Fishery Commission. (2024g). Convention of great lakes fisheries between the United States of America and Canada. https://www.glfc.org/pubs/conv.htm

Great Lakes Fishery Commission. (2024h). Council of lake committees. https://www.glfc.org/council-of-lake-committees.php

Great Lakes Fishery Commission. (2024i). The future of sea lamprey control. https://www.glfc.org/pubs/factsheets/FACT%205D_14-0913_HR.pdf

Hall, N. D., & Houston, B. C. (2014). Law and governance of the Great Lakes. *The De Paul Law Review, 63*(3), 723–770.

Haraway, D. J. (2008). *When species meet*. University of Minnesota Press.

Hartig, J. H., Krantzberg, G., & Alsip, P. (2020). Thirty-five years of restoring Great Lakes areas of concern: gradual progress, hopeful future. *Journal of Great Lakes Research*, *46*(3), 429–442. https://doi.org/10.1016/j.jglr.2020.04.004

Harvey-Samuel, T., Ant, T. & Alphey, L. (2017). Towards the genetic control of invasive species. *Biological Invasions*, *19*, 1683–1703.

Henderson, H., Ramit, G., Tolpa, T., Murdock. A., & Halpern, J. (2024) CRISPR & Ethics. In Hochstrasser et al. (Eds.) *CRISPRpedia*. Innovative Genomics Institute, University of California, Berkeley. https://innovativegenomics.org/crisprpedia/crispr-ethics/ (Last updated: November 21, 2024.) https://doi.org/10.60640/G2H59Q

Henderson, H., Ramit, G., Tolpa, T., Murdock. A., & Halpern, J. (2024b) What is CRISPR. In Hochstrasser et al. (Eds.) CRISPRpedia. Innovative Genomics Institute, University of California, Berkeley. https://innovativegenomics.org/crispr-made-simple/what-is-crispr/

Hochstrasser, M., Ford, T., Henderson, H., Doxzen, K., Tolpa, T., Cheung, B., Ramit, G., Murdock, A. & Wilson C. (2022). *CRISPR technology*. In Hochstrasser et al. CRISPRpedia. Innovative Genomics Institute, University of California, Berkeley. Retrieved from: https://innovativegenomics.org/crisprpedia/crispr-technology/ (Last updated: September 12, 2022.) https://doi.org/10.60640/G2WC7F

Hrodey, P. J., 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. *Journal of Great Lakes Research, 47*, S285–S296. https://doi.org/10.1016/j.jglr.2021.10.006

Johnson, J. A., Altwegg, R., Evans, D. M., Ewen, J. G., Gordon, I. J., Pettorelli, N., & Young, J. K. (2016). Is there a future for genome- editing technologies in conservation. *USDA National Wildlife Research Center, 19*, 97–101

Johnston, D. (2006). *Connecting people to place : Great Lakes Aboriginal history in cultural context*. Ministry of Attorney General.

Jones, M. L., & Adams, J. V. (2021). Eradication of sea lampreys from the Laurentian Great Lakes is possible. *Journal of Great Lakes Research, 47*, S776–S781. https://doi.org/10.1016/j.jglr.2020.04.011

Lander, E. (2016). The heros of CRISPR. *Cell, 164*(1), 18-28. https://doi.org/10.1016/j.cell.2015.12.041

Lower, E., Sturtevant, R., Iott, S., Martinez, F., Rutherford, E., Mason, D. M., Redinger, J., & Elgin, A. K. (2024). The Great Lakes' most unwanted: Characterizing the impacts of the top ten Great Lakes aquatic invasive species. *Journal of Great Lakes Research, 50*(4), 102365-. https://doi.org/10.1016/j.jglr.2024.102365

Lytwyn, V. P. (1997). A dish with one spoon: The shared hunting grounds agreement in the Great Lakes and St. Lawrence Valley region. In D. Pentlands (Eds.), *Papers of the twenty-eighth Algonquian conference*. Archives of the Papers Algonquian Conference.

McDonald, D. G. & Kolar, C. S. (2007). Research to guide the use of lampricides for controlling sea lamprey. *Journal of Great Lakes Research, 33*, 20-34.

McGregor, D., Latulippe, N., Whitlow, R., Gansworth, K. L., McGregor, L. & Allen, S. (2023). Towards meaningful research and engagement: Indigenous knowledge systems and Great Lakes governance. *Journal of Great Lakes Research, 49*, 22–31.

Miehls, S., Sullivan, P., Twohey, M., Barber, J. & McDonald, R. (2020). The future of barriers and trapping methods in the sea lamprey (Petromyzon marinus) control program in the Laurentian Great Lakes. *Reviews in Fish Biology and Fisheries, 30*, 1–24.

Miller, J.R. (2004). According to our ancient customs: Treaties. In *Lethal legacy: Current native controversies in Canada*. McClelland & Stewart

Moro, D., Byrne, M., Kennedy, M., Campbell, S., & Tizard, M. (2018). Identifying knowledge gaps for gene drive research to control invasive animal species: The next CRISPR step. *Global Ecology and Conservation, 13*, 1-15. https://doi.org/10.1016/j.gecco.2017.e00363

Mulvaney, K. K., Lee, S., Höök, T. O., & Prokopy, L. S. (2015). Casting a net to better understand fisheries management: An affiliation network analysis of the Great Lakes Fishery Commission. *Marine Policy, 57*, 120–131. https://doi.org/10.1016/j.marpol.2015.03.008

Nonkes, C., Duncan, A. T., Lauzon, R., Ryan, K., Reid, A. J., Cooke, S. J., & Young, N. (2023). Two-Eyed Seeing: Developing perspective and wisdom on sea lamprey in the Laurentian Great Lakes. *Journal of Great Lakes Research, 49*, 148–159. https://doi.org/10.1016/j.jglr.2023.03.001

Odjig, D., Boyer, B., & Podedworny, C. (2001). *Odjig : the art of Daphne Odjig, 1960-2000*. Key Porter Books.

Oye, K. A., Esvelt, K., Appleton, E., Catteruccia, F., Church, G., Kuiken, T., Lightfoot, S. B.-Y., McNamara, J., Smidler, A. & Collins, J. P. (2014). Regulating gene drives. *Science, 345*, 626–628

Phillips, C., Brown, K., Broome, K., Green, C. & Walker, G. (2018). Criteria to help evaluate and guide attempts to eradicate arthropod pests. https://www.researchgate.net/publication/328293616_Criteria_to_help_evaluate_and_guide_attempts_to_eradicate_arthropod_pests

Rath, J. (2017). Safety and Security Risks of CRISPR/Cas9. In S. Fenet, F. Hirsch, D. Schroeder, J. Cook & V. Muthuswamy (Eds.), *Ethics Dumping* (pp. 107-113). Springer.

Reid, A. J., Eckert, L. E., Lane, J., Young, N., Hinch, S. G., Darimont, C. T., Cooke, S. J., Ban, N. C., & Marshall, A. (2021). "Two-Eyed Seeing": An Indigenous framework to transform fisheries research and management. *Fish and Fisheries, 22*(2), 243–261. https://doi.org/10.1111/faf.12516

Sharpe, L. M. (2014). Public perspectives on genetic biocontrol technologies for controlling invasive fish. *Biological Invasions, 16*, 1241–1256.

Sterner, R. W., Ostrom, P., Ostrom, N. E., Klump, J. V., Steinman, A. D., Dreelin, E. A., Vander Zanden, M. J., & Fisk, A. T. (2017). Grand challenges for research in the Laurentian Great Lakes. *Limnology and Oceanography*, *62*(6), 2510–2523. https://doi.org/10.1002/lno.10585

Sullivan, W.P., Burkett, D.P., Boogaard, M.A., Criger, L.A., Freiburger, C., Hubert, T.D., Leistner, K., Morrison, B.J., Nowicki, S.M., Robertson, S., Rowlinson, A., Scotland, B.J., & Sullivan, T.B. (2021). Advances in the use of lampricides to control sea lampreys in the Laurentian Great Lakes, 2000-2019. *Journal of Great Lakes Research, 47*, 216–237.

Thambinathan, V., & Kinsella, E. A. (2021). Decolonizing methodologies in qualitative research: creating spaces for transformative praxis. *International Journal of Qualitative Methods, 20*. https://doi.org/10.1177/16094069211014766

Thresher, R. E., Jones, M., & Drake, D. (2019a). Evaluating active genetic options for the control of sea lamprey (Petromyzon marinus) in the Laurentian Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences, 76*, 1186–1202

Thresher, R. E., Jones, M., & Drake, D. (2019b). Stakeholder attitudes towards the use of recombinant technology to manage the impact of an invasive species: sea lamprey in the North American Great Lakes. *Biological Invasions, 21*, 575–586.

United Nations Declaration on the Rights of Indigenous Peoples Act, CRC, c. 14. https://www.laws-lois.justice.gc.ca/eng/acts/u-2.2/page-1.html

Walter, L. M., Dettmers, J. M., & Tyson, J. T. (2021). Considering aquatic connectivity trade-offs in Great Lakes barrier removal decisions. *Journal of Great Lakes Research*, *47*, S430–S438. https://doi.org/10.1016/j.jglr.2021.10.014

Waples, J., Eadie, B., Val Klump, J., Squires, M., Cotner, j. & McKinley, G. (2008). North American continental margins: a synthesis and planning workshop. https://www.glerl.noaa.gov/pubs/fulltext/2008/20080024.pdf?TB_iframe=true

Webber, B. L., Raghu, S., & Edwards, O. R. (2015). Opinion: Is CRISPR-based gene drive a biocontrol silver bullet or global conservation threat. *Proceedings of the National Academy of Sciences – PNAS, 112*, 10565–10567.

Yang, Z., Yu, Y., Tay, Y. X. & Yue, G. H. (2022). Genome editing and its applications in genetic improvement in aquaculture. *Reviews in Aquaculture, 14*, 178–191.

York, J. R., Thresher, R. E., & McCauley, D. W. (2021). Applying functional genomics to the study of lamprey development and sea lamprey population control. *Journal of Great Lakes Research, 47*, 639–649.

ANNEX A – Research Questions

Interview Guide

1. Introduce myself and explain my affiliation with the University of Ottawa;
2. State the purpose of the research;
3. Explain the framework of the interview (timing, # of questions, semi-structured interview);
4. Let the potential participant know that there are no perceived risks associated with this research and that this research will help me gain valuable experience as a researcher;
5. State that their participation is voluntary; they have the right to refuse to answer any question, and they can end the conversation at any time; and
6. Thank the participant for joining the research.

General Pool Questions

1. Can you provide an overview of your role or involvement in environmental work?
2. What experiences do you have with invasive species?
3. How do you see your role in shaping the policies and decisions related to the genetic control of sea lamprey/invasive species?
4. What histories does your community have with invasive sea lamprey?
5. How has your community traditionally controlled invasive aquatic species?
6. How has your community traditionally reported, monitored, and addressed sea lamprey control in the Great Lakes?
7. What concerns or questions do you have about the ethical, social, and environmental implications of using CRISPR/Cas9 technology for invasive sea lamprey control?

8. How should potential risks or uncertainties be addressed and communicated to your community/FN communities, concerning the use of gene editing technologies?
9. Are there specific principles, cultural considerations, or values that should guide the decision-making process around the use of CRISPR/Cas9 as a control method for invasive species?
10. How do you perceive the potential benefits of using CRISPR/Cas9 to control sea lamprey in the Great Lakes?
11. How do you perceive the potential risks of using CRISPR/Cas9 to control sea lamprey in the Great Lakes?
12. How do you think the proposed genetic control strategies could impact your community?
13. How do you think the proposed genetic control strategies could impact you?
14. How do you perceive the potential social and cultural impacts of genetic control strategies on invasive species in your community?
15. Are there cultural traditions, practices, or values that could be impacted due to the introduction of genetically modified organisms into the Great Lakes?
16. How do you see Indigenous perspectives and traditional knowledge being added into the process of genetic control efforts in the Great Lakes?
17. What role do you see Indigenous communities/your community playing in shaping the use of genetic control methods in the Great Lakes?
18. How should collaborative approaches between Indigenous knowledge holders and other stakeholders operationalize?
19. Are there specific perspectives that you believe are particularly important to addressing the complex environmental challenge of controlling invasive species?

20. What are your views on the potential economic impacts that could exist through the genetic control of sea lamprey in the Great Lakes region?
21. Could the genetic control of sea lamprey in your community benefit local businesses or persons who rely on a healthy environment?
22. How do you perceive the use and role of science in shaping decisions related to environmental resource management?
23. What challenges do you see in incorporating scientific research and expertise into the decision-making process?
24. What challenges do you see in incorporating Traditional Ecological Knowledge into the decision-making process?
25. How would you envision the regulation of bio-control technologies in Canada?
26. What role do you see the government playing in monitoring genetic control efforts?
27. What role do you see your community/department playing in the genetic control efforts of sea lamprey?
28. What opportunities do you see in adopting genetic engineering technologies to address invasive species in the Great Lakes?
29. What challenges do you see in adopting generic engineering technologies to address invasive species in the Great Lakes?
30. What barriers currently exist in your view to effectively engage in the discussion of modifying invasive organisms through genetic control (ex. capacity)?
31. What community impacts would exist if traditional forms of sea lamprey control were removed for new bio-control options (ex. employment, funding, ext.)?

32. What are your recommendations to the government as they advance a genetic control theme for sea lamprey removal?
33. How would you summarize the governments historical management of the land and water?
34. What do you perceive as the biggest issue with current control strategies for sea lamprey removal?
35. In what ways do you use the Great Lakes?
36. How would you perceive the Great Lakes after genetically modified organisms were introduced?
37. What role does the Great Lakes play in supporting your community or life?
38. What concerns do you have with the potential use of gene-editing technologies in the Great Lakes?
39. In your perspective, at what point is the optimal timing to begin communicating with Indigenous communities about the potential use of CRISPR/Cas9 as a management option for invasive sea lamprey?
40. How would you describe invasive species?
41. Can you provide a brief overview of your expertise and professional background, as it relates to genetic engineering and biotechnology?
42. What motivated your interest to work in science?
43. What experience do you have with CRISPR/Cas9?
44. How would you define science?
45. Can you provide an overview of CRISPR/Cas9 technology and its applications in genetic engineering?
46. How does CRISPR/Cas 9 enable precise gene editing?
47. What are some breakthroughs and advancements made possible by CRISPR/Cas9?
48. How has CRISPR/Cas 9 technology revolutionized genetic research and

biotechnology?

49. In what ways has CRISPR/Cas9 impacted various fields beyond genetics?
50. Can you provide a case where CRISPR/Cas9 was used in the field, what were the outcomes?
51. What are the potential benefits of controlling invasive species through the CRISPR/Cas9 technology?
52. What are the technical challenges and limitations associated with the control of sea lamprey through CRISPR/Cas9 technology?
53. How could targeted gene editing contribute to a more effective control strategy of invasive species?
54. What environmental or ecological implications exist through the utilization of CRISPR/Cas9 in the Great Lakes environment?
55. How might gene editing sea lamprey impact non-target species?
56. What potential risks or unintended consequences exist through the use of CRISPR/Cas9 in the environment?
57. What are the potential safeguards that could mitigate the potential risks associated with the use of CRISPR/Cas9 in the environment
58. What is the importance of having Indigenous People and Indigenous knowledge in the decision-making process and in leadership positions?
59. How do we get young Indigenous People working in technical positions?
60. How would you describe the historical and current relationship between Indigenous communities and the Government of Canada?
61. What is the importance of the UN Declaration Act and its interpretation?

Note: Semi-structured interview questions can be adjusted to reflect participant profiles. Some questions are intended to diversify into deeper conversation.

ANNEX B – Consent Form

uOttawa

Faculté des sciences sociales
Faculty of Social Sciences

Département de sociologie et d'anthropologie
Department of Sociology and Anthropology

Consent Form

Title of the Study: *Caring for Sea Lamprey: Risk Management, Biotechnology, and Eradication in the Great Lakes*

Researchers:

Noah Gauthier (Principal Investigator)
Institute of the Environment

Dr. Nathan Young (Supervisor)
School of Sociological and Anthropological Studies

Purpose of the Study: The purpose of this study is to examine the perspectives of stakeholders on the potential use of CRISPR/Cas9 to control sea lamprey in the Great Lakes. As part of this study, we are speaking with representatives of First Nations Natural Resource Departments, Great Lake practitioners, scientists from relevant disciplines, and policy analysts from government organizations, as well as seeking their recommendations on possible policy responses and needs for the technology's potential utilization.

Participation and Procedures: You are being invited to participate in Noah Gauthiers Masters research because of your position as _____. If you choose to participate, we will schedule an interview at a time and location of your choosing. We expect the interview to last between _____ minutes. The interview will deal with topics such as: sea lamprey control, environmental and natural resource management, the role of different types of knowledge in fisheries policy and ethics, and invasive species challenges and opportunities. The interviews will be hand-recorded and transcribed for accuracy. However, during the interview you are free to withdraw any statement and it will be disregarded.

Confidentiality and Anonymity: You are being given the option to remain anonymous or to have your name associated with any quotations or statements that appear in the thesis defense and publications. If you choose to remain anonymous, the researchers commit to keeping your identity in strict confidence. It is possible that your statements may be quoted in the master's defense or publications, but you will never be identified by name.

However, you should be aware that readers of publications may be able to infer your identity from the content of your quotations or descriptions of your organization. You may also indicate to me if you wish a particular answer given in the course of the interview to remain anonymous. Given the specialized nature of the interview topics, there's a possibility that certain information shared could still be identifiable, even with these measures in place. You will have the opportunity to review your transcripts upon request.

Procedures for Anonymity: If you choose to remain anonymous, the researchers will remove your name from the interview transcript following the analysis phase of the research and instead use a numerical reference system.

Conservation of data: The files and paper copies of our data will be kept under lock in the office of Noah Gauthier at his home office, and electronic copies will be password-protected on Noah Gauthiers office computer. The only persons who will have access to this data are Dr. Young and Noah Gauthier working on the project. All data will be conserved for a maximum of 5 years following completion of the study.

Voluntary Participation: You are under no obligation to participate, and if you choose to participate, you are free to withdraw from the study at any time and/or refuse to answer any questions, without any negative consequences whatsoever. If you choose to withdraw, all data gathered until the time of withdrawal will be disregarded in our research and copies destroyed. You may ask me any questions at any time during the interview. We do not anticipate that participation in this study will present any risks directly to you.

Benefits: The research will make four key societal contributions/benefits. First, the research will nuance the potential use of contemporary science in the Great Lakes by providing a policy analysis of the current political, social, and economic dimensions that exist with the genetic control of invasive sea lamprey. Second, it will add to conservation and multispecies scholarship by using 'care' as an interpretive term to engage a Two-Eyed Seeing analysis on the potential genetic control of sea lamprey in the Great Lakes. Thirdly, it will enhance an understanding of the diverse array of risks present within the Great Lakes region by forging new conversations with scientists, academics, government officials, and Indigenous partners, thereby generating novel insights. Fourth, it will provide First Nations Lands and Resource representatives with up-to-date information on new developments stemming from sea lamprey control methods.

Compensation: If you identify as an Indigenous participant, please notify this to Noah Gauthier and you will be given $100 for your contribution to the research, and should you wish to withdraw from the project, this compensation will still be respected.

Acceptance: I, _____, agree to participate in this research study conducted by **Noah Gauthier** of the Institute of Environment, University of Ottawa.

Anonymity: Please select your preferred option. You may change your preference at any time:

☐ I choose to remain anonymous

☐ I choose to have my name appear in subsequent publications

Transcripts: Please select your preferred options. You may change your preference at any time:

☐ I choose to review my interview transcripts

☐ I choose to not review my interview transcripts

If you have any ethical concerns regarding your participation in this study, you may contact the Protocol Officer for Ethics in Research, University of Ottawa, 550 Cumberland Street, Room 154, (613) 562-5387 or ethics@uottawa.ca.

There are two copies of the consent form, one of which is yours to keep.

Your signature below indicates that you consent to participate in this study. However, you understand that by agreeing to participate you are in no way waiving your right to withdraw from the study.

_____

Participant's Signature Date

_____

Researcher's Signature Date