COMPARATIVE ANALYSIS OF SOIL PROPERTIES INFLUENCED BY WILDFIRE AND SUSTAINABLE FOREST LICENCE HARVESTING PRACTICES

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September 28th, 2019

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ABSTRACT

Keywords: Forestry, harvesting, wildfire, carbon sequestration, global charcoal database, forest soil, nitrogen fixation, vegetation, soil classification

This thesis outlines the main differences and similarities between current forest harvesting practices and wildfire disturbances in the boreal forest. Boreal harvesting is carried out in a way that looks very similar to wildfire disturbances. But the chemical and physical changes that occur after each disturbance do not show to be identical. Where harvesting displays more physical change on the forest, wildfires tend to have stark chemical changes to the stand that succeeds the old one. This will outline the main differences in both of these disturbances and potentially suggest ways of more closely replicating a wildfire disturbance.

ACKNOWLEDGMENTS

I would like to thank Dr J. Wang for helping me complete this thesis and giving me feedback throughout the process. I would also like to thank Dr L. Meyer for being a second reader to my thesis.

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INTRODUCTION

In the context of forest operations and natural disturbances, forest soils act as the main cog that allow these functions to occur. They are constantly in a state of disturbance and change, and the forest relies on the integrity of its soil to thrive. Harvesting operations have evolved and adapted quickly in the last century. With climate change and over harvesting becoming a main issue in the global spotlight, the forest industry has developed new techniques in the practice of sustainable forest management. A relatively new management objective of forestry in Canada is to replicate a harvest in a way that simulates a large natural disturbance like wildfire. This technique comes from ancient traditional knowledge but has since been updated and put into practice in modern forestry. Wildfires are part of the natural cycle of succession in the Canadian boreal forest. They act as a necessary disturbance to restart the forest. An old growth forest is recycled, new growth begins, and the cycle repeats itself endlessly. Forest soils are continuously being exhausted and replenished of vital nutrients that allow plant life to grow in the first place. Forest soils act as a carbon sink, keeping carbon locked in the soil through multiple disturbance cycles. Climate change is now affecting legacy carbon being released with higher intensity and higher frequency wildfires. This is playing a significant role in the structure of the forest, the structure of the soil, and the surrounding climatic features. With forest soil properties in a constant state of change, and harvesting practices constantly adapting, it is only natural for One to wonder how closely modern forest practices replicate a wildfire disturbance.

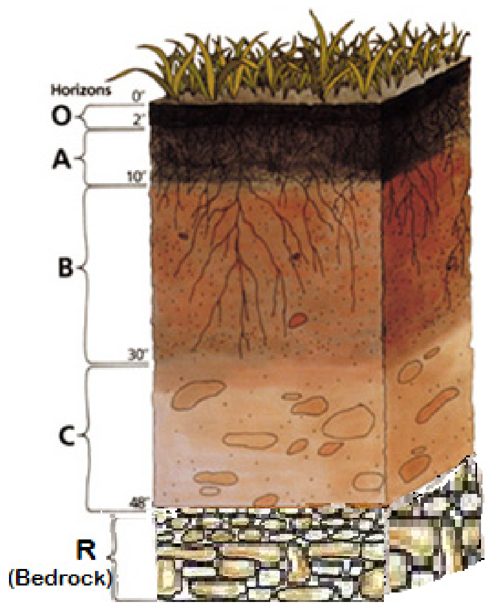
Objectives

The main objective of this paper is to quantify the relationship a high intensity wildfire has with the surrounding forest soil, and contrast those soil properties with those of forest operations. Several questions are to be answered in quantifying the soil properties of a wildfire and a harvest; What are the differences between soil properties in a post wildfire scenario and a post harvest scenario? What are the long term goals for site quality and soil properties to conduct optimal and ethical forest practice? How can a post harvest scenario be controlled to closer replicate a major disturbance such as a wildfire? This paper is the product of several literature sources from multiple media. Using multiple data from several literature sources will allow for a compilation of data used to accurately express the true nature of soil properties on a scale that expands across the Canadian boreal region. In forestry, change is inevitable. Studying soil properties as a factor that drives a forest through its life cycle may play a key role in monitoring climate change and future forest practices. It is essential that sustainable forestry accurately replicates a wildfire in the Canadian boreal. Research in this paper is conducted using modern policy regarding forestry. The goal of this paper is to conclude that modern policy creates sustainable harvest practices where such practices accurately replicate a wildfire disturbance in relation to soil properties in the post-harvest scenario. If such practices prove to be ineffective in doing so, this paper may act as a reference regarding how One might closer replicate these disturbances on a chemical level. Sustainable forest licenses offer strict regulations on forest soil properties, however with new research methods emerging in the last decade, it could possibly shed light on better and more well-adjusted practices.

LITERATURE REVIEW

Soil properties of a boreal forest

To understand the comparison made between a wildfire disturbance and an operations disturbance, it is important to first quantify the key components in soil properties of the Canadian boreal forest. The Canadian boreal forest expands through the entirety of Canada, taking up more than 270 million hectares of land (NRM Canada, 2019). This makes quantifying the soil properties of the boreal forest complex in that soil properties vary on multiple scales. To understand the comparisons being made on a large disturbance scale such as a wildfire or a harvest, it is important to quantify soil properties on the same scale. Soil properties in the boreal forest take many different forms, and change from one region to the other. That is to say, the biogeochemical processes that boreal soils go through in the Canadian Rocky Mountains are different from the biogeochemical processes the lowland spruce bogs of Ontario go through. However, having the same genus of tree species (ie: *Picea, Pinus, Populous, Juniperous, & Thuja)* acts as an indicator that there are some similarities in soil properties that expand throughout the boreal region of Canada.



Graphic: Soil Profile

Graphic courtesy USDA [1]

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Figure 1: *Classic soil horizons of a typical boreal forest landscape, showing the O layer as the organic material zone, and the A through C layers as the developing stages of the mineral soils layer. Where the R layer represents bedrock.*

Source: https://www.soils4teachers.org/soil-horizons

Carbon is one component of the boreal forest that exists throughout. Aboveground biomass carbon (ABC) is composed of the dead litter that began accumulating after the last fire occurrence in that region (I. P. Vijayakumar, et al. 2016). Some of this carbon will be burned off during the next fire cycle, and the rest acts as legacy carbon. Legacy carbon is carbon that persists in the soil through multiple fire cycles (Smith, R. et al. 2017). Legacy carbon, or total organic carbon (TOC) comes in the form of decayed, or decaying organic matter such as; pine and spruce needles, cones, dead branches and plant material, previously charred organic material, seeds and leaves. TOC can be predicted based on several factors; cover density, stand height, species composition, tree age, total precipitation, surficial deposits and fire interval. As forests grow over time, stand age is the best predictor of above ground biomass carbon, but a combination of these seven factors is best to define the total organic carbon concentrations in the soil (I. P. Vijayakumar, et al. 2016).

According to the Canadian System of Soil Classification, forest soils typically have an organic surface horizon, followed by a lower mineral horizon. These mineral horizons contain ≤ *17%*organic carbon by weight, and the organic horizons contain > 17% (SCWG 1998). Refer to figure 1 to view the major soil horizons. Major organic horizons are composed of the L, F and H which each occur at different stages of decomposition (Sarette, D. 2004). These organic horizons are developed from the accumulation of leaves, twigs and other woody debris on the forest floor.

The major mineral horizons are comprised of A, B and C horizons. The A horizon is found directly after the organic horizons and typically comprises both mineral soil and organic soil. Leeching tends to cause organic material to leech downward into the A and B layers (SCWG 1998). The B horizon is characterized by the enrichment in organic matter from the upper horizons. Typical B horizons include accumulated organic matter (Bh), mottling and gleying (Bg), and clay accumulation (Bt) (SCWG 1998). The C horizon is the final soil horizon before bedrock. Comparatively, the C horizon is less affected by pedogenic processes that the A and B horizons go through. Instead, the C horizon goes through the process of gleying and accumulates calcium and magnesium carbonates an other more soluble salts (SCWG 1998). Forest soil horizons will vary from region to region and depend on what tree species and vegetative flora grow in that area.

Understanding the standardization of soil horizon characteristics in the boreal setting is important in making connections on a broader scale. Soil properties tend to vary regionally and differ depending on species compositions, slope, temperature, and mean annual precipitation. To make the connections between the changes brought on by forest fires and harvesting operations, it is important to know what variables we expect to change and distinctly monitor them while omitting other characteristics that are less to do with forest fires and harvesting operations and more to do with the changes in soil properties brought on by these disturbances.

Wildfire:

Soil properties

Soil organic matter (SOM) is composed of Nitrogen (N), Phosphorus (P), Sulphur (S) and Carbon (C). Carbon comprises approximately 50% of the SOM (Stevenson, B.A., et al. 2016). Erosion can be a problem for many forests in a post fire setting. The temperature of the fire as well as severity and intensity play an important role in the predictability of the soil properties in a post wildfire setting. The main changes to soil properties at lower temperature fires (< 200 Degrees Celsius) are composed mainly of biological changes. This includes reduction of microbial biomass and the destruction of seed banks and fine roots. Physical properties such as water repellency and aggregate can be altered as well (Santin, C. Doerr, SH. 2016). Temperatures above 200 degrees celsius begin to alter the chemical properties of the soil through combustion of organic matter, production of pyrogenic organic compounds and increases in soil PH (Santin, C. Doerr, SH. 2016). The combination of all these tends to lead to a more friable and erodible soil. (Santin, C. Doerr, SH. 2016). Erosion is not always present after a wildfire, however. A study conducted in Northern Saskatchewan concluded that the rapid colonization by the liverwort (*Marchantia poly~norpha)* and mosses such as *Polytrichum pili- ferum, P. juniperinum,* and *Ceratodon purpureus* helped to prevent significant soil erosion (Scotter, G.W. 2019). It was also concluded that the long seven month freeze in the winter, as well as shallow soil conditions and lack of impeded water infiltration rates could also reduce the threat of erosion (Scotter, G.W. 2019).

Erosion poses a greater threat on sloped regions in the boreal forest. Loss of productive vegetation and litter in a post wildfire setting, combined with a loss in soil structure and increased water repellency can lead to enhanced erosion. This ultimately leads to the acceleration of surface soil loss in the post fire setting (Santin, C. Doerr, SH. 2016).

Presence of SOM in a post wildfire setting is largely dependent on fire intensity, vegetation type, fuel load, soil texture and slope. Lower intensity fires tend to increase

TOC due to input of partly charred organic material (Knicker, H. 2007). In the long term, higher intensity tend to reduce TOC. Intense fires remove the upper few centimeters of the soil. These intense fires also combust above ground organic material and leaf litter which ultimately decreases the organic matter inputs into the soil. The soil temperature also increases with its exposure after the burn. The increased soil temperature increases microbial activity and therefore increases the mineralization of the remaining SOM (Knicker, H. 2007).

Water levels

After a fire, ash covers the top of the soil surface. For a time, it provides temporary protection against erosion processes. The capacity at which these processes are defended depends on the severity at which the surface layer of ash is produced (Pereiera, P. et al. 2018). Ash created at higher intensity fires tend to be very fine in material and incorporates into the soil profile. This can cause clogs in the soil pores and reduces water infiltration (Pereiera, P. et al. 2018). However, since the ash produced at higher temperatures tends to be of a finer structure, it is easily removed which leads to an increase in bare soil surface area. The rich carbonates produced from the ash typically creates a crust on the top of the soil upon wetting, and increases overland water flow which is a contributor to soil degradation (Pereiera, P. et al. 2018). Some argue that ash produced at high temperatures is very hydrophilic and can increase water retention and the overall water table (Beatty, S. M. Smith, J. E. 2013). It is suggested that high fire recurrence can decrease overall water repellency, which can reduce overland flow and erosion (Pereiera, P. et al. 2018). This may not necessarily be a good thing however. High fire recurrence causes a high degree of nutrient and organic matter loss which is necessary for vetegative species to persist (Pereira, P. et al. 2018). Soil erosion is most prone to occur immediately after a wildfire disturbance, especially those on a slope. The nature of a fire is to climb the fuel ladder, where in a case of a sloped environment, the is a preheating of the fuel on the higher end of the slope, which decreases the moisture content in the fuel and causes a hotter and dryer burn (Beatty, S. M. Smith, J. E. 2013). Wind and rainfall immediately after the burn play an important role in the degree of soil degradation. The lack of ash cover on slopes from wind blow off can increase the impact brought on by rain drops and facilitates soil compaction and sediment detachment (Pereiera, P. et al. 2018).

Mycorrhizal development

Ecto-mycorrhizal fungus (EMF) development is lowest after a wildfire disturbance (LeDuc, S.D. et al. 2013). The abundance of EMF is primarily dependent on species composition and the degree of vegetative loss succeeding a wildfire. Fire may affect the EMF community directly through intense heat induced mortality, or indirectly by altering the plant-host composition or by changing characteristics in the surrounding environment (LeDuc, S.D. et al. 2013). Less severe fires that do not remove the entire overstory, especially the dominant leading species, tend to have lesser impact on the EMF community. Since the EMF community is in deeper soil pockets and low intensity fires only scorch the surface soil (the top few centimeters), there is a reduced impact (Barr, J. et al. 1999). There have been multiple findings (LeDuc, S.D. et al. 2013; Barr, J. et al. 1999) that suggest EMF taxa change over time. As species composition and understory development gains more complexity, there is a higher degree of mineralizable nitrogen accumulation in the soil which may play a role in what composition of taxa exists in the soil (LeDuc, S.D. et al. 2013; Barr, J. et al. 1999). Studies have also shown that the total material burned can alter the species composition of the EMF community. Altering post wildfire environmental conditions like the addition of a higher volume of down woody debris may play a role in shifting the EMF community from plant-symbiotic ectomycorrhizal (EM) fungi to more saprotrophic fungi (Owen, S. et al. 2019).

Harvest

Soil properties

Soil properties in the post-harvest setting primarily depends on the harvest method being utilized by the operations company. Where selective tree harvesting may have minor effects on the soil, large scale clear cuts with site prep like scarification following the harvest may cause massive alterations to the soil quality (Hope, G. D. 2007). Using the clear-cut method, followed by scarification site preparation may initially cause significant changes in soil chemistry in the first year after the harvest.

However, in year 10 after a harvest the chemical concentrations have largely been ameliorated (Hope, G. D. 2007). Bulk density of the soil is expected to decrease over time as the increased soil carbon causes a higher degree of abundant fine root structure which contributes to an improvement in soil structure (Hope, G. D. 2007). Much of Canada's boreal forest is victim to at least a century of fire suppression (Hatten, J. et al. 2005). This is cause for increased fuel loading which may result in larger slash piles in the post-harvest setting (Hatten, J. et al. 2005). It is suggested that low intensity ground fires prescribed to burn slash pile replicate a small lightning strike and have little to no effects on the soils chemical properties or physical attributes. This suggests that little to no below ground restoration would be needed in a post-harvest setting, following a prescribed burn (Hatten, J. et al. 2005).

In scarified soils, frost heaving can play a devastating role for vegetative survival in a harvested stand. Frost heaving occurs when there is an upwards swelling of mineral soil from freezing water in the deeper horizons of the soil (de Chantal, M. et al. 2006). Deep scarifications trenching tends to be the main cause of this, where deeper soil horizons are exposed and accumulate water before the winter sets in (Bergsten, U. et al. 2001). Frost heaving can kill the majority of seeds and living ground litter that exits. Some suggestions to negate frost heaving include a shallow scarification method where the only soil horizon disturbed is the A and Ah layer, where the B horizon (the beginning of mineral accumulation) is left untouched (de Chantal, M. et al. 2006). This cannot act universally as scarification and tree planting methods change regionally depending on site conditions (Bergsten, U. et al. 2001).

Water levels

Pre-commercial thinning is a common silvicultural treatment in operations. This treatment drastically reduces the number of trees in the canopy which are responsible for maintaining the evapotranspiration process. The result of this can be a significant rise in the water table (Jutras, S. et al. 2006). This is because the evapotranspiration process is curtal in regulating the hydrological balance. The rise of the water table is directly related to the basal area removed, which indicated the importance of woody debris in regulating water table depth in forest lands (Jutras, S. et al. 2006). Other studies (Xu, Y. J. et al. 2002) have also shown that the water table is directly related to the coarse woody debris that is removed, and the first year after the harvest shows the greatest change in water table rise. The years following show a gradual settling of the water table as new coarse woody debris take hold of the disturbed land (Xu, Y. J. et al. 2002; Jutras, S. et al. 2006). Trenching to lower areas outside of the harvest stand can sometimes be utilized to allow adequate filtration where the water table is expected to rise particularly high (Xu, Y. J. et al. 2002).

Mycorrhizal development

Much like in the case of wildfires, Mycorrhizal development is dependant on what species exists and what species is left behind. In a clear cut followed by scarification, EMF is limited, but gradually develops as coarse woody debris develops over time (LeDuc, S.D. et al. 2013). It is also suggested that unburned debris may change the taxa of EMF, and there may be a shift in the EMF community from plant-symbiotic ectomycorrhizal (EM) fungi to more saprotrophic fungi (Owen, S. et al. 2019).

Where are there gaps?

The literature presented above will act as the data used to generate an in depth comparison examining the difference between the soil properties in a post wildfire setting and post harvest setting. The data will be used to find holes in modern management strategies that attempt to imitate the effects of a wildfire and provide better strategies that might help to represent a given goal. The effects of wildfire and harvesting on soil properties are complex in that they vary regionally and on multiple scales. It may be impossible to fully replicate a wildfire through harvesting practices due to the scale and nature of the disturbance. However, within the management plan of a harvesting operation, the strategies used to rehabilitate forest soils are constantly adapting and changing as literature is presented. It is important to continually adapt our strategies in soil management to generate the best possible soil conditions for future forests to exist

METHODS & MATERIALS

This is a literature review-based thesis, where all data is gathered from peer reviewed articles and compiled together to draw conclusions about the differences between soil properties in harvesting operations and wildfire disturbances. The primary focus of this thesis is to outline the chemical compositions of each disturbance, as well as the characteristics of the water table and lastly, the changes in mycorrhizal communities shortly after each disturbance.

When choosing what articles to reference, some search limitations are used in order to generate the most accurate regional piece of literature. The peer reviewed articles must come from research projects conducted in the Canadian boreal forests. The soil properties in more southern regions of Ontario are different from boreal regions because the fire frequency and intervals are significantly different in semi deciduous forests (I. P. Vijayakumar, et al. 2016). Using research from these regions might generate a bias in the ultimate conclusion of this thesis. Literature from outside the country is avoided, but they are used to back up statements made from research conducted inside Canada. For example, Spanish researchers are currently conducting a lot of experiments regarding the reaction of soil to different slopes. The conclusions drawn from that research is used to back up the conclusions drawn from research in the Canadian Rockies. The search limitation means it cannot be used as a primary point, but rather a supportive piece from a usable literature source.

The ultimate goal is to show the comparisons of soil properties in a way that is easy to understand and follow.

RESULTS

Soil Organic Matter (SOM) and Bulk Density (BD) and water infiltration Properties:

Wildfire:

Given the volatility of wildfire burns and their fluctuations in severity, burs will be under two lenses; high intensity (>200 °C) and low intensity (< 200 °C) fires. Harvests will be strictly viewed using clear cut methods. Other harvest methods have profoundly different impacts on the soil and do not tend to replicate stand replacing natural disturbances (Wieting, C., et al. 2017).

To measure the soil properties in a post wildfire and post harvest setting, bulk density (BD) and total organic carbon (TOC) are used as primary indicators of changes in chemistry and physical changes.

Wieting, C., et al. (2017) conducted a study in the Boulder Creek Critical Zone Observatory in Colorado, USA. They compare soil property changes in a similar way. Using unburned soil as a control, they found bulk density increased with depth from roughly 0.4 g/cm^3 at the surface to 1.0 g/cm^3 in their deepest subsection (Wieting, C., et al. 2017). In low temperature fires the bulk density displayed a more variable trend, with bulk density averaging 0.4 g/cm^3 at the surface and 0.7 g/cm^3 in the deepest subsection. High temperature burned sites displayed a more homogenized bulk density with a surface bulk density of 0.7g/cm^3 and 0.9 g/cm^3 in the deepest subsection (Wieting, C., et al. 2017).

Wieting, C., et al. (2017) use loss of ignition (LOI) as a metric of TOC. They found LOI values to be around 16% between 0 and 2.5 cm of unburned soil sites, and decreased to 6% at the bottom of the soil core. Low temperature burns showed LOI values at the top of the core averaging 35% and 9% towards the bottom. In this case, high temperature burned soils also became homogenized with depth. Average LOI values were 9%. Similar studies have shown results to be similar; Ebel,. (2012) found unburned LOI values ranging from 11.2 to 20.0% towards the surface and 6-7.3% in the deeper subsections. Similar findings by Ebel (2012) show high temperature burns to have an LOI of 9% homogenized throughout the sample core, and low temperature burns showing 3.1-5.8% LOI in the top 4 cm (Ebel, A. B., 2012).

Harvest:

A case study by Wang, J., et al. (2005) attempted to quantify the relationship of mechanized harvesting practices on soil bulk density. Their findings describe bulk density in the context of pre and post-harvest points across the site as well as pre and post-harvest points in skid trails exclusively.

Soil bulk density across the site averaged 925.2 kg/m^3 in pre harvest sites and 954.4 kg/m3 in post harvest sites. That is a change of 29.2 kg/m^3. In sites measured exclusively in skid trails the data showed more variance. Pre-use bulk density measured an average of 1313.6 kg/m^3 and pose use Bulk density measure 1440.0 kg/m^3, with a density change of 126.4 kg/m^3 (Wang, J., et al. 2005). It was found overall that the number of skidder passes correlates with the bulk density on skid trails. However, it was found that the increase in bulk density with skidder passes was not exponential. *Wang, J., et al. 2005* suggests that after the first pass the bulk density statistically levels off, with only minor increases with second and third passes. Results show the bulk density to be 0.8979 g/cm^3 , after the first pass, increasing to 0.8995 g/cm^3 after the second, and 0.9931 g/cm^3 after the sixth pass.

Effects on microbial and bacterial communities:

Wildfire:

Soil fungal and bacterial communities are typically defined by vegetation communities, moisture regime, pH, total carbon, and texture (LeDuc, S.D. et al. 2013). *Whitman, T., et al. 2019*, describe one more variable that may affect microbial and bacterial communities in the boreal forest, and that variable is burned versus unburned soils. This study was conducted near Great Slave Lake in the Canadian boreal forest. The test looked for similar phylotypes in bacterial and fungal communities in burned and unburned sites. Other fungal and bacterial indicators like pH and moisture regime, were controlled as needed. Their results show that fire had little effect on bacteria and fungal communities in wellands, where here the greatest community indicator was vegetation types (Whitman, T., et al. 2019). Wider ranges of responsiveness to wildfire occurred in dryer upland regions. The most abundant bacteria in these sites (4% inburned samples and 0.09% in unburned sample identifies as an *Arthrobacter sp.* The third most abundant bacteria (2% in burned sites and not detected in unburned sites) identifies as *Massila sp*, and is known to be a positive fire responder (Whitman, T., et al. 2019). Bacteria showing to be fire-responsive, different bacteria tended to show different trends as burn severity changed. *Aeromicrobium sp, Blastococcus sp,* and *Massilia sp,* show increased abundance with increasing burn severity (Whitman, T., et al. 2019).

There were similar findings with fungal communities. There were wide ranges of responsiveness to burned vs unburned sites. *Dothideomycetes* and *Cystobasidiomycetes* tended to be enriched in burned sites and *Mortierellomycotina* tended to be depleted in burned sites. There were also fire responsive fungal communities that stood out such as *Neurospora* and *Geopyxis.* Much like the bacterial communities, there was one fungal community that showed increased abundance with increased fire severity. *Penicillium* seemed to follow this (Whitman, T., et al. 2019). *Fusicladium, Clayptrozyma,* and *Sorariomycetes* had a significant fire response but unlike *Penicillium,* they did not continue to grow in abundance with increasing fire severity (Whitman, T., et al. 2019).

Harvest:

As described above, fungal and bacterial communities depend largely on soil pH, vegetation communities and total carbon. All of these are being changed in harvesting practices, so the assumption can be made that there may be effects on fungal communities because of this (Shrestha, B. M., Chen, H. Y. H. 2010). *Varenius, K., et al. (2016),* conducted a study on the long term effects of tree harvesting on ectomycorrhizal fungal (EMF) communities in the boreal forest. They used 20 of the most frequent EMF's in natural forest stands and compared them to what was present in clear-cut and shelterwood harvests. For the purposes of this research paper, the data from natural stands and clear-cut harvests will be the only data used, with shelterwood cuts being omitted. Similar to the fire sequences, there were certain species that increased and decreased with abundance depending on disturbance and severity. In Natural stands, *Piloderma* *sphaerosporum* showed healthy increases in abundance with a frequency of 85% in natural stands and 91% in clear cut stands. Other species showing mean frequency increase include; *Cortinarius semisanguineus* (+10%), *Suillus variegatus* (+8%), *Cortinarius brunneus* (+14%). Conversely, there were some species showing a significant drop in abundance after a clearcut harvest. Those species include; *Tylospora fibrillosa* (-19%), *Cenococcum geophilum* (-24%), *Piloderma byssinum* (-27%) and *Cortinarius caperatus* (-12%) (Varenius, K., et al. 2016).

Table 1. Final chart comparing the largest and most frequent differences of soil, water and EMF communities in the boreal forest between harvesting practices and wildfire disturbances.

Harvesting	**Wildfire**
Increased localized bulk density. I.e. skidder trails	Overall homogenized bulk density during high intensity burns
Variable increase and decreases in common EMF boreal species. Their presence is site dependent	Reduction of Microbial fungi. Fire adapted species take over the site
Water infiltration can increase depending on harvesting method	Soil water repellency can increase after a high intensity fire
Chemical properties are not changed by harvesting, but the return of different species may change the chemical balance in the soil	Chemical properties in the soil are drastically altered after a fire with a temperature above 200 degrees Celceus
Erosion can occur as a result of harvesting	Soil is prone to erosion in a post fire setting

Soil organic matter may increase directly after a harvest, but numbers return to normal after several years	Soil organic matter tends to decrease with high intensity fires
Pooling is more common is harvested sites with localized heavy machine traffic	Overland water flow may occur from ash particles clogging soil pores
The water table may rise substantially after a harvest	High fire recurrence can lead to nutrient reduction
aggregated soil from harvesting is not affected by rainfall compaction	Rainfall on bare soil can cause soil matting and lead to compaction
Soil scarification can affect mycorrhizae that reside in the deeper horizons of soil	High intensity fries can alter EMF species but their main change comes as species compositions changes in the successional stand

DISCUSSION

Given the literature cited above, and the specific data presented by literature sources in the results section, there are connections we can make in the similarities and dissimilarities between wildfire disturbances and clear-cut harvesting practices. Regarding the physical and chemical nature of soils in the boreal forest; High intensity wildfires tend to burn soil organic matter in the top centimeters of the soil, resulting in a loss of soil structure. The loss of soil structure can increase soil bulk density if enough material is lost (Wieting, C., et al. 2017). Water infiltration rates can be affected by increases or decreases in bulk density. An increase in total BD can lead to loss of water infiltration and more surface run-off, leading to extensive soil erosion (Xu, Y. J. et al. 2002). Harvesting practices tend to have less of an impact on the total bulk density on a site, where major increases in BD are limited to skidder trails and landings. As less material is being removed from the forest floor, bulk density changes may remain null. Total carbon losses in wildfire scenarios may exceed the losses brought on by harvesting practices in removing ground litter alone. These limits harvesting practices to have mainly physical changes to the soil and its properties, where stand replacing fires may have a chemical followed by profoundly physical changes (Shrestha, B. M., Chen, H. Y. H. 2010). Low intensity fires seemed to have had less of an impact of bulk density. We could therefore assume there would be less effect on water infiltration and make that stand less susceptible to erosion and run-off.

Results show that both clear cutting and wildfire have profound impacts on microbial development in the soil. Both disturbance patterns show an immediate change of EFM communities. However, the main changes in species are not a long-term presence. The main indicators for these communities remain as vegetation type, soil carbon, and pH. As succession begins again, the abundance of EMFs that benefited from the immediate disturbance appears in most cases to ramify itself and revert back to what was present before in the long term (Varenius, K., et al. 2016).

CONCLUSION

Forestry and harvesting practices are two disturbances that frequent the boreal forest. Modern policy demands our clear cuts attempt to replicate that of a natural disturbance like wildfire. Based on the results and the literature reviewed in this paper, it is clear that there are some similarities and some glaring differences between the two that need to be addressed. In general, fires have a bigger role in the immediate chemical changes in the soil, which ultimately affect pH, bulk density, water infiltration and erosion. Harvesting effects tend to be more on the physical side because of less overall soil compaction and increases to bulk density.

The goal of this paper was to analyze literature in the forest sector to paint a bigger picture of what is being accomplished in forestry. In this paper it is not the numbers and the data that represent the results, but the connections made from them. It cannot be answered for certain whether modern harvesting practices replicate what a natural disturbance would be. This is because each site is different and complex in its own way. Dats from one region cannot translate to data from another region. Soil structure, forest structure and ecosystem structure vary from the finest microscale to the broadest regions.

This paper only took into clear cutting and forest fires into consideration, with little regard for variables that would apply if we looked at this on a stand level. For example, the type of machinery used to harvest would have a profound impact on the soil and the vegetation.

This thesis has demonstrated that there is not one simple formula for emulating a natural disturbance through harvesting. While there are some key similarities and functions, it is more important to understand the relationship and connection each piece of the environment has to the next, and approach each harvest independently because each stand will behave differently and require unique tending and treatment to accurately replicate what a normal natural disturbance would be in that region. It is suggested that more research be done on these environmental relationships to better our understanding of the forest and its functions and continue our reach for true forest sustainability.

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