Alternatives to Chemical Herbicides: Responding to Social Pressures in the Boreal Mixedwood Forest of Alberta

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Executive Summary

Forest Vegetation Management (FVM) can be defined as activities aimed at reducing vegetative competition with crop species. In Canada this is achieved mainly by using chemical herbicides, which kill or prevent the growth of the competing vegetation. Social opposition to herbicides has led to declines in herbicide spraying in some provinces. Alberta's herbicide use has increased, while Quebec is managing without chemical herbicides entirely. The spikes in herbicide spraying in the province of Alberta have sparked concern over the necessity of herbicide use and concerns over the effects of its use. The need for vegetation control also calls into question the viability of regeneration standards in Alberta, and whether it is necessary to change the landscape to such an extent. My capstone will discuss the implementation of different vegetation management alternatives, and their transferability from Quebec to Alberta. With the research presented in this paper, I aim to provide a comprehensive review of herbicide use in the mixedwood forests of Alberta and Quebec and an overview of some vegetation management alternatives that could be employed in the west. In doing this, I will answer several questions: How viable are regeneration standards and are they contributing to the need for chemical herbicides? How could mixedwoods be better managed in order to reduce the need for chemical herbicides? How transferable are the methods used in Quebec to a more western setting? Ultimately, I find that many methods in Quebec are transferable in contexts where the same ecological mechanisms exist in both places.

Introduction

Forest vegetation management is necessary for forest management, in order to encourage the growth of crop species, and to meet regulations on regeneration. As noted by little et al.

(2006), if vegetation management is successful it can result in increased production of the forest, better quality timber and pulp, shorter rotation time, and more consistent tree measurements. Herbicide is the main tool used to achieve this. With this said, stakeholders and communities across Canada are putting increasing pressure on the forest industry to reduce the use of herbicides. Glyphosate, as the most-widely used chemical herbicide, is the main target of concern, and it has been banned for use on public lands in Quebec since 2001(Thiffault & Roy 2010). Bell et al. (2011) note that this is despite the failure of years of research to show the toxic effects of glyphosate when used in the specified operational quantities and concentrations. Although this is true, the research is not necessarily conclusive, and the attitude against herbicide is still very much present. Although forest vegetation management (FVM) is a complex issue, there are three main issues that are consistently present within the herbicide debate (Bell et al. 2011). Firstly, forest managers are legally required to create forest cover from an ecosystem management approach, which includes regenerating conifer and mixed wood stands. Second, conifers are slow growing and sensitive to disturbances such as changes in light and temperature. This allows more tolerant pioneer hardwood species to take over. Lastly, herbicide is restricted or banned in some areas, and the pressure is mounting for bans in other areas. With this in mind, it is in a company's best interest to explore alternative methods in order to find those that are "silviculturally effective" (Bell et al. 2011). One recurring recommendation throughout herbicide research is that forest managers "conduct landscape-level sensitivity analyses on the use of alternative treatments" (Bell et al. 2011). This will help determine the goals of stakeholders and tenure holders and what they are willing to do to meet production objectives, and what can be done based on the specific ecosite. There is a social, ecological and financial cost to any type of forest management decision, regardless of whether chemical herbicides are used or not (Bell et al. 2011). With this approach in mind, I will review alternatives that have been presented by several different sources, with Quebec as a main operational example, and assess their viability in Alberta.

Mixedwood Dynamics in Alberta and Quebec

Mixedwood forests have been traditionally ignored due to their lower value than pure conifer forests, but the need for more ecological based management has sparked a renewed interest in them over the past several years (Comeau et al. 2005). One advantage of mixedwoods is that they are good for sustainable management objectives, including more diverse habitat and species mix and more structural diversity (Comeau et al. 2005). Aspen also hold nutrients in the soil, which can lead to better site productivity in the long-term than with pure spruce stands (Comeau et al. 2005). Aspen and birch decrease the acidity of the soil and increase the productivity of the site by improving nutrient cycling (Ewen and Froese 2010). Furthermore, the greater diversity and yield in mixedwoods can lead to greater economic gains due to the larger number of products which can be derived from them.

The majority of commercial forestry and herbicide application in Alberta occurs in the central mixedwood forest subzone of the province (Alberta Parks 2015). Quebec also harvests within the mixedwood region, although they have a larger area of pure deciduous and coniferous forest than Alberta. Mixedwoods in Canada are largely characterized by the presence of a white spruce overstory and an aspen understory. When aspen and white spruce regenerate at the same time after disturbance the aspen will form an overstory and the white spruce will form an understory. This is followed by the establishment of spruce, which can be immediate or take decades depending on the soil and seedlings characteristics (Lieffers et al. 1996). Typically, however, this stage takes about 50-60 years and then spruce will overtake the aspen in the canopy (Comeau et al. 2005). It is noted that it takes about 40 years for light levels to be high enough for spruce to begin to establish. Eventually, in the absence of large-scale disturbance, mixedwoods have the potential to become pure spruce stands (Comeau et al. 2005).

Mixedwood forests pose a significant challenge to forest managers across the country because of their unique dynamics. In the early stages of mixedwood regeneration, deciduous species typically take over the understory. Many deciduous species are shade intolerant pioneers, which are adapted to compete aggressively for light as soon as an opening in the canopy (such as the opening from harvesting) is created. As a result of competing deciduous species, light is one of the main limiting factors for "growth and survival of juvenile spruce" in the boreal mixedwood forest (Lieffers et al. 2002). Species such as aspen, which reproduce via suckering, are especially aggressive, and grow faster immediately after disturbance than more shade tolerant conifers. Through succession, conifers can eventually overtake the deciduous understory, but this stage often takes longer than the harvesting cycle itself, and managers are left to deal with pure deciduous stands, before the conifers can become dominant (Lieffers et al. 1996). Herbaceous species as well as grasses can also contribute significantly to competition in the mixedwood environment.

In Quebec, the mixedwood forest is slightly more diverse than in Alberta, and includes the presence of balsam fir, birch, and several maple species. A comparison of the western central north American boreal forest (Alberta) and the eastern north American boreal forest (Quebec), shows that while black spruce and balsam fir are the most common species in Quebec, while white spruce and trembling aspen are the most common species in Alberta. Furthermore, black spruce is one of the most common commercial species in Quebec, whereas it is not harvested commercially in Alberta. Within the province of Quebec, the majority of competition is from ericaceous species such as laurel, Labrador tea, and blueberry. Ericaceous species are flowering plants/shrubs that thrive in acidic or infertile soil with low lime. They compete aggressively for soil resources, even changing the chemical properties of the humus layer (Thiffault & Roy 2010). Where ericaceous species are the main vegetative competition, competition for soil resources is more limiting to crop trees than light is (Thiffault et al. 2003). Although the presence of ericaceous species reduces competition for light, "the "growth check" induced on regenerating conifers by ericaceous shrubs significantly reduces long-term forest productivity" (Thiffault et al. 2013). Grasses also make up a significant portion of the competition, and these species have a significant effect on soil temperature, water availability and nutrient content (Thiffault & Roy 2010). Quebec also has understory competition from forbs such as red raspberry and fireweed which compete more for light, and from deciduous shrubs/trees such as cherry, maple, aspen, alder, willow, which are the most aggressive light competitors. Alberta, on the other hand receives most competition from aspen and poplar. There is much less variation in understory competition in Alberta. With this said, grasses like Calamagrostis, hairy wild rye, blue joint reed grass are also problematic, as well as forbs/shrubs such as wild rose, fireweed, red raspberry, bunchberry, sarsaparilla. Ericaceous species exist in less fertile sites in Alberta (blueberry, cranberry, and Labrador tea) although ericaceous species are not nearly as problematic in the West.

These differences could be due to aridity and moisture regimes in the province. Quebec, although largely subarctic, is relatively humid (Urquizo et al. 2000). In comparison, the climate of Alberta can largely be described as dry due to the rain shadow effect (Alberta

Agriculture and Forestry 2003). Ericaceous species are more prominent in areas of higher moisture, with nutrient-poor soil, which exist in larger patches in Quebec (Urquizo et al. 2000). Aspen is also often cited as being more prominent in western Canada. The overall lower soil temperature in Quebec could be a reason for this, which has been shown to reduce aspen suckering (Wiensczyk et al. 2011). Despite these differences, Quebec and Alberta share the common problem of managing mixed woods in a commercial forestry setting and share many common commercial species and competitor species. There is therefore an opportunity for transfer of alternatives vegetation management techniques from Quebec to Alberta. It should be noted that there is much similarity between boreal mixedwoods in BC and Alberta in comparison to other regions in the country. Studies addressing mixedwoods in BC, therefore, can be expected to have results which are highly transferable to Alberta (Comeau et al. 2005).

Patterns of Herbicide Use

Chemical Herbicides are particularly useful for site preparation and conifer release in the boreal and specifically the boreal mixedwood forests of Canada. Release can be defined as freeing crop species from competition. Herbicides work by killing competitor species and allowing coniferous crop species the opportunity to grow unhindered by competition. It is important to note that, although release often involves killing off competition, the goal is simply to promote the growth of conifers, which does not necessarily require elimination of all other understory vegetation. Herbicides are usually applied 1-3 years post-harvest and can be applied following harvest and post-planting (Rolando et al. 2017). Specifically, glyphosate has been the most widely used herbicide in Canada since the late 80s. Aerial spraying is the most common application technique for glyphosate in commercial forestry today. Aerial application of herbicide is the most common method in Canada. Only about 18% of the area is treated using ground spraying, which is done by workers on foot (Rolando et al. 2017). Ontario is known as the heaviest user of glyphosate, treating about one third of their harvested areas, an area equal to the area planted (Thompson & Pitt 2011). In Alberta, herbicides are used heavily to ensure conifers are not overtaken by deciduous species in the mixedwood areas, in order to ensure an appropriate level of conifer regeneration. Changes in Free-To-Grow standards have resulted in a recent spike in herbicide use in Alberta because such standards are especially hard to achieve in boreal mixedwood forests (Thompson & Pitt 2011).

Glyphosate came into use in Alberta Forestry in 1991, after Free-To-Grow standards were added to the regeneration surveys for the province (Mihajlovich et al. 2012). Free-To-Grow determined a level of regeneration that the provincial government deemed satisfactory, in order to ensure that the forest was being regenerated. It was adopted slowly, and the Alberta Herbicide Task Force was developed in 1991 in order to develop an approach to herbicide use in the province. They came out with a set of guidelines in 1994, which emphasized a slow approach to implementing chemical herbicides (Mihajlovich et al. 2012). The guidelines included monitoring for herbicide outside the intended areas of application. GPS was made commonplace in application aircraft between 2005 and 2010, which made risk identification more effective for aerial applications (Mihajlovich et al. 2012). By 2005 the use of herbicides was commonplace in forestry in Alberta and the task force was disbanded. “The Forest Management Herbicide Reference Manual” regulates the use of herbicides in the province of Alberta (Mihajlovich et al. 2012). The newest version of the manual came out in 2004. The manual states that herbicide programs must be designed to achieve resource management objectives for a site. This includes objectives for biodiversity and wildlife, which are often tied to variations in vegetation, which occur from the types of natural disturbances that are common in that particular area. As a result, the manual states that management to emulate natural disturbances is recommended. The manual also includes guidelines for spraying around riparian areas and other sensitive areas. As of 2011 the province also uses *The Reforestation Standard of Alberta* to assess regeneration success for forest plantations (Mihajlovich et al. 2012). Current spraying rates in Alberta are evening out at about 35000 to 40000 ha per year (Mihajlovich et al. 2012).

In contrast to Alberta, Quebec began aerial spraying using chemicals 2,4-D and 2,4,5-T in the early 1980's. By the end of the decade, The Bureau d'Audiences Publiques sur l'Environment (BAPE) had outlawed the use of these chemicals due to their toxicity (Thiffault & Roy 2010). Soon after, glyphosate came into common use in the province for aerial and ground spraying. The Pesticides Act in 1988-89 brought the safety of spraying programs into question and once again the toxicity of herbicide was brought to the forefront (Thiffault & Roy 2010). This time BAPE requested that the province eliminate the use of all herbicides by the year 2001. Today, Quebec no longer uses chemical herbicides for forestry on public lands.

Social Drivers of Change

The social acceptability of forestry practices is often the strongest driver for change in the forest industry. Public concern not only drives changes, but skepticism often helps to alert professionals of gaps in research and practice. This has been the case recently for the use of chemical herbicides in Canadian forestry. The safety of glyphosate for human health and the environment has been under evaluation since the early 80's. As of 2015 Glyphosate is listed by the international agency for research on cancer (IARC) as a group 2a substance or, "probably carcinogenic to humans" (Thompson & Pitt 2011). The problem with the IARC evaluation of glyphosate, is that their organization does not evaluate its effects in realistic concentrations or doses, and therefore cannot give an accurate picture of its effects (Rolando et al. 2017). In addition to the IARC assessment of glyphosate, public attitudes towards the chemical are historically negative. A study from 1998 surveyed residents in Ontario on the acceptability of 9 different vegetation management techniques (Wagner et al.). Overall, public acceptance was highest for cover crops and grazing animals, while the acceptance levels for aerial spraying and ground spraying were very low (18 and 37% respectively) (Wagner et al. 1998). This study notes that opposition to herbicides is based on a negative view of the environmental and health risks in proportion to the benefits, and that the acceptability of alternatives will also be based on perceived risk (Wagner et al. 1998). It notes that the public's perception of risk is multifold and not easily understood.

Glyphosate has certainly been found to be toxic in certain circumstances. For instance, one study on the effects of glyphosate on aquatic environments notes that "the risk to aquatic organisms is negligible or small at application rates less than 4 kg/ha and only slightly greater at application rates of 8 kg/ha" (Solomon & Thompson 2011). Given this information, herbicide programs are regulated to ensure that the level of exposure to wildlife and humans is below toxic levels. The concentrations of glyphosate used in forestry in Canada do not exceed 4 kg/ha, with standard application levels not exceeding 2 kg/ha, which is below the known toxic level (Rolando et al. 2017). Furthermore, the "acute toxicity", referring to the single exposure to a product, of herbicides used in Canadian forestry is very low (Rolando et al. 2017). This is due to the fact that the frequency at which it is used in a forestry context does not allow for a large enough dose to accumulate in the environment. As such, in the case of glyphosate, a multitude of independent scientific reviews and regulatory risk assessments exist and commonly conclude that "glyphosate-based herbicides, when applied in accordance with the product label and applicable best management practices, do not pose a significant risk to human or environmental health" (Rolando et al. 2017). Studies regarding atypical use of glyphosate, or use in greater concentrations, are not applicable to its use in Canadian forestry practices.

Studies of glyphosate on wildlife in a forestry context consistently conclude that "the use of glyphosate products in accordance with product labels does not pose a significant risk to wildlife species in terms of either direct acute or chronic toxicity or through various potential sub-chronic or indirect effects," (Thompson & Pitt 2011). With this said, Glyphosate does often cause short term reductions in some types of wildlife due to a reduction in optimal habitat from a reduction of vegetation, but this effect is consistent with reductions in habitat after a natural fire or other natural regulatory effect (Thompson & Pitt 2011). Specifically, First Nations groups and trappers, who are often the main beneficiaries connected with the forest, are against its use due to concerns about effects on game and other wildlife (Thompson & Pitt 2011). A study done by Kayahara & Armstrong (2015) interviewed several first nations communities in Ontario and noted more than 20% higher opposition to herbicides in first nations communities. Many were concerned that herbicides will affect the food chain, specifically moose, which is a staple in the diet for some communities. Many of the communities surveyed noted the absence of moose from sprayed areas due to a loss of foraging species. They also were concerned about a lack of medicinal plants following herbicide spraying (Kayahara & Armstrong 2015). Many of these communities point out the dismissive reasoning on the part of the government who claim that the impacts to human health and the environment are false. Whether or not this is true, herbicide use results in changes in the structure of the forest and the plants and animals within it. And for communities whose lives are centered around the forest, this is simply unacceptable. Currently in

Alberta there is pressure from indigenous communities, hunters, trappers, and certification systems to discontinue the use of herbicide spraying in forestry.

Regardless of the factuality of glyphosate toxicity, the rejection of chemical herbicides is often on the basis of principle. In the future, there is a possibility that there will be a need to determine which method or combination of methods will result in the highest support from the general population. As a solution to this, Wyatt et al. (2011) suggest that the cost to public acceptance be taken into account when making decision on forest vegetation management. This should be done to determine which method or combination of methods will receive the most acceptance by the public in a specific area. Forestry benefits the public, and the stakeholders, and it is important that their voice, and their concerns, are echoed in forest policy. As such, it will soon be necessary to seriously address alternatives to herbicide application in Alberta and elsewhere.

Alternatives in Quebec

Preventative silviculture and natural regeneration are two of the main methods now used in Quebec in place of glyphosate. Stands are harvested in a way that mimics natural disturbance in order to try and emulate the natural regeneration which would occur after this. In this method, temperate forests are harvested using either shelterwood or single tree selection cuts (Thiffault & Roy 2010). The boreal sections are still clear-cut (using careful logging techniques), although advance regeneration is preferred over planting. With this said, planting still occurs and around 20% of the forest area harvested in public forests in Quebec are re-planted (Bureau du forestier en chef 2015).“From 1970 to 2013, reforested areas totaled approximately 1 297 000 ha, representing an investment of more than $ 1 billion in field preparation and planting” (Bureau du forestier en chef 2015). Careful logging ensures that the overstory is harvested without damaging crop growth in the understory to produce an even-aged stand, grown in full light conditions (Ontario Ministry of Natural Resources 1997). Mechanical site prep is another way that Quebec ensure the natural regeneration is viable enough to restock the stands. Soil manipulation allows natural and artificial regeneration to better establish themselves (Thiffault 2016). As a result, mechanical site prep is the main pre-planting method of vegetation management used in the boreal in Quebec. Quebec also relies on "early planting with size adapted stock" (Thiffault & Roy 2010). The size of the stock that is most effective largely depends on the fertility of the specific ecosite being planted, and therefore the amount of competition for light that will be present with the existing species (Thiffault 2004). Planting in the spring immediately after harvest is another method used to control the success of regeneration, although there is little evidence to suggest this is effective. Treatment is to be done "as soon as conditions dictate" (Thiffault & Roy 2010). The province of Quebec developed a tool that describes when release is necessary for seedlings depending on the level of light they are receiving. The goal is that this tool can be adapted to different scenarios.

Effects of Adopting Alternatives

Although Quebec has adopted FVM alternatives to chemical herbicides, the approach has not been altogether successful, and the province has not been able to achieve the same levels of regeneration without chemical herbicides. For instance, in a study by Quebec's Chief Forester's Office in 2015, it is noted that over 30% of planted areas across the province retained less than 50% of trees planted (Bureau du forestier en chef 2015). Furthermore, there was trouble with maintaining the ecological integrity of forested areas. 11-32% of softwood plantations in the province were found to be invaded by competing deciduous species to the point that they did not meet regeneration criteria. The main problem noted in this comprehensive study of forestry practices in Quebec, was a lack of monitoring. For instance, the report estimates a 42% increase in annual softwood yield "if the plantations had been monitored and maintained" (Bureau du forestier en chef 2015). This equates to about 76 million cubic metres lost, or about a third of productivity, which is no small amount, especially for communities depending on the economic success of mills and plantations. Furthermore, this report concludes of Quebec plantations that the situation is not expected to improve in the future with current lack of monitoring of plantation success (Bureau du forestier en chef 2015). This lack of monitoring observed can be used as a cautionary tale to companies looking to replace chemical herbicides with integrative approaches.

With all of this said, Quebec seems to mostly accept these effects in a practical sense. For instance, the *Forest Management Manual* states that a successful plantation includes: 1) more than 1,500 viable trees of the correct species per hectare; 2) more than 75% of the stems must consist of the desired species from the plantation or of natural origin (Bureau du forestier en chef 2015). But the concept of "plantation success" as seen by stakeholders is shown in this study to be different than what is listed in the manual. Maintaining a wide variety of species, as opposed to returning to "natural" composition, is seen as more desirable to many (Bureau du forestier en chef 2015). If more deciduous species thrive after harvest, it is simply noted the forest will have different and more dynamic values. Quebec has clearly had to adjust some principles in order for this to work for them, and perhaps there is not such strict enforcement and monitoring of plantation success as in other provinces. Based on this we may need to relax our regeneration standards in other provinces in order to adapt to forestry without the use of chemical herbicides. A study done in Nova Scotia came up with this exact conclusion stating the need to "amend the definition of plantation success" in the province (Charbonneau & Simpson 2010). This is after assessing non-treated conifer plantations in the province and concluding that, although they do not meet provincial standards, most include naturally regenerated crop species, and can therefore be considered a success in some sense of the word. Nova Scotia has recently faced criticism for their use of clear-cutting in the Acadian forest. Furthermore, although mechanical release was presented initially as an opportunity for employment in Quebec, they have had significant trouble gathering the workforce necessary for the manual treatments (Kopra et al 2006). Mechanical release in the form of brush sawing is not a desirable job for many. This may pose even more of a problem in Alberta as opposed to Quebec, as forest labor is less a part of the culture in other parts of the country. A history of family-managed forests is strong in Quebec, with a rich labor force as a result.

The economic impacts of this type of management have also been significant. Homagain et al. (2011) evaluated the use of FVM alternatives in Northwestern Ontario and noted a significant yield loss with alternative treatments as opposed to aerial and ground sprayed stands. This study concluded that "Aerial herbicide treatments produced the highest NPV" (Homagain et al. 2011). The value of herbicide-treated mixed spruce, pine and fir (SPF) stands was 36-53% higher than control stands, and the value of mechanical-release treated SPF stands was 24-37% higher. This translates to substantial losses in profitability of mechanically treated stands when compared with those treated with chemical herbicides. This could potentially translate to mill closures and job loss, depending on the specific area. Another study done in Northeastern Ontario evaluated the effects of brush sawing as a sole alternative to herbicide use. The results show that without herbicide (although herbicide is only used for 25-34% of the forest area) the conifer supply would decrease by 14-44%, the hardwood supply would decrease by 6-17%, and wood transportation and silviculture costs would increase by 16-20% (Dacosta et al. 2011). This is in addition to increased road networks, decreased habitat for some species, and changing spatial arrangement of cut blocks.

Regeneration Standards in Alberta

A clear problem with adopting alternative vegetation management techniques in Alberta has been the standards that seemingly make it impossible. The compromised monitoring in Quebec, and the seeming acceptance of more mixed stands represents a necessary compromise for the reduction of chemical herbicides. Free-To-Grow standards specifically, resulted in pressure to increase herbicide use in Alberta. As of 2006, the standards required that spruce trees at this point in a mixedwood stand be at least 1m in height and that competing vegetation be no taller than 2/3 the height of the crop tree, within a 270° arc, within a 1.78 m radius (Lieffers et al. 2007). A site was evaluated for Free-To-Grow standards 8-14 years after it is harvested.

The assumption with the creation of Free-To-Grow standards is that they resulted in much higher growth of commercially valuable tree species, but this was not necessarily the case. A study done by Lieffers et al. (2007) measured the height and growth of trees in Free-To-Grow versus non-Free-To-Grow stands in mixedwood stands in Alberta. They were assessed at year 13 for Free-To-Grow status and then again at year 18. The study detected “no significant difference in height growth in relation to Free-To-Grow status after year 18” (Lieffers et al. 2007). In other words, whether or not trees reached Free-To-Grow status by year 13, it did not appear to ultimately affect their growth. In fact, growth after year 18 was actually higher for non-Free-To-Grow trees than Free-To-Grow. This suggests that Free-To-Grow standards are not justified for mixedwoods in Alberta. Furthermore, this study notes that herbicide use in mixedwood forests results in simplification of the stand structure, to a point that may be unreasonable, but that it is in pursuit of attaining Free-To-Grow status. A spike in the amount of herbicide use after free to grow standards were implemented, attests to their ineffectiveness. Overall, Free-To-Grow showed us that we should work with the stand structure and the natural trajectory of mixedwoods rather than working against it.

In addition to Free-To-Grow, other provincial standards have been put in place to regulate how the stands are regenerated. As Lieffers et al. (2008) note, stands are generally required to be regenerated with a composition that mirrors that of the old stand at the time it was harvested. This requirement disregards the natural succession of mixedwood stands, and the fact that they exist in different compositions throughout stand development, often reaching maturity with a very different composition than in their juvenile state. This study notes that this often results in “un-mixing” of the mixedwoods. This highlights a gap between ecosystem management, which Alberta upholds, and the regeneration standards that forest managers are held to. These standards also enforce the idea that forests should be managed to maintain a simple composition and canopy structure. “These standards have been controversial for the boreal mixedwood forest, because they do not appear to be producing forests that are similar in composition and structure to those found naturally” (Lieffers 2008).

After sustained yield management became the law in 1949, regeneration standards were developed in order to evaluate stands for regeneration success (Alberta Agriculture and Forestry 2018). The first standard came out in 1972, but after studies done in 1985, the standard was changed. These studies found great impacts on supposedly established seedlings by competing vegetation, and therefore reduced the allowance for this competition (Alberta Agriculture and Forestry 2018). The standards were revised again several times, with the most recent study being done in 2005, resulting in the 2011 standards. Today we use The Reforestation Standard of Alberta, which is less strict than the earlier Free-To-Grow, but there is still pressure to unmix mixedwoods, simply because it is easier and more economical. Effective regeneration standards should take into consideration the long-term effects on stand structure and composition, and how this effects the entire forest area, as well as the production goals (Lieffers et al. 2008). Unrealistic expectations should be managed, to ensure that we are not using herbicides simply in an attempt to meet them.

Improvements for Mixedwood Management

Due to the high proportion of mixed-wood forest in Alberta, more research into the proper creation of mixed-wood stands in industry could be useful for reducing herbicide use and making its use more effective. Quebec has come under a lot of criticism for their complete rejection of herbicides in favor of methods which can also cause significant damage (Kopra 2006). One of the critiques of glyphosate in general is that it is simply overused, and a better understanding of mixedwood dynamics could be a possible solution for this. Forest managers are required to replace stands in the composition they previously existed, but this is mostly achieved by creating a patchwork of pure conifer and hardwood stands (Macdonald et al. 2010). This is because it is more cost effective, easily organized and executed by forest managers. Creating a mixedwood with the correct proportions is more difficult to achieve. For years "mixedwood management has been promoted as a solution to maintain forest productivity, conifer resistance and resilience to stress and disturbance, and to maintain biodiversity," (Macdonald et al. 2010). In this way, it would help to achieve a variety of objectives at once. The creation of mixedwood would require less use of herbicide, although herbicide spraying would still be necessary to complement mixedwood management, but its use would be much more moderate than levels currently used for commercial conifer release. It might be worth looking into the dynamics of mixedwood management in Alberta specifically, and for the different vegetation zones.

Currently, chemical herbicide is relied on a sole method of vegetation management for many companies. Glyphosate should simply be used as a tool, and not as a cure-all. A way to achieve this is by returning to stands in their more natural states. If we want to restock forests in their "natural" state while ensuring a steady wood supply, this will require new silvicultural treatments. For instance, Lieffers et al. (1996) recommend a two-stage harvesting regime for aspen and white spruce stands, rather than a clear-cut. This would allow for a more symbiotic relationship between the two main species. Aspen can help spruce development by protecting seedlings from frost (nurse crop). The overstory also reduces competition from shade-intolerant competitors such as grasses (Comeau et al. 2005). Partial harvest methods discourage shade intolerant competitors like raspberry, and aspen, and strip clearcutting can reduce aspen suckering (Wiensczyk et al. 2011). There may still be a necessity for site preparation and other vegetation management techniques to discourage deciduous pioneers when using partial harvest techniques (Lieffers et al. 1996).

Lieffers et al. (1996) recommend underplanting of spruce beneath mature aspen stands, 10-20 years before the harvesting of the aspen. This would allow the growth of the white spruce to around 1m in height, tall enough for it to be seen and avoided during aspen harvest (Lieffers et al. 1996). For this technique, the aspen would need to be harvested using understory protection techniques, and the spruce would need to be planted with enough space to allow for access by machinery. Lieffers et al. (2008) also comment on this, suggesting "partial cutting to preserve old-growth structure, partial harvesting with understory protection of shade-tolerant species to mimic succession, or fine-scale density management of deciduous species to enhance conifer presence. They go further to say that the reason these methods are not used now is because free to grow standards restrict the variation in species allowed in a harvested area.

Lieffers et al. (1996) also discuss the use of shelterwood for boreal mixedwood stands. This method can be used to regenerate white spruce and douglas fir, two commercial species in Alberta. This would involve leaving a strip of white spruce as seed trees, and clearcutting an area beside it to be reseeded by the residual spruce. Furthermore, a study by Comeau et al. (2005) concluded that systems for managing mixedwoods where spruce and aspen are harvested at year 60 and year 120 respectively will have the highest yields. Changing regeneration standards for mixedwood forests will be necessary as stands are usually just designated as hardwood or softwood by forest managers for regeneration purposes. Overall, it is noted that a good mixedwood strategy in Alberta will include flexible policy, which favours landscape level objectives over stand level objectives in order to "maintain the integrity of natural forest composition to ensure long term ecological and economic benefits for the ecosystem" (Comeau et al. 2005).

Recommendations

Without changes to regeneration standards and mixedwood management there is still a need for adopting herbicide alternatives in Alberta. Quebec's techniques can be seen as an example in this case. In terms of adopting these techniques in Alberta, it will be necessary to assess the differences in vegetation on specific sites in comparison with eastern Canada. A process will need to be developed to apply specifically to this area of the country. Wiensczyk et al. also suggest pre-harvest vegetation assessments to determine which treatments will be necessary given the vegetation present (2011). Quebec uses what they call an "integrated vegetation strategy" wherein "site preparation, stock type selection and release scenarios are adapted to the ecological characteristics of reforestation sites" (Thiffault & Roy 2010). This strategy is meant to be adaptable to the different ecozones in Quebec, and therefore could be applied to ecozones elsewhere in Canada. Within an integrative approach, competition prevention and competition removal strategies are used in different combinations to provide the best vegetation management depending on the competitor species, crop species, and overall environment. A 1996 report on integrated forest vegetation management done by the BC and Canadian government shed light on alternatives and their effectiveness in western Canada, when applied at different points in the silvicultural cycle (Comeau et al.). This report stresses the fact that, although several FVM alternatives such as brushing, grazing and girdling are already in use in BC, there is a need to understand when to use them and how often for optimal results. The idea of "integrated vegetation management" seeks to apply multiple treatments for maximum effect. "By practicing integrated forest vegetation management, we can identify "leverage points" where treatments can be applied to maximum effect with minimum cost or impact" (Comeau et al. 1996). The process involves 5 steps: 1) identification of the problem 2) identifying the ability of a landscape to respond to treatment 3) monitoring 4) applying treatments 5) evaluating treatment effectiveness. Perhaps this approach could be used to evaluate the implementation of different treatments in Alberta (Comeau et al. 1996). Based on this information, I recommend a mixed or "integrated" approach, wherein the effectiveness of methods is evaluated based on the site and applied with varying intensity and at different times depending on the site. As such, there is a need for alternatives to be evaluated in regard to their effects on each other and their effects on other vegetation. The specifics of different alternatives used in Quebec are evaluated below, with regards to their application in different contexts.

An integrative approach to vegetation management will require more monitoring, as more treatments will have to be applied at several different points in time during the silvicultural cycle. If monitoring is not kept up to date, then competition will not be properly managed, and losses will occur in harvest.

Mechanical Site prep

Mechanical site preparation involves the use of machinery to disturb soil and create microsites for seedlings and can be used to address factors that are limiting seedling success. Site preparation can result in some or all of the following positive effects: increased temperature in root zone, increased available oxygen in soil, decreased risk of frost damage, reduction in competing vegetation, increased nutrient availability, easier planting, decreased drying and waterlogging (Von der Gonna 1992). Plant survival and growth are directly impacted by the interaction of different soil properties after mechanical site prep (Löf et al. 2012). Site preparation includes the alteration of different layers of the soil, but too much disturbance can cause nutrient depletion, compaction and erosion (Von der Gonna 1992). With this said, site preparation techniques which are too light may not affect competing vegetation or can even encourage its growth (Von der Gonna 1992). For instance, MSP that is too light can encourage aspen regrowth (Wiensczyk et al. 2011). The key to site preparation is creating the right level of disturbance to remove the limiting factors from the site, while limiting damage to soil (Von der Gonna 1992). When it is applied at the right intensity site preparation is thought to be one of the most effective methods of vegetation management (Wagner et al. 2001). Mechanical site preparation also has a longer treatment window and is not as sensitive to weather conditions as chemical site preparation or prescribed fire (Comeau et al. 1996). The methods of mechanical site preparation used can determine the degree of soil disturbance and alteration of soil characteristics. Common methods include mounding, disc trenching, plowing, and mixing (madge, bedding plow etc.) (Von der Gonna 1992). Mounding results in the least area of ground disturbed (10-30%) because it is done in patches. Disc trenching and plowing result in moderate disturbance (25-50% and 30-65% respectively), whereas mixing methods can lead to up to 100% of the soil area disturbed (Von der Gonna 1992).

Thiffault et al. note that the humus layer of a site often determines the effectiveness of mechanical site prep, except in the case of ericaceous dominated sites (2003). In his study, sites with a thin organic layer did not benefit from scarification by disk trenching (Thiffault et al. 2003). Neither the growth of competing vegetation nor the seedlings were affected by this type of site prep. This soil type is common in the non-boreal zone of Quebec. In Northern Quebec, in the boreal zone, a thicker organic layer is present from the accumulation of litter. These sites are also dominated by ericaceous understory species such as *kalmia* and *rhododendron*. On these sites, mechanical site prep was shown to be more effective, and resulted in increased growth rates of seedlings of up to 154% in some areas (Thiffault et al. 2003). Ericaceous species especially have been shown to be especially receptive to MSP (Wiensczyk et al. 2011), but this does not necessarily mean that it will deter ericaceous competition. Thiffault echoes this result, and notes that although mechanical site prep is effective for improving conifer seedling growth on these sites, it will affect ericaceous shrubs on a species-species basis and can either stimulate or hinder their development (Thiffault & Roy 2011). Implementing this in Alberta could be problematic where dominance of mixedwood stands results in competition from more than just ericaceous species.

The results of a trial done in 1996 evaluate the effects of mechanical site prep on three variables (plant community establishment, successional pathways, and phenology) in the white and black spruce boreal zone in British Columbia (Bedford & MacKinnon). Bedford and MacKinnon stress the importance of understanding the mixture of vegetation that will form after certain treatments, and how these mixtures will grow and develop over time, in order to determine the effects on seedling health at any point in the season (1996). The competitive indices were recorded for each treatment over time, in order to reflect the effectiveness of the treatment in the long term. 4 treatments were tested: burned windrows, madge, breaking plow, and disc trencher. Vegetation outcomes for specific ecosystems are predictable for mechanical site prep and different MSP methods result in different but predictable vegetation (Bedford & MacKinnon 1996). The type of vegetation can also affect damage to seedlings by rodents. For instance, the plots treated with disc trenching in this study had sufficient vegetation and trenches to help rabbits travel and therefore sustained the most damage by rabbits (Bedford & MacKinnon 1996).

Knowledge of plant phenology is crucial for knowing when to apply mechanical treatments. For instance, Bedford and MacKinnon (1996) note that when using a treatment that will expose mineral soil one needs to know when the vegetation is seeding, because if the site prep is done during the seeding period the seeds will easily establish themselves on the mineral soil. For instance, fireweed seeds late in the growing season, therefore it would not be effective to use a site prep such as disc trenching at this time. An understanding of the developmental stages of the vegetation being controlled is also necessary. For instance, fireweed often invades initially, but develops to include a mix of species in the ground cover. Fireweed can be killed off early by chemical herbicide, but this will result in cover of mostly grass (Bedford and MacKinnon 1996). This knowledge can be used to provide forage for a mix of wildlife- which is often consistent with stakeholder demands. Overall, this study notes that variation in seedling performance can be mostly attributed to the vegetation rather than other factors.

The effectiveness of mechanical site preparation overall, will depend on the specific site factors, including the soil type, fertility, treatment intensity, and whether the competitive species establish via seed or suckers (Wagner et al. 2001). A forest manager needs to know vegetation you are trying to control, whether it is stimulated by it, when it seeds, if it seeds or suckers, type of soil and disturbance it can handle (fine soil or wet). This puts forward methods for aspen, ericaceous, and fireweed (herb), all of which are problematic in Alberta plantations. Ericaceous shrub species are the main competition on forest plantations in Quebec. As a result, it is often more effective to manage competition for soil, using site preparation, rather than managing for light (Thiffault & Roy 2010). Site prep is extremely effective against ericaceous species, which is why it won't work as a sole method in Alberta but may work on certain sites in combination with other methods.

An FRDA report on the fundamentals of mechanical site prep in BC states that fine mixing methods (achieved using madge rotoclear) will result in deciduous vegetation such as aspen being replaced by herbs and grasses (Von der Gonna 1992). In a study by Thiffault in 2006, site prep by madge discouraged aspen regrowth, but encouraged grasses to grow. The grass that appeared did not overtop seedlings until later in the season. As a result, the seedlings were more vulnerable to frost. This stresses the need for proper timing with site preparation. Another study done in the boreal mixedwood forest of BC tested the effects of strip and area mixing, mounding, and strip and area screefing (Sutherland and foreman 2000). They showed that aspen was most reduced after 5 growing seasons by using mounding and area-mixed site preparation treatments while Red raspberry was reduced on area-mix and area- and strip-screef treatments. By the fifth growing season, site-preparation treatment had little effect on the comparative growth of grasses and forbs (Sutherland and foreman 2000).

Another study done in northern BC showed that mounding with large mounds affected spruce growth the most when compared with spot scarification and disc trenching. Specifically, inverted humus mounding was the most effective regardless of the amount of mineral capping, after 20 years (Boateng et al 2006).

Stock Size and Early Planting

Increasing stock size of seedlings could aid with risk management in plantation success. One study claims that on fertile sites with a thriving understory, larger seedlings have a competitive advantage over smaller seedlings (Wiensczyk et al. 2011). In general, the growth rates of large seedlings tend to exceed those of the competing non-crop vegetation and thus large seedlings are likely to assume a dominant or co-dominant position sooner (Wiensczyk et al. 2011). This is due to their optimal health from extended nursery care, and their height which allows them to compete better for light. Thiffault & Roy (2010) note that the larger a seedling is, the more light it will have access too. He notes that although larger seedlings will have more shoot growth as a result, there is little increase in their need for water (Thiffault & Roy 2010). As such, larger seedlings are not limited by resources to the extent that smaller seedlings are. Furthermore, larger seedlings can reduce the need for multiple mechanical release treatments, because they will reach competitive height sooner (Thiffault & Roy 2010). The idea of an “optimum seedling” was coined by South and Mitchell in 1999. An optimum seedling is one that minimises overall reforestation costs while achieving specific establishment objectives (South and Mitchell 1999). On every site, there is a seedling size that exists that when surpassed, will not serve to further improve performance. It would result in unnecessary costs to grow seedlings past a point which will benefit productivity. This is where the idea of “size adapted stock” comes into play, because an exact size exists for each site, past which is not effective.

Over a series of studies, the optimum seedling size was established for a variety of specific sites in Quebec. For instance, Thiffault & Roy determined in 2010 that large type seedlings are best for Northern Temperate zones in the province, which are relatively fertile and therefore have a large amount of competition for light, while smaller stock is good for less fertile areas of the northern boreal commonly invaded by ericaceous shrubs. Because larger seedlings have an advantage over smaller seedling when competing for light, they are beneficial in fertile areas where competing vegetation is likely taller. In less fertile areas with smaller ericaceous shrubs, a larger seedling will not necessarily produce an advantage, because competition for light is not as intense.

Another study, based in southeastern Quebec, showed that large black and white spruce seedlings with high competition from red raspberry, pin cherry, and mountain maple had a very high growth potential when compared with smaller seedlings and when combined with mechanical release (brush sawing) (Jobidon et al. 2003). This was based on ground level diameter measured 8 years after planting. Furthermore, the larger seedlings were shown to respond better to mechanical release than smaller seedlings and grew at a faster rate after brush sawing had occurred (Jobidon et al. 2003). This multiplier effect has been shown to be unique to spruce seedlings. Pine seedlings do not see increased growth after release, although the positive effects of these two methods on seedling success are still additive (Thiffault 2004). Small seedlings in this study were 15cm in height while large seedlings were 60cm tall. Although pin cherry and mountain maple are not species one would encounter as competition in Alberta it can be likened to other deciduous competition in Alberta such as aspen and alder.

In terms of implementation of size-adapted stock, it is fairly simple. Initial research will have to be done to establish “optimum seedling” size. If it is thought that a larger seedling will be beneficial (a significant amount of tall competition) then an optimal size must be identified. Once an optimal size is identified based on the amount and type of competition, the planting can be combined with release treatments for either multiplier or additive effects. The need for further mechanical release treatments will be further reduced when using spruce seedlings due to the multiplier effects and may be reduced in general when using larger stock. Although this method will work in unison with mechanical release, there is a potential for negative interaction with site prep, as methods that do not expose mineral soil may result in difficulty in planting larger stock. Furthermore, planting soon after site preparation may be necessary to ensure ease of planting large pods. Improper site preparation could prevent larger seedlings from establishing themselves properly.

Scagel et al. (1993) note that because there is a higher cost associated with larger seedlings, it is prudent to evaluate the site properly to ensure that there will be a difference in performance. Early planting can also interact with stock size to ensure that larger seedlings can be planted with more ease. The ground in early spring contains more moisture than later in the season, and is softer to plant in. Furthermore, when seedlings are planted early in the growing season, they have a change to take advantage of the resources of the newly cleared site, before other species reach their peak growing conditions and are able to invade (Thiffault et al. 2003). This gives seedlings a grace period in which they are able to grow relatively unhindered without intense competition for light and soil resources. For instance, aspen, one of the main competitors in Alberta will not sucker in early spring, but rather suckers in June and later in the summer. In summation, if a site is allowed to sit after harvesting, resources become less available to seedlings. The amount of competing vegetation present on the site at the time of planting is directly related to the time that has elapsed since harvesting (Ehrentraut & Branter 1990).

Mechanical Release

Mechanical release treatments focus on the cutting/removal of competitive vegetation to "release" crop trees (i.e.allow them to receive light that they were otherwise blocked from and continue to grow). Brushing treatments include manual (e.g., shears, machetes, brush hooks and axes), motor-manual (e.g., brush saws, chainsaws) (Boateng and Ackerman 1990), and mechanical (e.g., brushing tools mounted on a prime mover such as a skidder or tractor) options (Wiensczyk et al. 2011). Motor manual options are the most common, however, and are typically applied after planting, at a point when light supply is cut off to crop seedlings by competing vegetation. Mechanical release is typically less effective in sites with aggressive hardwood competition which reproduce quickly to occupy gaps. For instance, aspen sprouts are known to develop within 2 years of disturbance, either from root suckers or stump sprouts, and respond aggressively after being cut back (Mulak et al. 2006). A survey by Wiensczyk et al. (2011) notes that where aspen brushing is concerned "sucker production is proportional to degree of cutting". Complete removal stimulates the most suckers. This is because residual aspen contains higher levels of the chemical auxin: cytokinin which supresses root suckering (Mulak et al. 2006). It is also important to note that although manual brushing can increase aspen suckering, it also allows light to spruce to improve growth (Ewen and Froese 2010). When residual trees are left, the shade provided by the mature trees can limit sprouting by lowering soil temperature and reducing light exposure.

A study of black spruce plantations in Northern Quebec found that mechanical release is effective at promoting growth of crop trees, while a study on mixed wood in Quebec found that mechanical release is less effective in sites with aggressive hardwood competition which reproduce quickly to occupy gaps (Cyr & Thiffault 2009). In these areas, multiple applications of mechanical site prep are often necessary. A study of chemical and manual treatment in the Northern interior of BC identified the effectiveness of different treatments for specific competition. Included in this study was the treatment of aspen/balsam poplar, a common competitor in the central mixedwood forest of Alberta. Thorpe found that brush sawing was least effective on aspen competition due to rapid regrowth and the need for several applications (1996). With this said, if the budget and labour force exists, brush sawing can be very effective. Thorpe states that brush sawing for aspen must be done when it has reached 2m in height, and when the coniferous crop trees have reached 50cm (Thorpe 1996). This is a crucial point when shade intolerant pine seedlings will die if they continue to be shaded. Ewen and Froese (2010) note that for optimal spruce growth, light levels must be at least 40%, and below this threshold growth may be supressed in the long-term. In general, shade-tolerant conifers need a longer period of mechanical release treatment than intolerant species during the "critical period" when yield loss must be prevented most critically (Thiffault & Roy 2010). Spruce, as a more shade-tolerant species, will not be as affected but will experience growth reductions at this point. Thorpe's findings, summarizing the silvicultural effectiveness of different treatments on aspen competition are shown in Figure 1.

Figure 1.

Table 1. Costs and silvicultural efficacy of aspen treatments

Treatments	Cost ($/ha)	Silvicultural efficacy and comments
Aerial herbicide		
Aspen highlighting	250 (150–400)	High degree of success under a wide variety of stand conditions. Most effective with proactive treatments. Coverage still a concern.
Ground-based herbicide		
Backpack	450	Coverage generally not as good as aerial. If aspen >2.0 m tall, effectiveness is diminished.
Cut stump	1,000 (650–1300)	Very effective on stems >2.0 m height. Cost is high, but treatment is highly selective.
Stem injection: Pre-harvest	150	Variable results. Effective for reducing intensity of aspen competition, but retreatment may still be required.
Stem injection: Post-harvest	700 (375–650)	Only effective when stems exceed 5 cm dbh, but this is often too late for effective release of understorey conifers.
Manual		
Girdling	750 (500–1000)	Effective; suckering is far less than with cutting. Stems take 1–3 years to die, thereby reducing thinning shock. Stems must be finger size or larger. New tools are introduced with almost every contract.
Manual cutting	800 (500–1100)	Sprouts and suckers grow 1.5–3.0 m in one season. Cutting usually results in a 5-fold increase in the number of shoots. Retreatment is required.

(Thorpe 1996)

Thorpe also evaluated the effectiveness of brush sawing on fireweed, another common competitor in the central mixedwood forests of Alberta. Thorpe notes that fireweed does not present a threat to coniferous crop seedlings until 1-2 years after establishment (Thorpe 1996). As such, mechanical management of fireweed is not necessary unless planting is delayed. In this case, mechanical treatments can be effective against fireweed but has a high risk of damaging seedlings. Mechanical vegetation management overall can be useful as a tool until aspen reach a size where they can be effectively girdled. In this way it can be included in an integrative approach.

June is often thought to be the most effective time to apply mechanical treatments to aspen, as this is when they are at the height of their growing season (Wiensczyk et al. 2011). A study by Mulak et al in 2006 compared suckering after complete removal and leaving different densities of residual aspen. This study was conducted in different seasons to determine the effects of timing on aspen regrowth. Leaving 1500/ha stems as opposed to 500 or 0 resulted in the least new suckers and sprouts. Furthermore, manual brushing treatments done in the spring after leaf flush were most effective at reducing the height and leaf area of juvenile aspen (Mulak et 1l. 2006). A similar study done by Mundell et al. in 2007 concluded that any difference in aspen suckering based on the season of harvest can be attributed to damage done to the soil and not the ability of aspen to sucker at different points in the season. Landhauser et al showed in 2007 that brushing that occurs during the dormant season may or may not help to reduce aspen regeneration in the long-term, as those cut during the summer months may not have the time or rapid growth to establish before winter. This was concluded due to the fact that aspen cut during the dormant season were observed to display more aggressive growth after treatment than during other periods in the season (Landhauser et al. 2007). A study done in Lac La Biche and Peace River Alberta shows that season of harvest may have an effect on aspen regrowth, due to the fact that aspen is very vulnerable to damage from frost and fungi (Wolken et al. 2009).

Monitoring of each site for indications of high competition pressures on the crop trees is necessary for successful mechanical release. Wiensczyk et al also highlight the fact that different vegetation will respond to treatment at different times (2011). For instance, vegetation which reproduces asexually through suckering or rhizomes will be most effectively controlled by treatments applied soon after the growing season when their resources are depleted from growth efforts. Therefore, identification of the species being targeted is crucial with mechanical release. Competitors that reproduce via seed are more effectively controlled by efforts that take place before their seeding season, so that it prevents them from spreading seed. In all cases, there is a possibility that resources may be freed up more quickly than crop trees can realistically take advantage of them, in which case the efforts are wasted. Furthermore, mechanical FVM is effective mainly for shrub species, with little effect on herbaceous understory. Thiffault (2003) stresses that there may be a need for multiple treatments, but that this depends on how quickly competition species are able to limit light after treatment. Some species such as aspen are able to re-sprout quickly and will often need two treatments (Thiffault 2003).

Overall, mechanical vegetation management is useful for controlling shrubs but not herbaceous competition and are typically only used for short-term control of deciduous species. Furthermore, brush sawing and other mechanical treatments often have a much higher cost than aerial herbicide application due to their high labour requirement. For instance, in the late 90's, aerial herbicide spraying was quoted at a minimum of $200 per ha, versus a minimum of $1500 per ha for manual cutting (Thorpe 1996). This could be cost prohibitive for forest managers depending on the context. Ewen and Froese (2010) note that brushing may be good for establishing mixedwood stands but it is not very effective for making pure conifer stands, which is another reason to manage for mixedwood forests.

Prescribed Burning

Prescribed burning/thermal treatment is described by Wiensczyk et al as a pre- or post-harvest method of vegetation management (Wiensczyk et al. 2011). They note that this method is not useful where there is a heavy reliance on advance regeneration of conifers as the main method of regeneration. Fire can be used to kill off intolerant species such as those with shallow root systems and allow tolerant species to thrive and grow in their absence. In the process, however, it can also allow other, sometimes more competitive species to propagate. This is true in the case of speckled alder, which can become more competitive after an intense burn (Wiensczyk et al. 2011). High intensity fire is only effective for aspen removal- too low of an intensity can encourage its growth (Wiensczyk et al. 2011). To control aspen, the fire must be severe enough to damage roots (Ewen and Froese 2010). Low intensity surface fires can aid sprouting species such as aspen and Calamagrostis, by giving them an advantage over species regenerating via seed. High intensity fires, although they can kill sprouting species, can prepare a rich seedbed for seeding species (Lieffers et al. 1996). As such, a thick herbaceous layer often develops after high intensity fire (Lieffers et al. 1996). The resulting buildup of ground vegetation can make it difficult for other species to establish themselves on the forest floor. In Alberta this would be a problem with fireweed. The Canadian Parks Service uses burning as a form of forest management. Specifically, Banff National Park uses prescribed burns for aspen reduction. It is possible, with this information, that there are opportunities for application of prescribed burning in Alberta forests as an alternative vegetation management technique (Lieffers et al. 1996).

Grazing

Although grazing as a method of FVM is typically thought of as logistically inviable, cattle and sheep grazing has played an important role in alternative vegetation management on the west coast. In 2001 it was cited as being used to control vegetation on 10% of cut blocks in BC. Grazing animals such as sheep, goats, and cows, have been shown to be effective at managing several different types of vegetation (Frazer et al.). Main concerns with this method include, destruction of crop trees, transfer of diseases, and the attraction of large carnivores (Little et al. 2006). Sheep especially can also graze on seedlings and can destroy advance regeneration. Frazer et al. address many of these concerns in their study of grazing in northern BC. This study notes that carnivore attraction is not an issue with the presence of sheep dogs and a shepherd. Before the animals are let out in the morning, the area is swept by a guard dog to ensure the area is clear of predators. Frazer et al. claim that "predation can be virtually eliminated in an effectively supervised operation" (2001).

Grazing animals will not be effective for vegetation management where the crop species is palatable and where the non-crop species are unpalatable. With this said, because spruce seedlings are of low palatability to sheep, risk of damage to seedlings is very low in these plantations. If there is a risk of seedling palatability to sheep, it is noted that conifer seedlings are most palatable after buds are shed, where growing leaders are new (Frazer et al. 2001). Frazer et al. (2001) list common non-crop vegetation and their palatability to sheep, as well as the palatability of different tree species to grazing animals. This is shown in Figure 2. In Alberta, it is possible that sheep could be used to control fireweed and blueberry, however they may not be effective for jack and lodgepole pine stands, as these are highly palatable. A study of a white spruce plantation in 1992 showed that 80% of herbaceous and woody vegetation was removed by grazing sheep (Frazer et al. 2001). Another study in the same area showed a 40-90% reduction in firewood by sheep (Frazer et al. 2001). Grazing is not effective for management of grasses but is more permanent for species that need to establish new buds for regrowth.

Figure 2.

Table 1. Relative sheep preferences of herbaceous and woody plant species[1]

High Preference	Low Preference	Poisonous
fireweed *Epilobium angustifolium*	thimbleberry *Rubus parviflorus*	bracken *Pteridium aquilinum*
aspen *Populus tremuloides*	wild red raspberry *Rubus ideaus*	common horsetail *Equisetum arvense*
willow *Salix* spp.	huckleberry *Vaccinium* spp.	tall larkspur *Delphinium glaucum*
showy aster *Aster conspicuus*	elderberry *Sambucus racemosa*	common Labrador tea *Ledum groenlandicum*
oak fern *Gymnocarpium dryopteris*	rhododendron *Rhododendron* spp.	choke cherry *Prunus virginiana*
marsh reed grass *Calamagrostis canadensis*	paper birch *Betula papyrifera*	water hemlock *Cicuta* spp.

[1]Adapted from Newsome *et al.* 1995, Newsome 1996, Kabzems *et al.* 1998.

(Frazer et al. 2011)

Although disease is often listed as a concern, Frazer et al. note that if an inspection of the flock is conducted prior to grazing, there is no risk of disease transfer to native ungulates (2001). Sheep grazing can cost anywhere between $800 to $1000/ha (Frazer et al. 2001). For this method to be implemented in a new area several factors need to be in place. Qualified personnel are necessary (Shepherds & flock owners). The terrain cannot too severely sloped or easily damaged, and the timing and type of vegetation need to be taken into account.

Bend and break and girdling

Other methods of manual vegetation management such as girdling, and the bend and break method can be very labour intensive and expensive. The bend and break method involves the manual bending of the stems of competing vegetation until they are broken, but not entirely removed (Camenzind 2002). The bending employed in this technique allows a portion of the stem and cambium to remain productive. The upper portion of the stem often dies off, but the bent stems are effectively eliminated as competitors during the period before new sprouts are able to form. This method is also helpful during the period before aspen and other clonal trees reach a diameter suitable for girdling (over 5cm). Girdling has been shown to be especially effective for aspen (Comeau et al. 1996). Specifically, girdling of aspen effective during the growing season (Wiensczyk et al. 2011). Aspen are especially known to aggressively regenerate soon after mechanical treatments such as brush sawing. Girdling can be a solution to this, as it allows the trees to survive, while eliminating them from the competition during crucial seedling development stages. Comeau et al. (1996) note that girdling is more effective when the bark of young trees can be easily peeled. This occurs between spring and mid-summer. The cost and labour requirement of this method is totally dependent on the density of competing species and the size of the competition.

Cover crops

In BC, grasses and clover have been used as cover crops since the late 80's (Comeau et al. 1996). As a method of vegetation control alone, cover crops have not been found to be entirely effective. When other objectives, such as increasing forage for wildlife, can be identified, this is when cover crops can be most useful. Furthermore, cover crops can result in a decrease in seedling viability depending on conditions. This is because, the planting of cover crops, while reducing the cover of native competition, will increase the vegetation cover overall. A study by Thompson & Steen, completed in Southern and central BC shows that the planting of crop species on dry sites can increase competition for moisture to the extent that it is harmful to seedlings (Wiensczyk et al. 2011). They found that on sites with higher moisture, the planting of red fescue and bentgrass resulted in high mortality of douglas fir specifically (Comeau et al. 1996). Furthermore, Comeau et al. (1996) point out that cover crops work by reducing soil competition, and therefore will not be effective for suckering species. Cover crops are therefore also not effective at controlling rooting species. Fireweed, alder, raspberry, cottonwood, and several types of grasses, all which establish themselves via seed, are examples of vegetation that could be controlled via cover crop in Alberta (Wiensczyk et al. 2011). In conclusion, for the implementation of cover crops to be viable in practice, it will have to be combined with site prep. Identification of the competitor species as well as the moisture conditions and the seedling hardiness will be necessary to determine the effectiveness of certain cover crops. Similar to cover crops, leaving slash can be used to discourage competitors. Slash can affect microclimates and provide shade to shade and moisture to shade tolerant species like white spruce while reducing soil temperature to discourage aspen regeneration.

Conclusion

Although herbicide is not being abused in a forestry context, the general consensus is that less herbicide could be used in the future. The lack of effective regeneration standards has pushed forest managers in the past to take drastic measures to change the landscape. A change to practices and standards would beneficial to allow for alternative mixedwood management in the province. In the absence of this change, there is some transferability of the methods used in Quebec to a more western context, however they are more heavily directed towards ericaceous species There are several non-chemical methods that can be used to ensure that chemical herbicides are not being used at such high levels.

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