BARRIERS WHICH PRECLUDE THE FORMATION OF STRONG, COMPREHENSIVE WILDFIRE MITIGATION PLANS AND STRATEGIES IN ONTARIO:

A KNOWLEDGE GAP ANALYSIS

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April 28th, 2023

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An Undergraduate Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Honours Bachelor of Science in Forestry

Faculty of Natural Resources Management

Lakehead University

April 30th, 2023

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ABSTRACT

Base, S.C. A. 2023. Barriers which preclude the formation of strong, comprehensive wildfire mitigation plans and strategies in Ontario: A knowledge gap analysis. [50] pp.

Keywords: Boreal, Canada, fuel management, fuel loading, wildfire mitigation, fuel reduction, forest thinning, prescribed burn, cultural burn, wildfire suppression, wildfire management, wildland-urban interface, fire break, firesmart, wildfire adaptation.

As occurrences of wildland-urban interface (WUI) wildfires become more frequent throughout Ontario, there has been an increasing need for mitigative approaches towards managing wildfire on landscapes, especially where human settlement has taken place. Since the provincial government and many communities based in Ontario's boreal forest have not yet implemented mitigative actions against wildfire risk, this study will explore which factors act as barriers to the formation of a comprehensive wildfire mitigation strategy in Ontario. This literature review will analyse factors such as gaps in knowledge in fuel management techniques, social barriers, economic barriers, and policy barriers, which prevent the formation of a wildfire mitigation program in Ontario. Findings from the literature review reveal that the following points act as the main factors which prevent the formation of effective mitigation strategies in Ontario: (1) there is a distinct lack in research regarding fire behaviour in fuel treatments specific to Ontario's forest types; (2) current forest management policies in Ontario are not conductive to wildfire mitigation; (3) there is an absence of funding and workforce for mitigation planning and implementation; and (4) there is a general lack in social and political understanding and support for community wildfire resiliency projects.

ACKNOWLEDGEMENTS

The following are acknowledgements of all individuals involved in providing me with guidance and advice through the development this thesis. The passion, dedication and support I have received by those who have advised me cannot go unnoticed.

Thank you to the following individuals:

Ana Gonzalez, my Fiancé

Dr. Wang, Professor, Lakehead University

Dr. Amishev, Assistant Professor, Lakehead University

Dan Johnston, Forest Fire Management Program Development Coordinator, OMNRF

Chelsea Osesky, Mitigation and Partnerships Lead, OMNRF

Ian Staley, Prescribed Fire and Fire Behaviour Specialist, OMNRF

Shayne McCool, Fire Advisor, OMNRF

Matt Corbett, Prescribed Burning Specialist, OMNRF

Thomas LePine, Incident Commander, Parks Canada

Table of Contents

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION & OBJECTIVES

Throughout Canada, over the twenty years, the frequency and intensity of wildfires on the landscape has increased (Coogan et al., 2021), straining the ability for wildfire management organizations to effectively respond to critical wildfires, especially when they occur in proximity to human infrastructure (OMNRF, 2017). The increased fuel loading due to the historical suppression of wildfires on the landscape, in combination with a warming climate are both noted factors which are responsible for this increase and intensification (Coogan et al., 2021). In addition to these inputs, the continued growth of the Wildland-Urban Interface (WUI) has, in part led to the increase in evacuations performed on communities threatened by wildfires (Johnston & Flannigan, 2018). The number of evacuations caused by wildfires increased by about 1.5 evacuations per year between 1980 and 2014, with more than 20 evacuations per year after 2010 (Bénichou, et al., 2021). For context, the WUI is the zone where human developments transfers into undeveloped wildland areas, therefore interface fires are wildland fires which have the potential to involve human infrastructure and forest fuel vegetation simultaneously (BC Wildfire Service, n.d.). With this, it is also observed that indigenous communities throughout Canada are disproportionally affected by wildland interface fires (McGee et al., 2021, pp. 2), in part due to their placement in the Boreal forest, which is a pyrogenic ecosystem, of which fire is a natural part of its regenerative cycle.

As a result, many provinces have begun to adopt mitigation strategies and efforts to reduce the risk of these fires, which are particularly challenging for emergency personnel to respond to (Tymstra et al., 2020). It is now understood that response and suppression of wildfire must also be accompanied by proactive wildfire management, which involves mitigative fuel treatment techniques to better protect human infrastructure (Tymstra et al., 2020). Although research and case studies has been published regarding the understanding of fire behaviour in modified fuel structures, there is however, still a distinct lack in data and research which is preventing government agencies from developing comprehensive mitigation programs and decision support tools based on forest fuel conditions and vulnerability to fire. This study therefore aims to analyse and identify gaps in knowledge and barriers which prevent the government of Ontario from developing prescriptive systems that allow for the implementation of wildfire mitigation strategies within its forest types.

More specifically, this study will focus on the barriers which the Aviation Forest Fire & Emergency Services (AFFES), faces regarding the development of comprehensive mitigation strategies. As of yet, the province of Ontario's management of wildfire on the landscape is still rooted in a responsive approach rather than a mitigative one (OMNRF, 2017), and in order for the AFFES to develop a comprehensive wildfire mitigation strategy, it must first base the program development on concrete research, data and case studies. Strategies have been outlined (D. Johnston et al., 2022), however, more specific studies relating to fuel management and fire behaviour must be conducted to implement the most effective mitigation strategies based on forest conditions and community needs.

To provide context, throughout the course of this thesis, the terms m*itigation* and s*trategy* will often be used to describe commonly referenced concepts. As such, when the term mitigation is used, it refers to measures taken on the local and landscape-levels to lower the risk of wildfire impacts within the WUI. Other mitigation measures not covered in this research involve structural mitigation measures, which incorporates the use of non-flammable building materials and sprinkler systems in the construction of human infrastructures. The term strategy encompasses the collective approaches taken to achieve wildfire management and mitigation objectives.

1.1 OBJECTIVES

There is a distinct need to transition from a purely responsive approach to wildfire on the landscape, to one that is more proactive, the government of Ontario has begun to explore mitigation strategies which can be utilized to prevent or mitigate future risk to human life and loss of infrastructure (OMNRF, 2017). The objective of this research is therefore to perform a knowledge gap analyse to determine barriers which preclude the formation of strong, comprehensive wildfire mitigation plans and strategies in Ontario. As a result of this research, the findings will help inform decision makers on the next steps required for the formation of such mitigation frameworks. In other words, conclusions drawn from this research will identify gaps in knowledge and challenges which prevent organizations from developing prescriptive systems and decision support tools which allow for the implementation of wildfire mitigation strategies.

Potential gaps which will be explored include the availability of data on various forms of fuel management in relevant fuel types such as forest thinning, stand conversion to fire-resistant conifer-dominant stands, the development of fire breaks, prescribed burning, as well as the thin and burn combination treatments. In addition to this, social, economic and policy constraints will be analysed. Most communities in Ontario vulnerable to wildfires find themselves in the boreal forest (Parisien et al., 2020). Therefore, this study will focus on data pertinent to this specific forest type.

2.0 LITERATURE REVIEW

2.1 THE WILDLAND-URBAN INTERFACE AND COMMUNITY VULNERABILITY

The top priority for wildfire management agencies in Canada is to protect human life and infrastructure. However, policies which have influenced decades of aggressive wildfire suppression in the boreal forest of Canada have resulted in the reduced proportion of recently burned forest near human settlements, resulting in an increased risk to wildfire (Parisien et al., 2020a). They measured the percentage of recently burned forest (RBF), which are less flammable than more mature forests, up to a 25 km radius around communities, compared to that in the surrounding regional forests. Their analysis of 160 communities across the boreal forest in Canada indicated that 54.4 percent of communities exhibited a deficit or lack of RBF, whereas only 15.0 percent showed a surplus in RBF. Overall, the research indicated that a majority (74.4 percent) of communities involved in the study are surrounded by a low proportion of RBF, which indicates a higher vulnerability of those communities to wildfire. These findings therefore confirmed the assumption that suppression policies are increasing flammability in the wildland–urban interface of boreal Canada (Parisien et al., 2020a).

With the increase of occurrence in WUI wildfires in North America (Manzello, 2013), this research suggests that there is a need to further study how to better protect vulnerable communities outside of the context of wildfire suppression. It suggests that research and development in vulnerability detection and mitigation must be conducted.

With this, researchers with Natural Resources Canada (NRC), in partnership with the University of Alberta, have mapped Canadian wildland fire interface areas and have highlighted locations of major concern due to their increased vulnerability to wildfire. Mapping of these interface areas is important, as basic information such as location of interface areas has not yet been available in Canada. This basic information serves as a foundation to the creation of mitigation strategies against WUI wildfires in boral communities, and act as a baseline for future research which will serve to deduce the barriers which prevent the development of mitigation strategies (Johnston & Flannigan, 2018). The research indicates that the province of Ontario possesses the second highest area of WUI in Canada (Table 1.), at 5 853 788 hectares (Johnston & Flannigan, 2018). Other research conducted by NRC in collaboration with the OMNRF suggest that the total WUI area for Ontario is over 9 million hectares, meaning that 11.5 percent of Ontario's burnable land has the potential for destructive interface fires (Gowman, 2012). This is a significant land area (Figure 1.), considering the potential impacts of WUI fires. The research also indicates that close to 80 percent of this WUI area is in fuel types where wildfire suppression efforts are difficult (Gowman, 2012). This was a key finding, since most suppression activities in the WUI, are expected to be high intensity fires in complex fuel types. This further cements the need for further research in the understanding of wildfire mitigation in fuel types relevant to Ontario's forests.

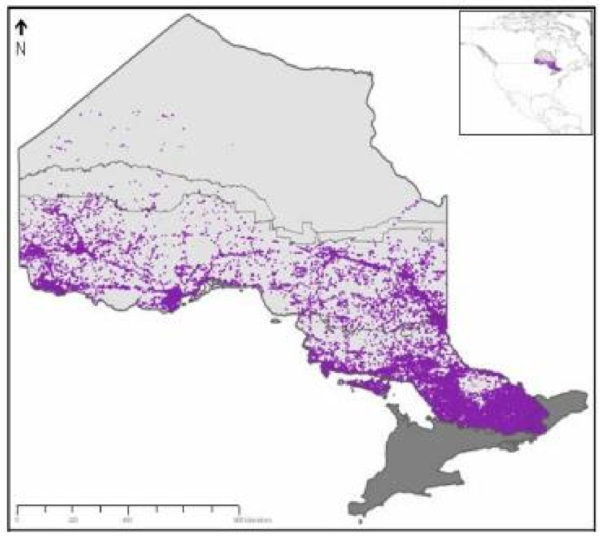

Figure 1*. A Wildland-Urban Interface map of Ontario depicted in purple. Southern Ontario is not included in the analysis (Gowman, 2012).*

Table 1. *Area of wildland–urban interface, wildland–industrial interface and infrastructure interface as total area (ha) and interface area as a percentage of provincial or territorial land area (%) (Johnston & Flannigan, 2018).*

	Area (ha)			Interface area/land area (%)		
	Wildland–urban interface	Industrial interface	Infrastructure interface	Wildland–urban interface	Industrial interface	Infrastructure interface
Alberta	3 165 144	3 409 839	18 027 267	5.1	5.5	29.0
British Columbia	5 520 686	1 762 337	17 617 488	6.4	2.1	20.5
Manitoba	2 282 665	389 097	7 023 709	4.4	0.7	13.5
New Brunswick	2 223 320	575 326	4 829 044	30.6	7.9	66.5
Newfoundland and Labrador	1 221 610	502 766	3 722 071	3.6	1.5	10.9
Northwest Territories	202 113	71 677	3 524 480	0.2	0.1	3.3
Nova Scotia	2 431 164	495 066	4 149 994	45.1	9.2	77.0
Nunavut	5029	1056	23 885	0.0	0.0	0.0
Ontario	5 853 788	1 233 240	21 569 534	6.6	1.4	24.5
Prince Edward Island	178 185	29 475	221 143	31.1	5.1	38.6
Quebec	6 984 261	1 470 985	18 471 946	5.6	1.2	14.9
Saskatchewan	1 907 723	365 110	7 501 080	3.3	0.6	13.1
Yukon Territory	294 795	224 353	3 112 059	0.7	0.5	7.0
Canada	32 270 485	10 530 326	109 793 700	3.8	1.3	13.0

2.2 FUEL MANAGEMENT TECHNIQUES AND GAPS IN KNOWLEDGE

2.2.1 Forest Thinning

Stand-level fuel reduction treatments in the Canadian boreal forest have predominantly been used as a form of community protection against the threat of wildfire. The aim of these fuel treatments is to inhibit the development of fast-spreading and high-intensity crown fires which occur in the boreal ecosystem (Beverly et al., 2020). More specifically, forest thinning, also known as fuel reduction, involves decreasing the stems per hectare in a given forest stand and the removal of debris accumulated on the forest floor to ensure there is no fuel loading in the thinning process. Forest thinning is a practice also used in forest management where the goal is to promote the growth of desired commercial tree species by reducing their surrounding competition. In doing so, this practice disrupts the horizontal continuity of a forest stand, which would affect the way fire moves through a given stand depending on certain environmental conditions. In the context of the Canadian boreal forest, much research has been conducted regarding fire behaviour in thinned forests and the effectiveness of thinned forests as mitigative fuel management method, however some studies have demonstrated that depending on certain environmental factors, fuel reduction alone may not be an effective fuel treatment (Thompson et al., 2020).

An experiment conducted in black spruce peatland situated at the Pelican Mountain Research Forest in Alberta, examined the effects of thinning on the behaviour of a crown fire. A 3.6-hectare experimental fire was conducted in this forest, which had undergone a 50 percent stem removal treatment one year prior. The resulting study from the experiment had shown that, in conditions which are favourable to crown fires, fuel load reductions appear to be the most significant contributor to the decline in fire intensity, despite drier surface fuels in the treatment, however there was no reduction in spread rate or total fuel consumption (Thompson et al., 2020). These findings are likely due to the increase in air turbulence within a thinned forest stand.

Another study examining stand-level fuel reduction treatments and fire behaviour in Canadian boreal conifer forest examined modeled fuel treatments in jack pine (*Pinus banksiana*), black spruce (*Picea mariana*), and lodgepole pine (*Pinus contorta*) stands. The models demonstrated that fuel treatments in these stand types were generally effective at reducing the modeled and observed fire behaviour and inhibiting crown fire development and spread under low to moderate weather conditions (Beverly et al., 2020). It was however demonstrated that under weather conditions where the Fire Weather Index is high to extreme, these fuel reduction treatments would be ineffective (Beverly et al., 2020). The high surface fuel loading combined with the relative short stature of boreal conifer trees has also been proven to undermine fuel reduction treatment efforts (Beverly et al., 2020).

A third study which aimed to quantify the effectiveness of four variations of fuel reduction treatments on fire behaviour in the boreal forest. These methods were analysed using prescribed burns, and their effectiveness was measured through the measurement of fire intensity and forest floor fuel consumption. The treatments included (1) thinning trees and removing debris, (2) thinning trees and burning the debris onsite, (3) shearblading and leaving the debris in place, and (4) shearblading and piling the debris in windrows. Compared with a control plot, treatments 3 and 4 exhibited the lowest peak temperatures of all the other treatment areas (170 °C and 66 °C) (Butler et al., 2013). All thinned treatments significantly reduced heat release compared to the control treatment, which indicated that this method is effective within specific environmental conditions (Butler et al., 2013).

In a case study conducted by FP Innovations, involving two test burns performed in thinned jack pine forest in Canada's Northwest Territories, the report describes the burns that where crown fires which burned into a fuel-managed plot following FireSmart guidelines. In both cases the crown fire changed to a surface fire as the fire passed through the fuel-managed plots (Figure 2.) (Schroeder, 2010). The natural plots where the crown fires burnt, was composed primarily of mature jack pine with an abundant understory of black spruce. The thinned plots were composed of mature jack pine, with little understory vegetation other than feathermoss and reindeer lichens, over glacial till. Both experiments concluded that the thinning treatment was effective at drastically decreasing fire behaviour from a crown fire into a slow- moving surface fire, however, the treatments did not stop the fires in their entirety. It should be noted that within the thinned stands, it was observed that embers were transported as far as 73 m from the plot boundary, which caused spot fires, likely due to the increased wind turbulence within the comparatively more open thinned stands. It can therefore be stated that flying embers could easily burn through thinned plots, and as a result, structures not protected against those ignition sources would be at risk. In addition to this, candling of trees in the thinned plots may have become sources of flying embers, potentially starting spot fires in adjacent stands (Schroeder, 2010). The report did however confirm that fire behaviour models developed to predict the type of fire and ROS showed good potential to be used for planning FireSmart treatments in stands dominated by jack pine (Schroeder, 2010).

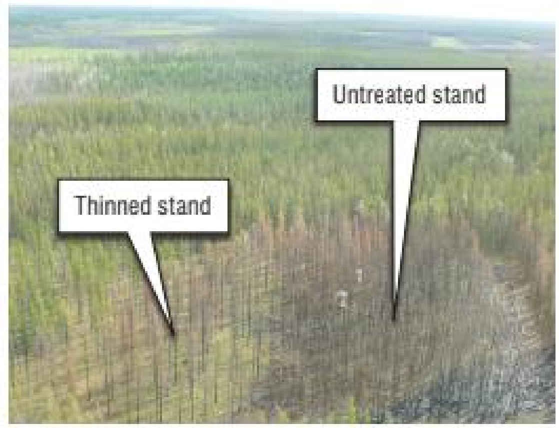

Figure 2. *One year following the 2005 experimental burn in natural and thinned jack pine forest (Schroeder, 2010).*

In the discussion of this report, it was also highlighted that thinning mature pine stands carries a risk of exacerbating the potential for blowdown events and subsequent vegetation changes. The desirability of these impacts should be considered when planning this kind of mitigation work

(Schroeder, 2010). It is thus imperative that thinning must therefore be considered a risk reduction technique which requires long-term site maintenance, and not a fire prevention technique. Wildland firefighters considering suppression efforts within these treated areas must keep in mind the potential for abrupt and dangerous changes in fire behaviour. Other observations from these research experiments indicate that abundant reindeer lichen in treated jack pine stands can result in much higher spread rates than predicted by some models, which should be considered for wildfire planning, safety, and suppression operations (Schroeder, 2010).

Models utilized in this research predicted the probability of crown fire occurrence in the natural and thinned plots. In Figure 3, wind speed is the determining factor which dictates the likelihood in occurrence of a crown fire within stand types. It is predicted and observed in trial burns that thinned forests require higher wind speeds to develop crown fires (Schroeder, 2010).

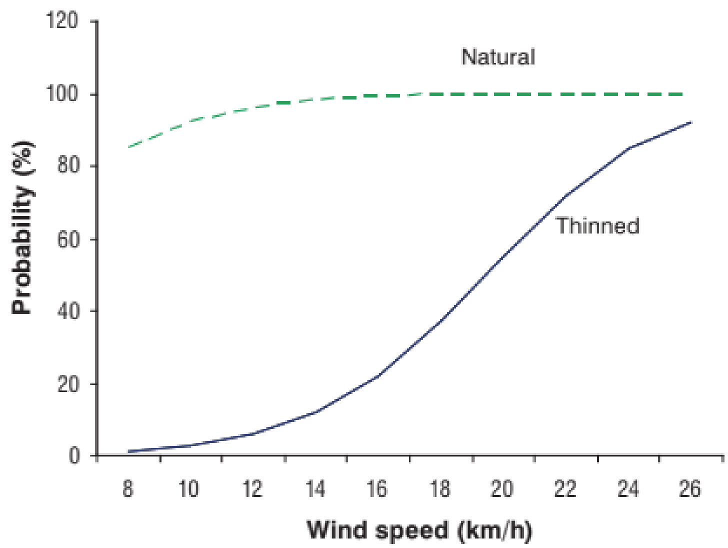

***Figure 3**. Predicted probability of crown fire occurrence in the natural and thinned plots. Model parameters: estimated fine fuel moisture content = 8%, fuel strata gap = 9.8 m (thinned) and 0.8 m (natural); surface fuel consumption = 1 to 2 kg/m2 (Schroeder,2010).*

With the extent of literature available regarding the relevant use of fuel reduction treatments within the boreal forest, there is still relatively little of research (and repetition of research) into the effectiveness of treatments in specific fuel types such as boreal mixedwood (M2), immature jack pine (C4), and mature jack pine (C3), which are all fuel types common to Ontario's forest cover. An increase in research specific to these fuel types is therefore necessary to better understand fire behaviour within fuel reduction treatments.

2.2.2 Prescribed Burning

Prescribed burning as a mitigative fuel treatment seeks to dampen the effects of wildfire on the landscape and reduce their risk to communities (Fernandes, 2015). Prescribed burns decrease the areal extent of wildfires by reducing fuel loading and by increasing the effectiveness of fire suppression (Fernandes, 2015). The assessment of prescribed burning effectiveness is frequently anecdotal or based on simulations, however, studies have begun to provide empirical support for the use of prescribed burning as an effective fuel treatment (Fernandes & Botelho, 2003). Much of the research conducted on the topic has been performed in western regions of North America or in the arid regions of Europe and South America, which do not represent the context of Ontario's boreal forest.

Prescribed fire is known to constrain the size and especially the severity of wildfires, even under extreme conditions. At larger spatial and temporal scales of analysis, the effect of forest age on fire severity is also evident, whether it comes from wildfires entering treated areas or from wildfires in fuel-reduced areas resulting from earlier wildfire occurrences (Fernandes, 2015). Empirical research is lacking regarding the use of prescribed burning in the boreal forest, particularly within, mixedwood, jack pine and spruce dominated stands. The prescribed fire treatments in Ontario are applied commonly in grassland areas (OMNRF, 2017), however, to form a comprehensive wildfire mitigation strategy, one must have a baseline of data regarding the effectiveness of this fuel treatment in relation to how it could serve as a tool for wildfire mitigation around human settlements specifically in the boreal forest.

2.2.3 Thin and Burn Combination Treatment

Thin and burn combination treatments have shown to effectively reduce fire behaviour in many forest types (Martinson & Omi, 2013). A meta-analysis was conducted to compile findings reported in the literature on the effects of fuel treatments on fire severity. It was concluded that the thin and burn method was one of the most effective methods for fire severity reduction, as both vertical and horizontal fuel components are significantly reduced, which would increase a forests resilience against high intensity fires. Findings suggest that sites treated with thin and burn prescription reduced tree mortality rates over time as percent crown scorch and burn severity index were significantly reduced in comparison to sites where thinning only treatments were applied (Fernandes, 2015).

While data regarding the effectiveness of thin and burn methods against fire severity is readily available, much of the research on the topic has been conducted in western United Stated or in Portugal, which is not representative of the forest types found in Ontario. To form a comprehensive wildfire mitigation strategy appropriate for fuel types found within the province, wildfire researchers must have a baseline of data regarding the effectiveness of this fuel treatment based on studies conducted within the boreal forest. There is, therefore, a need for further research into this specific fuel treatment.

2.2.4 Stand Replacement

Stand replacement to less flammable species is one of the fuel treatment strategies recommended by FireSmart Canada to mitigate wildfire risk (FireSmart Canada, 2023). On a landscape level, wildfire risk mitigation around communities could include conversion of highly flammable coniferous stands to stands dominated by deciduous species or less flammable conifers. To date, there have been no trials or research projects involving boreal deciduous dominant stands as wildfire mitigation tools. Wildfire behaviour in mixedwood stands and deciduous forests is however documented in the Canadian Forest Fire Behaviour Prediction (FBP) system. The data tables in the FBP system field guide demonstrate the comparative fire behaviours between boreal mixedwood forests with 75 percent conifer (M2-75), versus boreal mixedwood forests with 75 percent hardwood (M2-25), in which a distinctive difference in predicted behaviour can be observed (Tables 2 & 3). Tables 2 and 3 illustrate how M2-25 fuel types (hardwood dominant), require a much higher Initial Spread Index (ISI) and Build Up Index (BUI) to sustain high intensity classes and continuous crown fires within to forest canopy, compared to M2-75 fuel types (conifer dominant). This indicates that hardwood dominant mixedwood boral forest types are more resistant against extreme fire behaviour as it requires higher Fire Weather Indices (FWI), comparatively to conifer dominant forest types (William Taylor et al., 1997).

***Table 3.** Equilibrium rate of spread and intensity class table of M2-25, describing predicted fire behaviour in relation to the ISI and BUI (William Taylor et al., 1997).*

TABLE 4.15
Equilibrium rate of spread (m/min) and fire intensity class
M-2 boreal mixedwood-green
25% conifer / 75% hardwood

INTENSITY CLASS: 1 < 10 kW/m; 2 10 – 500; 3 500 – 2 000; 4 2 000 – 4 000; 5 4 000 – 10 000; 6 > 10 000

ISI \ BUI	0–20	21–30	31–40	41–60	61–80	81–120	121–160	161–200
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.8
4	[illegible]	[illegible]	[illegible]	[illegible]	1	1	1	1
5	[illegible]	[illegible]	[illegible]	1	2	2	2	2
6	[illegible]	[illegible]	[illegible]	2	2	2	2	2
7	[illegible]	[illegible]	2	2	2	3	3	3
8	[illegible]	[illegible]	3	3	3	3	3	3
9	[illegible]	3	3	3	3	4	4	4
10	[illegible]	3	3	4	4	4	4	4*
11	[illegible]	3	4	4	4	5	5*	5*
12	[illegible]	4	4	5	5	5*	5*	6*
13	[illegible]	4	5	5	6	6*	6*	6*
14	[illegible]	5	5	6	6*	6*	7*	7*
15	[illegible]	5	6	6	7*	7*	7*	7*
16	[illegible]	5	6	7	7*	8*	8*	8*
17	[illegible]	6	7	7*	8*	8*	8*	8*
18	[illegible]	6	7	8*	8*	9*	9*	9*
19	[illegible]	7	7	8*	9*	9*	9*	10*
20	[illegible]	7	8	9*	9*	10*	10*	10*
21-25	[illegible]	8	9*	10*	11*	11*	12*	12*
26-30	5	10	11*	13*	13*	14*	14	15
31-35	6	12*	13*	15*	16	16	17	17
36-40	7	13*	15*	17	18	19	19	19
41-45	8	15*	17*	18	20	21	21	22
46-50	8	16*	18*	20	21	22	23	23
51-55	9	17*	20	21	23	24	25	25
56-60	10	18*	21	23	24	25	26	27
61-65	10	19*	22	24	25	27	27	28
66-70	10	20*	23	25	26	28	29	29

Constants: foliar moisture content = 97%; crown base height = 6m
Type of fire: **surface** **intermittent crown*** continuous crown _ CFB 50% BUI0

***Table 2.** Equilibrium rate of spread and intensity class table of M2-75, describing predicted fire behaviour in relation to the ISI and BUI (William Taylor et al., 1997.*

TABLE 4.13
Equilibrium rate of spread (m/min) and fire intensity class
M-2 boreal mixedwood-green
75% conifer / 25% hardwood

INTENSITY CLASS: 1 < 10 kW/m; 2 10 – 500; 3 500 – 2 000; 4 2 000 – 4 000; 5 4 000 – 10 000; 6 > 10 000

ISI \ BUI	0–20	21–30	31–40	41–60	61–80	81–120	121–160	161–200
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	1	1	1	1	1	1
3	[illegible]	2	2	2	2	2	2	2
4	[illegible]	2	3	3	3	3*	3*	3*
5	[illegible]	3	4	4	4*	4*	5*	5*
6	[illegible]	4	5	5*	5*	6*	6*	6*
7	[illegible]	5	6	6*	7*	7*	7*	7*
8	[illegible]	6	7*	8*	8*	8*	9*	9*
9	4	7	8*	9*	9*	10*	10*	10*
10	4	8*	9*	10*	11*	11*	12*	12*
11	5	9*	10*	12*	12*	13	13	14
12	5	10*	12*	13*	14	14	15	15
13	6	11*	13*	14*	15	16	16	17
14	7	13*	14*	16	17	17	18	18
15	7	14*	15*	17	18	19	20	20
16	8	15*	17	18	20	20	21	21
17	8	16*	18	20	21	22	23	23
18	9	17*	19	21	22	23	24	25
19	9	18	20	22	24	25	26	26
20	10	19	22	24	25	26	27	28
21-25	12	22	25	28	29	31	32	32
26-30	14	27	31	34	36	38	39	40
31-35	17*	32	36	40	42	44	46	46
36-40	19*	36	41	45	48	50	52	52
41-45	21*	40	45	49	53	55	57	58
46-50	23*	43	49	54	57	60	62	63
51-55	24*	46	52	57	61	64	66	67
56-60	25	49	55	61	65	68	70	71
61-65	27	51	58	64	68	71	73	75
66-70	28	53	60	66	70	74	76	78

Constants: foliar moisture content = 97%; crown base height = 6m
Type of fire: **surface** **intermittent crown*** continuous crown _ CFB 50% BUI0

The feasibility of implementing such stand replacing fuel management projects must therefore be explored as there is no specific literature available to describe the process and viability of this treatment option. There is however initial research done on the subject by FP Innovations, where a review was conducted to explore the potential benefits, challenges, limitation, logistics and cost-effectiveness of different management options to convert conifer-dominant stands to aspen-dominated stands. The review discusses the differing methods for establishing aspen stands and reviews the cost of alternative planting methods. It highlights how extensive literature exists on the regeneration of aspen through suckering, research on artificial establishment with seedlings and its requirements is still in its infancy (Matute, 2021). There is, therefore, a need for further research into this specific fuel treatment. -The gradual conversion of forest stands around communities can theoretically help achieve other forest management goals and even be the source of funding for the mitigation project itself, through the sale of timber in the forest stand around the community.

2.2.5 Fire Breaks

Fire breaks, also known as fire guards, are a commonly used tool in wildfire suppression, where a strip of mineral soil is exposed using hand tools or heavy equipment. This strip serves as a non-flammable barrier to wildfire and is commonly effective against low intensity fires (LM Forest Resources, 2020). Wildfire management personnel often use fire breaks to lay hose through and to increase the relative humidity in the forest for the purpose of reducing a fire's intensity. Other features found on the landscape that could be considered fire breaks are lakes, rivers, rocky outcrops, wetlands, forest roads, and clear cuts among others. These are all landscape features that provide fuel discontinuity, which reduces fire’s rate of spread and decreases a community’s fire suppressibility depending on the fires intensity. Fire breaks are also used as a pre-emptive barrier which fire management personnel can use in response situation. The maintenance of fire guards can therefore allow for safer and more effective response if a community is under direct threat of wildfire. Although this strategy may not necessarily mitigate fire at a broader landscape-level, fire breaks can serve as a tool in the suite of options available for community protection against wildfire. There is currently no research which has analyzed the range of effectiveness of human-made fire breaks such as forest roads and heavy equipment guards. To quantify the effectiveness of such fire breaks, researchers will need to conduct controlled burn experiments in various fuel types and climactic conditions, while testing fire breaks of different sizes. To develop a comprehensive wildfire mitigation program, a baseline of data regarding the effectiveness of this fuel management technique is needed.

2.3 POLICY BARRIERS

2.3.1 Absence of Enabling Policies in Land Use Planning

Currently, wildfire management, fuel management or wildfire mitigation is not factored into Ontario Forest Management plans. Wildfire risk reduction is only mentioned in Ontario's FMPs in the context of its prevention during forestry operations. All forestry operations require a minimum amount of forestry suppression equipment based on the number of machines and individuals present for operations (MNRF, 2017). Additionally, operation restrictions are put in place which limit certain activities which are more at risk of starting wildfires, depending on the fire weather indices. This system is referred to as the Modifying Industrial Operations Protocol (MIOP), that applies to industrial operations within the Ontario Fire Region during the fire season, which is April 1 to October 31 each year (Government of Ontario, 2014). In summary, the Ontario Forest Management Planning Guide states that FMPs will include:

> *(a) a description of how sustainable forest licensees will promote fire prevention (e.g., communication, equipment standards and inspections, monitoring compliance with the Forest Fires Prevention Act), including a description of how fire prevention efforts will increase during periods of high fire danger;*
>
> *(b) a description of how forest workers will be made aware of fire prevention plans and initiatives; and*
>
> *(c) a description of how forest workers will be trained to take part in fire suppression, to be considered "trained and capable".*
> (MNRF, 2017)

Although wildfire mitigation, risk reduction and fuel management are rarely the focal point of the Long Term Management Direction (LTMD) in Ontario, strategic level planning in FMPs can still be implemented regarding this topic. In 2020, Al Tithecott published a report entitled "*The Integration of Wildfire Management with Sustainable Forest Management in Alberta*", in partnership with the Forest Resource Improvement Association. This report outlines gaps and opportunities in wildfire and forest policy, which could also be applied as a template for Ontario's forest policy framework. It also describes changes to forest management could reduce wildfire risk and contribute to sustainable, resilient forests.

Tithecott states that provincial fire management strategy statements that set the stage for protecting both lives and values at risk while also encouraging sustainable, healthy and resilient ecosystems, help provide policy guidance for strategic operational decision-making. This can encourage better strategic operational decision-making on large wildfires, so that wildfire managers can focus on priorities, find opportunities for fire to play its natural role in the ecosystem an manage suppression costs. Strategic policy statements can also be foundational guideposts for interactions with the public and other land-use decision processes, such as forest management planning. In 2014, Alberta's Wildfire Management Branch (WMB) approved the first Wildfire Management Plan (WMP) designed to provide additional strategic direction and values at risk information for wildfire response. WMP's have not yet, however, bridged the gaps between wildfire management and sustainable forest management (Tithecott, 2020).

The report also discusses approaching wildfire management with a coarse filter approach early in the FMP process. Tithecott discusses the use of larger and strategic disturbance patches which may have a real impact on wildfire risk. Such discussion may open ideas about whether it is lower risk to manage larger harvest blocks, widen breaks in fuel along roads, concentrate harvesting in one area, etc." (Tithecott, 2020).

While defining the ideal future environment, forest planning should also look for ways to simultaneously lower the risk of wildfire by creating larger harvest blocks that emulate natural disturbance which reduce flammability by deliberately breaking up continuous conifer stands, for instance, by making larger harvest blocks that mimic natural disturbance may lessen flammability while also concentrating harvesting labour. At the ecoregional scale, however, wildfire is more certain to have an impact somewhere every decade. Tithecott states that this bigger risk picture is missing. This strategy of large-scale coarse filter planning could be well suited for the province of Ontario as it's Forest Management Units (FMU) cover vast areas.

To encourage changes that could reduce wildfire risk and contribute to sustainable and resilient forests, Tithecott suggests seven (7) action item which the government and industry can apply. He suggests that (1) the government develops challenge goals which they must be accountable for, that (2) pilot projects should be undertaken to better develop fire management plans, that (3) adaptive management strategies should be more openly be used in forest management planning, (4) prescribed burning should be more supported, (5) wildfire incident management plans should be supported, (6) FireSmart's roles and strategies should be revisited, and finally (7) that education and outreach is necessary to bring understanding and support to stakeholders (Tithecott, 2020). It is noted by professionals in Ontario's wildfire industry that the current absence of binding policies has led to inaction and lack of funding or structure for the development of any of mitigation efforts (Osesky, 2023). These suggestions could therefore be implemented in Ontario's development of mitigation programs, especially concerning the role that FireSmart Canada plays in the province, since currently it only serves as an outreach and education tool.

2.3.2 Addressing Management Goals and Challenges

Planning and implementing fuel treatments primarily involves working through several important challenges. Jain et al. describes how when fuel treatments are combined with multiple-objective management, achieving fuel treatment goals sometimes becomes more limiting. Fuel treatments are a subset or type of vegetative silvicultural treatment in which the purpose of the manipulation is to alter fire behaviour, or its effects, which is why it is important to understand what it cannot achieve when considering silvicultural objectives (Jain et al., 2012):

- Forests cannot be fireproofed.

- A fuel treatment is not static; vegetation grows and develops over time, and consequently, treatments must be repeated.
- Unless properly positioned, treatments may not have the intended effect. Even large and extensive landscape fuel treatments may not reduce the size of an area burned. Treatments can, however, change post-fire outcomes, protect areas of concern and provide suppression opportunities.
- Depending on the residual forest structure and composition, some fuel treatment may not necessarily improve forest health.
- Some vegetation manipulation treatments such as forest thinning may increase the fuel hazard in the short-term if fine fuels are not removed, as they take time to decompose and would contribute to surface fuel loading. In the long-term, these practices do decrease the fuel hazard by treating ladder and surface fuels.

Defining short and long-term objectives of given fuel treatments early in the planning process is the most critical step in the management process. Included in the planning objectives is the recognition of what fuel treatments cannot do and how they may meet other silvicultural goals. For example, short-term objectives such as protecting values at risk and providing suppression opportunities or wildland firefighter safety, drives the rational behind certain fuel treatments. However, because forests continue to grow and develop, fuel treatment maintenance and frequency of maintenance must be incorporated into project objectives. This said, forest type, objectives, spatial extent of the treatment area, current forest conditions and surrounding forest will influence which combination of treatments will create the most effective post-fire outcome or response opportunities. In treatment planning, it is also important to consider vegetation dynamics, growing space and species response to vegetation treatments. The key point is that the exact set of treatments will vary for each site, as there is not one treatment or combination of treatments that fit all situations (Jain et al., 2012).

Social, economic, and political aspects also influence the type, location, and intensity of treatments. For instance, prescribed fire is often restricted near communities because of smoke limitations and the possibility of the fire escaping containment. In crown lands however, achieving desired conditions for the purpose of wildfire mitigation and implementing management actions may often meet multiple and sometimes conflicting objectives (Jain et al., 2012).

When planning fuel treatments as the primary objective or as one of many objectives, there is no specific recipe or treatment combination. There are always benefits and trade-offs among a seemingly infinite number of treatment options that can be applied over time and space. Thus, the best suite of fuel treatment combinations incorporates science, experience, values, and common sense to create innovative solutions when treating fuels within the context of multiple-objective forest planning (Jain et al., 2012).

2.4 ECONOMIC BARRIERS

2.4.1 Cost of Mitigation and Funding Availability

Over the past ten years, Canadian wildland fire management organisations have committed between $800 million and $1.4 billion annually to protect citizens, private homes, companies, the supply of wood, and essential infrastructure against wildfire events (Natural Resources Canada, 2015). Spending on wildland fire management, which includes costs for planning, mitigation, response, and recovery, can be used to estimate the cost of preventing wildfires. The price of wildland fire suppression serves as a proxy for the total cost of wildland fire control expenses. According to future predictions, the price of preventing wildland fires will likely continue to rise quickly, especially in western Canada (Natural Resources Canada, 2015). Over the 2021 fire season, the province of Ontario alone spent $239 million in responding to the season's wildfire events, exceeding the Emergency Fire Fund by $139 million (Kenora Online, 2022). The cost of mitigation efforts in Ontario is however unclear. Currently only one main funding programs exist as an option in Ontario which allocates funds towards mitigation, preparedness, response and recovery for communities. This federal program, known as The Emergency Management Assistance Program (EMAP) in partnership with FireSmart Canada, only provides funding to First Nation communities for the purpose of building resiliency in the face of natural disasters (Indigenous Services Canada, 2022). Although First Nation communities are disproportionally impacted by wildfire risk, there is no other government-sourced funding available for non-indigenous communities, which makes for a non-unified approach to wildfire mitigation throughout the province.

To elaborate, through the FireSmart funding stream, the EMAP supports wildland fire non-structural mitigation and preparedness projects. In First Nations communities, the program develops skills for preventing and preparing for wildland fires. Training First Nations teams in wildfire suppression tasks, fuel management, and vegetation clearing are all part of the programming. To enhance emergency planning, preparation, and response to wildfires, FireSmart also makes use of Indigenous knowledge of the local environment and topography (Indigenous Services Canada, 2022). Funding for the FireSmart project is available for the following types of projects:

- Suppression planning,
- Risk assessment,
- Fuel modification,
- Fire breaks,
- Wildfire crew training,
- Mapping, and
- Community engagement.

The 2022 federal budget announces $39 million over 5 years, to support wildland-urban interface firefighting and training in First Nation Communities. Additionally, the 2019 federal budged allocated $47 million over 5 years to expand FireSmart mitigative programming to support resiliency efforts in First Nation Communities (Government of Canada, 2023).

Current lack of provincial policy directives in emergency management and forest management planning do not allow for this type of funding in non-Indigenous communities. Although there is no funding currently available for non-Indigenous communities in Ontario, funding programs from other provinces can serve as a template for potential initiatives to be developed in Ontario. The Community Resiliency Investment Program (CRIP) was introduced by the British Columbian government in 2018, with the intent of reducing wildfire impacts in communities by providing financial support to complete FireSmart initiatives, including priority fuel management activities on private and Crown lands to reduce the risk of wildfire in the WUI. Secondly, the Forest Enhancement Society of BC (FESBC) was introduced by the provincial government as an organization in which wildfire prevention projects can qualify for funding. The BC government provided an initial contribution of $85 million to the FESBC to aid in funding these projects (BC Wildfire Service, 2016).

The cost of fuel management and mitigation measures vary in scale based on the management type and size of the operation, and often require regular upkeep. As such, reoccurring mitigative activities require consistent funding from year to year, therefore, single "lump-sum" investments in these projects are not feasible.

2.4.2 Workforce Availability

Because mitigation strategies have been conducted relatively minimally in Ontario compared to provinces like British Columbia, there is also a comparatively low amount of internal government technical expertise on the subject within the province. On top of this, there is a lack of third-party organizations and professionals in Ontario currently specializing in wildfire mitigation and fuel modification projects (Gatti et al., 2019). If the province was to utilize its current Aviation Forest Fire & Emergency Services (AFFES) personnel, Forest Fire Rangers, for mitigation projects, these tasks would need to be accomplished outside of the wildfire season. Forest Fire rangers can perform a broad range of tasks concerning emergency response to natural disasters such as wildfire and flood events, and possess much of the skills, knowledge and understanding of fire behaviour required to conduct mitigation activities. Utilizing this well-equipped workforce over the "off-season" would however require a reclassification of their job description, which comes with challenges such as pay, compensation and budgetary changes, union negotiations, bureaucratic motivation, and the approval of government representatives in the OMNR.

This complex and challenging process is seen as a sizeable barrier to the use of this workforce for mitigation activities (Osesky, 2023). In addition to this, the AFFES is experiencing high turnover rates of their professional workforce over several issues such as pay and work-life balance issues (Callan, 2022). As a result of this Ontario's wildfire agency is losing experienced staff year after year, creating gaps in knowledge and expertise within the program. This poses as another barrier since the AFFES is losing professional and technical expertise in wildfire management.

2.5 SOCIAL BARRIERS

2.5.1 Cultural and Community Uptake of Mitigation Projects

Most of the resources used by wildfire management agencies go towards reactive responses to wildfires. However, the need to lessen the risk to communities prior to a wildfire is being emphasized more and more, especially in areas where the perceived risk has been higher due to previous exposure to community threatening wildfires. This requires knowledge of both the social and ecological risks associated with wildfire risk management. The development of communication strategies, goods, wildfire mitigation programmes and policies, as well as working with the general public, Indigenous groups, and stakeholders, can all be aided by an understanding of the social dimensions of wildfire management. Researchers, including those who work for the Canadian Forest Service, are involved in a number of projects examining the social aspects of wildfire and wildfire mitigation.

A study conducted by Ergibi et al., examined the socio-demographic factors that influence the awareness and adoption of the FireSmart program in Canada. After conducting extensive surveys of the population within the country, four key findings were outlined. The initial finding suggests that a majority of respondents had never heard of FireSmart Canada, with only 8.4 percent of Ontarian respondents reporting any familiarity with the program (Table 4). The other findings suggest that the most influential factor leading to the adoption of FireSmart was the respondents perceived risk of damage from wildfire. In addition to this, it was confirmed that both

Table 4. *Familiarity with FireSmart by Province (Ergibi & Hesseln, 2020).*

Province	#Respondents	#Familiar with FireSmart	%
AB	209	73	34.9
BC	272	104	38.2
MB	85	32	37.6
NB	171	43	25.1
NF	69	34	49.2
NT	5	4	80.0
NS	378	136	35.9
NU	2	1	50.0
ON	602	51	8.4
PEI	12	2	16.6
QC	626	80	12.7
SK	80	15	18.7
YK	15	14	93.3

individuals and organizations responded positively to mitigation strategy incentives relating to insurance deductions (Ergibi & Hesseln, 2020).

A study examining the relationship of hazard experience on wildfire risk perceptions and the adoption of mitigation strategies explored resident's wildfire experiences and their responses to the 2003 Lost Creek and McLure wildfires in Western Canada one year after the incidents. Interviews were done with 40 locals who had a variety of wildfire experiences, such as losing their home, being evacuated, leaving their home ahead of schedule, staying put during a wildfire, and being out of the area. The findings indicate that variations in hazard experiences can affect post-event risk perceptions and mitigation measure adoption, suggesting that the implementation of mitigation measures is closely tied to previous experience of risk (McGee et al., 2009).

Another similar study conducted by the Canadian Forest Service compared the responses of homeowners to wildfire risk among towns with and without wildfire management. Few studies have examined how homeowners might reduce their wildfire risk and how government organisations manage wildfires. The purpose of this study was to compare how homeowners in towns where wildfire management activities have been completed by the government (management group) and towns where no activities have been completed (no management group) perceive the risk of wildfire, how responsibility for mitigation is assigned, their awareness of wildfire and mitigation, and how they adopt wildfire mitigation activities. Homeowners in six areas in Alberta, Canada, were surveyed by mail to gather data in 2007. According to the findings, those in the management group expressed higher levels of perceived risk and greater levels of wildfire and mitigation awareness than those in the no management group, but neither group assigned more responsibility for mitigation to the homeowner nor carried out more mitigation tasks on their properties (Faulkner et al., 2009). Results of both studies suggest that overall low perceived risk and lack of action on the part of governing bodies can explain in part the lagging uptake in wildfire mitigation strategies in Ontario. It should however be noted that some smaller communities throughout Northern Ontario have taken on mitigation projects as a result of previous wildfire events which put their community at risk, however a broader transition to fire adapted communities has not yet been seen.

Although the government of Ontario hasn't broadly implemented mitigation strategies throughout the province's vulnerable communities, there exists many more examples of these initiatives in western Canadian provinces where there have also been many recent notable incidents where communities have been threatened by wildfire or even destroyed as a result. These initiatives can serve as templates, or at least a precedent for how the province of Ontario can implement mitigation strategies before a tragedy involving wildfire arises. Another study by the Canadian Forest Service examined the implementation of wildfire risk management by municipal governments in Alberta, where written surveys and telephone interviews were conducted with participants in 18 different municipalities. Many participating local governments were working on emergency preparedness plans, infrastructure improvements, outreach initiatives, evaluations of the wildfire risks on both public and private lands, and vegetation control. Few municipal government buildings had structural mitigation measures and land use planning in place. Among the listed factors that influenced the implementation of wildfire mitigation measures, included was the presence of issue advocates, communication with internal and external stakeholders, financial and human resource availability, backing from higher levels of government, along with other biophysical and demographic variables (Harris et al., 2011). These factors should therefore be considered when establishing community initiatives and demographic studies prior to the implementation of these efforts.

2.5.2 Political Support, Motivation, and the Proactive Risk Reduction Paradox

To reduce wildfire fuels and create community protection plans, governments, management agencies, communities, homeowners, and other stakeholders must collaborate between each other. Gaining support from the public for management practises like controlled burning or forest thinning depends in large part on the level of citizen trust in the various levels of government and management agencies (Jain et al., 2012).

It is therefore imperative that the government of Ontario and its emergency management agencies establish good communication and trust with the public regarding what it is doing to prevent catastrophic wildfire events. As demonstrated by the above-mentioned studies, the overall lack of provincial government action relating to wildfire mitigation is in part due to the perceived low risk towards wildfire and the lack (or ignorance) of recent disastrous or “close call” events in Ontario (Ergibi & Hesseln, 2020). This can also be explained in part by the Ostrich Paradox (Meyer & Kunreuther, 2017), a theory which explains why governing bodies tend to underprepare for disasters. The theory describes how various biases lead to inaction and a tendency to be more reactive than proactive in the face of disaster planning, even if it more costly to take a responsive approach to dealing with natural disasters. This theory expresses the disconnect between knowledge and action, often the result of behavioral, political, and economic constraints (Meyer & Kunreuther, 2017).

There are currently few incentives that are advertised to encourage mitigation planning; however most are focussed on the community or private land-owner level. These incentives do not incentivise broader land-use planning strategies. A large part of the responsibility for mitigating wildfire risk is therefore put on homeowners and community organizers.

3.0 MATERIALS & METHODS

3.1 METHODOLOGICAL APPROACH

The findings of this research are the outcome of a gap analysis literature review with regards to the potential barriers which preclude the formation of strong, comprehensive wildfire mitigation plans and strategies in Ontario. The factors potentially serving as barriers to the formation of a wildfire mitigation program in Ontario which are explored, discussed are the following: gaps in knowledge for fuel management techniques, social barriers, economic barriers, and policy barriers. Research into these subjects is collected and analysed to determine barriers which are specific to the context of wildfire mitigation in Ontario.

The scope of the literature reviewed is specific to studies and reports conducted within North America, as most forest management and wildfire protocols are similar in how they are conducted within the region. The literature publication time range spans from 1997 to 2023 and is relevant to current practices in wildfire and forest management.

3.2 DATA COLLECTION

Data is collected through online and physical databases. Interviews with subject matter experts are also utilized to aid in the collection of data and information for the review. All relevant literature has been screened and compiled in a database and is categorized by topic within the scope of the research.

3.3 ANALYSIS

The qualitative and qualitative findings accumulated from this literature review are organized to clearly identify gaps in knowledge which act as barriers to the formation of strong, comprehensive wildfire mitigation plans and strategies in Ontario.

4.0 RESULTS

The analysis of the literature reviewed through the course of this research has highlighted four principal gaps which act as barriers to the formation of wildfire mitigation planning and implementation in Ontario. These barriers are broadly categorized as the following: (1) Gaps in knowledge for fuel management techniques in Ontario, (2) economic barriers, (3) policy barriers, and (4) social barriers. As a common theme, it can be noted that many of the studies and papers referenced took place outside of the province of Ontario, which demonstrates the over all gap in dialogue regarding the topic of wildfire mitigation in the province. The general lack of literature relevant to Ontario's context contributes to the discussed barriers outlined in the literature review. As a result of this, the principal barriers can be summarised as the following findings:

1. There is a distinct lack in research regarding fire behaviour in fuel treatments specific to Ontario's forest types.
2. Current forest management policies in Ontario are not conductive to wildfire mitigation. Concerning wildfire management, Ontario's forest management plans only include prevention strategies. The inclusion of wildfire mitigation planning in FMPs could contribute to an improved overall management of forest resources.
3. There is little funding and workforce available for mitigation planning and implementation. The lack of policy directives prevents the development of any unified mitigation strategies, and does not allow for more comprehensive federal, provincial or municipal funding for mitigation planning and projects. There is minimal internal technical expertise and an absence of third-party organizations and professionals in Ontario currently specializing in wildfire mitigation and fuel modification projects.

4. There is a general lack in social and political understanding and support for community wildfire resiliency projects. The perceived low risk of wildfire events impacting communities in Ontario, is in part, the reason for low uptake of general disaster planning efforts. Much of the responsibility is placed upon private homeowners to mitigate for wildfire risk in FireSmart programs, whereas there is less incentive for community-scale mitigation initiatives. There is a common phenomenon known as the "Ostrich paradox", which explains the lack of political will to take on proactive risk reduction measures concerning natural disaster planning.

5.0 DISCUSSION

5.1 RECOMMENDATIONS

The implementation of mitigation strategies and programs requires complex systems thinking in areas where there is still very little engagement and initiative for such efforts. A multi-faceted approach must be undertaken with the efforts of multiple stakeholders and experts in the field of wildfire management, policy, forest management, and community engagement. Recommendations derived from the results of the literature review are the following:

1. Include more comprehensive fuel management and mitigation strategies in Ontario Forest Management Planning.
2. Conduct more fuel modification studies in Ontario fuel types.
3. Conduct pilot projects.
4. Use more fuel treatments as silvicultural tools to achieve multiple goals outside of wildfire management.
5. Address workforce issues.
6. Build community understanding and support for mitigation projects.
7. Work with communities to better address their needs.
8. Create more incentives for private landowners to "FireSmart" their properties, such as insurance deductions.
9. Develop and utilize decision support tools for assessing community vulnerability and developing appropriate context-based mitigation strategies.

5.2 LANDSCAPE-LEVEL PLANNING

At the landscape and planning level, since the boreal forest and mixedwood conifer forests in Ontario are fire dependant ecosystems, professionals in the field of wildfire management recommend that at the very least, discussions should be had concerning fuels and wildfire mitigation during the development of forest management plans, even if fuel management isn't the primary objective (Johnston et al., 2022). Timber production requires a long-term investment, and in fire-dependant

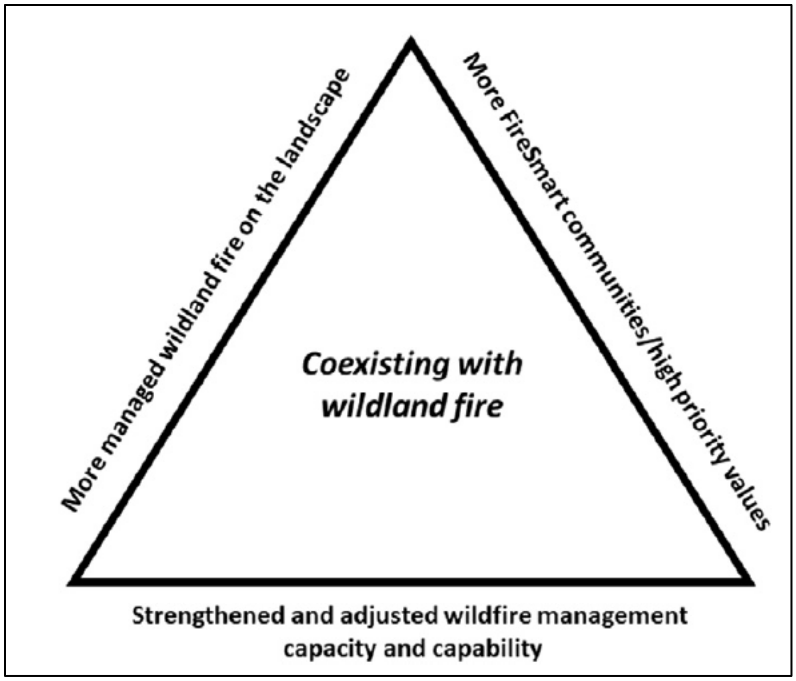

Figure 4. *Wildfire management paradigm shift triangle (Tymstra et al., 2020).*

forest, wildfire always acts as a variable of uncertainty. It would be beneficial to integrate fuel planning into forest management planning, thus accepting and addressing the potential for wildfires and recognizing potential post-fire outcomes. Including fuel modification planning with other forestry objectives makes communicating the management goals for a particular forest unit one of the most difficult tasks in forest management, however it is an important element that must be done thoroughly with care and attention to detail. By fully understanding the treatment objectives, desired forest conditions can be described over time and space and a series of treatments which addresses all objectives can be designated (Jain et al., 2012).

Utilizing the described wildfire management strategies at the landscape, wildland-urban interface, and operational levels can permit governments, communities, and agencies to better develop fire adapted communities that thrive in coexistence with wildland fire (See Figure 4).

5.3 OPPORTUNITIES FOR FUTURE RESEARCH

A common strategy utilized in Ontario's remote communities is the use of fire breaks as a form of protection against encroaching wildfires. Not only do these provide a break in fuels to create discontinuity in the effort to slow the progress of wildfires, but they also serve as an anchor point for wildfire response personnel to use in suppression efforts. Since this strategy is a relatively popular and easy mitigation option to undertake, it would be advantageous to conduct further studies on the efficacy of this fuel modification option.

To assess how vulnerable some communities may be to wildfire, there are opportunities for research in the development of technologies, monitoring systems for determining such vulnerabilities. The development and utilization of decision support tools for assessing community vulnerability based on forest fuels can aid in the creation of appropriate context-based mitigation strategies. With the advent of LiDAR and drone technology, forest condition monitoring could aid in the development of vulnerability assessment tools.

Finally, as mentioned in the literature review and recommendations, there are several gaps in knowledge concerning fire behaviour in fuel treatments specific to Ontario's fuel types. This presents itself as an opportunity to further explore and broaden the literature on wildfire behaviour research. To commit to certain fuel modification projects within the province, decision makers and management personnel must be able to justify their planning objectives through proven trials and research.

6.0 CONCLUSION

Wildfires pose a significant threat to public safety and has the potential to cause significant social, and economic damage. In Ontario, like many other regions of the world, the increasing frequency and intensity of wildfires is a growing concern. In response, there has been an increasing interest in developing and implementing wildfire mitigation planning and strategies to reduce the risks associated with wildfires.

The literature review conducted in this research has identified four principal barriers that act as obstacles to the formation and implementation of wildfire mitigation planning and strategies in Ontario (See Figure 5). These barriers include gaps in knowledge for fuel management techniques, economic barriers, policy barriers, and social barriers.

One of the key findings of the literature review is that there is a distinct lack of research regarding fire behaviour in fuel treatments specific to Ontario's forest types. This knowledge gap highlights the need for more research and understanding of the unique characteristics of Ontario's forests and the implications for wildfire mitigation planning and strategies (Figure 5).

***Figure 5**. Summary of the main findings within the literature review.*

Another significant barrier identified in the literature review is the near absence of funding and workforce for mitigation planning and implementation. This lack of resources is a significant obstacle that prevents the development of any unified mitigation strategies, and does not allow for more comprehensive federal, provincial, or municipal funding for mitigation planning and projects. There is also minimal internal technical expertise and an absence of third-party organizations and professionals in Ontario currently specializing in wildfire mitigation and fuel modification projects (Figure 5).

Moreover, the literature review highlights a general lack of social and political support and motivation for community wildfire resiliency projects (Figure 5). This lack of support is in part due to the perceived low risk of wildfire events impacting communities in Ontario. As a result, there is less incentive for community-scale mitigation initiatives. This finding underscores the importance of building community understanding and support for mitigation projects and creating more incentives for private landowners to “FireSmart” their properties, such as insurance deductions.

To overcome these barriers and improve wildfire mitigation planning and strategies in Ontario, it is recommended that a multi-faceted approach involving multiple stakeholders and experts in the field of wildfire management, policy, forest management, and community engagement be utilized. This approach includes developing more comprehensive fuel management and mitigation strategies, conducting more fuel modification studies, utilizing decision support tools for assessing community vulnerability, conducting pilot projects, addressing workforce issues, working closer with communities, and creating more incentives for private landowners to FireSmart their properties.

At the landscape and planning level, integrating fuel management planning into forest management planning can lead to better management of forest resources, coexistence with wildland fire, and the creation of fire-adapted communities.

In summary, this literature review has identified key barriers to the formation and implementation of wildfire mitigation planning and strategies in Ontario. The recommendations outlined in this research provide a roadmap for overcoming these barriers and improving wildfire mitigation planning and strategies in Ontario, with the goal of reducing the risks associated with wildfires and promoting fire-adapted communities.

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