Analyzing the Relationships between Peer-Reviewed Literature and Ontario Best Practice Guides to aid the Understanding of Invasive *Phragmites* Control Methods

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Abstract

Invasive *Phragmites* have been a challenge in North America for numerous decades, depleting the overall biodiversity of landscapes and surrounding habitats. Being identified as Canada's worst invasive plant in 2005, invasive *Phragmites* have specifically been a significant detriment to natural areas in the Niagara region. This research study worked to formulate an understanding of the available invasive *Phragmites* control methods from both peer-reviewed literature and published Ontario best practice guides. The knowledge from both the scholarly and practical sectors has been compared to formulate a full understanding of effective control methods, which aided in the production of an infographic targeted at private landowners in the Niagara region. Above all, this research will work to educate a previously underrepresented group, with the goal to improve the long-term biodiversity and sustainability in the Niagara region.

Keywords: Invasive *Phragmites*, control methods, knowledge mobilization, sustainability

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1.0 Introduction

Invasive species tend to share characteristics in which give them an advantage over the present native species (Brown, 2019). Invasive species account for an approximate cost of $120 billion dollars in the United States alone (Silliman et al., 2014). The *Phragmites australis* species has invaded and been dominant in North America for multiple decades. The invasion of non-native *Phragmites* into North American ecosystems leads to a decrease in the health of the habitat and the overall reduction in biodiversity (Sturtevant, 2022). The decline in ecosystem biodiversity is caused by the formation of monocultures, that may cause the death of numerous animal and aquatic specie habitats while becoming a management concern in almost all North American natural areas (Mal and Narine, 2004). This common reed, categorized as a perennial grass, can grow up to six meters in height with densities of over 200 stems/m² (Figure 1) (Krzton-Presson et al., 2018 & Mal and Narine, 2004). The *Phragmites australis* species have numerous haplotypes, with one being native to North America (Krzton-Presson et al., 2018). The immense growth of invasive *Phragmites* is due to an invasion of the non-native Eurasian lineage, haplotype M, that was introduced to North American ecosystems in the 1800s (Mozder and Zieman, 2010). The invasion into North American ecosystems takes place through vegetative propagation and high-seed production (Krzton-Presson, 2018). Since the introduction of the Eurasian lineage, the native *Phragmites*, haplotype F, have been almost completely replaced in North America (Mozder and Zieman, 2010). This means that over the course of a single century, the invasive *Phragmites* have taken over from the native *Phragmites* and caused a complete shift in biodiversity (Mozder and Zieman, 2010).

Figure 1: Invasive Phragmites growing along the roadside.

The term invasive species is dependent on what society deems to be damaging or dangerous to the surrounding environment (Brown, 2019). Conservation efforts have focused mainly on the control of invasive *Phragmites* for the past 30 years (Hazelton et al., 2014). In 2005, invasive *Phragmites* were identified as Canada's worst invasive plant by Agriculture and Agri-food Canada, being identified in all provinces and territories, excluding the Yukon and Nunavut (Nichols, 2020). The Ontario Ministry of Natural Resources and Forestry (2015) also identified that 25% of species at risk in the province are considered to be threatened by invasive *Phragmites* (Nichols, 2020). Invasive *Phragmites* are also a significant concern in the Niagara region, where they have been identified by Brown (2019) through a comprehensive mapping system. In addition, Brown (2019) gave a recommendation that there must be an increase in the control methods for invasive *Phragmites* in the Niagara region. However, through an initial search of the literature, there is an obvious gap between the published control methods and those being suggested in the Niagara region. The Niagara region encompasses a geographic area of twelve municipalities, governed by a two-tier municipal system, with this research study being interested in the political boundaries of these towns (Figure 2). Due to the drastic decrease in biodiversity in the Niagara region, caused by invasive *Phragmites*, there must be greater recommendations developed and adequately communicated.

Figure 2: Map of the Niagara region (Wikimedia Commons, 2021).

In the Niagara region, authorities such as Niagara Parks have implemented management strategies that include chemical controls, mechanical removals, burning, and solarization to limit invasive species such as invasive *Phragmites* (Niagara Parks, n.d.). The Niagara Parks Commission, is part of the Ontario Ministry of Tourism, Culture, and Sport, who are self-financed with the goal to maintain and protect over 3,274 acres of land in the Niagara region (Niagara Parks, 2022). In 2016, the City of St. Catharines called on the Ontario Ministry of Transportation to implement control measures outlined in the developed Best Management Practices, published by the Ministry of Natural Resources and Forestry to manage the infestations of invasive *Phragmites* along provincial highways (Niagara Peninsula Conservation Authority, 2016). To control the spread within a Grimsby wetland, the Niagara Peninsula Conservation authority approved the commencement of an herbicide application project in 2018 (Niagara Peninsula Conservation Authority, 2018, p.3). However, in 2019, it was noted that the herbicide used to typically eradicate invasive *Phragmites* was not approved for use in Niagara-on-the-Lake (Niagara Peninsula Conservation Authority, 2019). While this herbicide product was not approved, key members of the Niagara Peninsula Conservation Authority have identified the need to eradicate the invasive *Phragmites* species prior to moving forward with any type of restoration in the area (Niagara Peninsula Conservation Authority, 2019). The Niagara Peninsula Conservation Authority, is one of 36 conservation agencies in Ontario, with a vested interest in protecting watersheds in the Niagara region from damage against invasive species or other threats (Niagara Peninsula Conservation authority, 2022). While efforts have been in place to control and eradicate invasive *Phragmites,* published documents are few and far between. The major barriers existing for management, and control are a lack of funding and physical resources (Brown & Vasseur, 2020).

It has been stated by Rohal et al., (2018) that land managers find peer-reviewed literature to only be somewhat helpful when implementing control measures against invasive *Phragmites*. This is due to a lack of time to interpret the evidence produced by scholars, coupled with the lack of access to certain useful studies (Rohal et al., 2018). Therefore, this study analyzes both peer-reviewed literature and the more practical Ontario best practice guides to understand the varying levels of agreement between the two sectors regarding invasive *Phragmites* control methods. As Brown (2019) was unable to access private landowners, the developed suggestion will be targeted towards private landowners, to educate a previously missed subset of the population. Brown (2019) excluded private landowners due to the lack of feasibility when it came to accessing and identifying members of this group interested in invasive species management. This study will not work to identify private landowners, but work to target them through the communication of knowledge gained from peer-reviewed literature and practical best practice guides, in addition to the production of an infographic. This research study will work to understand the current challenges faced in the Niagara region, and their implemented control practices to cope with invasive *Phragmites.* This knowledge will be formulated with the overall goal to produce an infographic for private landowners in the Niagara region, therefore working to bridge the gap between scholarly and practical work.

2.0 Literature Review

The field of invasive *Phragmites* management sees significant debate regarding the feasibility, efficacy, and safety of various control methods. The field itself is expanding on a yearly basis as the effects of this invasive reed are worsening, continuing to degrade the surrounding landscape and impact society. It has been noted by Blossey et al. (2018) that the US herbicide application expenditures before 2010 were estimated at $4-5 million. However, between the years of 2010-2015, the organization of the Great Lakes Restoration Initiative provided more than $25 million for the control of invasive *Phragmites*, showcasing the growing need for control of this non-native reed (Blossey et al., 2018). Despite the great monetary investment into the control of invasive *Phragmites* there has been a significant lack of long-term ecological impacts (Blossey et al., 2018). The most discussed control methods through both peer-reviewed literature and Ontario best practice guides include herbicide application, cutting/mowing, biological control, and grazing. Through a survey completed by Rohal et al. (2018) it was found that 97% of land managers employed herbicide application, 49% grazing, 65% burning, and 43% cutting/mowing. In the grand scheme of the literature, there is some-to-minimal discussion surrounding burning, flooding, plastics, and cultural practices in both peer-reviewed literature and Ontario best practice guides.

The most popular control method, as identified by Hazelton et al. (2014) is herbicide application, which has been employed by land managers in the United States and Canada for decades. Through the survey completed by Rohal et al. (2018) it was found that 97% of land managers had employed herbicide application against invasive *Phragmites*. Currently in Canada, the herbicides of Glyphosate and Imazapyr have been approved for use against invasive *Phragmites,* but cannot be used near or around water (Nichols, 2020). However, as the document by Nichols

(2020) was published, a new Imazapyr based herbicide, Habitat Aqua, has been approved for use around or near water features. However, only users with special aquatic pesticide licenses can employ the product (Nichols, 2020). Herbicides can be applied through multiple different methods, including spraying or wicking, as well as backpack spraying or through the use of all-terrain vehicles for larger infestations. (Ontario Ministry of Natural Resources, 2011). An example of herbicide application over a large infestation of invasive *Phragmites* can be seen in Figure 3. Along with most other control methods, there is debate surrounding herbicide application, as it may not always be a feasible choice due to certain policy or land use certifications.

Figure 3: Herbicide treatment taking place over a large invasive *Phragmites* infestation (Herring, 2013).

Arguably the most controversial control method is biological control, which constituted the introduction of natural enemies to control a non-native invader (Kiviat et al., 2019). The debate surrounding this management strategy stems from the efficacy of introducing specific moth herbivore species (*Archanara spp.)* to act as biological control agents. There are currently two species of European moths, the *Archanara geminipuncta* and *Archanara neurica*, being tested as biological control agents against invasive *Phragmites* (Blossey et al., 2018 & Cronin et al., 2016). The debate surrounding the European moths (*Archanara spp.*) focuses on the safety implications for native *Phragmites* lineages and the surrounding environment (Kiviat et al., 2019). As the native *Phragmites* lineages in North America have significantly declined leaving

them increasingly susceptible to new stresses (Kiviat et al., 2019). It is important to understand that these biological control agents are still being studied and are not currently being released for use against invasive *Phragmites*. However, Cronin et al. (2016) note the New York Department of Transportation had been lobbying for the release of biological control agents to control invasive *Phragmites* in the New York State. Within peer-reviewed literature there is an even debate with some scholars supporting the use of biological control agents against invasive *Phragmites*, with others outlining the evidence against. While biological control agents have not currently been approved for use in Ontario, there is a chance this management strategy can become a reality for land managers in the future. As there are control options being discussed that have such high potential to impact the native environment, it is important that debates such as these and the overall efficacy of methods such as biological control be communicated to underrepresented groups such as private landowners in biologically diverse regions such as Niagara.

The mechanical control of invasive *Phragmites*, such as cutting/mowing is another control method that sees a high-level of discussion in both peer-reviewed literature and Ontario best practice guides. Cutting/mowing is argued to be the first reaction of land managers to remove invasive *Phragmites* (Hazelton et al., 2014). Also, moderately popular among land managers with 43% of surveyed users by Rohal et al. (2018) employing mowing. Within the overarching theme of cutting/mowing there are a significant number of varying strategies recognized within Ontario best practice guides. With Nichols (2020) dividing the category of cutting/mowing into selective cutting/spading on land, selective cutting/spading in water, mulching, excavating, and cutting seed heads. Then, the Ontario Ministry of Natural Resources (2011) dividing cutting/mowing into the sections of mowing, compressing or rolling, and hand pulling, or mechanical excavation. The control method of cutting/mowing has been sub-divided at a significantly higher level than any other management strategy, outlining the variety of activities available for private landowners. With the high-level of access to cutting/mowing tools, this control method is vital to be understood by private landowners to make the most informed decision against invasive *Phragmites* control.

Rohal et al. (2018) has identified that 49% of land managers surveyed within their study have employed grazing. Primarily employed in Europe, grazing is the use of animals, typically goats or cows, to control invasive *Phragmites* through their consumption (Hazelton et al., 2014). The act of grazing has been implemented in Europe for a significant period of time before the modern-day controls such as herbicide application (Silliman et al., 2014). Grazing is significantly discussed within peer-reviewed literature, with little recognition in Ontario best practice guides. The control method of grazing is rarely implemented in the United States or Canada and has almost never been recorded for use in wetland areas (Brundage, 2010). Overall, Brundage (2010) argued the effects of grazing on water quality and wetland soil are not fully understood and it would be irresponsible to recommend this control method without a full knowledge. Therefore, through the comparison of peer-reviewed literature and Ontario best practice guides, a more complete understanding of grazing can be gained, in order to be communicated through knowledge mobilization to private landowners in the Niagara region.

Another semi-popular control method employed by land managers is burning. Where Rohal et al. (2018) identified that 65% of surveyed land managers had implemented the method of burning. Prescribed burning is the purposeful use of fire to control invasive *Phragmites* (Ontario Ministry of Natural Resources, 2011). The knowledge gained from both peer-reviewed literature and Ontario best practice guides does not match the level of popularity among land managers, as there are few published documents analyzing this method. Hazelton et al. (2014) state that burning is a sufficient alternative control method to the physical removal of invasive *Phragmites* with results similar to mowing. However, the use of burning alone typically produces variable results and may not be suitable for all land users (Hazelton et al., 2014). The employment of burning can be complicated, and it has been stated in Ontario best practice guides that only authorized personnel should apply this method (Ontario Ministry of Natural Resources, 2011). Meaning, it is vital for private landowners to have a full understanding of prescribed burning in order to ensure their safety and to ensure a benefit to the surrounding environment.

Flooding is minimally discussed within peer-reviewed literature. Flooding is the use of specific water levels to limit oxygen to invasive *Phragmites*, therefore working towards eradication of the reed. It has been discussed that both invasive *Phragmites* seedling survival and seed germination are incredibly sensitive to flooding (Elsey-Quirk and Leck, 2021). For an effective flood to occur, literature has stated that the treated area must allow for water levels to be easily controlled, while cutting the invasive *Phragmites* stands as low as possible prior (Ontario Ministry of Natural Resources, 2011). As flooding can have a high impact on society and the safety of the users if not completed properly, it is important for private landowners to fully understand the efficacy of this invasive *Phragmites* treatment.

The use of plastics for invasive *Phragmites* control is the least popular of ones identified, as it has been stated that it is typically employed as an offensive measure, rather than a defensive (Willcox, 2013). At the time of publication, Willcox (2013) stated there had been no publications analyzing the use of plastics against invasive *Phragmites*, with there still being very few articles. The use of black plastic over cut invasive *Phragmites* prevents photosynthesis from occurring (Willcox, 2013). While the use of plastic coverings would be accessible for private landowners, it is important to understand what the literature has deemed regarding efficacy of the method.

Cultural practices are only mentioned once within the best practice guides literature, making it minimally understood by scholars and land managers. Acting as an offensive measure, rather than defensive it is unique compared to other control methods, and may be why it is minimally investigated (Nichols, 2020). It is important for this method to be understood by private landowners in the Niagara region as it can be employed prior to an outbreak of invasive *Phragmites*, while potentially preventing an infestation from occuring.

2.1 Knowledge Mobilization

It has been a topic of discussion in professional literature that there must be higher levels of association between scholarly literature and land managers (Rohal et al., 2018). Ontario best practice guides are produced by conservation authorities and environmental groups, with the goal to share information for the benefit of the user. The comparison of this sector and peer-reviewed

literature will work to understand the current levels of association between the two. This knowledge will then support the determining of the best practices available to private landowners in the Niagara region, that will be communicated to this group through an infographic. It was found that decisions between varying control methods are typically guided by budgetary limitations, as opposed to consensus on effectiveness, or the impact on surrounding native vegetation (Rohal et al., 2018). By presenting the efficacy of control methods in a succinct manner such as an infographic, it may be possible to guide management practices more based on impact and benefit to the environment, as this information will be easier to access and interpret.

The produced infographic will be directed towards private landowners in the Niagara region, as this group has been previously underrepresented in the conversation of invasive *Phragmites* control, with Brown (2019) being unable to target this group. The targeting of private landowners may allow for policy development between this group and others such as government or volunteer organizations (Brown, 2019). Therefore, the rationale for this study is the need for knowledge mobilization. Knowledge mobilization is the sharing of comprehension across the typical boundaries of organizations or sectors (Trivellato et al., 2018). Powell et al. (2017) argue that knowledge presented for public services must be mobilized quickly. By translating and condensing the already produced literature for private landowners in a format that may be easily understood, it is hoped that this currently underrepresented group will be able to implement the best possible invasive *Phragmites* control strategies. It is important to mobilize knowledge to address complex challenges in the field of invasive *Phragmites* management. It is argued that as challenges in many disciplines become more complex, the knowledge being shared must bridge cultural and political boundaries to reach a variety of groups (Powell et al., 2017).

By bridging the gap between scholarly research and practical work, a space for knowledge mobilization is created. Currently, it has been argued that three strategies for knowledge mobilization exist. The first is a transmedia approach, that mobilizes knowledge across varying forms of media (Anderson and McLachlan, 2015). The second is a strategy to build bridges, to mobilize knowledge across varying communities (Anderson and McLachlan, 2015). With the final argued strategy of knowledge mobilization being layering, which allows for numerous levels of detail to be created regarding a certain subject (Anderson and McLachlan, 2015). The completion of knowledge mobilization through this study words to bridge the gap between the communities of peer-reviewed literature and Ontario best practice guides, which aligns with strategy two or bridging, as proposed by Anderson and McLachlan (2015). In addition, this knowledge mobilization, completed through an infographic for private landowners in the Niagara region aligns with the first strategy of using a transmedia approach, again proposed by Anderson and McLachlan (2015). The completion of this research project has maximized the impact of already completed research for the benefit of this underrepresented group, the environment, and surrounding society through the method of knowledge mobilization.

This study will work to achieve three core objectives. The first objective is to understand what invasive *Phragmites* control methods have been recognized and studied within peer-reviewed literature. This was achieved through the completion of a literature review, analyzing scholarly

articles published within the last 10 years. Hazelton et al. (2014) was used to formulate keywords from the control methods recognized in their work. This literature review was completed to align with the second objective of understanding control methods that have been employed in Ontario, through an analysis of best practice guides published within the last 10 years. Finally, these peer-reviewed pieces and Ontario best practice guides were compared to fulfill the third objective of formulating a full understanding of the best possible invasive *Phragmites* management strategies, that developed into an infographic communicating the best possible control methods for private landowners in the Niagara region. Therefore, by comparing these two sectors of scholarship and best practice guides, a comment was able to be made regarding the current level of collaboration between scholarly and professional individuals, while also supporting the underrepresented group of private landowners.

3.0 Methodology

This research was formulated in multiple phases to fulfill each of the stated objectives. The first phase consisted of a literature review to analyze the invasive *Phragmites* control methods that have been mentioned within peer-reviewed research. The second phase of this study formulated a review of invasive *Phragmites* control methods mentioned in best practices guides published within the province of Ontario. The final phase of the methodology consisted of the comparison of phase one and two, to understand the level of agreement between the academic and professional literature. This is completed with the goal to understand what control methods have been developed, what can be suggested for private landowners in the Niagara region, or what methods should be avoided.

3.1 Literature Review

The first phase of the research, consisting of a literature review has taken the form of a collection, review, and synthesis of peer-reviewed literature analyzing the invasive *Phragmites* control methods that have previously, are currently, or will be implemented globally. The collection of literature was mainly limited to papers published within the last 10 years, with minimal exceptions being made for review papers that have been cited significantly. Analyzing these review papers allowed for a background of knowledge to be gained regarding invasive *Phragmites* control methods. Hazelton et al. (2014) was used to establish a basic list of common invasive *Phragmites* control methods. These previously mentioned control methods have acted as key questions in the literature review research process, which can be seen in Table 1.

Table 1: Identified search terms and strategies for Phase 1.

Database	Keywords
Web of Science + OMNI Library	Review AND *Phragmites* AND Control OR Manag* OR Remov*
Web of Science + OMNI Library	*Phragmites* AND Herbicide
Web of Science + OMNI Library	*Phragmites* AND Cut*

Web of Science + OMNI Library	*Phragmites* AND Mow*
Web of Science + OMNI Library	*Phragmites* AND Burn
Web of Science + OMNI Library	*Phragmites* AND Flood
Web of Science + OMNI Library	*Phragmites* AND Graz*
Web of Science + OMNI Library	*Phragmites* AND "Biological Control"
Web of Science + OMNI Library	*Phragmites* AND Plastic
Web of Science + OMNI Library	*Phragmites* AND Manual OR "Manual Remov*"

For each control method the same key questions have been recorded, analyzing the history of use, where it has been used, any identified benefits or challenges, as well as the use-specifications, and if there are any innovative measures taking place. The information collected for each key question acted as a basis for developing a deductive codebook, with an outline being produced in Table 2.

Table 2: Outline of Deductive Codes reflected during the literature synthesis.

Code	Description
Benefits	An advantage or something gained from the particular control method
Challenges	An objection or downfall related to a particular control method
Use-Specifications	Any specifics related to the use of a control method. I.e., what time of the year for best use or what duration of use.
History	The background of use regarding a particular control method
Innovation	Any new or innovative methods the scholarly literature of practice guide discusses
Type of Guide	The identification of what type of guide is being analyzed in Phase II of the research
Private Landowners	If the analyzed best practice guide mentions private landowners

Location	Where a control method is or has previously been employed

The deductive codebook was beneficial in organizing the knowledge gained from both the peer-reviewed literature and collected best practice guides. Key questions acted as main codes within the deductive codebook, with notes from varying articles divided between the codes. An example of the notes from specific articles, such as Blossey et al. (2018) can be seen in Figure 4. Following the collection and initial analysis of all documents, all pieces were coded again looking for patterns, causing several of the codes to be used repeatedly. Secondary codes were developed through an inductive approach, reflecting on numerous patterns from multiple analyzed sources. As all pieces were coded for patterns, several of the same secondary codes were developed, which is a core characteristic of the inductive coding process, as identified by Saldaña (2016). During the secondary coding process, like-notations of the collected documents were color-coded to best understand the overall patterns. Overall, within the deductive codebook all written pieces were organized under the control method they discussed, with notes from the document aligning with each of the main codes. Each identified secondary code or theme was associated to a specific color, that would then be used to highlight each note associated from varying articles. The goal of the color-coding process within the deductive codebook was to allow for easier association when reviewing the data and writing the overall findings and discussion. An example of the coding process, with associated colors can be seen in Figure 4.

Control Method	**Herbicide Application**			**Burning**	
	Blossey et al., 2018	Paper 2	Secondary Codes	Paper 3	Paper 4
Main Code					
Benefits	*Phragmites* cover decreased with years managed		Successful		
Challenges	Larger sites required multiple applications		High Cost		
	Larger sites required multiple applications		Time Consuming		
	Eradication success depends on rapid response		Time Consuming		
Innovation					
Use-Specification	Treat during favourable weather				
	Avoid extreme heat or cold				
	Avoid precipitation				
	Avoid high-wind				
History	Treated for 7-year period (2010-2016)				
Location					

Figure 4: Example of the coding approach.

3.2 Review of Best Practice Guides

The second phase of this research formulated a review of best practice guides that had been published in Ontario, focused on controlling invasive *Phragmites*. The search focused on professionally published documents, created within the last 10 years, using publicly available search engines such as Google. A simple search strategy can be seen in Table 3. The search parameters included best practice guides from all of Ontario, with preference to influential guides, meaning those that are referenced most by others. It was found that these influential guides were published by large provincial organizations, such as the Ontario Invasive Plant Council, or the Ontario Ministry of Natural Resources. These influential guides were then referenced by smaller municipal organizations. This led to only a small subset of municipal guides being included in the research, giving preference to the larger influential publications.

Table 3: Identified search terms and strategies for Phase 2.

Database	Keywords
Google	*Phragmites* Best Management Niagara
Google	*Phragmites* Control Methods Niagara
Google	Controlling *Phragmites* Niagara
Google	*Phragmites* Best Practice Guide
Google	*Phragmites* Best Practice Ontario

The review of best practice guides considered the same key questions as Phase 1, the literature review. These key questions then acted as the basis for deductive codes, focusing on the benefits or challenges of the control method, where it has been used, for how long, any use-specifications, and if the suggested measure was innovative. The key questions and developed codes were the same for both the Literature Review and Review of Best Practice Guides to ensure the two could be connected and compared in the final phase of the research. A second round of inductive coding was completed to identify overall themes within the best practice guides that have been published in Ontario over the last 10 years.

3.3 Connecting the Published and Local Literature

The final portion of this research looked at connecting the peer-reviewed and best practice guide literature. Using the developed codes, the identified invasive *Phragmites* control methods were able to be compared to understand if the current management strategies were effective and identify new ones. This portion of the researcher helped to answer the question of what from the scholarship is represented within the best practice guides and what is not. In addition, connecting the peer-reviewed literature and best practice guides helped identify what control methods the

Niagara region should implement that were previously successful in published work. The answer to these questions aided in the development of an infographic to be potentially made available to private landowners in the Niagara region.

Overall, this guide to invasive *Phragmites* management is formulated with the goal to allow for private landowners to make the most informed decision possible. Within the management guidelines a description of invasive *Phragmites* is given, along with the importance of management and identification of all recognized control methods in the peer-reviewed literature and published best practice guides. This guide outlines the level of agreement between the peer-reviewed literature and best practice guides. The level of agreement is organized into three categories, beginning with most agreement, some, or no consensus between the peer-reviewed literature and best practice guides. A control method would fit into the category of most agreement if both the peer-reviewed literature and Ontario best practice guides identified a high level of the same or similar themes from the coding process, allowing for a variance of one or two themes. A control method would fit into the category of some agreement if both the peer-reviewed literature and Ontario best practice guides identified some of the same themes through the coding process, give or take two or more themes. A control method would also be deemed some agreement if one sector was to investigate the management practice in significant more detail, leading to the allowance to identify significant more themes. Finally, a control method would fall within the no consensus category if the peer-reviewed literature and Ontario best practice guides did not agree on any themes from the coding process. The rating of no consensus would also be given if the recognition of the management strategy was limited or entirely absent from one of the sectors, therefore allowing no themes to be identified.

Included in the information for private landowners is also a level of risk rating system. The level of risk was assessed for each control method based on four major factors. The first being the possibility for negative consequences to be felt by the user, meaning the possibility for physical harm. The second factor is the risk for surrounding society, which would account for the possibility of damaged infrastructure, such as surrounding homes or businesses. The third factor in assessing risk is the possibility for damage against the surrounding native environment, accounting for the potential for death or degradation of native plants, animals, or wildlife habitats. Finally, the requirement of expert knowledge was a factor for assessing risk, as the user would need specialized training or skills, meaning the possibility for damage to oneself or surroundings is high. If there is a recognized risk against oneself, society, the environment, or the need for expert knowledge, the risk associated to a control method would increase. For example, if a control method was dangerous for the user, the risk rating would increase from one to two. The risk rating would continue to increase if danger for society or infrastructure was present, or if the need for expert knowledge was required. If a control method is incredibly controversial, or the arguments for a certain risk factor are strong, the rating may have increased by more than one point. This risk rating system is especially beneficial for private landowners to make an informed decision between implementing a specific control method or choosing to forego. For example, if a control method were to have no consensus on agreement between peer-reviewed literature and

other best practice guides, the private landowners would be able to reflect on the level of risk when deciding on implementation.

This guide also includes any relevant policy related to specific control methods, such as provincial guidelines surrounding the use of herbicide application. This policy information is outlined to allow for private landowners to understand what invasive *Phragmites* control methods are available to them, dependent on their level or training or understanding of the reed.

4.0 Findings

In this section, the results of this study are presented and discussed. Each identified invasive *Phragmites* control method is divided into sub-headings outlining what has been discovered from the peer-reviewed literature, the analyzed best practice guides, and a presentation of private landowner information. The presentation of information for private landowners includes the decided level of agreement between the peer-reviewed literature and best practice guides, as well as the risk rating if users were to employ a specific control method.

Following the production of codes from the literature review and local document review, comparisons have been made between the peer-reviewed literature and analyzed Ontario best practice guides. The level of agreement between these two sectors is identified to understand the perceived effectiveness of discussed invasive *Phragmites* control methods. This portion of the research has worked to answer the question of what from the scholarship is represented in local best practice guides and what is not. Answering this question aided in the development of an infographic for private landowners in the Niagara region. The level of risk is included when discussing potential invasive *Phragmites* control methods to allow for the most informed decision to be made by users. The level of risk takes into account the potential for harm for the user when implementing the control method, while also analyzing the possibility for destruction against the surrounding natural environment or society. Figure 5 analyzes the level of agreement between the peer-reviewed and local literature, compared to the perceived level of risk of a specific control method. Figure 5 is a visual representation of which invasive *Phragmites* control methods would be suggested for employment for private landowners in the Niagara region. With the ideal control method falling into the upper-left quadrant of Figure 5, associated with a high-level of agreement between peer-reviewed literature and Ontario best practice guides, coupled by a low level of risk rating.

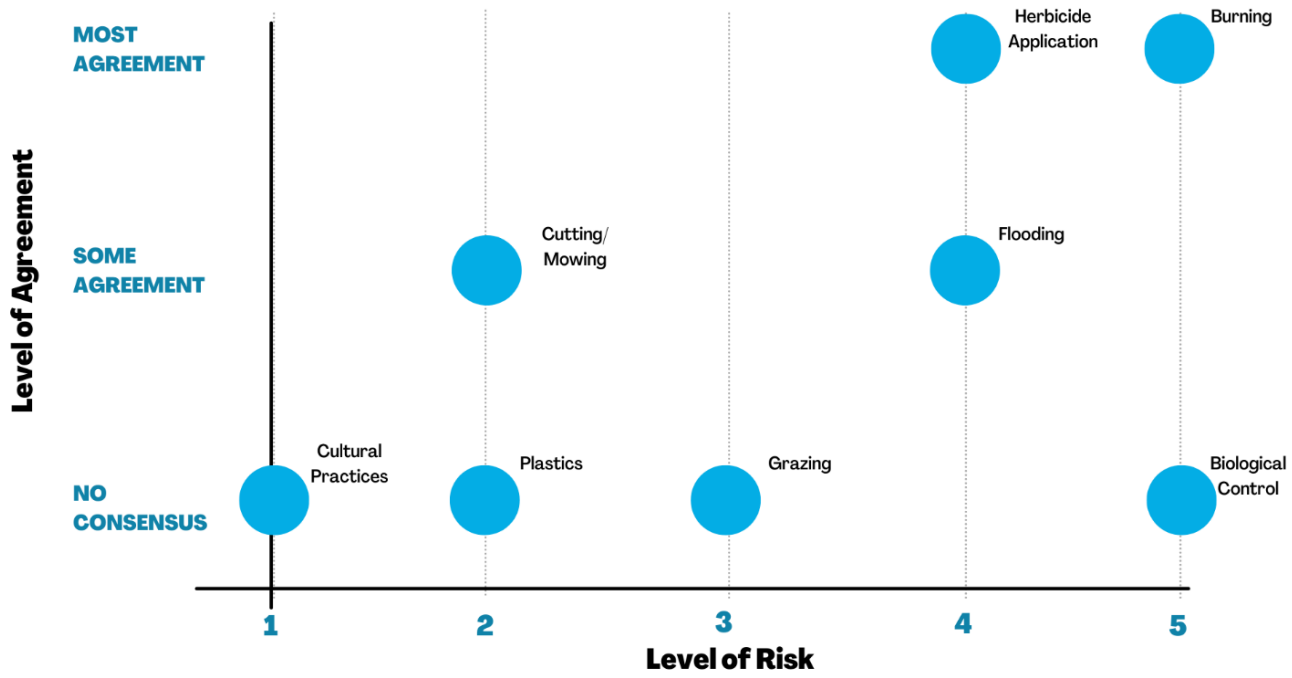

Figure 5: Matrix of Level of Agreement versus Level of Risk for invasive *Phragmites* control methods (risk level 1 = very low, 2 = moderately low, 3 = average, 4 = moderately high, 5 = very high).

4.1 Herbicide Application

Regarding the control method of herbicide application, there is an abundant number of resources studying the effectiveness of these products. Table 4 outlines the major themes associated to each main code from the deductive codebook from both the peer-reviewed literature and analyzed best practice guides. From the peer-reviewed literature, herbicide application is found to be successful and effective. However, in terms of major challenges, herbicides are found to be high cost and time consuming. In terms of use-specification, the peer-reviewed articles were unable to agree on the most effective application times during the growing season, however, there was significant agreement that spraying should only take place during favorable weather. There was little innovation present regarding herbicide application. With it also being impossible to draw on themes regarding the length of treatment and locations. In terms of Ontario best practice guides, a major benefit was that herbicide application is successful and effective. However, best practice guides found this method to be high cost, time consuming, and inaccessible for users. Another theme noted in Table 4 is in regards to use-specification, as best practice guides found herbicide application to fall under limited land-usage, and must be applied during favourable weather.

Table 4: Description of overall themes related to the main codes related to the consensus regarding herbicide application from peer-reviewed literature and reviewed best practice guides.

Main Code	Theme for Peer-Reviewed Literature	Theme for Best Practice Guides
Benefits	Successful/Effective	Successful/Effective
Challenges	High Cost Time Consuming	High Cost Time Consuming Can be inaccessible
Innovation	N/A	N/A
Use-Specification	No agreement on application times Treat during favourable weather	Limited Land-Usage Treat during favourable weather
Treatment Time	N/A	N/A
Location	N/A	N/A

Peer-Reviewed Literature

From the peer-reviewed literature, it is evident that herbicide application is the most popular control method among scholars. Herbicide application is deemed the most popular control method due to it being effective against invasive *Phragmites*. Robichaud and Rooney (2021) found herbicides to be so effective that after the first year of treatment only 1 in 40 study plots had living invasive *Phragmites*. With the employment of Glyphosate, only 13.6% of the 40 plots used by Robichaud and Rooney (2021) had long-term regrowth. However, some articles argue that Imazapyr is more effective than Glyphosate; with the two formers being significantly more successful than Imazamox. With Knezevic et al. (2013) finding that alone, Imazapyr applied at 560g/ha produced 100% control, but when mixed with Imazamox, control was reduced to 89%.

The need for reapplication of herbicides is also discussed in peer-reviewed literature. With almost every analyzed article stating that reapplications must occur over numerous years to prevent reinvasion if invasive *Phragmites*. The requirement for multiple herbicide applications is an identified challenge as it leads to the method becoming costly and time consuming. Without the continued reapplication of herbicides, invasive *Phragmites* had significant regrowth, with some returning after as little as one year (Quirion et al., 2017). The early detection of invasive *Phragmites* infestations is key to reduce the need for such long-term applications. Quirion et al. (2017) found that when there was early detection of infestations complete eradication was possible, with approximately 35% of sites analyzed by Quirion et al. (2017) had successful eradication due to the early detection. Other scholars, such as Quirion et al. (2017) agree that eradication success depends on the rapid response to the invasive plant.

When it comes to the application of herbicides, peer-reviewed literature had little agreement on best times to spray throughout the season. Some articles argued that herbicides should be applied at the beginning of the growing season, with others stating it should occur in the fall (Elsey-Quirk and Leck, 2021 & Taggart et al., 2015). Only one article, written by Hazelton et al. (2014) mentioned the intended application period of the herbicide, by following the instructions of

Glyphosate. All other peer-reviewed articles seemed to apply herbicide products at periods they personally deemed to be correct, disregarding the professional instructions. With the overarching disagreement on when is the best time during the growing season to apply herbicides, Knezevic et al. (2013) argue that specific spraying times were overall ineffective. While peer-reviewed literature had significant disagreement regarding effective application times, it was universally agreed that invasive *Phragmites* should only be treated during favourable weather conditions. The application of herbicides should not take place during periods of extreme heat, cold, or any type of severe weather (Quirion et al., 2017). Periods of high-wind of precipitation should be avoided as well (Quirion et al., 2017). Significant themes from peer-reviewed literature can be seen in Table 4, with the major benefit being this method is effective and successful. The major challenges of herbicide application include it being high cost and time consuming. Regarding use-specification, peer-reviewed literature was unable to agree on effective times during the growing season to apply the herbicide, but all agreed that spraying should only take place during periods of favourable weather. Overall, herbicide application has been deemed the most popular control method, which is evident through the quantity of peer-reviewed literature published (Hazelton et al., 2014). By understanding the themes regarding herbicide application from peer-reviewed literature, the first objective of understanding what has been developed for invasive *Phragmites* control from the scholarly realm can be achieved.

Reviewed Best Practice Guides

Through a review of best practice guides published in Ontario, significant themes regarding the use of herbicides for invasive *Phragmites* control can be noted. Table 4 outlines the major themes associated to the main codes. Regarding the benefits of herbicide application, the analyzed best practice guides agree this method is successful and effective. Regarding the challenges of herbicide application, this method is high cost, can be time consuming, and may be inaccessible for some. For use-specification, the analyzed best practice guides agree that this method can only be used on limited land-types. There was little innovation present regarding herbicide application strategies. No themes could be drawn regarding treatment time or the location of studies.

Through the analysis of best practice guides in Ontario, all agree that the use of herbicides to control invasive *Phragmites* is an effective choice. The Ontario *Phragmites* Working Group (2015) found that complete control can be expected after two treatments, and after just one the mortality rate should be between 70-95%. In Ontario, Glyphosate and Imazapyr have been registered for use (Nichols, 2020). With some best practice guides arguing that Imazapyr is more effective than Glyphosate (Ontario Ministry of Natural Resources, 2011).

While the analyzed best practice guides agree this control method can be effective, there are multiple challenges that have been noted. A major challenge of herbicide application is the inaccessible nature of the method. Some equipment required for infestations, such as tractors or all-terrain vehicles, can be difficult to obtain (Gilbert and Vidler, 2013). In addition, the Ontario Ministry of Natural Resources (2011) noted that those wishing to use herbicides for invasive *Phragmites* control must have an appropriate exterminator license, or gain approval from the

branch or Regional Director of the Ministry of Natural Resources. The regulation of herbicide storage, use and sale falls under the Pesticides Act and Regulations 63/09, which can be accessed through: laws.gov.on.ca/html/source/regs/english/2009/elaws_src_regs_r09063_e.htm#BK37. Due to the strict regulations and required licensing, the use of herbicides may be inaccessible for majority of people.

Best practice guides in Ontario have identified that repeat applications of herbicides can be necessary. This leads to the conclusion that herbicide application for the control of invasive *Phragmites* can become time consuming, due to the repeat nature. In addition, some best practice guides suggest combining herbicide application with other control methods such as burning, leading to the need for more time to be spent (Gilbert and Vidler, 2013). Finally, herbicide application can be time consuming, as many of the methods related to herbicide application are labor intensive. Due to the need for repeat applications or coupling herbicides with another control method, can lead to the high-cost nature.

Best practice guides published within Ontario have noted the constraints of applying herbicides on varying lands. As a theme under the code of use-specification, herbicide application has limited land-uses. Multiple best practice guides stress that no herbicides in Ontario are approved to be applied over or near any type of water or wetland. In addition, the Lambton *Phragmites* Community Group (2015) noted that without the proper method of herbicide application, it can be harmful to surrounding native vegetation. Therefore, the type of lands where herbicides can be applied is limited to certain land types or uses. Another use-specification theme noted in best practice guides is the need to apply herbicides during times of favourable weather. The Ontario *Phragmites* Working Group (2015) note herbicides cannot be sprayed if plants are wet. With the Ontario Ministry of Natural Resources (2011) also stating that the wind and weather must be taken into account when applying herbicides to limit the drifting of products. To conclude, the overall themes noted from best practice guides published in Ontario outline that herbicide are successful and effective control method against invasive *Phragmites*. However, they also note that herbicide application can be time consuming, high cost, and inaccessible for typical users. In terms of use-specifications, herbicides can only be used on limited land types, while also needing to applied during periods of favourable weather. It is agreed that herbicide application is popular among best practice guides, however, the required licenses and certifications are stressed among these groups.

Private Landowner Information

Herbicide application is a control method that falls within the top-right quadrant of Figure 5, noting that between the peer-reviewed literature and best practice guides there is a high-level of agreement, but it is also a moderately high to high-risk control method. Within both peer-reviewed literature and the analyzed best practice guides, there was no mention of control methods related to herbicide application specific to private landowners.

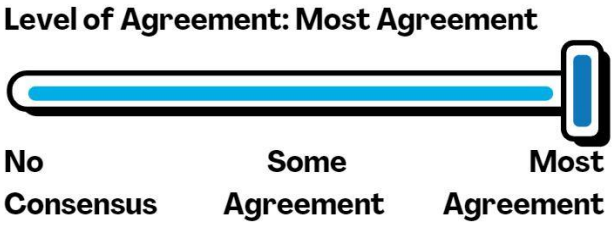

Figure 6: Level of Agreement for herbicide application.

There is a consensus between peer-reviewed and practical literature that herbicide application is an effective control method, leading to a rating of most agreement (Figure 6). Hazelton et al. (2014) note that herbicide application is the most popular choice of control method among land managers as it is effective. However, both the peer-reviewed and practical literature agree that this method is time consuming, as there is a need for multiple applications. Herbicide application is also time consuming as it requires rapid response to infestations, and if not treated early on, may become unmanageable for private landowners. In addition, while the repeated treatments may be successful, herbicide application is a high-cost strategy due to the multiple purchases of the product. Herbicide application may also be too costly for the typical private landowner, as some equipment for spraying denser infestations, such as tractors or all-terrain vehicles can have a high cost (Ontario Ministry of Natural Resources, 2011). Finally, between the two accessible herbicide products of Imazapyr and Glyphosate, it is agreed that Imazapyr is more effective, but the costliest of the substances (Knezevic et al., 2013). While the peer-reviewed and practical literature agree on the themes of effectiveness, time consumption, and cost, there is mixed perspective on application times. Some publishers believe herbicide application should be completed early in the growing season, while others argue they are to be sprayed at the end of the growing season (Hazelton et al., 2014 & Taggart et al., 2015). It is best to follow the instructions of the specific herbicide being used, however, all publications agree that spraying cannot occur over water and should only be applied in favourable weather.

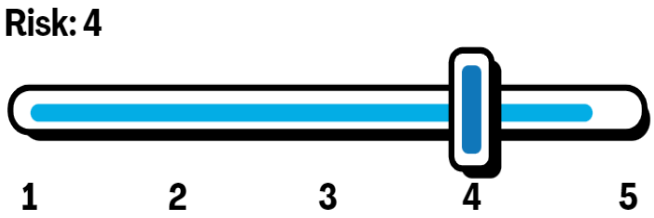

Figure 7: Risk rating of 4 for herbicide application.

Herbicide application has been deemed a relatively high-risk control method for invasive *Phragmites*, with a rating of 4 as seen in Figure 7. The risk level of herbicide application is relatively high as numerous specific instructions must be followed to carry out this method in a safe and effective manner. Provincial laws have been put in place to reduce the risk of herbicide application. In Ontario, the use of herbicides is regulated under the Pesticides Act and Regulation 63/09 (Ontario Ministry of Natural Resources, 2011). If extermination of invasive *Phragmites* by

herbicides is to be completed by a person without an appropriate license, a written letter of Opinion is required from the Regional Director of the Ministry of Natural Resources (Ontario Ministry of Natural Resources, 2011). Once special permissions have been given to apply herbicides for the control of invasive *Phragmites*, users are to follow the specification labels on their pesticide product, whether it be Imazapyr or Glyphosate. More information and regulations can be found at: http://pr-rp.pmra-arla.gc.ca (Ontario Ministry of Natural Resources, 2011). Overall, the employment of herbicide application can have great risk against the natural environment and surrounding society. Due to this potential of great risk, herbicide application has received a risk level of 4/5.

4.2 Burning

Compared to other invasive *Phragmites* control methods, the quantity of peer-reviewed literature that analyzes burning is limited. Table 5 outlines the major themes associated with burning from the peer-reviewed literature and the analyzed best practice guides. Within the peer-reviewed literature there was a consensus that the control method of burning had only challenges. No major themes were discovered for benefits, innovation, use-specification, treatment time, or location. In terms of challenges regarding burning, major themes are surrounding the ineffectiveness of the method. Scholars have noted that burning is overall ineffective, it is ineffective when used as the sole control, and is ineffective for use against live invasive *Phragmites*. From the analyzed best practice guides, Table 5 also outlines solely challenges, which are the consensus that burning is ineffective and dangerous.

Table 5: Description of overall themes related to the main codes related to the consensus regarding burning from peer-reviewed literature and reviewed best practice guides.

Main Code	Theme for Peer-Reviewed Literature	Theme for Best Practice Guides
Benefits	N/A	N/A
Challenges	Ineffective	Ineffective Dangerous
Innovation	N/A	N/A
Use-Specification	N/A	N/A
Treatment Time	N/A	N/A
Location	N/A	N/A

Peer-Reviewed Literature

From the analyzed peer-reviewed publications it is agreed that the control method of burning to remove invasive *Phragmites* is ineffective. Hazelton et al. (2014) noted that burning can actually stimulate the growth of invasive *Phragmites* rather than eradicating an infestation. As fire tends to rejuvenate reed beds, in areas that were burning in a study completed by Mester et al. (2015), the invasive *Phragmites* grew back within 2-3 years. Peer-reviewed literature also argues that burning is ineffective if used as a stand-alone invasive *Phragmites* control method. Hazelton et al. (2014) has noted that burning is ineffective unless coupled with herbicide application or

flooding. This leads to the challenge that burning is ineffective if employed alone. The final facet of ineffectiveness is related to the use of burning against live invasive *Phragmites*. Researchers have noted that when burning live invasive *Phragmites*, the reeds grew back from rhizomes and was therefore not effective (Mester et al., 201). In addition, Mester et al. (2015) found that the reed covers doubled in newly burned areas, if the method was employed during the flowering period. Overall, from the peer-reviewed literature studies it was found that burning is ineffective, with the facets of being ineffective as a stand-alone method, as well as being discouraged for use against live invasive *Phragmites*.

Reviewed Best Practice Guides

From a review of best practice guides published within Ontario, the discussion of burning brought forth two major themes, surrounding the challenges of this control method. Table 5 outlines the major themes found within the best practice guides, with no significant benefits, innovation, use-specifications, treatment time, or locations being noted. Regarding challenges, Table 5 outlines the best practice guides have deemed burning to be ineffective and dangerous.

Best practice guides in Ontario deem the control method burning to be ineffective if used alone. It is believed that burning is best used in conjunction with herbicide application (Nichols, 2020 & Ontario Ministry of Natural Resources, 2011). With the burn occuring at least 2-3 weeks following herbicide application (Nichols, 2020 & Ontario Ministry of Natural Resources, 2011). However, Gilbert and Vidler (2013) argue that burning is overall ineffective, as invasive *Phragmites* tend to thrive after a burn. Also stating that this method only results in thinning of the dead biomass, rather than eradication (Gilbert and Vidler, 2013). Overall, the best practice guides agree that the control method of burning is ineffective, with Nichols (2020) and the Ontario Ministry of Natural Resources (2011) believing it can be somewhat redeemed if paired with herbicide application. The final theme noted within the best practice guides that reflects as a challenge for the method of burning is the fact that it can be dangerous. This danger reflects on the user, as well as the surrounding environment or infrastructure. If a burn were to become uncontrolled the consequences could be deadly. Overall, the best practice guides within Ontario have recognized multiple challenges related to the control method of burning, regarding its ineffectiveness and potential for danger.

Private Landowner Information

The control method of burning falls within the upper-right quadrant of Figure 5, outlining that there is significant agreement between the peer-reviewed literature and best practice guides, with a high-risk rating. Within both peer-reviewed literature and the analyzed best practice guides, there was no mention of control methods related to burning specific to private landowners.

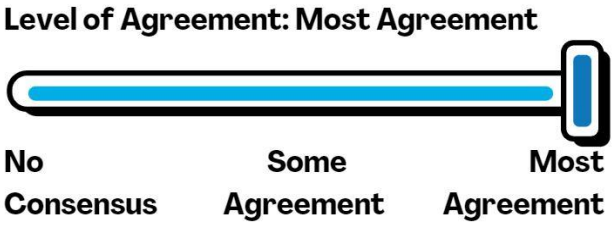

Figure 8: Level of agreement for burning.

Through the comparison of the peer-reviewed and practical literature, it is deemed that the two sector have the most agreement (Figure 8). Overall, the two sectors tend to agree that the method of burning is ineffective. It is argued that burning is not effective when employed alone, and not ideal for the removal of live invasive *Phragmites*. Nichols (2020) and the Ontario Ministry of Natural Resources (2011) argue that burning is best used in conjunction with herbicide application; this argument is echoed in the peer-reviewed literature. In addition, multiple studies in the peer-reviewed literature found that after 2-3 years the invasive *Phragmites* grew back, and in some cases the reed cover doubled, leading to the overall conclusion that this method is not effective long-term. The reviewed best practice guides also made note that this control method can be dangerous, due to the use of fire. Overall, there is significant agreement between peer-reviewed and practical literature that the control method of burning is ineffective and not recommended.

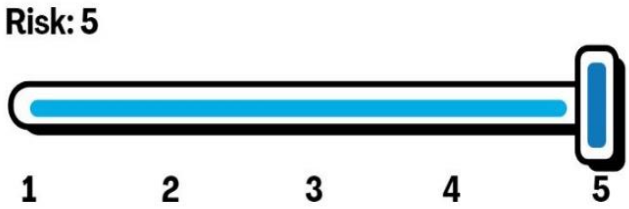

Figure 9: Level of risk rating for burning.

Employing burning as a control method for invasive *Phragmites* has been deemed high risk. This is due to the potential for harm against people employing the method, surrounding society, and the non-invasive environment. In Ontario prescribed burning should only be undertaken by authorized personnel, as the employment of this method by those without proper training can be dangerous. However, unlike herbicide application, it is not possible to receive special permission for a prescribed burn and can only be completed by authorized individuals. In addition, prescribed burning can become unmanageable if used on standing dead invasive *Phragmites* stands (Ontario Ministry of Natural Resources, 2011). This method should only be used as a way to clear excess above-ground seeds and litter (Ontario Ministry of Natural Resources, 2011). If a prescribed burn were to become out of control it can cause harm to the user, to those in surrounding neighborhoods, and surrounding native vegetation. As individuals without specific training cannot complete this method due to the extreme danger, prescribed burning is given a high-risk level of 5/5.

4.3 Cutting/Mowing

Cutting/mowing is a control method moderately discussed within peer-reviewed literature. Table 6 outlines the major themes relating to the main codes that form a consensus of cutting/mowing from both the peer-reviewed literature and analyzed Ontario best practice guides. While scholars did not note specific arguments for the benefits of cutting/mowing, the innovation of the method, the treatment time, or location; there are themes regarding challenges and use-specification. Scholars have argued that a major challenge of cutting/mowing is its level of ineffectiveness, some believing it does not work as a stand-alone method, with others stating it is overall unrecommended. In addition, peer-reviewed literature believes this method is time consuming. Finally, regarding use-specification, there is lack of agreement between scholars on application time. Ontario best practice guides believe a major benefit of cutting/mowing is its accessible nature. However, noted challenges of the method include it being ineffective and time consuming.

Table 6: Description of overall themes related to the main codes related to the consensus regarding cutting/mowing from peer-reviewed literature and reviewed best practice guides.

Main Code	Theme for Peer-Reviewed Literature	Theme for Best Practice Guides
Benefits	N/A	Accessible
Challenges	Ineffective Time Consuming	Ineffective Time Consuming
Innovation	N/A	N/A
Use-Specification	No agreement on application time	N/A
Treatment Time	N/A	N/A
Location	N/A	N/A

Peer-Reviewed Literature

Scholars have argued that cutting/mowing is ineffective, whether that be in general, or as a stand-alone method. This is due to the long-term implications of cutting/mowing, as Xu et al. (2016) found that the aboveground biomass of invasive *Phragmites* is rarely impacted by this method. In addition, as the aboveground biomass is unaffected, the effects of cutting/mowing was lost after approximately 190 days (Xu et al., 2016). It was also noted that the soil type has a significant impact on the effectiveness of cutting/mowing, with the method being considerably ineffective if completed on aerated or sandy ground (Hazelton et al., 2014). Some scholars suggest that cutting/mowing is best to be employed in partnership with herbicide application (Rohal et al., 2019). Other scholars believe that both cutting and mowing need to occur in combination for the most effective control to occur (Hazelton et al., 2014). Overall, it is evident within the scholarly literature that the long-term use of cutting/mowing can be ineffective, with others believing it is not effective as a stand-alone method. Another noted challenge of cutting/mowing is its time-consuming nature. Some scholars believe that hand cutting specifically is time-consuming due to the labor-intensive nature and therefore would be considered ineffective and unrecommended (Hazelton et al., 2014). It is believed that due to the

time-consuming nature of cutting/mowing it is only recommended on small patches (Hazelton et al., 2014).

There is debate within the peer-reviewed literature regarding the best application time of cutting/mowing to effectively irradicate invasive *Phragmites*. The use-specification of application time varies, as some scholars believe it should only be completed within the winter months, while others have begun in April, or just before the flood season (Fogli et al., 2014 & Hazelton et al., 2014 & Xu et al., 2016). Fogli et al. (2014) have stated that winter mowing is recommended, as it is believed that summer application led to the possibility of fires. However, Hazelton et al. (2014) believe that cutting/mowing should take place prior to the flood season to improve effectiveness. While Xu et al. (2016) employed cutting/mowing in the month of April, at the start of the growing season. The lack of agreement regarding application time is a major theme in peer-reviewed literature and may be lending itself to the belief that his control method is ineffective.

Reviewed Best Practice Guides

The reviewed best practice guides in Ontario explore cutting/mowing in significant detail, with the larger influential guides choosing to separate this application method into specific strategies such as compressing or rolling, excavating, or hand pulling (Nichols, 2020 & Ontario Ministry of Natural Resources, 2011). Table 6 outlines major themes evident within best practice guides, based on the main codes of the deductive codebook. There were no evident codes for innovation, use-specification, treatment time, or location. However, a noted benefit of cutting/mowing is the accessible nature of the method. With key challenges of this method being ineffective and time consuming.

Ontario best practice guides believe that cutting/mowing is an accessible control method for the general public. This is evident as most strategies that fall under cutting/mowing, such as mowing and hand cutting are relatively low cost and can be completed with minimal training (Ontario Ministry of Natural Resources, 2011). This accessible nature is only relevant for some strategies within cutting/mowing, as choosing to excavate invasive *Phragmites* would require specialized machinery at a cost (Nichols, 2020). For the general public cutting/mowing would be a simple application method to implement, with the typical machinery, such as a lawn mower, being tools that most private landowners would already have in their possession.

A major challenge noted within Ontario best practice guides is the belief that cutting/mowing is an ineffective method long-term, and if used alone. Best practice guides believe that cutting/mowing is ineffective if used alone and suggest pairing with herbicide application (Ontario Ministry of Natural Resources, 2011). It is also argued that there is potential for mowing to stimulate the growth of invasive *Phragmites* if used as a stand-alone method and is therefore considered ineffective (Ontario Ministry of Natural Resources, 2011). For the specific method of cutting seed heads, Nichols (2020) found this strategy to be entirely ineffective and unsuccessful. Overall, best practice guides have deemed that cutting/mowing and the specific strategies that fall under this control category are not to be employed alone and can sometimes being entirely ineffective.

A final challenge of cutting/mowing is the belief that this invasive *Phragmites* control method is time consuming. Ausable Bayfield et al. (2015) believe this method will only slow the growth of invasive *Phragmites* and not cause death, leading to the need of a regular cutting regime or else all effects will be lost. The significant regular cutting regime leads to a time-consuming nature of this control method. In addition, some strategies that fall within the cutting/mowing category can be time consuming, such as hand pulling, as it requires significant attention to detail and labor (Ontario Ministry of Natural Resources, 2011). Overall, the completion of cutting/mowing as a method to control the growth of invasive *Phragmites* can be significantly time consuming, especially dependent on the strategy employed, as there is a difference in labor needs between hand pulling and excavating. As a whole, best practice guides in Ontario have noted that cutting/mowing can be beneficial due to its accessible nature. However, this method tends to be ineffective if used alone and long-term, while also being time-consuming due to the labor-intensive nature.

Private Landowner Information

Cutting/mowing falls within the lower-left quadrant of Figure 5, with the level of agreement between peer-reviewed literature and reviewed best practice guides being some, with the risk rating being moderately low at 2/5. Within both peer-reviewed literature and the analyzed best practice guides, there was no mention of control method related to cutting/mowing specific to private landowners.

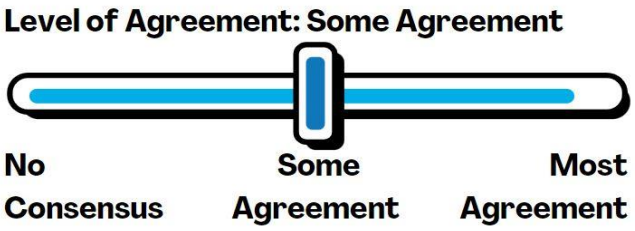

Figure 10: Level of agreement for cutting/mowing.

The discussion of cutting or mowing in peer reviewed versus practical literature brings some agreement (Figure 10). It is interesting to see that the best practice guides go into significantly greater detail when dividing individual methods that fall under cutting/mowing, whereas peer reviewed publications stick to basic strategies. For example, within the *Invasive Phragmites (Phragmites australis) Best Management Practices in Ontario: Improving species at risk habitat through the management of Invasive Phragmites* by Nichols (2020), the overarching method of cutting/mowing was divided into hand cutting, hand cutting in water, mulching, cutting seed heads, and excavating. Whereas, for all analyzed peer-reviewed literature, the overarching method of cutting/mowing was only divided between hand cutting and mowing. Through all publications, it was agreed that cutting or mowing were not effective as stand-alone methods, and would fare best coupled with herbicide application (Ontario Ministry of Natural Resources, 2011). Peer-reviewed and practical literature also agree that most cutting/mowing methods can

be time consuming due to the labor-intensive nature. Repeated cutting or mowing processes would be necessary, with some methods, such as hand cutting being deemed as ineffective based on time and resources (Hazelton et al., 2014). While cutting and mowing can be labor and time intensive, it is an accessible method to control invasive *Phragmites* as it is relatively easy to complete with minimal training and some methods such as mowing with a regular mower can be fairly inexpensive, as most private landowners likely already own this equipment. Overall, the method of cutting and mowing sees some agreement between peer-reviewed and practical literature due to the limited recognition of methods within this grouping, however, the critiques of the practices are similar.

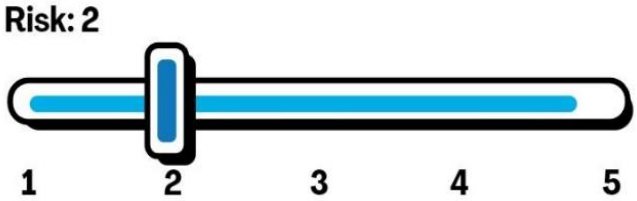

Figure 11: Level of risk rating for cutting/mowing.

Cutting/Mowing has been deemed to be low-risk at level 2 and fairly accessible for users to control invasive *Phragmites* (Figure 11). This control method is easier to implement, compared to others discussed, and the tools required are accessible to those with minimal training. Cutting/mowing can be labor intensive, leading to the risk of repetitive strain or personal injury. However, if completed in a safe manner cutting/mowing is relatively low-risk in terms of the non-invasive environment, surrounding society, and for the users themselves.

4.4 Flooding

The control method of flooding is minimally discussed in peer-reviewed literature. Table 7 outlines the major themes associated to the main codes related to flooding in peer-reviewed literature. There is a lack of benefits, innovating, use-specification, treatment time, or location themes related to flooding. With the only major theme associated to this control method, being the challenge of no agreement on effectiveness. From best practice guides, only challenges were noted in Table 7. These challenges include the arguments that flooding is ineffective, in accessible, and time consuming.

Table 7: Description of overall themes related to the main codes related to the consensus regarding flooding from peer-reviewed literature and reviewed best practice guides.

Main Code	Theme for Peer-Reviewed Literature	Theme for Best Practice Guides
Benefits	N/A	N/A
Challenges	No agreement on effectiveness	Ineffective Inaccessible Time Consuming
Innovation	N/A	N/A
Use-Specification	N/A	N/A

Treatment Time	N/A	N/A
Location	N/A	N/A

Peer-Reviewed Literature

There are very minimal publications regarding flooding, with scholars being unable to agree on the effectiveness of the method. Higgisson et al. (2022) found that the sites that had been flooded had higher levels of invasive *Phragmites* than prior to control. Whereas Elsey-Quirk and Leck (2021) argue that a flooding treatment of at least 1 centimeter successfully reduce the ability of invasive *Phragmites* to germinate. Overall, through these publications it was unclear how effective the control method of flooding was, with one scholarly article arguing it can be successful, with the other finding it unsuccessful.

Reviewed Best Practice Guides

Flooding is minimally discussed within the reviewed best practice guides. The main codes associated to flooding are focused on the challenges, with no discovered themes related to the benefits, innovation, use-specification, treatment time, or location. The main themes related to the challenges from the reviewed best practice guides are the idea that flooding may be ineffective as a stand-alone method, inaccessible to most users, and it can be time consuming.

It has been discovered that flooding may be an ineffective control method if employed alone. Most best practice guides suggest coupling flooding with some sort of cutting/mowing strategy (Gilbert and Vidler, 2013 & Nichols, 2020). In addition to being ineffective alone, best practice guides agree that flooding is not a possible control method for all land types. Interested users should consult with their local environmental authorities before attempting (Nichols, 2020). As flooding is not appropriate for all land types, it is inaccessible to many users. A final challenge of flooding is the time-consuming nature of this control method. When choosing to flood an area of land, water levels must be maintained for an extended period of time. With some best practice guides arguing the water level must be maintained for at least 6 weeks (Gilbert and Vidler, 2013 & Ontario Ministry of Natural Resources, 2011). The water level required to be maintained is extensive as well. With Nichols (2020) stating the water level must be greater than 30 centimeters, but the Ontario Ministry of Natural Resources (2011) and Gilbert and Vidler (2013) arguing it must be above 1.5 meters. Due to the requirement of close monitoring during the flooding season to maintain the correct level of water, this control method can be incredibly time consuming and may not be possible for private landowners to effectively complete. Overall, the challenges associated with flooding are the argument that this method is ineffective if employed alone, coupled with the inaccessible and time-consuming nature.

Private Landowner Information

Flooding falls within the lower-right quadrant of Figure 5, with the level of agreement between peer-reviewed literature and reviewed best practice guides being some, with the risk rating being moderately high at 4/5. Within both peer-reviewed literature and the analyzed best practice

guides, there was no mention of control method related to flooding specific to private landowners.

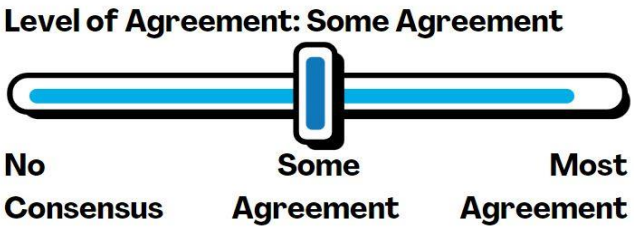

Figure 12: Level of agreement for flooding.

Within the peer-reviewed and practical literature, flooding had limited publications. However, the content within the analyzed publications has some consensus on effectiveness (Figure 12). Overall, through the peer-reviewed literature there is little agreement on effectiveness, but reviewed best practice guide documents have deemed this control method to be ineffective, inaccessible and time consuming. Between the two sectors, peer-reviewed literature stated that flooding treatments can be effective with only 1cm of flooding, whereas practical literature believes it must be 1.5m taller than the stands and maintained for at least 6 weeks (Elsey-Quirk and Leck, 2021 & Ontario Ministry of Natural Resources, 2011). Therefore, between the sectors there is no use-specification agreements. The best practice guides deem flooding to be ineffective and time consuming, as maintaining proper water levels for at least 6 weeks requires constant monitoring, coupled with the fact that not all sites can be safely or adequately flooded. Overall, there is consensus between the peer-reviewed literature and best practice guides that this method may be ineffective, however there is little agreement beyond that.

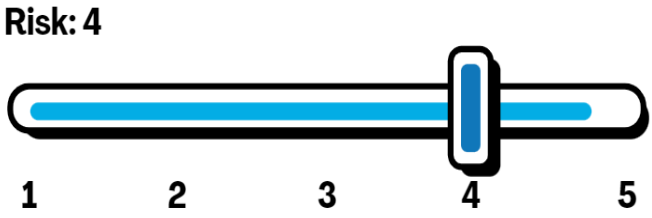

Figure 13: Level of risk rating for flooding.

Flooding has been deemed a relatively high-risk method for controlling invasive *Phragmites* (Figure 13). This is mainly due to the potential implications or damage the water may do to the surrounding society and environment. If the flooded area was not managed correctly, the water could pose a threat to the stability of surrounding homes or infrastructure. In addition, if the flooded plot was not effectively managed the flooding may do damage to surrounding non-invasive vegetation, or damage habitats of wildlife. It is important to check with local authorities

to learn about water level management and deem if a site may be most appropriate or safe for flooding (Nichols, 2020).

4.5 Grazing

Grazing is heavily discussed within peer-reviewed literature, with scholars discovering mixed results. Notable themes regarding benefits and challenges from peer-reviewed literature are evident in Table 8, with a lack regarding innovation, use-specification, treatment time, and location. The peer-reviewed literature has agreed that a significant benefit of grazing is the successful nature of the method, followed by the benefits grazing has for the surrounding environment. In terms of challenges, long-term grazing can have implications on the animals, coupled with the non-selective nature of the method. From best practice guides, only challenges were noted in Table 8. These challenges include the belief that grazing is impractical, high cost, and high risk.

Table 8: Description of overall themes related to the main codes related to the consensus regarding grazing from peer-reviewed literature and reviewed best practice guides.

Main Code	Theme for Peer-Reviewed Literature	Theme for Best Practice Guides
Benefits	Successful Beneficial to Environment	N/A
Challenges	Implications on Animals Not-Selective	Impractical High Cost High Risk
Innovation	N/A	N/A
Use-Specification	N/A	N/A
Treatment Time	N/A	N/A
Location	N/A	N/A

Peer-Reviewed Literature

Peer-reviewed literature has discovered that a benefit of grazing is the successful nature of the control method against invasive *Phragmites*. It was found that the growth of invasive *Phragmites* was lowered by 50%, with the stem height also falling by 60% over three periods of 1-month deployments (Silliman et al., 2014). During a more long-term study, completed over 3-years by Volesky et al. (2016), the stem height of invasive Phragmites was reduced by 33% and density by 38%. Hazelton et al. (2014) also notes that grazing is successful in reducing the height, biomass, and density of invasive *Phragmites*. However, the success of grazing is not only due to the consumption of invasive *Phragmites*, but also from the trampling of the ground. Therefore, grazing is considered successful since the reed cover of invasive *Phragmites* is kept low long-term due to both trampling and grazing (Mester et al., 2015).

Another benefit of grazing noted from the peer-reviewed literature is the welfare of the surrounding environment. It has been noted that the control method of grazing is beneficial to the surrounding habitat and species diversity (Hazelton et al., 2014). This is due to the discovery of a

direct link between the act of grazing and amphibian species richness (Mester et al., 2015). In addition to the understanding that as grazing successfully reduces the growth and presence of invasive *Phragmites*, other native plants are then able to grow in their place (Silliman et al., 2014). Overall, a noted major benefit of grazing is the welfare for the surrounding environment, as this method allows for increased species density, diversity, and richness.

The peer-reviewed literature has also noted significant challenges for grazing, including the fact that this method can have implications against the animals as well as it being non-selective. This comes from the fact noted by Volesky et al. (2016) that long-term grazing of the same plant of invasive *Phragmites* would not be nutritional for the animals. The grazing of only invasive *Phragmites* may lead to health challenges, which would be unethical for the livelihood of the animals, while also being costly to maintain their health (Volesky et al., 2016).

Another major challenge of grazing is the non-selective nature of the animals. Many peer-reviewed studies were completed on plots of land where only invasive *Phragmites* were present, leading to a non-selective study. However, when the selective option was given, Hazelton et al. (2014) found that if given the choice between invasive *Phragmites* or other plants, the grazing animals of goats would choose to consume any other option before irradicating the invasive plant. This may mean that the grazing animal could consume native beneficial plants, leaving the invasive plant of invasive *Phragmites* to flourish. Overall, the peer-reviewed literature found both benefits and challenges to the control method of grazing. Major benefits of grazing include the fact that it has been successful and can be beneficial to the biodiversity of the surrounding environment. Major challenges noted from the peer-reviewed literature include the long-term detriment to the animals, as well as the non-selective nature of grazing.

Reviewed Best Practice Guides

Grazing is minimally discussed within Ontario best practice guides. The analyzed best practice guides have noted significant themes associated with challenges. The themes of grazing can be seen in Table 8, with no significant information noted for benefits, innovation, use-specification, treatment time, or location. The themes noted for challenges include the belief that grazing is impractical, high cost, and high risk.

The reviewed best practice guides in Ontario believe the control method of grazing is impractical. This belief is noted as not all treatment sites are suitable for grazing (Nichols, 2020). The most effective management sites for grazing are believed to be upland, degraded, or developed areas, meaning for all other areas it would be deemed ineffective (Gilbert and Vidler, 2013). Another challenge theme noted for grazing is the high-cost nature. It is noted that obtaining the animals for grazing and the long-term commitment to their care would be expensive (Nichols, 2020). In addition, a high number of livestock is required to consume a dense cell of invasive *Phragmites*, meaning dependent on the size of the management site the costs associated would multiply (Gilbert and Vidler, 2013).

The final challenge associated with grazing is the high-risk nature of the control method. There is a high chance of non-selective grazing within the management site, meaning the livestock would

consume more plant species than the intended invasive *Phragmites* (Gilbert and Vidler, 2013). The chance of non-selective grazing is high risk for the continued health and biodiversity of the ecosystem. Grazing is also noted to be a high-risk control method as releasing the animals at the wrong time of year could stimulate the growth of invasive *Phragmites*, however, the correct time of year to complete this method was not noted (Nichols, 2020). Finally, grazing is a high-risk control method as there is significant potential of trampling and soil erosion from the animals (Gilbert and Vidler, 2013). Overall, Ontario best practice guides have noted multiple challenges related to the control method of grazing, including the belief that it is impractical, high-cost and high-risk.

Private Landowner Information

In Figure 5 grazing falls within the middle of the risk rating system, at the bottom of the matrix due to the lack of consensus between peer-reviewed literature and Ontario best practice guides, with an average risk rating of 3/5. Within both peer-reviewed literature and the analyzed best practice guides, there was no mention of control methods related to grazing specific to private landowners.

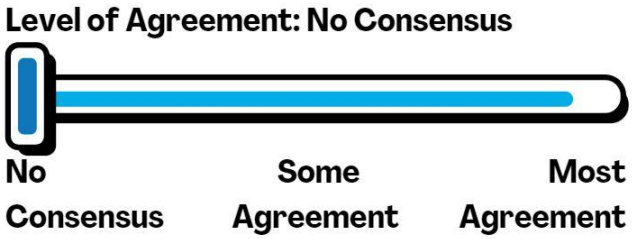

Figure 14: Level of agreement for grazing.

The control method of grazing sees little agreement between peer-reviewed literature and Ontario best practice guides (Figure 14). The overall consensus within peer-reviewed literature deems grazing to be a successful and beneficial method, with some downfalls. Whereas, the best practice guides deem grazing to be impractical, high-cost, and high-risk. Within the peer-reviewed literature it is believed grazing is a successful control method, where goat grazing can successfully limit the density, biomass, and height, with one study finding invasive *Phragmites* growth was reduced by 50% and stem height by 60% (Hazelton et al., 2014 & Silliman et al., 2014). It is also argued that grazing is beneficial to the overarching environment, as the trampling from livestock increased the surrounding species diversity and amphibian species richness (Mester et al., 2015). However, it is important to note that the majority of peer-reviewed studies conducted experiments where invasive *Phragmites* where the only choice plant to consume, meaning the consumption of other native or beneficial plants is possible within a typical private landowner landscape. The only downfall peer-reviewed literature and best practice guides agree on is the long-term challenges related to the grazing animals. The long-term grazing on invasive *Phragmites* may not be beneficial to the livestock and the care for them, coupled with the high number of animals required to be effective can be costly (Gilbert and Vidler, 2013 & Nichols, 2020 & Volesky et al., 2016). The best practice guides find that

grazing is mainly impractical, as many sites are not suitable for this control method. Gilbert and Vidler (2013) note that the only sites suitable for grazing of invasive *Phragmites* are to be upland, degraded, or developed areas. The reviewed best practice guides view grazing as risky, as majority of the time there is a very high chance of non-select grazing, meaning the consumption of beneficial plants, coupled with trampling and soil erosion, leading to the degradation of landscapes (Gilbert and Vidler, 2013). Finally, grazing is deemed to be risky if facilitated at the wrong time of year it can stimulate *Phragmites* growth, however, the correct time of year to complete grazing was not outlined in practical documents. Overall, there is no consensus between the peer-reviewed literature and the Ontario best practice guides. It seems the peer-reviewed literature analyzes grazing through a specific scope, as the completed studies were completed on ideal management sites, with a high number of livestock, and only on sites that only had invasive *Phragmites* to consume. The Ontario best practice guides analyze the efficacy of grazing through a lens that understands all sites are not ideal, animals can be costly, and it is unlikely will only have the choice to consume invasive *Phragmites*. Therefore, while there is no consensus between the literature, the peer-reviewed scholars do not seem to be analyzing this method through a practical lens.

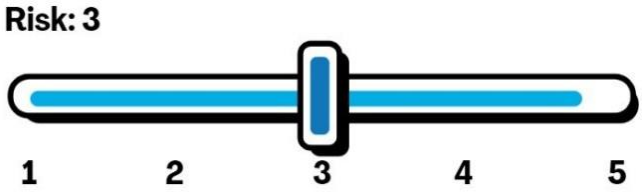

Figure 15: Level of risk rating for grazing.

Grazing has a moderate risk level of 3/5 (Figure 15). While the level of risk has previously been measured based on potential for harm against the user, the natural environment, and society; this method also must determine the threat towards livestock. This control method poses some threat to the surrounding environment, as the livestock can lead to trampling and soil erosion of the grazed area (Gilbert and Vidler, 2013). In addition, there is a chance for livestock to graze on non-invasive plants, causing damage to the surrounding environment (Gilbert and Vidler, 2013). The constant consumption of invasive *Phragmites* may lead to long-term challenges for the livestock, as it would not be nutritious and could cause health problems (Volesky et al., 2016). Overall, grazing does not pose a threat to the user or surrounding society, but can damage the natural environment and cause health issues for the livestock. These conditions must be taken into account if choosing to employ the control method of grazing against invasive *Phragmites*.

4.6 Plastics

From Table 9, the major themes regarding the control method of plastics from both the peer-reviewed literature and Ontario best practice guides. While being rarely discussed within peer-reviewed literature, no themes were able to be draw. However, the control method of plastics is regularly discussed within Ontario best practice guides. Table 9 outlines major themes from the deductive codebook, focusing on challenges. No significant themes were noted for benefits,

innovation, use-specification, treatment time, or location. The themes recorded for challenges are the belief that plastics is laborious and time consuming for users.

Table 9: Description of overall themes related to the main codes related to the consensus regarding plastics from peer-reviewed literature and reviewed best practice guides.

Main Code	Theme for Peer-Reviewed Literature	Theme for Best Practice Guides
Benefits	N/A	N/A
Challenges	N/A	Laborious Time Consuming
Innovation	N/A	N/A
Use-Specification	N/A	N/A
Treatment Time	N/A	N/A
Location	N/A	N/A

Peer-Reviewed Literature

The use of plastics as a method within peer-reviewed literature is rarely discussed. Due to the lack of literature focusing on the efficacy of plastics against invasive *Phragmites* it was not possible to create themes from the main codes. However, from the peer-reviewed literature that discussed plastics, the study was ended early due to the return of invasive *Phragmites* (Rohal et al., 2019). Therefore, the treatment of invasive *Phragmites* using plastics was considered to be a failure.

Reviewed Best Practice Guides

A main challenge of plastics is the argument that this method is labour intensive. Best practice guides have argued due to the reed stalks having to be cut first to successfully install the tarp, this control method is labour intensive (Gilbert and Vidler, 2013). In addition, as the reed stems grow along the sides of the tarp they must quickly be cut (Nichols, 2020). Due to the constant need to cut the reed stems this method has been deemed labour intensive. Plastics has also been noted to be time consuming. This method requires constant monitoring after the initial installation of the tarp for up to 6 months while it is in place (Ontario Ministry of Natural Resources, 2011). The need for long-term monitoring can be time consuming, and if the growth of invasive *Phragmites* is missed, the control using plastics would be null. Overall, the Ontario best practice guides have found that the major challenges surrounding the control method of plastics are the laborious nature of it as well as being time consuming.

Private Landowner Information

Plastics is in the lower-left hand quadrant of the matrix in Figure 5. This is due to the fact that there is no consensus between peer-reviewed literature and Ontario best practice guides, but the control method has a relatively low risk of 2/5. Within both peer-reviewed literature and the analyzed best practice guides, there was no mention of control methods related to plastics specific to private landowners.

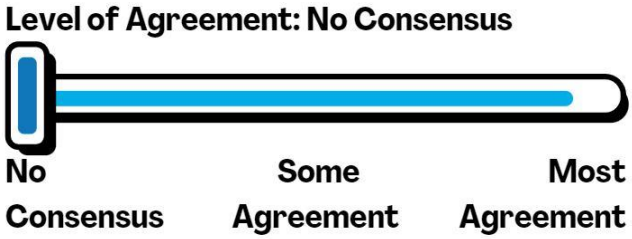

Figure 16: Level of agreement for plastics.

The control method of plastics does not see agreement between peer-reviewed and practical literature (Figure 16). This is due to being underrepresented in peer-reviewed literature, with too few publications to draw conclusions regarding the efficacy of the method. Within the best practice guides, the control method of plastics has not been recommended while being deemed laborious and time consuming. For the process to be successful, all invasive *Phragmites* stalks must be cut first, leading to this method becoming labor intensive. Following the cutting, a tarp is laid over the stalks for at least six months, with the need for constant monitoring to ensure growth is not spreading from under, leading to this method being time consuming (Nichols, 2020). Above all, the Ontario Ministry of Natural Resources (2011) notes that this method will affect native vegetation, leading to it not being recommended for the overall health and biodiversity of ecosystems. From the singular piece of literature outlining the method of plastics from peer-reviewed literature the study ended early due to the return of invasive *Phragmites* in study plots, therefore being deemed non-effective. Overall, there is a lack of consensus between the two sectors, due to limited resources being published within peer-reviewed literature. However, from the accessed literature, this method is not recommended.

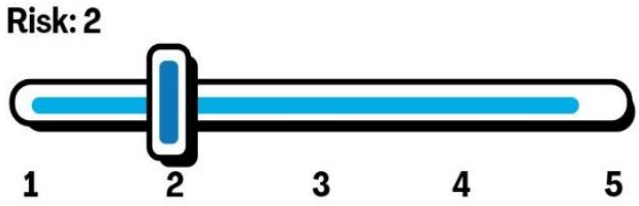

Figure 17: Level of risk rating for plastics.

Plastics has a relatively low risk level of 2/5 (figure 17). This method requires little technical training, and limited use of tools, leading to low risk to the users. In addition, this control method produces little risk to surrounding infrastructure or society. However, the use of plastics for controlling invasive *Phragmites* has been shown to negatively affect native vegetation, leading to risk against the surrounding environment. Overall, the risk against the natural environment must be taken into account if choosing to employ this control method.

4.7 Biological Control

Biological Control is heavily discussed within the peer-reviewed literature. In addition to being controversial and highly debated, the major themes deducted from this control method can be seen in Table 10. No major themes were discovered for benefits, innovation, use-specification,

treatment time, or location. Only themes related to challenges were deducted, with scholars believing biological control can be harmful to native *Phragmites* and it is not suitable long-term. In addition, through the analysis of the peer-reviewed literature, the inability to agree on the cost of biological control was discovered, leading to a significant challenge. However, it was not possible to draw major themes regarding biological control from Ontario best practice guides.

Table 10: Description of overall themes related to the main codes related to the consensus regarding biological control from peer-reviewed literature and reviewed best practice guides.

Main Code	Theme for Peer-Reviewed Literature	Theme for Best Practice Guides
Benefits	N/A	N/A
Challenges	Harmful to native *Phragmites* Not Suitable Long-Term No Agreement on Cost	N/A
Innovation	N/A	N/A
Use-Specification	N/A	N/A
Treatment Time	N/A	N/A
Location	N/A	N/A

Peer-Reviewed Literature

Many scholars believe the introduction of biological control methods can be harmful to the surrounding environment, due to the high chance that the introduced species will inadvertently damage native *Phragmites*, instead of the intended invasive lineage (Kiviat et al., 2019). The concern for the environment is supported by an argument from Tewksberry et al. (2002) cited in Cronin et al. (2016), stating that of the 21 herbivores that had previously been introduced into North America, all now feed on native *Phragmites*. Cronin et al. (2016) go as far to state that biological control may lead to the complete extinction of native *Phragmites* in North America, as there has not previously been a successful case of biological control at the subspecies level. This argument is supported by Kiviat et al. (2019) whom believed it is difficult to find host-specific biological control at the subspecies level, meaning the introduced herbivores would inadvertently damage native *Phragmites*. Overall, most scholars argued the introduction of herbivores for the biological control of invasive *Phragmites* would lead to a high chance of harming or irradicating the native lineages.

Another major challenge of biological control is the belief that it would not be suitable for long-term management of invasive *Phragmites.* It is believed that the degree of impact had by the introduced herbivores is not high enough (Hazelton et al., 2014). This is due to the fact that the larvae will only feed on invasive *Phragmites* for short periods of time, not surviving for more than 2 weeks in tests completed by Blossey et al. (2018). Therefore, the success of introduced biological control agents is difficult to sustain long-term (Silliman et al., 2014).

The final challenge of biological control is the lack of agreement between scholars regarding cost. Hazelton et al. (2014) believe biological control is a low-cost management alternative

compared to other strategies, whereas Silliman et al. (2014) argue it is costly to implement. The lack of consensus regarding costs acts as a major challenge for biological control as it causes the efficacy of implementation to be brought into question. A high-cost and controversial management strategy would likely not be one user implement. With little information regarding the cost of biological control it leaves a significant gap in the peer reviewed literature and acts as a challenge against this control method.

Reviewed Best Practice Guides

The discussion of biological control methods is virtually non-existent within Ontario best practice guides. This is due to the fact that biological control is not currently approved to be implemented by users or land managers in the province.

Private Landowner Information

Biological control is found in the lower-right quadrant of Figure 5, with no consensus between peer-reviewed literature and reviewed best practice guides, coupled with a determined high-risk factor of 5/5. Within both peer-reviewed literature and the analyzed best practice guides, there was no mention of control methods related to biological control specific to private landowners.

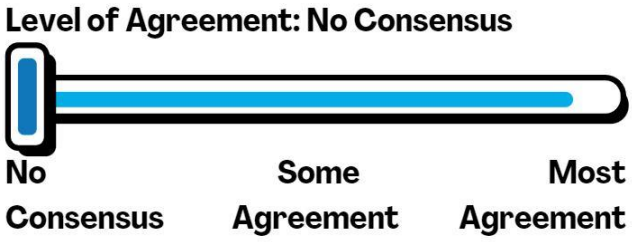

Figure 18: Level of agreement for biological control.

The discussion of biological control was virtually non-existent within the Ontario best practice guides, leading to their being no consensus between the two analyzed sectors (Figure 18). Within peer-reviewed literature, researchers believe this control method is controversial and have very little agreement surrounding effectiveness and potential consequences. Some researchers argue that biological control may be harmful to the native environment and not suitable long-term, due to the difficult nature of implementing biological control at the host-specific species level (Kiviat et al., 2019). In addition, it is believed that biological control will negatively affect native *Phragmites* due to the potential for the agents to attack the wrong plant. Cronin et al. (2016) go as far as to say that biological control may lead to the extinction of native *Phragmites*. Overall, this control method has little to no consensus due to the lack of acknowledgement within Ontario best practice guides, however, it is not recommended for use in the peer-reviewed literature due to its controversial nature.

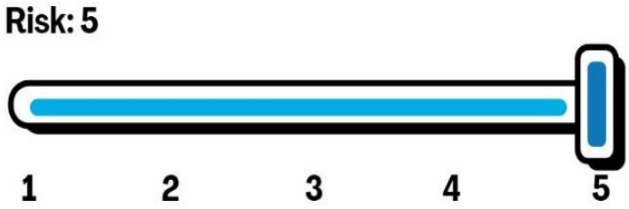

Figure 19: Level of risk rating for biological control.

Biological control has been deemed a risk level of 5/5 due to its controversial nature and ability to impact the surrounding natural environment (Figure 19). Implementing this control method would require an expert understanding surrounding the European noctuid moths. The expert nature of this control method leads to an increased risk level, as there is a high potential for negative consequences to occur. Biological control also brings forth significant risk to the surrounding environment, as researchers note there is a high likelihood that native *Phragmites* will also be fed on by these introduced species. Cronin et al. (2016) noted, from Tewksberry et al. (2002) that of the 21 herbivores that have previously been introduced in North America, all now feed on native *Phragmites*. Due to the high likeliness that the introduce herbivores would damage the overall biodiversity of the surrounding environment, the level of risk is high. Overall, the risk associated with the surrounding environment, and the expert knowledge required to implement this control method, a risk level of 5/5 must be taken into account.

4.8 Cultural Practices

Table 11 outlines major themes regarding cultural practices from both the peer-reviewed literature and analyzed Ontario best practice guides. It was impossible to draw major themes from the peer-reviewed literature, with only the recognition of innovation being discovered from the best practice guides.

Table 11: Description of overall themes related to the main codes related to the consensus regarding cultural practices from peer-reviewed literature and reviewed best practice guides.

Main Code	Theme for Peer-Reviewed Literature	Theme for Best Practice Guides
Benefits	N/A	N/A
Challenges	N/A	N/A
Innovation	N/A	Yes
Use-Specification	N/A	N/A
Treatment Time	N/A	N/A
Location	N/A	N/A

Peer-Reviewed Literature

Cultural practices are not discussed within peer-reviewed literature; therefore, no significant themes can be applied from Table 11.

Reviewed Best Practice Guides

Nichols (2020) is the only Ontario best practice guide to discuss cultural practices. While no significant themes from Table 11 can be noted regarding benefits, challenges, use-specification, treatment time, or location, the significance of innovation is present. The concept of cultural practices is basic, as it works from an offensive standpoint rather than a defensive. However, there is only one document to mention the planting of native vegetation to provide resistance against the growth of invasive *Phragmites* (Nichols, 2020). Therefore, the theme of innovation is present within cultural practices.

Private Landowner Information

Cultural practices are located in the lower-left quadrant of Figure 5, due to the lack of consensus between peer-reviewed literature and Ontario best practice guides, coupled with a low-risk rating of 1/5. Within both peer-reviewed literature and the analyzed best practice guides, there was no mention of control methods related to cultural practices specific to private landowners.

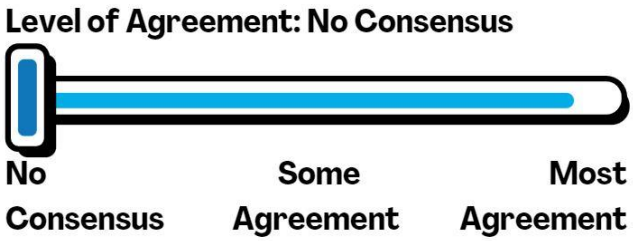

Figure 20: Level of agreement for cultural practices.

Cultural Practices is not a control method mentioned in peer-reviewed literature, and has only been discussed in one best practice guide, written by Nichols (2020), leading to a level of agreement of no consensus (Figure 20). The implementation of cultural practices, mentioned by Nichols (2020) is easily accessible, as it is the replanting of native vegetation. While this is not necessarily an offensive control method, meaning it will not attack invasive *Phragmites*; the replanting of native vegetation would act as a defense, requiring less time be needed for other strategies. This has been deemed as a successful precautionary measure (Nichols, 2020). The purchasing of native plant seeds is relatively simple and accessible for private landowners, however, certain knowledge regarding botany would be required to understand which plants are best in varying locations (Nichols, 2020). Overall, the implementation of cultural practices would be beneficial for the surrounding biodiversity, is relatively accessible, and would provide resistance against unwanted plants long-term.

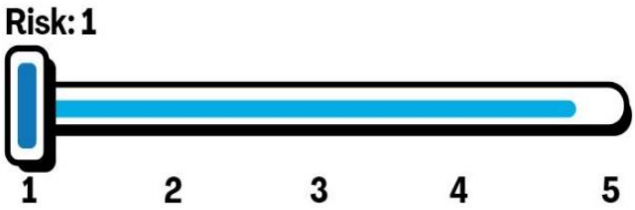

Figure 21: Level of risk rating for cultural practices.

Cultural Practices has been deemed a risk of 1/5 (Figure 21). Cultural Practices has been given a low-level risk rating due to the limited potential for there to be harm against the user, against society, or against the surrounding environment. As this is employed as a precautionary measure, there is limited negative effects that may occur against society or the surrounding environment. In addition, as this control method requires little expert knowledge or tools, there is little risk against the user. However, the low risk level is reflected in the fact that this is a precautionary method and would likely require other control strategies to be implemented to manage an already established invasive *Phragmites* infestation. Overall, the risk associated with cultural practices should be taken into account before implementation.

4.9 Discussion

This study worked to achieve three main objectives. The first objective was to understand what invasive *Phragmites* control methods have been implemented and studied within peer-reviewed literature. It was found that, within the last 10 years, peer-reviewed literature has thoroughly analyzed herbicide application, biological control, and grazing. With a moderate level of studies analyzing cutting/mowing. There is minimal research published within the last 10 years analyzing burning, flooding, or plastics. Peer-reviewed literature failed to discuss cultural practices which were analyzed within Ontario best practice guides.

The second objective of this study was to understand control methods that have been implemented in Ontario through the analysis of best practice guides, published within the last 10 years. Ontario best practice guides have thoroughly discussed herbicide application and cutting/mowing, with moderate discussion of plastics, grazing, burning, and flooding. Ontario best practice guides minimally discussed cultural practices, while failing to discuss biological control as it is not an approved method to be employed in Ontario. It was interesting to note that the majority of analyzed best practice guides from Ontario were not targeted to specific groups. The larger influential guides published by the Ontario Ministry of Natural Resources (2011) and Nichols (2020) were broad for the province of Ontario. With only smaller best practice guides, such as the Ausable Bayfield Conservation et al. (2015) the Ontario *Phragmites* Working Group (2015), and Gilbert and Vidler (2013) being targeted towards specific areas or groups of people. The best practice guide published by Ausable Bayfield Conservation et al. (2015) was targeted towards agricultural and rural areas, with the Ontario *Phragmites* Working Group (2015) being shared for invasive *Phragmites* control along roadways. Finally, Gilbert and Vidler (2013) are a published management plan targeted towards the municipality of Lambton Shores. While it is most common for the best practice guides published by smaller organizations to target groups,

none mentioned private landowners. However, Ausable Bayfield Conservation et al. (2015) targeted a group that may overlap private landowners, which are agricultural and rural areas.

The third objective of this study was to compare the findings from the peer-reviewed literature against the Ontario best practice guides to formulate a full understanding of the best possible invasive *Phragmites* management strategies, noted within the private landowner's information section. This understanding may be communicated to private landowners through the production of an infographic (Appendix A). The practical implication of the production of an infographic is to educate a new group of users, who have likely had no previous education or training regarding invasive *Phragmites* management. This then provided a new insight into the state of invasive *Phragmites* management in the Niagara region, while lending itself to the improvement of biodiversity in the region through successful eradication.

As Rohal et al. (2018) noted a current lack of collaboration between the scholarly sector and practical land managers, the comparison of publications from these two industries also allowed for patterns and relationships regarding their overlap or separation to be discovered. Through the comparison of the peer-reviewed literature and Ontario best practice guides, some unexpected results have been noted. It was unexpectedly found that a lack of agreement between the two sectors of peer-reviewed literature and practical best practice guides is typically from an absence of discussion, as opposed to differing opinions. This is evident through the discussion of biological control, which can be seen in Figure 5 as having no consensus between the two sectors. Biological control was deemed to have no consensus as it is significantly discussed within peer-reviewed literature, but no comment has been made regarding the efficacy in best practice guides as it is not approved for use in Ontario. The same comment can be made for cultural practices, as the efficacy of this strategy was only recognized in best practice guides.

However, a lack of agreement is typically due to an absence of discussion, it is interesting to see the level of agreement between the two sectors of scholarly research and practical best practice guides. As Rohal et al. (2018) highlights a significant knowing-doing gap between the two sectors, they tend to come to similar conclusions. It is important to note the agreement between the two sectors, as this only strengthens the arguments for or against certain invasive *Phragmites* control methods. The parallel agreement between peer-reviewed literature and Ontario best practice guides is evident when discussing herbicide application, as both sectors avidly agree it is an effective control option.

The content presented by the two sectors of scholarly work and practical best practice guides was also found to vary. It was evident that Ontario best practice guides were developed with the thought of practicality in mind, in terms of implementing control methods. With peer-reviewed literature, comments were made on the effectiveness of control methods, however, it was common for multiple parameters of the study to be controlled, not giving a full picture as to the efficacy of the strategy. For example, within the discussion of grazing, peer-reviewed literature found this method to be effective, as many studies were completed as no-choice assessments. Meaning the grazing animals did not have a choice between plants to consume, but rather could only eat invasive *Phragmites*, making the control of the plant successful. Whereas, in Ontario

best practice guides, it was highlighted that this method may not be practical, due to its limitations. The variability in content presented within peer-reviewed literature versus Ontario best practice guides agrees with Rohal et al. (2018) who highlighted that land managers decisions were typically guided by budgetary limitations, rather than environmental impact or effectiveness; meaning the priorities between the two analyzed sectors are overall different.

While this study worked to educate an underrepresented group of private landowners on the best management practices for invasive *Phragmites,* certain limitations are present within this study. There was found to be a lack of data or research on certain control methods, not allowing for secondary themes from the coding process to be produced. The lack of data on invasive *Phragmites* control methods does not paint a full picture on the real-world implications of these strategies. Therefore, within the peer-reviewed literature, for specific methods such as flooding, plastics, or burning further research regarding the benefits, challenges, and long-term impacts is needed. Within the best practice guides, a further discussion surrounding biological control, grazing, and cultural practices is required to give the most information possible to the users. Another limitation of this study is present within the analyzed data. As many studies were completed in different climates, the recommendations could not all be suited to the weather of the Niagara region. For example, Fogli et al. (2014) recommended cutting/mowing to be completed in the winter months, which would not be possible in the Niagara climate. Therefore, it is suggested that further research be completed within Ontario to fully understand the scientific outcomes of invasive *Phragmites* control methods. The design of this study may have had certain limitations for the results. As this study did not typically analyze literature or guides published more than 10 years ago, it is possible to have overlooked strong background research regarding certain control methods, potentially limiting the conclusions that have been made.

While this study worked to suggest invasive *Phragmites* management strategies to private landowners in the Niagara region, a comment was also made on the level of association between peer-reviewed literature and practical Ontario best practice guides. Now that the level of collaboration is understood, this study agrees with Rohal et al. (2018) that further research is needed to determine how the scholarly and practical sectors can form a stronger alignment. It is necessary that scholars begin to publish information that is accessible and relevant to land managers and vice versa. In addition, the findings of this study agree with Rohal et al. (2018) that scholarly research must begin to take into account the practical and economic implications of management actions. As this study found peer-reviewed literature lacked a connection to the real-world implications of invasive *Phragmites* control methods, further research is required connecting their work to the practical implementation of management strategies. Finally, as this study was able to tailor information towards private landowners in the Niagara region, it is suggested that practical organizations begin to target underrepresented groups within their management strategies. For example, as some invasive *Phragmites* control methods cannot be completed over water, it would be beneficial to target a guide towards those with water features on their property, or companies with private beaches on their land. The tailoring of information to underrepresented groups would not be difficult to produce and would take significant guess-work out of such important control methods.

5.0 Conclusion

This research worked to fulfill three core objectives. The first focused on understanding what invasive *Phragmites* control methods have been studied within peer-reviewed literature. The second reviewed what invasive *Phragmites* control methods have been suggested for use in Ontario through best practice guides. The third and final objective developed an understanding of the best possible control methods for private landowners in the Niagara region by comparing the two sectors of peer-reviewed literature and best practice guides. This understanding of control methods was then mobilized through the production of an infographic (Appendix A) to potentially be shared with the goal to educate private landowners. Some major findings associated with achieving the third objective were that both herbicide application and burning had the most agreement between peer-reviewed literature and best practice guides, while also having high risk ratings of four and five. It was also found that cultural practices, plastics, grazing, and biological control had no consensus between peer-reviewed literature and best practice guides. However, the majority of control methods that were found to have no consensus, also had low to relatively low risk ratings of one, two, or three, with biological control being the only high rating of five. Through the achievement of the third objective, it was found that both peer-reviewed literature and Ontario best practice guides tended to agree on numerous benefits and challenges related to invasive *Phragmites* control methods. When disagreement occurred between sectors it was typically due to the lack of discussion surrounding a control method, rather than varying viewpoints or results. In addition, it was found that no available best practice guides currently target private landowners, presenting an opportunity for this infographic to educate an underrepresented group.

The need for invasive *Phragmites* control is evident in the Niagara region. With the Ministry of Transportation being called on to implement control measures, as well as the approval of multiple herbicide application projects by the Niagara Peninsula Conservation Authority (Niagara Peninsula Conservation Authority, 2016; Niagara Peninsula Conservation Authority, 2019). As strategies have been put in place to control invasive *Phragmites* in the Niagara region, physical documents tailored to the area of specific groups, such as private landowners or those with water features on their land are few and far between. As invasive *Phragmites* have previously been deemed Canada's worst invasive plant, while simultaneously threatening a quarter of species at risk in Ontario, the development of easily understood practice guides or infographics has never been greater (Nichols, 2020).

As invasive *Phragmites* have invaded North American ecosystems and almost completely replaced the native haplotype F *Phragmites,* it is vital to understand and implement effective control methods. The implementation of invasive *Phragmites* control methods will restore high levels of biodiversity in the Niagara region, while protecting animal and aquatic species habitats long-term. Further research is needed to understand control methods that have been minimally discussed, such as flooding, plastics or burning. In addition, it is suggested that future peer-reviewed research be more tailored to the needs of land managers, covering topics such as budget or feasibility. As there is significant need for greater control method implementation in the Niagara region, future research and implementation is required to aid in the long-term

sustainability of the area. It is hoped by communicating control method strategies to private landowners in the Niagara region, this underrepresented group will implement appropriate methods, contributing to an increase in biodiversity and overall ecological health.

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Appendix A: A Private Landowner's Guide to Invasive *Phragmites* Control

A PRIVATE LANDOWNER'S GUIDE TO INVASIVE PHRAGMITES CONTROL

Figure 1: Invasive *Phragmites* along a roadside.

WHAT ARE PHRAGMITES?

The *Phragmites australis* species is an invasive reed, that has been invading North American ecosystems for numerous decades. The invasion of this common reed causes a significant decline in the health of surrounding ecosystems, leading to the death of animals and aquatic species habitats. The invasive *Phragmites* plant has become a major concern in Canada, leading to the need for control.

ARE YOURS INVASIVE?

	Native	Invasive
Stand Height	> 2 meters	~ 5 meters
Leaf Color	Yellow/Green	Blue/Green
Seedhead Density	Small/Sparse	Large/Dense

Table 1: Native vs invasive *Phragmites* (Adapted from Ontario Ministry of Natural Resources, 2011).

Figure 2: Representation of the significant height of invasive *Phragmites* stands (Banda, 2019).

SUGGESTED CONTROL METHODS

	HERBICIDE APPLICATION	CUTTING/MOWING	CULTURAL PRACTICES
EFFICACY	HIGH - effective against invasive *Phragmites*	AVERAGE - repeat applications necessary	N/A - typically employed as an offensive measure
FOR USE BY	Those with appropriate extermination licenses or permissions	Those capable of long-term repetitive labour	Those with access to native seeds/seedlings
METHOD SPECIFICS	- Cannot be applied over water - Access http://pr-rp.pmra-arla.gc.ca for full information	- Stalks must be cut below the soil surface - Can be completed with minimal training	- Not to be used as a stand-alone method - Consult a botanist for appropriate native species planting

USEFUL RESOURCES

https://www.ontarioinvasiveplants.ca/wp-content/uploads/2021/05/OIPC_BMP_Phragmites_April302021_D10_WEB.pdf

https://www.ontarioinvasiveplants.ca/wp-content/uploads/2016/07/Phragmites_BMP_FINAL.pdf