A Comparison: Forest Fires and Clear-Cut Harvesting Impacts as Disturbances Within the Boreal Forest

By

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ABSTRACT

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Clear-cut harvesting is often said to be an imitation of fires impact on the landscape when discussing how harvesting is thought out or planned. Clear-cut harvesting and fires have significantly different impacts on the landscape and the site. These impacts range from different impacts on soil minerals and, soil acidity to landscape forest mosaic management and the implications of different fire regimes across the landscape. Fire as a disturbance is highly variable, and as such any attempt to substitute one form of Clear-cut harvesting to act in its place is inadequate, alternative forms of harvesting may better emulate fire. Further research is required in order to understand long term impacts of logging on successional patterns and the spatial arrangement of harvests.

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INTRODUCTION

Fire as a disturbance in the boreal plays a significant role governing succession, as well as influencing characteristics which make up stands, the features within stands, and the species of stands. Clear-cut harvesting modifies many of the same processes and features of stands, but in different ways. Comparisons between Clear-cut harvesting and natural fire are consistent throughout forestry discussions. Clear-cut harvesting can be used as an emulation of fire and can be used to emulate the role of natural disturbances within ecosystems. Obviously, there are significant differences between what occurs as a fire passes through an area and what occurs when a harvest takes place within a stand or a group of stands. To understand both the similarities and differences between clear-cut harvesting and forest fires within the boreal, a literature review has been conducted to establish where the differences and similarities lie and what impacts the natural process (fire) and clear-cut harvesting have on boreal forest species and ecological processes.

First a description of the forest is necessary. The description will serve as an aide to understanding the size and the scope of the impacts of fire as historically it is the dominant stand replacing disturbance. The boreal forest is massive, and as such is not uniform in its composition, nor is it uniform in terms of fire's historic influence on the forest. The Eurasian boreal forest is comprised of different species and as such fire occurs differently within the Eurasian boreal when compared to how fire occurs in the North American boreal. Within the two forests, fires occur at different intensities characteristic of each region (de Groot et al. 2013).

The same way there is variation across the boreal, differences in intensity between Canadian and Russian forests, there are difference regionally within the boreal. Fire regimes and return intervals shift and change throughout Canada. Different zones within the boreal demonstrate different fire regimes as well as fire return intervals (Prisien et al. 2020). Canadian boreal forests are disturbed by large, infrequent, high intensity fires (Parisien et al. 2020). Species compositions change relative to geography within the Canadian boreal, different forest mosaics are resultant of regional fire regimes which are representative of different areas of the Canadian boreal (Cumming 2001; Bouchard and Pothier 2011).

The boreal forest as a whole and the mosaic of forest patterns within it are constantly changing. Climate change, clear-cut harvesting as well as forest fires shape this landscape: regenerating stands, causing mortality on a smaller scale within stands, and causing widespread mortality which may cover a few square meters or the entire stand. Spatial aspects of forest mosaics such as size of patches, dispersion of regeneration areas and stand age class distributions play a large part in governing the habitability of the boreal forest. If emulation of natural disturbances for biodiversity's sake were to occur, harvesting patters could match disturbance regimes and, structure could be left on site to emulate other disturbances (Angers et al. 2011). Changes to the forest mosaic within the boreal forest could have large implications on biodiversity and other functions as such harvesting rates should be managed to meet burn rates and reflect them (Hunter 1993; Carlson and Kurz 2007). In some ways forest clear-cut harvesting can adequately imitate what occurs in nature, but in others clear-cut harvesting and forest management fail to preserve the integrity of the boreal.

To understand the variability of fire within the Canadian boreal forest a brief description of fire regime and within that understandings of fire cycle and fire return interval are necessary. These three terms are the primary descriptors of a fire's role or function within an ecosystem. Each term describes different aspects of a fire and its impact. Some interjection is necessary in pointing out that although these terms make complicated ecological phenomenon easier to understand, there are, however, failings within these terms and our understanding of the phenomenon.

Forest fires and clear-cut harvests are regarded as two of the most important disturbances occurring on the boreal landscape (Angelstam 1998; Shrestha and Chen 2010). Fire and clear-cut harvesting can impact succession as a process and influence whether succession is cyclic or directional (Brassard and Chen 2006). Because of significant variability in size, shape, intensity, and occurrence fire affected stands succeed in different ways than stands which have been disturbed via clear cut harvesting (McRae et al. 2001; Brassard and Chen 2006). The retention of advanced regeneration likely plays a role in determining species composition following clear-cut harvesting as a disturbance (Bouchard and Pothier 2011). Management of the boreal forest is reflective of economic constraints and what is socially acceptable to meet the needs for raw materials (Bergeron et al. 1999). Some regard fire as a stabilizer within the boreal, ensuring conifers, while clear-cut harvesting can establish hardwoods within stands impacted (Van Wagner and Methven 1978; Payette 1992; Carleton and MacLellan 1994; MacDonald 1996; McRae et al. 2001).

Clear-cut harvesting as well as fire have distinct impacts on processes much more specific than succession. Both disturbances act upon other forest processes differently by virtue of the difference in their own processes. Forest fires impact the thickness of the organic layer, change the composition of soils, and impact nitrogen content. Forest fires may allow stands to hold carbon and change the acidity of soils on burned sites. Clear-cut harvesting on the other hand allows for the creation of more soluble forms of carbon and may act similarly to wildfires with the addition of prescribed burning, therefore, individual harvesting operations may affect soils differently.

Forest fires also have an impact on water courses throughout the landscape but over a longer period of time and this impact may be lessened in areas with larger proportions of water (Attiwill 1994). In the absence of disturbances like fire or clear-cut harvesting it is also possible that stands may undergo a process called paludification, resulting in lessened growth. Clear-cutting has been shown to negatively impact water systems, resulting in increased dissolved organic carbon as well as increased light attenuation in lakes nearby harvest operations (Attiwill 1994). It is possible, however, that modified harvests could play a role in emulating disturbances in riparian areas while mitigating harm in these sensitive areas.

As a result of forest fires and clear-cut harvests, mortality occurs differently throughout the stand. Clear-cutting and fires produce a large pulse of mortality initially. In clear-cuts much of the biomass is removed. On burned sites some biomass is destroyed while a large portion remains. A secondary pulse of mortality comes years after the fire and the residual biomass (snags and woody debris) remains on the site providing structure and habitat for years following the disturbance. Forest fires as well as forest harvests also change the age class distribution of the landscape forest. Clear-cut harvesting attempts to emulate the processes observed after fires but reduced snags and reduced residual woody debris left on the site have large impacts.

Reduced content of snags, woody debris, and changes to the forest pattern via harvesting rather than fire all play a role in changing habitat availability. Changes to these processes could result in reduced biodiversity across the landscape, however modifying or using alternative harvest options could present a source for mitigation of the issues while maintaining outputs for human consumption.

Some areas regarding the differences of clear-cut harvesting and forest fires have not been adequately studied. In the future, studies could improve the understanding on the relationships between clear-cut harvesting and forest fires making for more efficient, environmental forms of harvesting.

Fire as the prominent forest disturbance has been accepted since the days of Aldo Leopold and his work towards conservation and emulation silviculture is the basis for modern silviculture (Conedera et al. 2009; Angers et al. 2011). Superficial similarities are the most demonstrable difference between clear-cut harvesting and fire species composition and structural differences are just a few, but differences are much more significant. These processes occur differently and have different results, fire as a disturbance within the boreal is the pretext for management in this way (Johnston and Elliott 1996; McRae et al. 2001). Although much more than appearances impact clear-cutting's use the generalization of fire's role in ecosystems enables its justification in use and frequency and intensity are focused upon (Angelstam 1998)

THE BOREAL

To understand the roles of forest fires and clear-cut harvesting in the boreal forest it is important to first set the stage with some description of the boreal and the historic role fire has played in the forest. Forest fires as well as clear-cut harvesting play significant roles in the boreal forest. They are the most widespread forms of disturbance acting upon the largest forest in the world. It is estimated that between five and twenty million hectares of forest burn each year (de Groot et al. 2013). Estimates place the area clear cut in Canada at between 900 000 and 1 000 000 hectares (McRae et al. 2001; Shrestha and Chen 2010). The boreal forest is primarily split between Canada and Russia, seventy percent of the boreal forest is in Europe and Asia while the remaining thirty percent in North America, mostly Canada (McRae et al. 2001). Because of its sheer size the boreal forest contains one third of the world terrestrial carbon (McRae et al. 2001). The size of the boreal forest also influences the ecology and processes which occur within it. Fire and the boreal forest have a complex relationship. Fire shapes the boreal forest and the boreal shapes fires. Fire regime differences relate to forest composition, species' fire ecologies (McRae et al. 2001), and fire frequencies influence successional trends (Brassard and Chen 2006).

EUROASIAN BOREAL

The North American and the Eurasian boreal forest shares many similarities many of the same tree species appear over the entire forest but vary in composition throughout the landscape. The Eurasian boreal contains a few species which are not present in the North American boreal: *Pinus Sylvestris, Pinus Sibirica, Larix Sibirica, and Albies Sibirica* (Angelstam 1998). Eurasian boreal species typically have much longer lifespans than species occupying the North American extent of the boreal, Eurasian species may live 400-600 years while Canadian boreal species only live between 150 -250 years. Functions occurring within the forest remain much the same, wildfire is the most widespread and important natural disturbance on the landscape (Angelstam 1998). Like the North America boreal, fire occurs within the Eurasian boreal forest with different intensities and at different frequencies allowing for the understanding of statistically predictable fire regimes across the landscape (Angelstam 1998). This predictability allows for the use of models to understand fires impact on the landscape for biodiversity management (Angelstam 1998). Angelstam (1998) used absent, seldom, infrequent, and often to describe fire occurrence on pine sites as often as every 40-60 years, or as infrequently as once in 300 years on permanently wet ground (Angelstam 1998).

Because the boreal forest is managed under the assumption that fire is the main disturbance shaping the landscape it is important to understand fire and its relationship to succession. Areas where the fire return interval is long are often connected and form networks, with succession driven by gap-phase dynamics, wind events, insect out breaks or anthropogenic disturbances without fire (Angelstam 1998). Up to 86% of fires in Russia are human caused while 80% of fires in Canada are caused by lightning highlighting the difference in fires influence on succession (Angelstam 1998). Where fire is occurring more regularly, in pine forests, lower intensity fires clear competition creating forests with several cohorts (Angelstam 1998). Species composition in the Eurasian forest is likely one of the reasons for reduced fire intensity. The Russian boreal contains approximately 32% *Larix* sp. and 15% *Picea* sp. compared to 2% and 64% in Canadian forests (de Groot et al. 2013). *Picea* sp. allow for the formation of ladder fuels aiding in the transition of a fire from the ground to the canopy and thereby significantly increasing in intensity while *Larix* sp. generally contain a much higher moisture content and are less likely to burn (de Groot et al. 2013). Canadian fires are larger on average as well as more intense than Eurasian fires (de Groot et al. 2013). In a study ranging from 2001 – 2007, de Groot et al. (2013), found that Canadian fires burned less area: 6.10 million hectares compared to 39.67 million hectares. However Canadian fires were on average significantly larger, 5930 hectares compared to 1312 hectares in the Russian study area (de Groot et al. 2013). 57.00% of the fires in the Canadian study area were crown fires while only 6.50% in the Russian study area were crown fires (de Groot et al. 2013). de Groot et al. (2013) determined that the Canadian boreal is characterized by high intensity crown fires while the Russian boreal is characterized by low intensity, surface fires. Density of large trees in northwestern North American old-growth boreal forests was found to be significantly higher than other boreal areas (Nilsson et al. 2002; Bouchard and Pothier 2011).

NORTH AMERICA BOREAL

The same way there is variation between the North American boreal and the Eurasian boreal, variation exists internally within the different zones of the boreal. The Canadian Boreal forest can be broken down in to four distinct zones dominated by characteristic fire regimes. The Atlantic-Maritime, Boreal Shield, Boreal Plains and Boreal Cordillera represent the variation occurring from east to west (Brassard and Chen 2006). Boreal forest species have evolved with fire over the last 30 million years (McRae et al. 2001). Most fires in the Canadian boreal forest are small and low to moderate intensity, these fires burn disproportionately small amounts of area compared to the 3% of fires, which burn 97% of the area burned within the forest (Parisien et al. 2020). These are the large, high intensity crown fires. Stock et al. (2003) found that it was fires which were larger than 200 hectares that represented 97% of the area burned. In Quebec it was found that fires smaller than 1000 hectares were responsible for less than 10% of the area burned, fires over 20 000 hectares are responsible for 40% of the land burned (Bergeron et al. 2002). Within Balsam fir stands burned in Quebec, fires ranging from 265 to 15 000 hectares represent more than 55% of the area burned in those stands. Between 1961 and 2000, in Alberta, 5% of fires burn 98% of the area (Carlson and Kurz 2007). In North America, large, uncommon fires typically burn most of the area.

In areas where the fire cycle is long or where fires are severe if seed sources are distant species such as jack pine which, require stand replacing disturbances may face difficulty regenerating and may disappear from the landscape (Bouchard and Pothier 2011). In the Western Canadian boreal large wildfires play a role in shaping mixed wood stands but are unlikely to burn until a proportion of spruce is present in canopies (Cumming 2001). In the Eastern boreal, however fire cycles are longer and spruce budworm outbreaks play a greater role in shaping mixed wood stands (Bouchard and Pothier 2011).

IMPACTS ON FOREST MOSAIC

HISTORIC BOREAL AND CHANGES TO FOREST CONDITION

Since the mid 19th century emulation of natural disturbances has been discussed in forest management. But natural disturbances have meant different things in the past and our understanding of how to emulate them has evolved (Kuuluvalnun and Grenfell 2012). Natural disturbance emulation preserves biodiversity and species populations because it hopes to be more similar to the natural range of variation (Kuuluvalnun and Grenfell 2012). Natural disturbance emulation though clear-cut harvesting could be used to recreate forest mosaics across the landscape (Bergeron et al. 2004). Clear-cut harvesting has difficulties emulating some of the features left by stands both untouched by fire and burned to varying degrees. Management should attempt to emulate natural disturbances patterns at landscape scales by examining and modifying harvest patterns to reflect fire distributions on the landscape. Alternative styles of cutting could be used to reflect the role mortality plays in stand structure, appearance of the disturbance and landscape species composition. More diverse cutting practices and more thoughtful pattern management for harvests could better approximate the historic boreal forest. Using alternative management strategies could be beneficial rather than justifying clear-cut harvesting through positing that only severe stand replacing disturbances impact the boreal forest's succession (Bergeron et al. 2002).

First, harvests dispersed across the landscape can potentially cause landscape fragmentation resulting in a less natural forest mosaic (Carlson and Kurz 2007). Forest harvests organized in groups or cluster may be a more accurate representation of natural forests mosaic (Carlson and Kurz 2007). The use of smaller harvest areas and a few larger blocks could better approximate fires landscape impacts and distributions, i.e. large fires burning a proportionately large percentage of the landscape area (McRae et al. 2001). Differences between harvest blocks and fires have led to a large increase in the amount of edge on the landscape which can have implications regarding species populations (McRae et al. 2001; Perera and Baldwin 2000).

Forest regulation could lead to issues involving the forest mosaic. Full forest regulation seeks to have all the forest in an area harvested by its rotation age. Clear-cut harvesting in correspondence with rotation age rather than forests regenerating via fire could result in different species occupying a site because of changes in the forest mosaic (Niemela 1999). Clear-cut harvesting has been found favorable to angiosperms potentially leading to more of those species (McRae et al. 2001). The application of this would lead to the loss of mature and over-mature stands and the structures and processes present within (Bergeron et al. 2002). Research by Van Wagner (1985) suggests that 37% of stands which are a result of fire would occupy later seral stages such as mature and over-mature designations (Carignan et al. 2011). In order to emulate historic disturbance pattern's influence on the forest stands across the landscape partial cutting can be used on stands which should emulate old forest conditions, and clear-cutting can be used on stands representing younger age classes (Bergeron et al. 2002). A regulated forest compared to stands allowed to succeed via fire seen below are the corresponding distributions of stands (Figure 1).

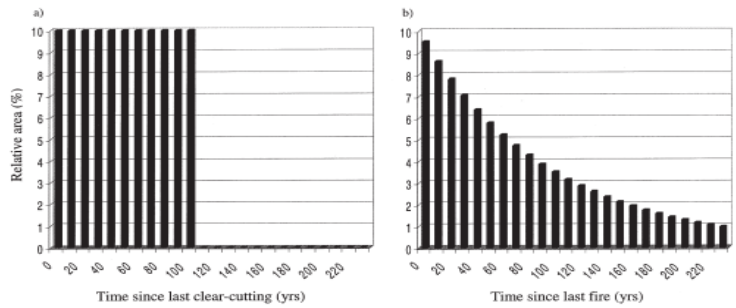


Figure 1: demonstrates changes to forest age structure in a regulated forest and a naturally succeeding forest. Source: Bergeron et al 2002

Reserves may be left in stands which may not be harvested due to topographic limitations, however simply not harvesting stands which have difficult access does rectify the mosaic on the landscape (McRae et al. 2001). The removal of such stands from the landscape would have untold consequences on biodiversity.   Bergeron et al. (2002), however, suggested dispersing regeneration areas to limit impacts and questioned whether the current amount of young even-aged stands on the landscape was representative of history. This would depend on the fire cycle of the area. Bergeron et al. (2002) suggest variable retainment strategies to further emulate what would appear to be normal structure.

Where the return interval is short it may be best to emulate a large stand replacing disturbances, where the fire cycle is long, it may be ideal to emulate through selection harvesting or partial cuts representing less intense fire or less severe disturbance (Bergeron et al. 2002).

FIRE CYCLE, FIRE RETURN INTERVAL, FIRE REGIME

Fire cycle, fire return interval and fire regime all describe the role of fire on the landscape. Because the boreal forest is massive and one fire cycle in unable to accurately represent fire and its occurrence across Canada (Bergeron et al. 2004). These terms describe fire in different ways. First the three terms are described highlighting differences between them. Next the role of fire cycles across the Canadian boreal forest is highlighted and the failings of attempting to describe fire cycles as well implications in management.

Fire cycle in the Canadian boreal is described as the time it takes for a fire to burn over the area covered by study (Bouchard and Pothier 2011). A fire return interval is characterized as the time it takes for fire to return to a stand (Bergeron et al. 2002). Fire regime is reflective of times or windows in time, spatial units, origin of fire, fire characteristics, occurrence, and impact (Conedera et al. 2009). Fire regime was created in the 1960s with the purpose of describing ecologically relevant characteristics of fire (Conedera et al. 2009). Within the Canadian boreal forest, a fire cycle is affected by geographic region it represents. Generally, fire cycle decreases with proximity to the coast. Coastal areas may have less fires while interior areas have more. Fire return interval and burn frequencies are typically highest on the coasts or nearer to the coasts (McRae et al. 2001; Bouchard and Pothier 2011). Fire frequencies can be as little as twenty years in Northern Ontario's boreal forest or up to 500 years on the East and West coasts (McRae et al. 2001). Changes in fire cycle relate to climate, probability of lightning strikes and likely more factors (Bouchard and Pothier 2011). In the west dry summers and severe fire weather likely contribute to a higher fire occurrence (Bouchard and Pothier 2011).

Girardin et al. (2010) point out that given fifty years of statistical information on forest fires it is likely impossible to understand or represent an accurate fire return interval. Attempting to qualify fire return intervals or fire cycles fail because fire activity is time dependent, fire variability is complicated, and fire return intervals and cycles would have to be associated with large confidence intervals due to variability (Girardin et al. 2010). Fire return intervals and fire cycles could however be useful in developing management strategies through even-aged or uneven-aged management (Bergeron et al. 2004). The boreal forest has a large proportion of trees older than 100 years and also contains areas where fire cycles may reach up to 500 years partial or selection harvests should be considered as uneven management rather than clear-cutting or even aged management for these areas (Bergeron et al. 2002; Bergeron et al. 2004).

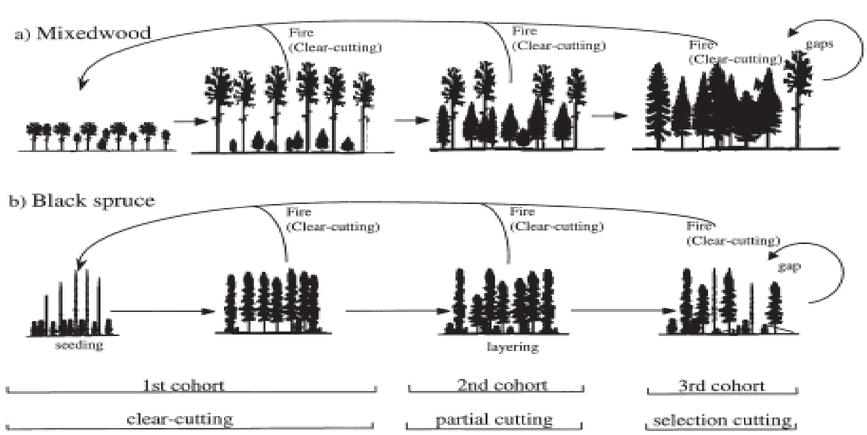
IMPACTS ON SUCCESSION

FIRE AND NATURAL SUCCESSION

Fire in the boreal varies significantly in severity. Because of this so too does mortality within affected stands and the succession patterns which follow a fire (Bouchard and Pothier 2011). This variability specifically impacts depths of the organic layer, the preparation of seedbeds, and remaining residual trees and as a result routes a stand may take in succeeding (McRae et al. 2001). Succession in the boreal forest acts in two primary ways, cyclic and directional succession (Brassard and Chen 2006). Time between fires affects landscape species compositions and the forest mosaic differently with conifers and deciduous trees regenerating through different means after a fire or a harvest (Girardin et al. 2010).

Cyclic succession takes place in stands where the fire return interval is short so species replacement does not occur and essentially a species occupies an area from the time the site was disturbed until the time it will be disturbed again (Brassard and Chen 2006). Cyclic succession often leads to sites controlled by jack pine, trembling aspen and birch, the shade intolerant, pioneer species (Brassard and Chen 2006). However black spruce may occupy an area and in the absence of fire spruce will regenerate via layering, when fire occurs spruce has also demonstrated an ability to establish post-fire because of removal of advanced regeneration and semi-serotinous cones (Bouchard and Pothier 2011). Jack pine will respond better on post fire sites than spruce though (Thiffault et al. 2007). Directional succession on the other hand occurs where there is replacement by shade-tolerant species, species like white and black spruce and balsam fir (Thiffault et al. 2007). A typical scenario for directional succession is described by Bouchard and Pothier (2011), pioneering jack pine establish, with the prolonged absence of fire spruce come to dominate the site. If there are enough jack pine left on the site at the time of the disturbance it may regenerate to jack pine, however if a significant portion of the jack pine has died the stand may succeed other ways (Bouchard and Pothier 2011).

Figure 2 below demonstrates directional succession on top, a stand of shade intolerant hardwoods is eventually colonized by a shade tolerant species. And on the bottom a black spruce forest regenerating from fire or forest harvest having been an even-aged forest, succeeds to an uneven aged forest without another species to regenerate in the area will remain a black spruce forest (Figure 2).



Source: Bergeron et al 2002

Figure 2: Shows directional and cyclic succession (top and bottom)

Shade intolerant hardwood species are impacted by smaller less severe fires and occur because of short fire cycles (Girardin et al. 2010). Shade tolerant species, typically conifers, are impacted by larger fires with longer fire cycles (Girardin et al. 2010). This cannot be true for the entire boreal forest, in the Quebec boreal mixed wood forests have been shown to be preserved by outbreaks of spruce budworm (Bouchard and Pothier 2011). With the prolonged absence of fire conifers become more prevalent on the landscape (Bouchard and Pothier 2011). Bergeron et al.. (2002) described typical succession in the boreal over 200 years, hardwood stands are replaced by mixed wood stands which are in turn replaced by softwood stands. Hardwood species have little issue regenerating in the boreal. Hardwood components are maintained by spruce budworm's removal of conifers in cases where the fire return interval is long (Bouchard and Pothier 2011). Birch and aspen have been known to regenerate either by seed or by sprouting post fire (Bouchard and Pothier 2011). There is some concern climate change's lengthening of fire cycles could remove pure deciduous stands from some landscapes (Bouchard and Pothier 2011).

ANTHROPROGENIC MANAGEMENT

Clear-cut harvesting can be linked to dominance of deciduous tree species as well as an increase in the presence of balsam fir (McRae et al. 2001; Bergeron et al. 2002). McRae et al. (2001) found that clear-cut harvesting tends to lead to the dominance of hardwood tree species and results in a lessening of the presence of conifers. Harvesting with advanced regeneration protection, or HARP, what has also been called careful logging, has been found to preserve features which may be structurally characteristic of old growth forests (Bouchard and Pothier 2011). HARP has also been blamed by Bouchard and Pothier (2011) as the likely culprit for the increased presences of balsam fir in stands which have been previously clear cut. Balsam fir varies in its economic viability in different areas and its preservation is atypical of what would be seen after a disturbance, typically fire would remove fir from the post-burn area (Bouchard and Pothier 2011). The preservation of balsam fir is uncharacteristic of fire disturbances as even a lower intensity fire can remove balsam fir from the site (McRae et al. 2001). Clear-cut harvesting has demonstrated an ability to replicate structure observed in old growth or mature stands more quickly than post fire stands (Bouchard and Pothier 2011). Bouchard and Pothier (2011) suggest this may be because of retaining smaller tree during the harvest, where these smaller trees would have been killed by a fire disturbance.

IMPACTS ON THE LANDSCAPE

SITE NUTRIENTS

On the surface, most impacts from wildfire seem to be associated with mortality, changes to forest patterns, a blackening of the forest floor. Clear-cut harvesting and wildfire both act upon the soils of sites. Fire changes the character of soils by reducing the organic layer thickness and releasing nutrients via the burning process, fire can capture carbon, change soil acidity, and removes nitrogen in some cases (Bergeron et al. 1999; McRae et al. 2001; Ward et al. 2014; Thiffault et al. 2008) clear-cut harvesting also impacts nutrient cycling and soil nutrients, however some aspects of wildfire can be emulated using prescribed burns and alternative techniques (Carlson and Kurz 2007; Carignan et al. 2011).

Many factors influence the flammability of the organic layer in the boreal forest and the flammability in turn influences how much of the organic layer is burned during a fire. Across the boreal forest there is considerable variations on both depths of the organic layer and in terms of depth of burn within the organic layer. By burning the organic layer large amounts of nutrient are released. In Quebec, the mass of the forest floor has been reduced, at times, by 10-20% post-wildfire, in Finland another study found a 20% reduction (McRae et al. 2001). McRae et al. (2001) also presented other studies that in Ontario and Alaska there were reductions of 79-91% in Western Ontario, up to 100% in Eastern Ontario, and 27-63% in Alaska. This burning and reduction in the mass of the forest floor and the organic layer serve to release nutrients in the post-fire environment such as nitrogen, phosphorus and base cations potassium, calcium, and magnesium (Ward et al. 2014).

As part of the normal burning process soils lose some nitrogen, it can be significant in the cases of high intensity fires (McRae et al. 2001). In Finland typical nitrogen losses were around 10% (McRae et al. 2001). Some soils undergo nitrification in part because of the deposition of base cations after the passage of fire (McRae et al. 2001). Higher concentrations of nitrogen were found to have been produced in some soils, providing additional nutrients to the site immediately post fire for several years and in one case up to 27 years after fire (McRae et al. 2001).

Thiffault et al. (2008) showed that wildfire affected plots retained carbon which showed low solubility and was less likely to break down. Two decades after the disturbance the carbon was still present in forms difficult to break down this carbon also offer little in the ways of nutrition and suggesting that this carbon would be stored for thousands of years (Thiffault et al. 2008).

The deposition of ash and base cations post fire plays a role in reducing the acidity of soil (McRae et al. 2001). One fire in Finland reduced soil acidity to a pH of 5.9, where it took thirty years for the soil to return to a pH of 4.0 (McRae et al. 2001). In Quebec, soil acidity was compared between burned and unburned stands, the difference was a pH of 3.65 in unburned mature stands and 5.50 in burned stands.

Clear-cut harvesting's impact on soil nutrients is more complicated. Clear-cut harvesting used in conjunction with prescribed burning has been found to affect nutrient cycling like burning (Bergeron et al. 1999). The removal of trees, specifically the boles of trees result in the removal of carbon and organic nutrients from the site (Thiffault et al. 2007). Clear-cut harvesting also has the opposite impact of fire, where carbon is relatively insoluble after fire, carbon after harvesting may be more prone to degradation by microbes (Thiffault et al. 2008). So, where fire may act as a carbon sink in a minor way by storing carbon in the soil, the carbon that is not stored in forest products may be more prone to breaking down after harvests (Thiffault et al. 2007; Thiffault et al. 2008). Clear-cut harvesting is typically blasted as having negative impacts on the site and soils, however McRae et al. (2001) were unable to find differences in soil respiration between burned and cut sites. Poor harvesting practices such as rutting or other such activities would degrade the site.

IMPACTS ON WATER

Attiwill (1994) suggested that forest fires in the Canadian boreal affect aquatic ecosystems every 50 to 300 years. A study by Parisien et al. (2020), cited Nielsen et al. as having determined that substantial reduction in fire likelihood is possible in areas close to large lakes, Greater than 5000 hectares, or where water occupies 40% or more of the landscape. Because of the moisture saturating forest soils near water systems stands are not impacted strongly by fires, these stands are impacted more by gap-dynamics during succession (Angelstam 1998). Simard et al. (2007) determined that stands which fail to have stand replacing disturbances can potentially undergo a process called paludification leading to decreased growth in trees. Paludification is caused by increased soil water over time because of the organic layer increasing in thickness over time and is a phenomenon typically found on lowland sites. Ward et al. (2014) determined that boreal forests may not need disturbances to remain productive. There may be an increase in productivity post disturbance but decline without disturbance for a long period (Simard et al. 2007; Ward et al. 2014). After fires, some streams in these areas may have additional phosphate, nitrate, and other nutrients (Tiedemann et al. 1979; Freedman 1981; Bayley et al. 1992; McRae et al. 2001). Dissolved organic carbon in lakes which had experienced cutting nearby rose in some cases threefold, as did light attenuation coefficient, reducing available light in lakes, this could have potentially negative implications (Attiwill 1994). It is possible that partial harvesting could be used to emulate fire in riparian areas, however clear-cutting was shown to be more detrimental than wildfire on streams and watercourses in short and long-term scenarios (Nitschke 2005).

STAND STRUCTURE AND PROCESSES

When a fire burns a stand it impacts different structural aspects of the forest, both at the micro and macro level. At the micro level, fire impacts individual trees by causing mortality throughout the stand. Fire has a role in shaping the amount of downed woody debris as well as coarse woody debris throughout the stand in the years after its occurrence. As a result of mortality, fire produces standing dead trees or snags which provide potential for habitat. Then at the large-scale fire plays a role in shaping the forest landscape in years following by creating residual patches through different burning conditions.

After the passage of a fire, the creation of many dead trees impacts nutrient cycling as well as creates habitat for species (Angers et al. 2011). Although some mortality occurs immediately following a fires passage Angers et al .(2011) found that a significant amount of mortality caused by fire occurs in the first two years after fire followed by delayed mortality of up to 4 to ten years in low and moderate severity fires in poplar stands. Bergeron et al. (2002) found that 30-50% mortality was possible in lightly burned areas up to two years after the initial fire. Angers et al. (2011) cite Harmon et al. (1986) in establishing that delayed mortality allows for the recruitment of snags overtime which can act as nurse logs for regeneration of seedlings.

Parisien et al. (2020) established that younger stands were less likely to burn due to reduced biomass resultant from previous disturbances. Young stands regenerated by fire typically contain a large amount of coarse woody debris left over from the previous disturbance as stands age this amount becomes lessened, and as trees reach senescence this amount rises again (Bouchard and Pothier 2011). Although fire is not the greatest determiner of coarse woody debris content on the site, Bouchard and Pothier (2011) suggest that fire cycle may play a role in its abundance. Downed and coarse woody debris have been found to be important in recycling nutrients (Harmon and Hua 1991; Karjalainen and Kuuluvainen 2002), storing water (Fraver et al. 2002; Karjalainen and Kuuluvainen 2002), establishing regeneration (Hofgaard 1993;

Takahashi 1994; Parent et al. 2003; Lampainen et al. 2004), habitat (Tallmon and Mills 1994; Pearce and Venier 2005; Bouchard and Pothier 2011). Before a log becomes downed or coarse woody debris it may act as a snag, or standing dead tree and has influences in terms of habitat and regeneration even at this stage.

Typical forestry in North America establishes that around 25 standing dead trees per hectare is an adequate recreation of habitat, however, post-wildfire there may be up to 10 000 standing dead trees per hectare (McRae et al. 2001). This abundance of post-fire snags may serve to protect jack pine seedlings regenerating on the site. Jack pine produces optimal growth with 85% sunlight McRae et al. (2001) cite (Fraser and Farrar 1953; Cayford and McRae 1983; Carleton and MacLellan 1994) and (Steneker 1974; Schier et al. 1985) and state that shade produced by standing dead trees may enhance pine seedling survival as well as limit the amount of poplar suckering which occurs. The increased shade allows for reduced damage by weevils (Schier et al. 1985). Angers et al. (2011) cite Bond-Lamberty and Gower (2008) who established in one study that jack pine snags lasted consistently longer than black spruce snags, 86-100% of jack pine snags were still standing 9 years after fire, while 23% of black spruce snags were left standing. Jack pine's ability to persist as snags may be because of high resistance to breakage as well as having the highest modulus of rupture (Angers et al. 2011). Angers et al. (2011) and Bouchard and Pothier (2011) determined that larger dbh snags were more common than smaller ones.

In many cases burn patterns are inconsistent. Some areas mortality is near 100% while others remain untouched. The creation of islands or residuals is an important process occurring after the passage of a fire. Bergeron et al. (2002) found that low severity portions of burns may sometimes represent up to 50% of the burn area. Lee et al. (2002) discovered that some residuals in Alberta fires varied from 5.6 to 10.8% of the area, up to 80 hectares in size. Trees which survive the fire help regenerate the surrounding area and can be considered habitat features (Bergeron et al. 2002). Because fire does not simply remove all the biomass from the site, snags and other such structures are left was well as some surviving trees, Smaller fires can be emulated by partial cutting and selection or partial cutting which could create stand structure as well as influence future composition (Bergeron et al. 2002). Bergeron et al. (2002) suggested that 15 - 20% of the initial standing volume should be preserved to provide habitat for species present after the disturbance. Within larger harvest areas, preserves varying between 50 and 200 hectares could be used with variable retention strategies to maintain volume attained from the forest and provide habitat. The shape of a burn could be compared to the shape of a harvest. Harvests could be more elliptical in shape paralleling fires (McRae et al. 2001). Bergeron et al. (2004) suggested that clear-cutting could not emulate over-mature forests and the structure present within, however, strategies for retaining old and dying tree could be left to preserve some structures present in those types of forests (Bergeron et al. 2002).

Bergeron et al. (2002) suggested that the 5% of burns occurs as untouched islands may be approximately what appears as reserves in some cutovers. Large fires never burn all fuels within the forest and allow for the creation of residual habitats within the burn (Bergeron et al. 2002). Clear-cut harvesting emulates fire by retaining islands and refugia for species present after the burn.

IMPACTS ON BIODIVERSITY

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Clear-cut harvesting and management serve human interests providing resources from the forest, as disturbances both play a role in modifying the site and thereby influence biodiversity on the landscape (Kuuluvainen 2002). Across the boreal biodiversity differs because of disturbance regimes, topography, climate and species interactions, in no way is disturbance the only process acting upon biodiversity (McRae et al. 2001). However, management through via attempting to emulate historic disturbance patterns has shown promise in conserving maximum biodiversity (Johnston and Elliott 1996). Clear-cut harvesting and forest fires affect biodiversity in different ways within the boreal. First, the presence of snags and woody debris as habitat varies with each disturbance and has implications (Kuuluvainen 2002). Forest age and species composition across the landscape can be altered by clear-cut harvesting operations as well as fires (Bouchard and Pothier 2011). The presence of both burned and cutover sites have implications on biodiversity both positive and negative. Some processes such as salvage logging and prescribed burning can meet objectives and mitigate harmful impacts on biodiversity.

After the passage of a fire, many snags can be created. These trees can be used by animals as habitat (McRae et al. 2001). These snags eventually fall and become considered downed woody debris serving much the same ecological function. Siitonen (2001) found that in managed boreal forests and unmanaged boreal forests there was a large difference in downed woody debris in unmanaged forests woody debris content was at 60-90m^3 per hectare whereas in managed forests it was 2-10m^3 per hectare a reduction of ninety percent. This kind of reduction of a habitat feature could have an impact on biodiversity. Bouchard and Pothier (2011) noted similarly compositional and structural attributes in clear-cut compared to post-fire stands can accumulate and have impacts on the landscape.

The boreal forest is made up of different types of forest at varying points throughout their successional development, the succession of these stands is driven by fire cycles and disturbances (McRae et al. 2001). Although species richness is likely highest during early successional periods within stands, it is important to maintain distributions of old and young stands within historical levels (McRae et al. 2001). Preserving distributions of these stands aids in maintaining ecological integrity stands are considered to have ecological integrity if they are characteristic of the natural area and maintains ecological aspects and processes (McRae et al. 2001). Reducing distributions of older forests which could happen because of forest regulation or significant fire would impact species which require old-growth features and structures (Bouchard and Pothier 2011). These reductions are an issue and structural difference between Northern and Southern boreal areas have been discovered and become more of an issue given potential differences in disturbance substitution have been low historically (Bouchard and Pothier 2011) Some species require longer periods than forest rotation ages span to recover (McRae et al 2001). If forest regulation occurs typically regeneration areas are close together and older stands are in inaccessible areas, while with fire these distributions would be random (McRae et al. 2001).

On burned sites in Northern Quebec, Shaft and Yarranton (1973) discovered species diversity was found to hit a maximum within ten years and declining after, another study, Morneau and Payette (1989) found species diversity reached a peak at 23 years after fire and declined until 250 (McRae et al. 2001). Rowe (1983) suggested that burned sites have lower biodiversity than harvested sites. But recently Hart and Chen (2008), discovered that diversity of vegetation within the understory can be high under moderate stand replacing fires.

It was believed that species diversity was found to be higher on cutover sites rather than burned ones (Johnston and Elliott 1996), However, Hart and Chen (2008) determined that there were similar levels of species richness on both sites. There is an increase in vascular species on clear cut sites, but a reduction in non-vascular plant species on the same sites (Hart and Chen

2008). Clear-cutting may negatively impact biodiversity however by leaving fewer snags and pieces of downed woody debris as habitat features (McRae et al. 2011). Cuts themselves are habitat features, it is theorized that cutting is responsible for rises and moose and wolf populations resulting in the decline of woodland caribou population (McRae et al. 2001). If inbred seed lots are used genetic diversity could be hurt on regenerated stands (McRae et al. 2001). The loss of older forests by clear-cutting could represent a drain on biodiversity from the site, large and old trees represent trees of high fitness and the removal of trees could result in an inability to pass on seed (McRae et al. 2001; Bouchard and Pothier 2011)

Some alternative forest operations can impact biodiversity differently. A study by Van Wilgenburg and Hobson (2008) found salvage logged areas were more ecologically similar to burns than harvests. In 1983, Rowe suggested that burned cutovers contained more similar species to areas which had wildfires. Hart and Chen (2008) found that stand replacing fires and clear-cutting as well as overstory composition influence post disturbance understory vegetation.

AREAS TO BE RESEARCHED FURTHER

Two areas necessitating further study relating to fires and clear-cut harvesting's impact on the landscape are succession of post-logging sites. Timoney et al. (1997) suggest there is no convergence between logged sites regenerated as deciduous forests and the conifer forests they would have likely become. If there is no convergence species composition would be changed across the landscape in many areas treated by logging as a disturbance. This issue could be further exacerbated by a lack of knowledge on how cut blocks should be distributed on the landscape for optimum disturbance emulation. Some argue cut blocks should be dispersed, some argue that cut-blocks should be clustered or close together to mitigate impact (McRae et al. 2001). More information on sites which have been logged over the long term are needed to fully understand the consequences of logging as a substitute for fire.

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