The Effects of Fire and Salvage Logging on Early Post-Fire Succession in Mixedwood Boreal Forest Communities of Saskatchewan

A Thesis Submitted to the
College of Graduate Studies and Research
In Partial Fulfillment of the Requirements for the
Degree of Master of Science
in the Department of Geography
University of Saskatchewan
Saskatoon

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Abstract

This study compared the effects of fire severity and salvage logging on early successional vegetation in the mixedwood boreal forest upland of Saskatchewan. The effects of salvage logging on post-fire forest stands are poorly understood. Few studies have investigated the short-term effects of salvage logging on the regeneration of boreal plant species or the long-term impact on overall forest composition and diversity. This study examines salvage logged and wildfire leave stands across three burn severity classes (no burn, low/moderate burn, and high burn) over two time periods (1 year post-fire and 10 years post-fire). The results indicate that salvage logging has a significant impact on the early regeneration of burned mixedwood boreal plant communities with the effect still evident in forest stands ten years post-fire. Salvage logging has long-lasting residual effects on boreal forest plant community development.

Salvage logging one year post-fire reduced the number, diversity, and abundance of species within each of the burn severities, creating a less abundant and simplified plant community. It was also shown that salvage logging one year post-fire tended to create more homogenous plant communities similar to those communities typical of areas of moderate burn severity, constraining the effects of burn severity and decreasing the range of the vegetation communities. These findings are less pronounced, but still evident, within salvage logged stands ten years post-fire as three regrowth cover types have developed, characterised by no disturbance, moderate disturbance either by fire or salvage logging, and severe disturbance. The convergence of plant community characteristics between burn severity classes across logging treatments suggests that the effects of salvage logging do not have long lasting effects within areas of high burn severity.

Acknowledgments

I am very grateful for all the help and encouragement offered to me by my supervisor Dr. O.W. Archibold, Dr. Robert Wright, and committee member Dr. Dirk de Boer, for all of their insight and guidance. I must also thank Dr. Jeff Thorpe for his contributions as the external examiner. Funding, field training, and equipment for this research project were obtained through the Forestry Development Fund of the Saskatchewan Forestry Centre and Saskatchewan Environment. I could not have completed the fieldwork without the assistance of Dwayne Keir, Robert Schmidt and Ame Wunderle, who helped me through many bug infested days, identifying plants and having a great time camping in Northern Saskatchewan. I have to acknowledge Ed Beveridge and Genny Greif, who started the Burned Forest Monitoring Project, as they laid the foundation that my field research was based on. I must also thank Weyerhaeuser Canada Ltd, specifically Rod Pshebnicki and Deb Desrosiers who helped out with many forestry related questions.

My family deserves a lot a graditude from me as they all helped me out during my studies. My parents, Garry and Ramona, were always there for encouragement and support, for that I will always be indebted to them. My brothers, Quinn and Devin, and my sister Brooke were always there for me when I needed them, even though at times they might not have understood what I was doing. The Geography Department staff was always helpful and cheerful, making my time there quite enjoyable. I must also acknowledge my fellow graduate students in the Geography Department, who were always good for a laugh and a great time, making this an incredible experience. Thanks also go to Digit Ash, whom without I would not have gotten through this project with as much fun and understanding. Her encouragement and confidence were of great significance to me and helped me throughout my studies.

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1. Introduction:

The boreal forest is the dominant forest region in Canada, extending from Newfoundland and the Labrador coast to northern British Columbia (Rowe 1972). It is a complex and dynamic biome that is strongly influenced by natural disturbances, especially fire, which creates a canopy heterogeneous in stand structure and age. Fire is the most ecologically important stand-replacing disturbance in the boreal forest (Bonan and Shugart 1989; Barnes *et al.* 1998; Schulze *et al*. 2005). The boreal forest disturbance regime is also influenced by storms, insect and disease outbreaks.

Fire disturbances within the boreal forest consume the tree canopy, understory vegetation and organic layer of the forest floor, altering tree stand structure, vegetation patterns, and successional dynamics (Johnson 1992). The combustion of organics within the understory layer after a wildfire event leaves patches of bare mineral soil covered with a nutrient enriched layer of ash, and causes an increase in topsoil pH (MacLean *et al*. 1983), facilitating the quick germination of many shade intolerant, early successional species (Rowe 1983). The capability of regeneration by *in situ* propagules in a post-fire environment is dependant on the burn severity and depth of burn (Archibold 1979; Rowe 1983; Schimmel and Granström 1996), which ultimately influences successional processes and stand development.

Historically, the fire cycle in western Canada typically ranges from 50 to 100 years (Johnson and Rowe 1975; Bonan and Shugart 1989, Weir *et al*. 2000). A fire cycle is defined as the number of years to burn over an area equal to the entire area of interest (Johnson and Van Wagner 1985). Over the last century, the natural fire cycle has been altered by fire suppression and other human influences on the boreal forest. Long-term fire management policies, increased efficiency of fire detection and response, large-scale timber harvesting operations, and the expansion of agriculture have significantly altered the forest environment and the natural fire cycle (Weir *et al*. 2000; Timoney 2003). Boreal forest communities now commonly develop after an anthropogenic disturbance as opposed to a natural disturbance. The replacement of natural disturbance by logging may profoundly influence the structure and composition of the forest.

Burn severity influences early successional processes by determining the depth of burn, exposing patches of mineral soil exposure and consumption of the leaves and branches of the tree canopy, all of which affect the regenerative ability of boreal species (Rowe 1983; Schimmel and Granström 1996). Plants within the boreal forest have evolved in a fire driven ecosystem and have adapted to the effects of fire (Rowe 1983). For species which may regenerate by rhizomes or suckering (such as *Populus tremuloides* and *Betula papyrifera*) buds within the organic layer will suffer lower mortality rates when a shallow burn occurs, allowing for regeneration without the need for exposed mineral soil. Species which rely on seed dispersal for regeneration (such as *Pinus banksiana*) depend on a deep burn to consume the organic layer, leaving behind bare mineral soil and a more favorable seedbed (Rowe 1983; Schimmel and Granström 1996). Charron and Greene (2002) have shown that exposed mineral soil improves survivorship of both *Pinus banksiana* and *Picea mariana* seedlings while increasing depths of the organic layer cause elevated seedling mortality. The act of salvage logging disrupts the post-fire areas by tilling the soil with machinery and leaving a layer of woody debris over top of the burned surface, diminishing the area of open mineral soil used by aerial seed. Compounded by the removal of seed bearing branches, specifically those containing serotinous cones (*Pinus banksiana*) the aerial seed bank is essentially removed and input of seeds is relied on by cone bearing trees along the cut-block perimeter. This lowers the chances for aerial seed germination and ultimately creates successional stands dominated by species which rely on suckering (*Populus tremuloides*) for regeneration (Greene *et al*. 2006).

Within burned areas it is now common practice to salvage harvest post-fire mixedwood stands immediately following the burn. The act of salvage logging (clear-cut harvesting after a fire event) within burn areas causes a secondary disturbance which alters the forest structure and influences plant regeneration (Martinez-Sanchez *et* al. 1999; Kurulok 2004; Purdon *et al*. 2004, Donato *et al*. 2006; Greene *et al*. 2006). The initial conifer seedling regeneration and aspen suckering have been observed to be less abundant within salvage logged areas compared to wildfire areas, due to mechanical damage from harvesting and removal of the seed bank. Stress on the seedlings also increases due to altered microclimate conditions, increased sunlight and the tillage of the forest soils. The varied burn intensities within the fire perimeter, coupled with the effects of salvage logging, could delay forest regeneration and affect early post-fire succession in western mixedwood boreal forest stands.

After a fire disturbance, salvage logging decisions are made quickly to maximize the volume of merchantable timber which can be harvested before the timber depreciates in quality. Research with the Canadian boreal forest has shown that this creates profound changes in species richness and diversity (Kurulok 2004; Purdon *et al*. 2004) and tends to homogenize the stand structure within the early stages of regeneration. These decisions are made without the knowledge of the long term effects that salvage logging has on the forest ecosystem. More research and insight is needed on what effects salvage logging has on the forest ecosystem and this question needs to be properly addressed for recommendations on the future of salvage logging and forest resource management within the Western Canadian boreal forest. A comparative analysis of the effects of fire and salvage logging on forest flora and microclimate is the main component of this study.

1.2 Objective and Hypotheses

The principal objective of this study is to determine if salvage logging within areas of different forest fire burn severities has an effect on early succession in a mixedwood boreal forest community. The effect of burn intensity and salvage logging was investigated in three comparative mixedwood stands in the boreal forest of Saskatchewan. This study incorporates species composition, environmental characteristics, plant community comparisons, and microclimate variations between unlogged and salvage logged forest stands one and ten years post-fire. To address the objective of the study, the following research hypotheses were developed:

1. H_o: plant communities of unlogged burn areas = plant communities of salvage logged burn areas.
2. H_o: plant communities and microclimate do not vary among burn severities.
3. H_o: plant communities of salvaged logged burn sites converges with plant communities of adjacent unlogged burn sites.

The impacts of salvage logging on the forest resource will be assessed in light of the results of the study.

2. Background

648 forest fires burned in Saskatchewan in the summer of 1995. Over 1,600,000 ha of forestland were burned (IFFN 2005), with a record number of forest fires occurring within the southern commercial forest. Salvage logging in 1995 and 1996 reached record levels, creating over 1,200 jobs and producing an estimated 1.4 million cubic meters of fire-killed timber (Saskatchewan Environment 1996; Saskatchewan Environment 1997; Greif 2000). This large output of salvaged timber was made possible by the use of portable mills, an improved technique for utilization of charred stems and a newly developed market for salvaged timber products (Greif 2000; Araki 2002).

Concern about the effects of salvage logging on the post-fire environment and the dearth of research on the impact of burn severity on forest succession prompted the Fish and Wildlife Branch of Saskatchewan Environment to initiate the Burned Forest Monitoring Project (BFMP) in 1995. That project created a baseline on the effects of several large 1995 forest fires near Beaupré Creek and Mahigan Lake in Saskatchewan. The project focused on burn severity patterns and their effects within fire perimeters. The field information collected was also intended to be used as baselines for comparison with salvage logged areas of the same forest type to assess the effects of post-fire logging practices on the forest ecosystem.

Permanent sites consisting of a variety of forest stand types were established within Weyerhaeuser Canada Ltd's Prince Albert Forest Management Agreement (FMA) area. Through cooperation with Weyerhaeuser, the study sites were reserved from logging in the interests of research on the forest ecosystem. A grid pattern of survey lines spaced at 50 meters was established at three study sites and fire severity was recorded at each grid point using scorch heights on trees and degree of consumption of the ground flora and surface duff. These permanent sample plots were designed as part of a long term monitoring program which would catalogue the effects of fire severity on plant succession and the ecosystem over a ten to twenty year period. Adjacent to the study sites were areas that were salvage logged following the fires, or had been logged just previous to the fire and then were site-prepared and planted in 1996 or 1997. This created an ideal research area for comparing post-fire succession in wildfire and salvage logged areas. However, due to a change in departmental priorities within the Fish and Wildlife Branch of Saskatchewan Environment all work on the BFMP was halted in 1997 and no further research was conducted (Greif 2000).

Before the project was halted, burn severity maps were created for the three sampled sites with markers left to facilitate relocation for future research. A four-class burn severity rating system was also devised. A portion of the present study expands the initial work on fire severity effects conducted by the staff of the BFMP in the Beaupré and Mahigan Lake areas.

3. Literature review

3.1 Introduction

Salvage logging increasingly has become a very common practice within boreal forest management to harvest fire-killed merchantable timber present after fire. Previous ideologies within forest management and general public perceptions are that forested areas affected by a major fire disturbances are considered wasted and damaged. The loss of the ecological and aesthetic qualities of an old growth forest often leads to a misunderstanding of the vital role that fire plays within the boreal forest ecosystem. This attitude towards post-fire forest environments has allowed forestry practices to increase within recently burned areas to harvest the charred stems before they become what the industry may refer to as a “wasted” forestry product. Ecologically, burned forest stands are hot-spots of boreal plant diversity, early successional species regenerate and stand turn-over occurs while burned stems and dead trees act as instruments of shade, nutrients and homes for many species of plants and animals. Consequently, there is no “waste” on a biological scale (Rowe 1983; Nappi *et al.* 2004).

Salvage logging under current legislation within Saskatchewan does not take into account the ecological implications of disturbance on the post-fire productivity of forest stands. Forest companies are encouraged to harvest disturbed stands as a measure to ensure allocated timber supplies are not reduced due to large-scale wildfires. This places pressure on forestry companies to salvage harvest areas disturbed by wildfire, increasing the amount of disturbance within the wildfire perimeter without an understanding long term effects that salvage logging incurs on the boreal forest ecosystem. As the frequency of salvage logging increases throughout the boreal forest, there is growing uncertainty on what effects this practice has on the post-fire integrity and health of the forest.

3.2 The mixedwood boreal forest of Saskatchewan

The mixedwood boreal forest of Saskatchewan has an approximate area of 11,156,000 ha and extends across the province in a northwest to southeast direction between 52° and 56° North latitude. The mid-boreal upland ecoregion is located within the Boreal Plain Ecozone. The mixedwood upland is characterized by trembling aspen (*Populus tremuloides*), white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), white birch (*Betula papyrifera*), and balsam poplar (*Populus balsamifera*), with *Picea glauca* and *Abies balsamea* found prominently in old growth stands. Depressions and areas of poor drainage form stands of black spruce (*Picea mariana*) and tamarack (*Larix laricina*). Jack pine (*Pinus banksiana*) is found on more rapidly drained sandy soils typical of sand dunes and plains (Rowe 1972; Canadian Forestry Service 1986; Beckingham *et al*. 1996).

The western mixedwood boreal forest area is composed of overlays of fluvial-lacustrine deposits and areas of glacial till. Soils found within this region include Luvisols, Brunisols, Gleysols and Organic soils (Canadian Forestry Service 1986). Luvisolic soils develop in moderately cool climates, under deciduous and coniferous forest vegetation. The soils form in well-drained areas of sandy-loam to clay based parent material. They are characterised by an eluviated light-colored A (Ae) horizon, a brownish illuvial B (Bt) horizon in which silicate clay has accumulated from the eluviated top layer, and a usually calcareous C (k) horizon. Brunisolic soils are well drained soils exhibiting brownish Bm or Btj horizons. In this region they are typically sandy in texture and occur in areas under deciduous and coniferous forest vegetation. Gleysolic soils form in poorly drained areas that show signs of prolonged periods of soil saturation with water and a lack of oxygen. They are defined by the presence of grey gleyed colours, prominent mottles or both within a soil horizon located within 50 cm of the mineral soil surface. Organic soils form in low lying areas which are water saturated for much of the year and have developed from deposits of fen or bog peat. Organic soils support coniferous vegetation comprised principally of *Picea mariana* and *Larix laricina*.

3.2.1 Forestry in Saskatchewan

Each year an average of 24,000 ha of mixedwood boreal forest is harvested from Crown lands in Saskatchewan (Saskatchewan Environment 2003). Approximately 58 percent of the commercial forestland is allocated to Forest Management Agreement areas (FMA) with approved Forest Management Plans and Environmental Impact Assessments (Figure 1). The majority of the harvest within the allocated FMA is done through clear-cutting with extensive road networks throughout the region. Disturbances, such as fragmentation of the forest and soil compaction, have led to concerns for the long term biodiversity of the mixedwood boreal forest (Saskatchewan Environment 2005).

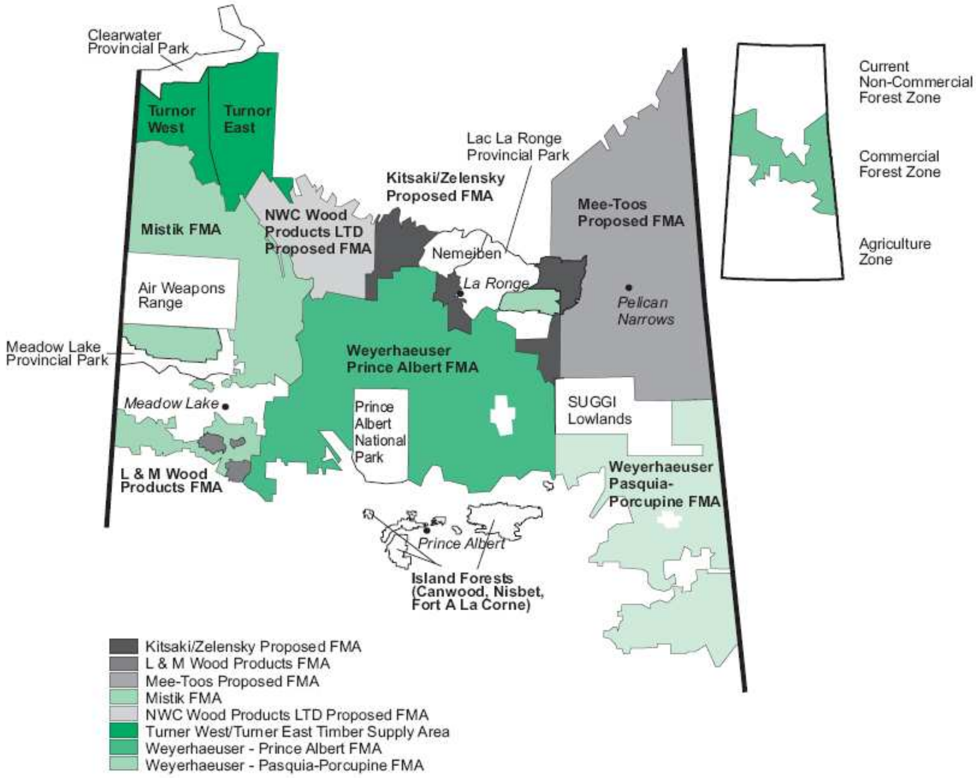

Figure 3.1 Forest Agreement Areas (FMA) in Saskatchewan's forests as of 2001 source: Saskatchewan Environment, 2003.

Based on a ten-year average for the period 1987-97, approximately 500,000 ha of the mixedwood forest is burned annually by an average of 785 fires. This disturbance is equivalent to 500% of the area harvested each year in Saskatchewan. The volume of merchantable forest burned each year is approximately 3 million cubic meters with a potential value of $72 million for the forest products industry of Saskatchewan (Saskatchewan Environment 1998). Following a wildfire disturbance, accessible burned forest stands are assessed immediately and salvage harvesting operations ideally occur within the first two years following a fire to utilize the burned timber before decomposition renders it unmerchantable. Salvage harvesting operations are focused on the first two years post-fire to safeguard the trees regenerating after disturbance.

3.3 Wildfire disturbance regime

The boreal forest is a wildfire ecosystem and fire plays an essential role in stand dynamics, killing existing forest trees and decreasing understory organic matter (Johnson 1992). Wildfire plays a central role in the forest structure, composition, and ecological function of the boreal forest. Crown fires occur where a predominantly coniferous overstory builds a large and very flammable fuel load over time. Bonan and Shugart (1989) also suggest this is related to the slow decay of twigs and needles with low hanging branches which allow ground fires to quickly spread into the canopy. Deciduous canopies tend to burn with less intensity, as recorded by Wang (2002), due to higher moisture contents within the canopy and understory. Consequently, mixedwood stands tend to burn in a more heterogeneous pattern with varying degrees of burn intensity and severity within the wildfire perimeter (Rowe and Scotter 1973; Johnson 1992).

The heterogeneity of the forest is maintained through variations in the frequency and severity of forest fires. Wildfires range from ground fires, which burn in the organic layer and root systems of the forest floor, to surface fires, which consume the organic layer and shrubs in the understory, scorching the bottom of tree trunks, to full canopy crown fires that may reduce most of the leaf and branch biomass to ash and charcoal (Johnson 1992; Archibold 1995; Johnson and Miyanishi 2001). The size and frequency of wildfires is highly variable, creating both small and large scale disturbances which produce a mosaic of young, middle-aged and old aged forest stands throughout the boreal forest (Johnson 1992; Rowe and Scotter 1973). The availability and condition of fuels, such as standing dead trees (snags), ladder fuels, small trees (seedlings and saplings), dry litter, and any other decaying material in the area, affect fire severity (Archibold 1995;

Franklin *et al.* 2002). Fire severity is further influenced by weather conditions at the time of the fire and during the antecedent period (Johnson 1992),

3.3.1 Plant adaptation and succession

Plants within the western boreal forest have evolved with fire and are adapted to this form of disturbance, and even depend on fire for regeneration. Adaptive characteristics include serotinous cones, root and trunk suckering, and small wind dispersed seeds that need exposed mineral soil created by fire for successful germination. Rowe (1983) differentiates five functional adaptations utilized by boreal forest plants to cope with frequent forest fire disturbances. In Rowe's scheme, forest species are categorized by reproductive strategy following disturbance. The five strategies are invaders, evaders, avoiders, resisters, and endurers (Table 3.1).

Table 3.1 Plant adaptations and strategies in the context of fire (Rowe, 1983)

Strategy	Description
Disseminule-based, propagating primarily by diaspores	
Invaders	Highly dispersive, pioneering fugitives with short-lived disseminules
Evaders	Species with relatively long-lived propagules that are stored in soil or in canopy
Avoiders	Shade-tolerant species that slowly reinvade burned areas; late successional, often with symbiotic requirements
Vegetative-based, propagating primarily by horizontal and vertical extensions	
Resisters	Shade-intolerant species whose adult stages can survive low-severity fires
Endurers	Re-sprouting species, shade-intolerant or tolerant, with shallow or deep buried perennating buds

Boreal plant species such as fireweed (*Epilobium angustifolium*) are early invaders of the post-fire environment, as they are shade-intolerant, needing an open canopy and areas of exposed mineral soil in which to establish. Invader species regenerate both by seed dispersal and vegetative means. Evader species such as Bicknell's geranium (*Geranium bicknellii*) and corydalis (*Corydalis sempervirens*) rely on seed banks within the soil to regenerate. Typical avoiders include *Abies balsamea* and bishop's-cap (*Mitella nuda*). These species often need some modification of the post-fire environment, such as a shade-producing leafy canopy before they can regenerate successfully. Resisters, such as *Pinus banksiana*, can survive low intensity surface fires due to the thickness of the bark which protects the underlying cambium. *Pinus banksiana* has also adapted to the fire regime by developing serotinous or semi-serotinous cones which open when the heat from a wildfire melts the resin bonds which seal the cone shut (Wright and Bailey 1982). Resister species, such as *Pinus banksiana* and *Picea mariana*, typically regenerate in high densities following a wildfire event providing the *in-situ* seed bank and mineral soil are available (Greene *et al*. 1999). Endurers, such as *Populus tremuloides*, exhibit large densities of saplings in post-fire environments due to suckering from the root systems.

The reproductive strategies of species present combined with the environmental conditions mould succession after a disturbance. Many boreal species display more than one method of reproduction (Rowe 1983). Following a wildfire event, early successional communities are dominated by species which utilize *in situ* seed bank germinants and vegetative reproduction plus seed dispersal tactics for regeneration (Archibold 1979; Lee 2004). Later stages are dominated by species which rely on vegetative regeneration, with old growth communities dominated by shade tolerant species that can reproduce under a fully developed canopy.

3.3.2 Fire impact

Wildfires within the boreal forest vary in their intensity and frequency, resulting in differing mortality rates for canopy and understory species across the forest. Fire frequency is defined as the average number of fires that occur per unit of time at a given point. Fire intensity is the rate at which heat is given off by the flame; this energy transfer allows adjacent fuels to become heated and burned, thereby transferring more heat and propagating the fire outwards (Johnson 1992; Kafka *et al.* 2001). The mortality of plant species within a wildfire will depend on the local intensity of the burn itself and the fires ability to raise the temperature of a species to a lethal level. The intensity, frequency, and size of wildfires in the mixedwood boreal forest directly affect the spatial and temporal patterns in the vegetation cover (Alexander 1982; DeGrandpre *et al.* 1993). Fire intensity determines the mortality of above ground vegetation in both the canopy and understory, but has less effect on the temperature and survival of vegetation and seed stored below the surface, both of which are crucial to successful regeneration of the post-fire environments.

Ecological effects of fire on the mixedwood boreal forest depend on the fire severity (Alexander 1982; Schimmel and Granström 1996). Fire severity is generally characterized as the amount of organic material, or duff, consumed by the fire and the extent and depth to which the soil is heated (Alexander 1982; Rowe 1983). Fire severity is different from fire intensity in that it is characterized by duff removal and depth of burn, while intensity is the measured as the rate at which heat is given off by the flame.

Severity looks at the physical effects of the burn on plant and forest floor structure, while intensity measures the behaviour of the fire. The period in which forest soils endure direct heating of a wildfire is usually short and the effects of heat transfer within the soil layer depend on the thickness of the duff layer and the heat capacity of the soil itself (Aston and Gill 1976). Therefore the level of soil heating and its effects on underground vegetation can be assessed through the amount of the duff layer that is consumed. A greater level of duff consumption results in a larger area of exposed mineral soil (Nguyen-Xuan *et al*. 2000). Schimmel and Granström (1996) found that depth of burn and amount of duff consumed affects the initial succession of boreal forest species, with the effects lasting over many years post-fire. Rhizomatous plant species regenerate quite quickly following light fire occurrences, while species which rely on seed dispersal need severely burned areas with an exposed seed bed of mineral soil for more successful germination. This is shown in the hypothetical model derived from Schimmel and Granström in Figure 3.2.

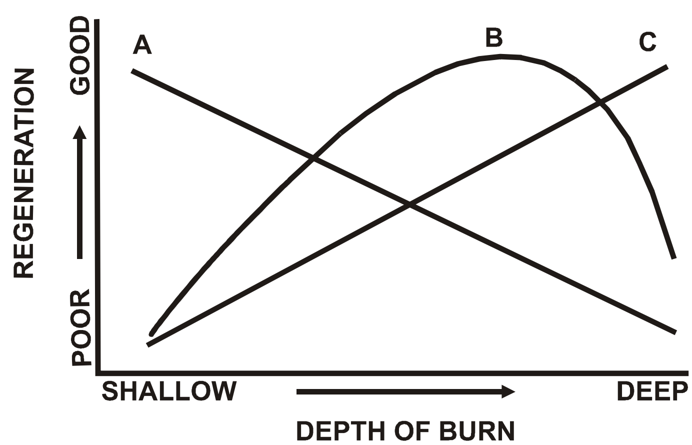

Figure 3.2 Hypothetical model of the regeneration of different categories of plants in relation to depth of burn: A - rhizomatous species; B - seed bank species; C - species that depend on post-fire seed dispersal.
source: Schimmel and Granström, 1996.

Fire severity will vary throughout the burned area due to the fuel load, natural fire breaks, duff moisture, and topography of the forest stand and weather conditions during the burn (Rowe and Scotter 1973; Johnson 1992). Miyanishi and Johnson (2002) reported that variations in fire severity within the burn perimeter create patches of burned, partially burned, and unburned areas. Such variability affects the amount of mineral soil exposure and is a key factor which determines of the early stages of succession. Fire severity generally tends to be higher in areas where conifer species dominate the canopy and lower where aspen is dominant (Wang 2002); this implies that fire severity will be heterogeneous within mixedwood areas (Flinn 1977; Granström 1993).

3.3.3 Standing-dead trees (snags)

Disturbance created by wildfire creates an environment with increased resources available to the plant species. Removal of the local vegetation cover increases light levels, nutrients and water for plant growth (Barnes *et al*. 1998). Post-fire mixedwood stand structure varies with the severity of the burn. Typically, it is composed of many standing dead and downed trees and varying amounts of litter on the forest floor. One of the longest lasting effects of a stand replacing wildfire is the presence of standing dead trees (snags).

The standing dead tree component of the post-fire environment plays an important role in the early successional stages. The removal of the canopy by a high severity fire immediately increases the amount of light that reaches the forest floor (Figure 3.3), and this alters soil and microclimate conditions in the post-fire environment (Ahlgren and

Ahlgren 1960). Snags will still cast shadows which may partially limit the amount of incident light at ground level and will help to moderate temperatures (Carleton and MacLennon 1994). Snags also provide an environment for a wide variety of early post-fire habitat specialists, such as bark beetles (*Scolytidae*) and wood boring beetles (*Cerambycidae*), which quickly colonize burned snags (Hutto 1995; Drapeau 2000). The large influx of wood-boring beetles imposes economic damage on the salvaged timber which may lower returns if harvest is delayed. However, post-fire environments also host a large number of woodpeckers (*Picoides*) which feed on the insects, and the snags provide habitat for many cavity nesters (Hutto 1995; Hitchcox 1996).

Plot N2 – 31.9 % Open Sky **Plot H1 – 72.9 % Open Sky**

Figure 3.3 Canopy coverage at the Candle Lake burn site in an unburned forest stand (left) and a high severity burned stand (right). Note the large number of burned snags still standing within the high severity burn.

Snags can remain standing up to 10-15 years after the burn (Figure 3.4), by which time most snags have fallen due to wind and decay. Snags can remain as a prominent element within post-fire environments for up to 25-30 years (Greif *et al.* 1999; Lee and

Crites 1999; Russell *et al*. 2006). The standing dead tree component of the mixedwood forest plays an important role in nutrient cycling as fallen snags decay slowly. Thus, they provide a long-term source of nutrients (Barnes *et* al. 1999) in contrast to the rapid release of nutrients which occurs through combustion (MacLean *et al*. 1983; Brais *et al* 2000).

Figure 3.4 Large numbers of standing-dead snags still persist in an area of high burn severity at the Mahigan burn site approximately 8 years after the fire.

3.3.4 Nutrient Cycling

Wildfire greatly alters the distribution of nutrients within the post-fire environment (MacLean *et al.* 1983). Changes in the radiation balance of a burned site due to removal of the canopy, blackening of the forest floor, removal of the insulating organic layer and altered moisture regimes may contribute to a shift in nutrient availability (Nguyen-Xuan *et al*. 2000). Fire temporarily increases the soil temperature and pH, as well as removing large amounts of high carbon:nitrogen woody debris which may promote nutrient cycling in the post-fire environment (Kimmens 1996). The volatilization of nitrogen through fire (Raison 1979) and increase of phosphorus in the form of ash create an initial nutrient imbalance following a fire disturbance (Certini 2005). The magnitude of these effects depends on the severity of the fire.

Within a burn perimeter, a complex blend of burn severity is found ranging from areas of severe high burn to residual green patches of unburned forest (Eberhart and Woodard 1987). Similarly, the nutrient regime will vary between the areas of burn intensity (Nguyen-Xuan *et al*. 2000), which creates an environment for early successional species which rely on wildfire disturbance. The long term result is a healthy heterogeneous forest stand (Johnson and Miyanishi 2001; Rees and Juday 2002). The introduction of salvage logging operations alters the post-fire environment away from the natural state by removing snags and disturbing of the forest floor. This may alter the environment making it less favourable for early successional species, thereby adversely affecting forest diversity.

3.4 Salvage logging

3.4.1 Salvage logging operations

Salvage logging within wildfire disturbances not only harvests fire-killed or damaged trees, but also removes the residual areas of unburned forest. This creates an additional incentive for forestry companies to invest resources in salvage. Salvage logging operations by Weyerhaeuser Canada Ltd in Saskatchewan, as of 2004, use a burn code to target areas when salvage harvesting. The burn code consists of five categories ranging from light scorching of the understory and lower tree trunk to a severe stand replacing high trunk canopy burn. These burn codes are used to target the most commercially viable areas within the burn perimeter (Pshebnicki per. comm. 2004).

Unburned or green timber within Weyerhaeuser's Saskatchewan FMA areas has on average a volume of 140-170 m^3/ha. When these forest stands are disturbed by wildfire, variable amounts of timber are rendered non-merchantable within the burned areas. Generally timber crews contracted by Weyerhaeuser will target burn codes 1 and 2 (stands burned 1m or 2m up the trunk) for salvage as they are the most valuable for the production of pulp and saw timber.

Burn code 1 stands are considered areas affected by a ground burn with timber loss being as little as 0 m^3/ha. However there may still be small areas within these stands with stems partially to completely consumed resulting in a 30-40 m^3/ha loss. Burn code 2 stands will have a higher timber loss as any charred portions of the wood will need to cut off before the stem is processed. These stands may incur losses as high as 50 m^3/ha. Burn code 3 stands are rarely targeted for harvest intended for pulp or saw timber as losses may exceed 70 m^3/ha. Burn code 3 stands, as well as burn code 4 stands, are generally targeted by third party operators who convert the wood into alternative products, such as rail road ties and fencing posts. Stands classified with a burn code of 5 or higher are too damaged to harvest as they would not provide any economic return (Pshebnicki per. comm. 2004).

3.4.2 Effects of salvage logging

Salvage logging operations, when feasible, will usually occur immediately after the fire is extinguished. All timber is usually salvaged within one to two years of the fire disturbance to ensure that it is commercially viable, because post-fire quality deteriorates quickly due to weathering of the timber and damage by invasive species, such as wood-boring beetles. The post-fire environment provides an important habitat for many early successional bird and insect species. Removal of standing timber from post-fire environments by salvage logging negatively affects early post-fire habitat specialists. Morissette *et al*. (2002) and Nappi *et al*. (2004) have both shown in separate studies that the removal of habitat and nesting sites through salvage logging creates a greater disturbance than fire alone, negatively affecting songbird communities. Russell *et al*. (2006) support this claim by showing that remaining snags within areas which have been salvage logged fall at an accelerated rate, shortening the time span for cavity nesting bird habitat. Older-aged, burned forest stands are essential habitat for many breeding boreal forest bird species (Stambaugh 2003); salvage logging within a burn significantly diminishes that habitat.

The act of salvage logging alters an already disturbed forest environment. Clear-cutting modifies the forested environment by removing the tree cover and understory shrubs from the area, opening up the forest floor to sun and higher wind velocities which severely alters the local microclimate, disturbs the forest floor, lessens the ability of the forest to regenerate naturally and creates different post-disturbance conditions than those following most natural disturbances (Franklin *et al.* 2002). This in turn affects soil properties, reducing soil fertility and altering the moisture regime and chemical attributes (Nguyen-Xuan *et al.* 2000). The removal of timber from the post-fire environment can be quite variable on the forest floor due to the amount of coarse woody debris left by the salvage logging operation (Figure 3.5). This coarse woody debris is mainly composed of unmerchantable wood materials such as branches, twigs, bark and wood chips. A large increase in the coarse woody debris cover within salvage logged areas compared to non-logged areas has been observed by Donato *et al*. (2006) and has been found to impede the regeneration of *Populus tremuloides* up to two years following salvage logging (Kurulok 2004).

Figure 3.5 Downed woody debris on ground surface in a high severity burn salvage logged site (right) and a high severity burn unlogged site (left) at the Candle Lake site.

During harvesting, heavy machinery may compact soil, especially along skid trails and roads (Archibold *et al*. 2000; Van Rees and Pennock 2001). This can create variable microsites by compressing soils and creating wetlands through the construction of ditches along skid trails and haul roads. Haul roads and skid trails also tend to persist in the post-harvest area for many years if they are not reclaimed after harvesting is complete (Buckley *et al.* 2003; Sumners 2005; Figure 3.6). The presence of skid trails within salvage logged sites increases the amount of exposed mineral soil available for aerial germinants within the first few years of harvest, which is a crucial period for successional regeneration. However, Greene *et al*. (2006) concluded that the exposed mineral soil from skid trails does not provide a hospitable environment for seedlings due to the removal of the seed bank from the salvage harvest and the drier soil conditions created by the removal of the forest canopy.

Figure 3.6 Salvage logging effects on the forest environment. A clear-cut stand one year post-fire (left), and a residual haul road (right) ten years after a salvage logging operation.

3.4.3 Impacts of salvage logging on boreal plant species

Until recently most of the research on salvage logging occurred in non-boreal forest stands (Martinez-Sanchez *et al*. 1999; McIver and Starr 2001; Lindenmayer 2004; Hanson and Stuart 2005; Donato *et al*. 2006; Lindenmayer and Noss 2006) and has focused on the disturbance effects on the dominant tree species. Studies in the Canadian boreal forest have mainly taken place in Quebec and Alberta (Brais *et al*. 1999; Crites and Hanus 2001; Fraser *et al*. 2004; Purdon *et al*. 2004; Greene *et al*. 2006) and have considered the understory components as well as the effects of fire severity within salvage logged sites.

Purdon *et al*. (2004) reports that salvage logging in areas of differing burn severity in the eastern Canadian boreal forest tend to homogenize understory composition and make it more representative of a severe fire environment. They note that species diversity fell within all fire severity ratings that had been salvaged logged. The overall effect is not to create a new successional pathway, but rather to create a sparser and more simplified post-fire environment than that seen in similar unsalvaged stands. Plant regeneration was less abundant along with a decrease in diversity, due to factors such as forest floor disturbance and accelerated forest floor drying creating a difference in plant communities between salvage logged and unlogged stands. Similar results are reported by Kurulok (2004) in early successional (2 years post-fire) mixedwood boreal stands in western Canada.

Initial tree establishment following salvage logging is typically reduced within the first four years. The mechanical process of tilling soils and the deposition of woody debris onto the burned forest surface tends to lower initial seed and suckering within salvage logged areas compared to wildfire controls. Martinez-Sanchez *et al*. (1999) found that conifer seedling regeneration was reduced by 33% in pine dominated forests of Spain, while Donato *et al*. (2006) support this claim as salvage logging reduced conifer regeneration by 71% within conifer forests of Oregon, U.S.A. Greene *et al*. (2006) also reports a loss of seedling regeneration, four times less for spruce and five times less for pine in salvage logged stands in comparison to non-salvaged stands. Within deciduous dominated forests Fraser *et al*. (2004) observed a severe impact on aspen sucker densities and growth in Alberta when salvage logging was implemented two years after the fire occurrence. Areas of severe burn combined with high salvage logging traffic showed significantly lower densities and growth height of aspen suckers in comparison to unsalvaged sites of the same burn severity.

Mechanical disturbance and local network of skid trails and haul roads within salvage stands may act as a conduit for invasive species. Kurulok (2004) observed an increase in species diversity within salvage logged stands 2 years post-fire, due mainly to weedy species such as common dandelion and Canada thistle. Similar changes in diversity have been reported by Hanson and Stuart (2005) in Douglas-fir/hardwood forests of northern California where invasive species were found exclusively within salvage logged stands.

Salvage logging following a wildfire disturbance within the mixedwood boreal forest has not been fully researched to understand the short term and long term effects on post-fire stand development. Secondary disturbance inflicted by machinery and the removal of burned timber disrupt initial regeneration, disturb the forest floor, creating an early successional environment with sparse regeneration and lower species densities in comparison to unlogged burned forest stands. The introduction of invasive and weedy species within salvage logged stands can alter the heterogeneity of the forest structure. In addition, the removal of the aerial seed bank and mechanical tillage of the soil diminish the chance for regeneration by conifer species, increasing the likelihood that the regenerating forest stand will be dominated by deciduous species which rely on suckering for regeneration.

4. Study area

4.1 Location

The study area was located in the Mid-Boreal Upland Ecoregion of the Boreal Plain Ecozone in north-central Saskatchewan (Ecoregions of Saskatchewan 1994), situated between 53° and 55° N latitude and 105° and 107° W longitude. All sites examined are located in the commercial forest within the Weyerhaeuser Canada Ltd - Prince Albert FMA area (Figure 2). The Mid-boreal Upland Ecoregion is characterized by well-drained uplands with a mixture of coniferous and deciduous trees interspersed with wetlands dominated by *Picea mariana* with a moss understory (Acton *et al*. 1998).

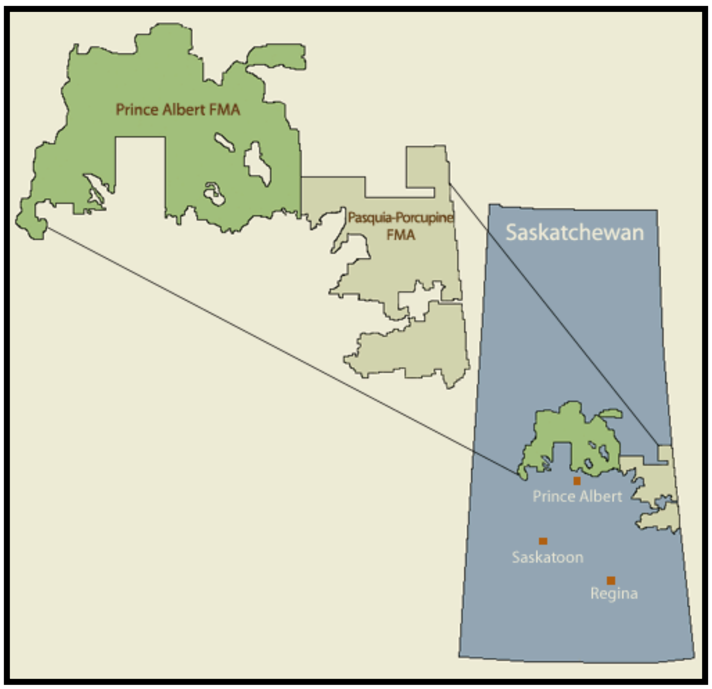

Figure 4.1 Prince Albert FMA, Weyerhaeuser Canada Ltd.
source: Weyerhaeuser, 2005.

Topography of the study area is of gently to strongly rolling hills. The area is composed of overlays of fluvial-lacustrine deposits and glacial till, with common occurrences of Brunisolic soils found throughout the ecoregion (Canadian Forestry Service 1986). The climate is continental with typical summer (May-August) temperatures ranging from 9.3 to 16.2°C and winter (November – February) temperatures ranging from -7.4 to -17.9°C Mean annual precipitation is 467 mm with the majority occurring as rainfall during the summer (Environment Canada 2005).

4.2 Vegetation

Research was conducted within upland mixedwood boreal forest communities in which the forest canopy was dominated by mature *Populus tremuloides* and *Picea glauca*. Stands dominated by *Populus tremuloides - Picea glauca* had a stand classification of HS (25 to 50% softwood by volume) and *Picea glauca - Populus tremuloides* have a stand classification of SH (50 to 75% hardwood by volume). These stand types were selected as they are the principal commercially viable stands harvested within the region.

Other tree species commonly found within mixedwood stands of this region are balsam fir (*Abies balsamea*), white birch (*Betula papyrifera*), balsam poplar (*Populus balsamifera*), jack pine (*Pinus banksiana*) and black spruce (*Picea mariana*). Common tall shrub species found in upland mixedwood stands include various willow species (*Salix* spp.), alder (*Alnus* spp.), beaked hazelnut (*Corylus cornuta*), red-osier dogwood (*Cornus stolonifera*), and buffalo-berry (*Shepherdia canadensis*). Short shrub species include prickly rose (*Rosa acicularis*), wild red raspberry (*Rubus idaeus*), low bush-cranberry (*Viburnum edule*), and currants (*Ribes* spp.), blueberries (*Vaccinium* spp.), and Labrador tea (*Ledum groenlandicum*). Herb species catalogued within the study sites belong to the following plant families: clubmoss (Lycopodiaceae), horsetail (Equisetaceae), grass (Gramineae), dogwood (Cornaceae), evening-primrose (Onagraceae), honeysuckle (Caprifoliaceae), lily (Liliaceae), madder (Rubiaceae), orchid (Orchidaceae), pea (Leguminosae), rose (Rosaceae), violet (Violaceae) and wintergreen (Pyrolaceae). The plant nomenclature was taken from Johnson *et al.* (1995).

4.3 Site selection

Three unsalvaged burned forest sites and adjacent salvage logged sites were selected, representing two early successional stages (1 and 8 years) in mixedwood forest stand development. Two sites were burned in separate wildfire events in 1995 and set aside for study by the BFMP, with the third site being burned in the summer of 2003. Each site is representative of upland mixedwood boreal forest stands and their typical fire disturbance regime (Table 4.1).

Table 4.1 Study site attributes

Study Site	Fire Name	Year	Fire Size (ha)	Location
Mahigan burn site	Late/Swan Fire	1995	51,438	54°43’ N, 106°26’ W
Beaupré burn site	Hillyer Fire	1995	48,745	54°31’ N, 107°17’ W
Candle Lake burn site	Pasture Fire	2003	21,028	53°44’ N, 105°28’ W

Prior to establishing sample plots within the field site, fire severity maps were created using the burn severity rating system described by the BFMP (Greif 2000). Burn severity maps for the Mahigan burn site (Figure 4.2) and Beaupré burn site (Figure 4.3) utilized a 50 meter grid system. Areas of differing burn severity within the Candle Lake burn site (Figure 4.4) were marked off using a handheld GPS device.

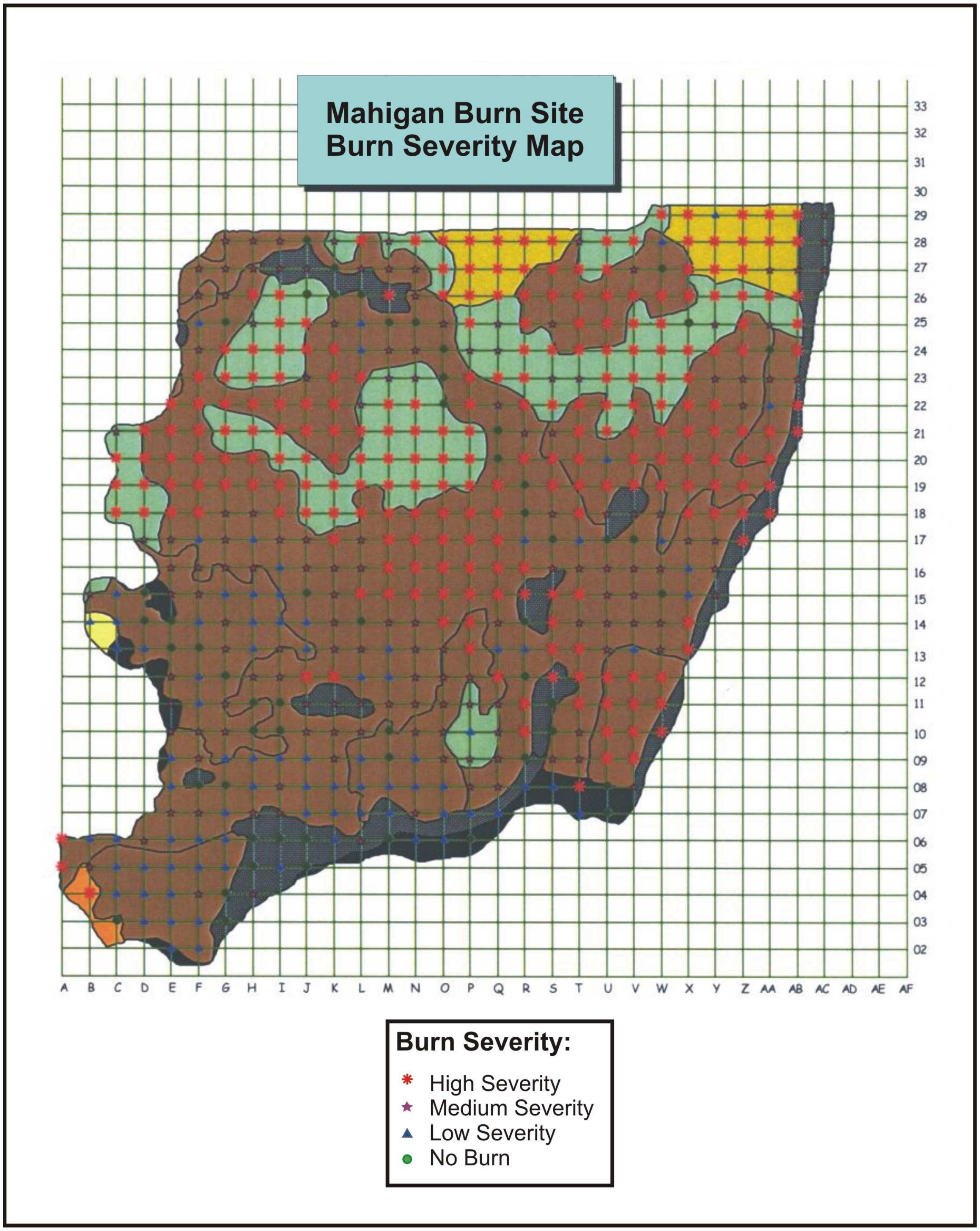

Figure 4.2 Mahigan burn site – Burn severity map produced by the BFMP (Greif 2000).

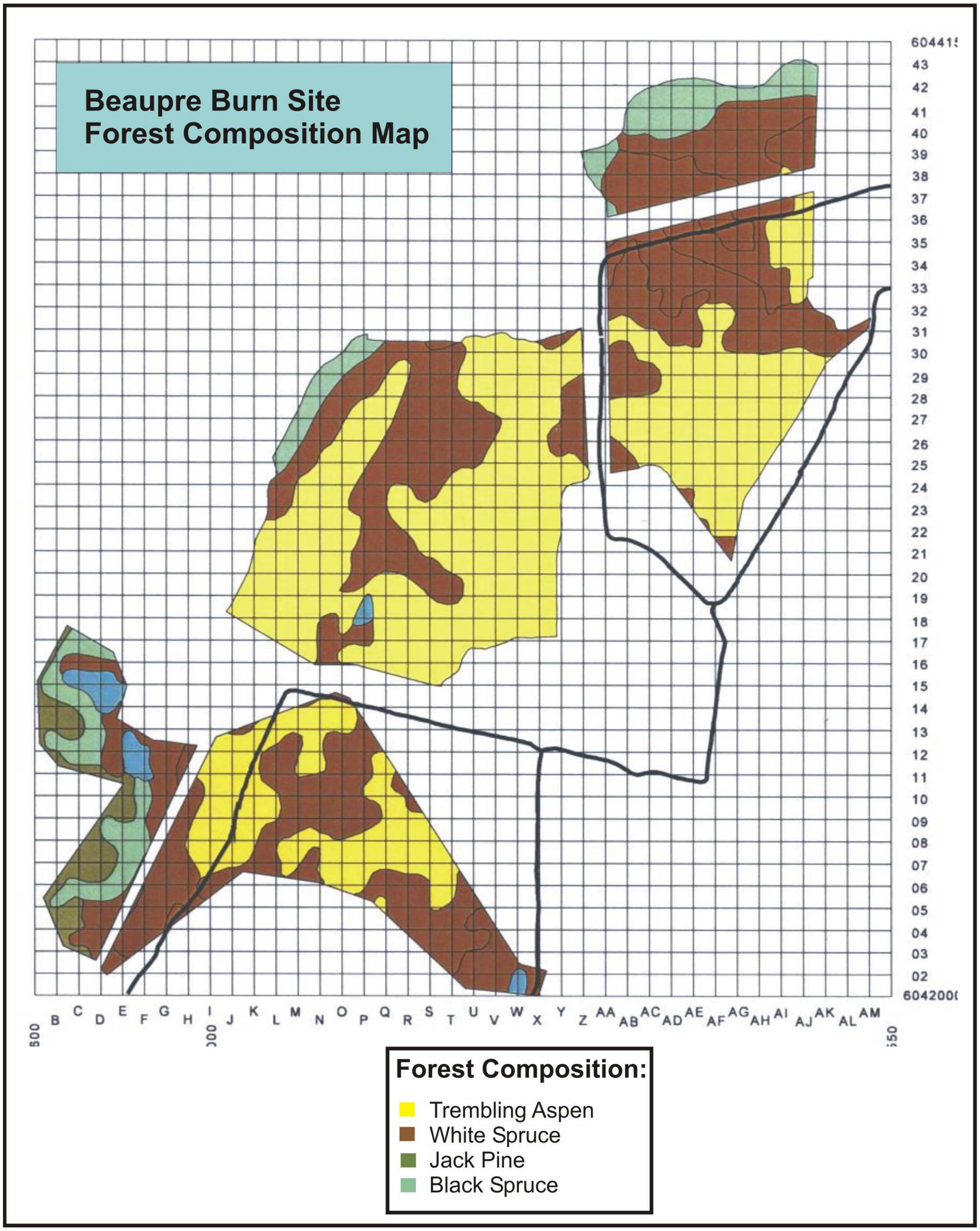

Figure 4.3 Beaupré burn site – Forest composition map produced by the BFMP (Greif 2000).

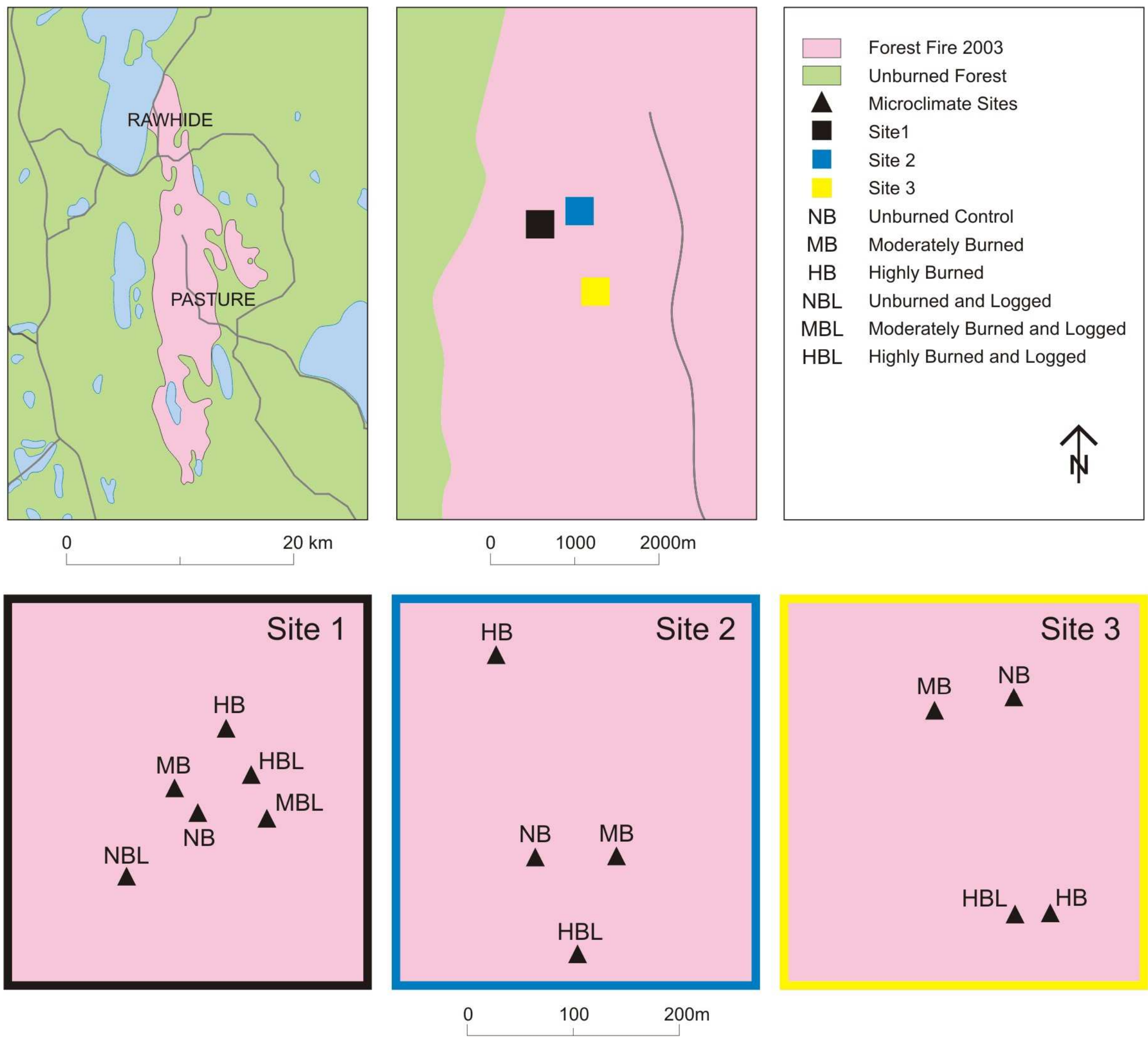

Figure 4.4 Candle Lake burn site – Leave stands and Microclimate sites.

4.4 Site descriptions

Mahigan burn site

The study site is accessible from the Pear Lake Road, adjacent to the southwest corner of Mahigan Lake. A large leave stand approximately 147 ha in area, was secured from salvage operations (Figure 4.2). The leave stand is dominated by *Picea glauca* and *Populus tremuloides* on the upper slopes with stands of *Picea mariana* found in low-lying areas. Logging operations were occurring within the adjacent area during the time of the fire disturbance, allowing easy access to the site from established road networks. Salvage logging operations occurred on the southern border of the leave stand and the area was prepared with a disc trencher and replanted with jack pine (*Pinus banksiana*) by a Weyerhaeuser contractor (D. Desrosiers, Weyerhaeuser Canada Ltd, pers. com.). Characteristics of the leave stand are listed in Tables 4.2 and 4.3 respectively.

Table 4.2 Mahigan Burn Site – Burned Leave Stand Characteristics

Characteristic	No Burn	Light - Medium Burn	Heavy Burn
Mean Tree Height (m)	12.37	13.05	12.58
Mean Tree DBH (cm)	23.95	24.23	16.36
Soil Group*	Gray Luvisol, Eutric Brunisol	Gray Luvisol, Eutric Brunisol	Gray Luvisol, Eutric Brunisol
Overstory Veg based on Basal area	WS, TA	TA, WS, JP	WS, BS, JP, TA, WB
Primary Understory Vegetation**	*Alnus crispa*	*Epilobium angustifolium*	*Cornus canadensis*
	Aralia nudicaulis	*Equisetum arvense*	*Epilobium angustifolium*
	Cornus canadensis	*Equisetum pratense*	*Ledum groenlandicum*
	Equisetum arvense	*Gramineae spp.*	*Pinus banksiana*
**Common great group as per Canadian Soil Classification system*	*Equisetum pratense*	*Petasites palmatus*	*Populus tremuloides*
	Ledum groenlandicum	*Populus tremuloides*	*Salix* spp.
***all species that covered 10% or more of a 100 m^2 plot*	*Petasites palmatus*	*Rosa acicularis*	*Vaccinium myrtilloides*
	Rosa acicularis	*Rubus idaeus*	
	Rubus pubescens	*Salix* spp.	

BS = Black Spruce *(Picea mariana)* TA = Trembling Aspen *(Populus tremuloides)*
JP = Jack Pine *(Pinus banksiana)* BF = Balsam Fir *(Abies balsamea)*
WS = White Spruce *(Picea glauca)* WB = White Birch *(Betula papyrifera)*

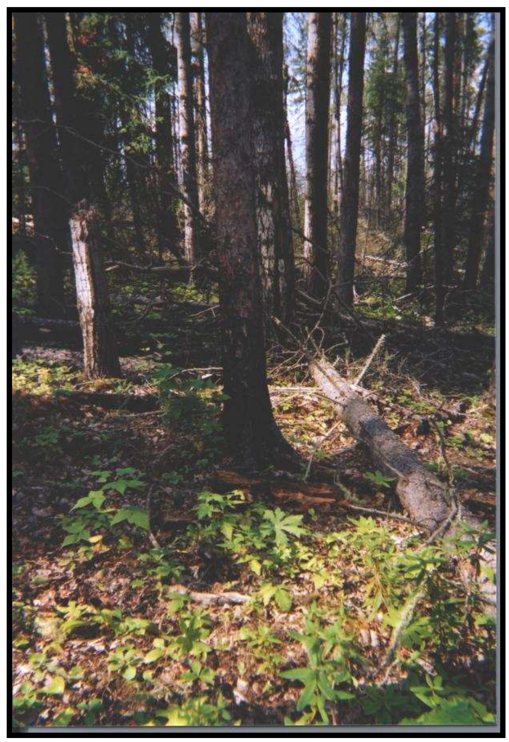

Figure 4.5 Representative photographs of the Mahigan burn site – Leave stand showing an area of high burn (above) and an area of surface scorching (right). Note the high density of standing snags left within a high burn leave stand. Scorching is still visible on the lower trunks of white spruce 8 years following the fire disturbance.

Table 4.3 Mahigan Burn Site – Burned Salvage Logged Stand Characteristics

Characteristic	No Burn	Light - Medium Burn	Heavy Burn
Mean Tree Height (m)	--	--	--
Mean Tree DBH (cm)	--	--	--
Soil Group*	Gray Luvisol	Gray Luvisol	Gray Luvisol, Eutric Brunisol
Overstory Veg based on Basal area	TA, JP, WB	TA, JP, WB	JP, TA
Primary Understory Vegetation**	*Alnus crispa* *Aralia nudicaulis* *Aster* spp. *Cornus canadensis* *Equisetum arvense* *Gramineae spp.* *Ledum groenlandicum* *Linnaea borealis* *Lonicera involucrata* *Mertensia paniculata* *Petasites palmatus* *Rosa acicularis* *Rubus idaeus* *Rubus pubescens* *Salix* spp. *Viburnum edula*	*Alnus crispa* *Aralia nudicaulis* *Cornus canadensis* *Epilobium angustifolium* *Equisetum arvense* *Ledum groenlandicum* *Linnaea borealis* *Petasites palmatus* *Populus tremuloides* *Ribes triste* *Rosa acicularis* *Rubus idaeus*	*Cornus canadensis* *Epilobium angustifolium* *Ledum groenlandicum* *Pinus banksiana* *Populus tremuloides* *Salix* spp.

**Common great group as per Canadian Soil Classification system*

***all species that covered 10% or more of a 100 m^2 plot*

BS = Black Spruce *(Picea mariana)* TA = Trembling Aspen *(Populus tremuloides)*

JP = Jack Pine *(Pinus banksiana)* BF = Balsam Fir *(Abies balsamea)*

WS = White Spruce *(Picea glauca)* WB = White Birch *(Betula papyrifera)*

Figure 4.6 Representative photographs of the Mahigan burn site – Salvage logged stand. Decomposing salvage stump (left), area of regrowth following a salvage logging operation (right). Note the open bare surface of haul road ten years following salvage logging operations.

Beaupré burn site

The study site is accessible from logging trails located off highway #924 near the community of Dore Lake. The Beaupré Burn site was originally planned as harvest leave blocks by Weyerhaeuser logging operations. Clear cut operations occurred prior to the 1995 fire event leaving three separate leave stands, approximately 25 ha, 49 ha, and 20 ha in area (Figure 4.3). The leave stands are dominated by *Populus tremuloides, Picea glauca* and *Abies balsamea* growth types. Prior to the 1995 burn the non-leave areas were harvested in early 1994, site prepared by a disc trencher and V-blade, and replanted. Seedlings were again replanted in 1996, following the 1995 Hillyer Fire, by a Weyerhaeuser contractor (D. Desrosiers, Weyerhaeuser Canada Ltd, pers. com.). Characteristics of the leave stand are listed in Table 4.4.

Table 4.4 Beaupré Burn Site – Burned Leave Stand Characteristics

Characteristic	No Burn	Light - Medium Burn	Heavy Burn
Mean Tree Height (m)	13.81	11.97	13.13
Mean Tree DBH (cm)	22.96	24.09	22.60
Soil Group*	Gray Luvisol, Eutric Brunisol	Gray Luvisol, Eutric Brunisol	Gray Luvisol, Eutric Brunisol
Overstory Veg based on Basal area	TA, BF, WS	TA, WS, BF	WS, TA, JP
Primary Understory Vegetation**	*Cornus canadensis* *Cornus stolonifera* *Aralia nudicaulis* *Equisetum pratense* *Mertensia paniculata* *Mitella nuda* *Petasites palmatus* *Rosa acicularis* *Rubus pubescens* *Viburnum edula*	*Aralia nudicaulis* *Cornus canadensis* *Cornus stolonifera* *Gramineae* spp. *Linnaea borealis* *Mertensia paniculata* *Petasites palmatus* *Rosa acicularis* *Rubus idaeus* *Rubus pubescens* *Salix* spp. *Viburnum edula*	*Cornus canadensis* *Epilobium angustifolium* *Gramineae* spp. *Mertensia paniculata* *Petasites palmatus* *Populus tremuloides* *Rosa acicularis* *Rubus idaeus* *Salix* spp.

**Common great group as per Canadian Soil Classification system*

***all species that covered 10% or more of a 100 m² plot*

BS = Black Spruce *(Picea mariana)* TA = Trembling Aspen *(Populus tremuloides)*

JP = Jack Pine *(Pinus banksiana)* BF = Balsam Fir *(Abies balsamea)*

WS = White Spruce *(Picea glauca)* WB = White Birch *(Betula papyrifera)*

Figure 4.7 Representative photographs of the Beaupré burn site – Leave stands. Transition area between high burn and no burn (top). Fallen trembling aspen snag in a no burn area (bottom).

Candle Lake burn site

The research site is composed of three separate leave stands and is located approximately 2 km west off of the Snowfield Road, approximately 42 km from the Candle Lake town site. After the Pasture Fire disturbance in the spring of 2003, three leave stands were secured from salvage logging operations, approximately 2.3 ha, 2.6 ha, and 5.0 ha in area (Figure 4.4). The leave stands are dominated by *Populus tremuloides* and *Picea glauca*. Other species, occurring in varying proportions between the three separate stands include *Abies balsamea*, *Betula papyrifera*, *Pinus banksiana* and *Picea mariana*. Characteristics of the leave stand and salvage logged stands are listed in Tables 4.5 and 4.6 respectively.

Sections within the Candle Lake study site were originally clear cut by Weyerhaeuser prior to the 2003 Pasture Fire with plans for harvesting to continue. With roads already established in the area, the area was subsequently allocated for salvage logging operations in early 2004. Three leave stands located within un-harvested burned forest were selected in November 2003 and their boundaries were flagged in December 2003. Salvage logging operations occurred adjacent to the leave stands in January and February, 2004 by both Weyerhaeuser Canada and third party operators (Montreal Lake Enterprises and Quin-Tec). The area was salvage logged using a feller buncher and skidded with a grapple skidder as well as by conventional chainsaw - cable skidder combination. The salvage logged areas and adjacent leave stands were replanted with white spruce seedlings. Planting was completed in July and August, 2004 by a Weyerhaeuser contractor (R. Pshebnicki, Weyerhaeuser Canada Ltd, pers. com.).

Table 4.5 Candle Lake Burn Site – Burned Leave Stand Characteristics

Characteristic	No Burn	Light - Medium Burn	Heavy Burn
Mean Tree Height (m)	20.56	20.49	17.84
Mean Tree DBH (cm)	24.09	25.07	22.70
Soil Group*	Gray Luvisol, Eutric Brunisol	Gray Luvisol, Eutric Brunisol	Gray Luvisol, Eutric Brunisol
Overstory Veg based on Basal area	TA, WS, BF	WS, TA, JP, BF	WS, TA, JP, BF, BS
Primary Understory Vegetation** **Common great group as per Canadian Soil Classification system* ***all species that covered 10% or more of a 100 m2 plot*	*Alnus crispa* *Aralia nudicaulis* *Cornus canadensis* *Equisetum arvense* *Equisetum pratense* *Ledum groenlandicum* *Linnaea borealis* *Maianthemum canadens* *Mertensia paniculata* *Petasites palmatus* *Rubus pubescens* *Salix* spp. *Viburnum edula*	*Alnus crispa* *Aralia nudicaulis* *Cornus canadensis* *Dracocephalum parviflorum* *Epilobium angustifolium* *Geranium bicknellii* *Gramineae* spp. *Linnaea borealis* *Mertensia paniculata* *Petasites palmatus* *Populus tremuloides* *Rosa acicularis* *Rubus pubescens*	*Aralia nudicaulis* *Cornus canadensis* *Corydalis aurea* *Dracocephalum parviflorum* *Epilobium angustifolium* *Geranium bicknellii* *Gramineae* spp. *Mertensia paniculata* *Petasites palmatus* *Populus tremuloides*

BS = Black Spruce *(Picea mariana)* TA = Trembling Aspen *(Populus tremuloides)*
JP = Jack Pine *(Pinus banksiana)* BF = Balsam Fir *(Abies balsamea)*
WS = White Spruce *(Picea glauca)* WB = White Birch *(Betula papyrifera)*

Figure 4.8 Representative photographs of the Candle Lake burn site – Leave stands. Microclimate station within an area of no burn (left). High burn stand one year following fire disturbance (right). Note the dense regrowth of hardwood and herb species in the high burn understory.

Table 4.6 Candle Lake Burn Site – Burned Salvage Logged Stand Characteristics

Characteristic	No Burn	Light - Medium Burn	Heavy Burn
Mean Tree Height (m)	20.77	19.47	16.63
Mean Tree DBH (cm)	25.30	21.19	24.23
Soil Group*	Gray Luvisol, Eutric Brunisol	Gray Luvisol, Eutric Brunisol	Gray Luvisol, Eutric Brunisol
Overstory Veg based on Basal area	Clear-cut, several standing TA, WS	Clear-cut, several standing TA, WS	Clear-cut, several standing WS, JP
Primary Understory Vegetation**	*Aralia nudicaulis*	*Cornus canadensis*	*Epilobium angustifolium*
	Cornus canadensis	*Epilobium angustifolium*	*Geranium bicknellii*
**Common great group as per Canadian Soil Classification system*	*Epilobium angustifolium*	*Petasites palmatus*	*Gramineae* spp.
	Rosa acicularis	*Populus tremuloides*	*Mertensia paniculata*
***all species that covered approximately 10% or more of a 100 m^2 plot*	*Rubus pubescens*	*Rosa acicularis*	*Petasites palmatus*
		Rubus pubescens	*Populus tremuloides*

BS = Black Spruce *(Picea mariana)* TA = Trembling Aspen *(Populus tremuloides)*

JP = Jack Pine *(Pinus banksiana)* BF = Balsam Fir *(Abies balsamea)*

WS = White Spruce *(Picea glauca)* WB = White Birch *(Betula papyrifera)*

Figure 4.9 Representative photographs of the Candle Lake burn site – Salvage logged stands. Note the large amounts of woody debris left scattered over the forest floor within salvage logged areas and the sparse regrowth of vegetation.

5. Methods

5.1 Study design

The field sites were sampled during the summer growing periods (mid-June through August) of 2003, 2004, and 2005. The study sites were selected because they were representative of upland mixedwood stands and were commercially viable for salvage harvesting operations. The study sites provided an experimental design comprised of combinations of disturbance types (salvaged or unsalvaged forest stands), time since disturbance (1 year to 10 years), and burn severity within each treatment (unburned, low to medium burn, and high burn areas).

The time since disturbance was separated into two categories (1 and 10 years following disturbance) to represent two stages in early successional development within the mixedwood boreal forest. In both successional stages, the salvage logged stands were clear-cut for hardwood and softwood timber, with some smaller areas of selective logging for softwood within the 1 year since disturbance study site. For both successional stages, the forest stands were salvage logged within one year of the wildfire disturbance.

The range of burn severity was divided into three categories: NB (no burn), MB (light to medium burn), and HB (high burn). These burn severity categories were used for both the leave stand and salvage logged stand treatments. Each burn severity category was identified by specific characteristics (Table 5.1) and was based on a modified version of the burn severity classification system developed for the Burned Forest Monitoring Program (Greif 2000).

Table 5.1 Burn severity classification

Severity	Description
No Burn (NB)	- no sign of damage
Moderate Burn (MB)	- damage/charring of tree trunk up to 3 meters - ground vegetation slightly to mostly consumed
High Burn (HB)	- taller shrubs (alders, willows) may be consumed - majority of trees sustained severe fire damage - tree branches and crowns have been consumed - shrubs and ground vegetation consumed

5.2 Field methods

5.2.1 Vegetation sampling

Sample plots (100 m^2) were established using a stratified random design within the study stands differentiated by three fire severity classes and two logging treatments. Within each stand, fire severity boundaries were identified and plots were selected based on a random pin drop on map coordinates of each site. All sites had a total of 12 to 18 plots with an overall total of 102 plots established during the 2003-2005 field seasons (Table 5.2). Sampling occurred between the months of June to late August to facilitate plant identification. A higher number of plots were established in leave stand treatments due to an absence of a salvage logged treatment at the Beaupré Burn Site and the limited spatial extent of salvage logged treatment at the Mahigan Burn Site.

Table 5.2 Study design field plot selection

Site	Salvage Logged			Leave Stand		
	NB	MB	HB	NB	MB	HB
Mahigan Burn Site	4	4	4	6	6	6
Beaupré Burn Site	--	--	--	6	6	6
Candle Lake Site	9	9	9	9	9	9
Total		39			63	

Field sampling was conducted using protocols outlined in the Forest Ecosystem Classification (FEC) plot establishment and field data collection manual (Jiricka *et al*. 2002). For each sample plot a primary quadrat size of 10m × 10m was established, with 2m × 2m sub-quadrats located in the Northwest and Southeast corners (Figure 5.1). Plots were randomly established within burn severity boundaries with a minimum of 50 meters between each plot, and if possible, 50 meters from the margins of the burn severity patch or cut-block to reduce the edge effect.

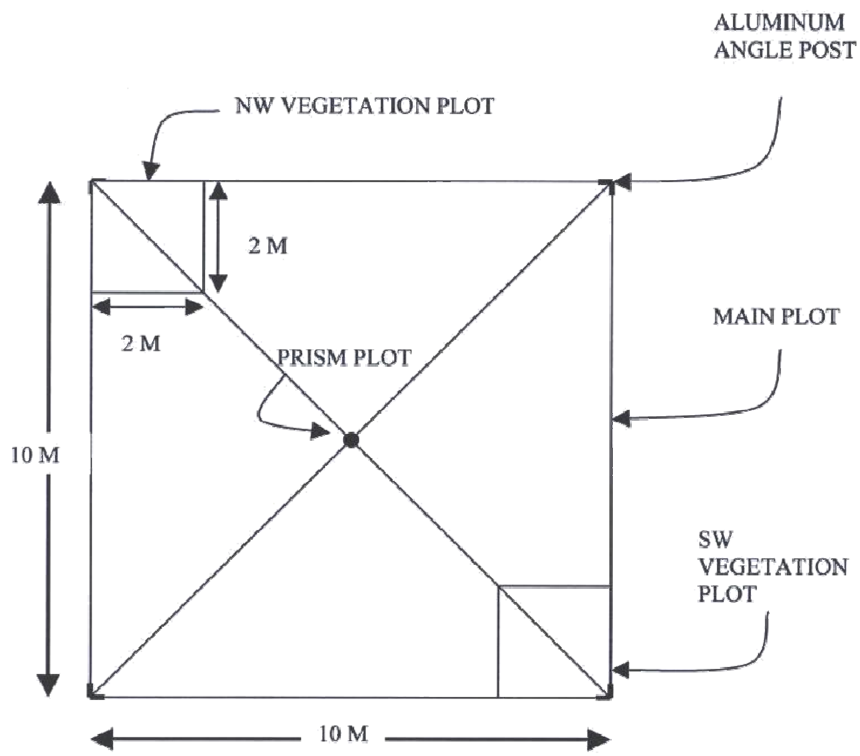

Figure 5.1 Sample plot and subplot design (Jiricka *et al*. 2002)

In each of the sample plots, data were collected on cover and stratum layer of each plant species. Plants were identified to the species level except for certain plant groups (willow and sedges) which were classified at the genus level. Species cover was recorded using a percent cover class based on a modified version of the Braun-Blanquet scale (Table 5.3) and plant stratum layer was recorded according to codes and heights listed in Table 5.4. All cover class data collected was converted to mid-point percentages for statistical analysis. Assessments of woody debris, leaf litter, needle litter and exposed rock or soil also were based on the cover/abundance scale.

Table 5.3 Saskatchewan FEC cover-abundance scale (Jiricka *et al*. 2002)

Class	Description
7	> 75%
6	≥ 50 and < 75%
5	≥ 25 and < 50%
4	≥ 15 and < 15%
3	≥ 5 and < 15%
2	≥ 1 and < 5%
1	< 1% - more than one plant stem of the species
0	< 1% - one plant stem only

Table 5.4 Saskatchewan FEC stratum layer classes and height ranges (Jiricka *et al*. 2002)

Physiognomy class	Height Range	Physiognomy Class Code
Trees	≥ 10 m (dominant in canopy)	1
Trees	≥ 10 m (subdominant in canopy)	2
Tree & Shrub	≥ 2 m & < 10 m	3
Tree & Shrub	≥ 0.5 – 2 m	4
Tree & Shrub	< 0.5 m	5
Forbs & Graminiods		6
Bryophytes & Lichens		7

5.2.2 Tree composition

Within each plot all tree species with a diameter at breast height (dbh) greater than 7.5 cm were numbered and recorded. The trees were identified to the species level and their condition, living or dead, noted. The dbh of each tree in the plot was recorded using a dbh measuring tape. Each tree within the plot also had its height measured in meters using either a hand held clinometer (2003 field season) or a laser hypsometer (2004, 2005 field season). A prism sweep from the center of the plot was conducted using a 2 m^2 BAF prism. Trees were tallied by species in each sweep.

5.2.3 Site attributes and soil profiles

For each plot the slope of the main quadrat was measured with a hand held clinometer and the corresponding aspect was recorded in azimuthal degrees. The slope position of the plot (e.g. crest, upper slope, lower slope) and general physiography (e.g. level, concave) were also noted. Soil pits were dug to determine the depth of the organic layer, the type of parent material, seepage, drainage, and soil type (such as luvisol or brunisol). Soil data also included depth and soil texture of the different horizons. The soil profiles were recorded outside of the Southwest corner of the main plot to reduce vegetation disturbance.

5.2.4 Microclimate

During the 2004 field season at the Candle Lake burn site a comparative study was conducted of the microclimates in six different treatment types. Within Stand 1 of the burn site, a small recording station was set up within each treatment type (near the centre of the most representative area to minimize any edge effect) and data were collected from April 2004 until August 2004. The treatment sites used were divided into six categories: a highly burned plot (HB), a low to moderately burned plot (MB), and an unburned plot (NB) in an unsalvaged leave stand, with corresponding plots within an adjacent salvage logged stand (HBL, MBL, NBL) (see Figure 4.4). Canopy openness, solar radiation, humidity, air temperature, soil temperature, soil moisture, and precipitation were recorded (Figure 5.2). The data were used to determine the effect of stand structure on microclimate under various burn severity and logging conditions.

Figure 5.2 Weather monitoring equipment at salvage logged micro-sites HBL (left) and MBL (right). Note large amount of woody debris left from salvage logging and scattered distribution of the regrowth vegetation.

Each weather station measured soil temperature at 4 depths (5 cm, 10 cm, 20 cm, and 50 cm) using soil temperature probes (Model 107B) connected to a CR10X Datalogger (Campbell Scientific) excluding site MB, which used 4 soil thermistors (Model 101) connected to a CR21 datalogger (Campbell Scientific). Air temperature and humidity at 50 cm and 150 cm were measured using combination temperature and humidity probes (Model 207) connected to a CR10X datalogger at micro-sites NB, HB, HBL, and MBL. Thermistor and Humidity Sensors (Model PCRC-11) for the CR21 datalogger were used at micro-sites MB and NBL. Incoming and outgoing radiation were recorded using Li-Cor pyranometers (L1-2000SZ) at a height of 2 m at sites NB, MB, HB, and HBL, and incoming radiation only was recorded at sites NBL and MBL. Precipitation was measured using copper rain gauges, though these were not recorded daily. In addition, precipitation at micro-site MB was measured using a Sierra Tipping Bucket Rain Gauge (Model RG2501) connected to a CR21 datalogger.

Supplemental data were collected manually from stands 2 and 3 during the period of vegetation sampling, from July 19-August 3 and August 14-19, 2004, respectively. Each site comprised of two Copper-Constantan (Cu-Co) thermocouples at heights of 50 cm and 150 cm to measure air temperature. Soil probes also with Cu-Co thermocouples at 5 cm, 10 cm, 20 cm, and 50 cm were set up to measure soil temperature. A Licor hand held pyranometer (LI-2000) was used to make 10 random incoming/outgoing radiation measurements at 1.3m along two transects. Random soil moisture measurements were made (12 cm and 20 cm) with a hand held HydroSense Device. At all micro-sites, hemispherical photographs were taken with a Nikon 990 Coolpix digital camera with Nikon FC-E8 fisheye lens. These photos were analyzed with Gap Light Analyzer (GLA), Version 2.0 (Frazer et al, 1999) to ascertain canopy openness and LAI values.

5.3 Statistical analysis

5.3.1 Vegetation analysis methods

The primary comparisons within this study were among the burn intensities of the two logging treatments (wildfire leave stand and salvage logging) and the burn intensities within each logging treatment. Descriptive statistics were calculated by treatment and burn intensity for both the environmental and vegetation data sets for all three study sites (1 year and 10 years). Several methods were used to examine the vegetation data at different levels of organization: species richness and diversity through a 2-way fixed factor analysis of variance (ANOVA); direct gradient analysis using Canonical Correspondence Analysis (CCA) ordination; comparative species compositions using multi-response permutation procedure (MRPP); at the species level through indicator species analysis (ISA); and grouping plot similarity through a hierarchical cluster analysis. All tests for outlier analysis, CCA, MRPP, ISA, and cluster analysis were performed using PC-ORD, version 4 (McCune and Mefford 1999).

Species richness was calculated down to the species level for each plot. Using the tree, shrub, and understory species, richness was calculated as the number of species per unit area (100m²). Diversity for all regenerating tree, shrub and understory plants was calculated with species abundance data using the Shannon-Weiner index (H')

$$H' = -\sum_{i=1}^{s} p_i (\ln p_i) \tag{5.1}$$

where s = the number of species
p_i = the proportion of the vegetation cover, in the plot, belonging to species i

Species richness measures the number of species within each sample plot, while species diversity is a combined measure of the number of species and the distribution (sharing of resources) of vegetation cover among the species (Barbour *et al*. 1999). The species richness and diversity distributions for all burn severity and logging treatments were found to be normal using the Shapiro-Wilks's tests.

Differences among treatments were tested using 2-way fixed factor Analysis of Variance (ANOVA); this allows both factors to be tested independently of one another on the response variable. When comparing differences among treatments for the Candle Lake and Mahigan sites the equation for the 2-way fixed factor (Model I) ANOVA was

$$Y_{ij} = \mu + B_i + L_j + BL_{ij} + \varepsilon_{ijl} \qquad (5.2)$$

where Y_{ij} = dependent variable;
μ = the parametric mean of the population;
B_i = burn severity;
L_j = logging treatment;
BL_{ij} = interaction between burn severity and logging treatment;
ε_{ijk} = residual error (sampling plot within burn severity within treatment).

When comparing differences among treatments for the Mahigan and Beaupré sites the equation for the 2-way fixed factor (Model I) ANOVA was

$$Y_{ij} = \mu + B_i + S_j + BS_{ij} + \varepsilon_{ijl} \qquad (5.3)$$

where Y_{ij} = dependent variable;
μ = the parametric mean of the population;
B_i = burn severity;
S_j = site;
BS_{ij} = interaction between burn severity and site;
ε_{ijk} = residual error (sampling plot within burn severity within treatment).

The ANOVA assumes that all variances are equal within each variable tested. Equality of variance among the treatments was tested using Levene's test with a critical value of 0.05. If the test was found to be significant, the variable was declared unbalanced and the data heteroscedastic. All ANOVA's were performed with SPSS (1999) using a critical level (p-value) of 0.05 for the rejection of the null hypothesis being tested. All F-ratios and p-values based on a Type III sum of squares with the confidence interval for the calculated means set at 95%.

An outlier analysis test was run on all the individual plots using a Sørenson (Bray-Curtis) distance measurement. All plots found with a distance greater than 2.0 standard deviations from the overall mean were identified as strong outliers. These potential outlier plots were monitored over the course of the multivariate analysis procedures, but did not adversely affect the outcomes. All plots were included within all multivariate procedures.

Canonical Correspondence Analysis (CCA) was used to visualize the variation in plant community composition (ter Braak 1986, 1994). The use of a direct gradient analysis (CCA) allows examination of the relationship between species composition and environmental variables measured within the treatments. Environmental variables measured were ground cover (downed woody debris, needle litter, leaf litter, and exposed soil), bryophyte cover, and lichen cover. When a CCA is displayed visually the plots are shown as points and the environmental variables are shown as lines. The greater the correlation with the environmental variable the longer the line that is depicted in one of the quadrant established by the axes; the direction of the line relative to an axis indicates the strength of the relationship with that axis. The use of a CCA ordination displays the importance of environmental variables on species composition between disturbance types.

Differences in species composition between and within logging treatments and burn severities were examined using multi-response permutation procedure (MRPP)

(Biondini *et al*. 1985; Miekle and Berry 2001; McCune *et al*. 2002). The use of a MRPP analysis provided comparisons of species composition and structure between and within both the treatment and burn severity classes for the 1-year and 10-year data sets. All analysis using MRPP were run using a Sørenson distance measurement to deemphasize the presence of outliers. The test statistic *A* is known as the 'chance-corrected within-group agreement'; when all species are identical within the groups A=1, the highest possible value for *A*. For ecological data from relatively diverse stands it is common for *A* to fall in the range <0.1 to 0.3 (McCune *et al*. 2002).

Indicator species analysis (ISA) was utilized using methods outlined by Dufrêne and Legendre (1997). ISA was conducted on the vegetation composition to determine specific species indicators for the logging treatments and within the burn severities. Tests were first run between the logging treatments and then between each burn severity within each treatment; reciprocal tests were then run separately for each burn severity between each treatment. Indicator values for the ISA tests range from 0 to 100, with 100 being equal to a perfect identification where the presence of a particular species is contained within a particular group or disturbance without error. In all cases the statistical significance of indicator species was examined using a Monte Carlo test (n = 10,000).

Similarities between treatments and burn severity were examined using a hierarchical cluster analysis to group the different treatments based on their similarity in species composition and abundance for both the 1-year and 10-year data sets. Cluster distance was measured using the Sorensen (Bray & Curtis) distance as it retains its sensitivity with larger data sets and gives less weight to outliers, and groups were then linked using the nearest neighbor method. The hierarchical structure of the cluster analysis groups smaller more similar groups together and links them to larger dissimilar groups until all groups have been linked. The use of a cluster analysis provides a visual representation of similarity in species composition between the different treatments.

6. Results

6.1 Candle Lake burn site (1 year post-fire)

6.1.1 Species richness and diversity

A total of 68 species were catalogued within the Candle Lake Burn Site between both the salvage logged and wildfire leave stands. Sixty-eight species were recorded within wildfire leave stands and a total of 57 within salvage logged stands (Table 6.1). Species richness, which is the number of species in the sample plots, was significantly lower within the salvage stands in comparison to the leave stands (Figure 6.1 and Table 6.2). Burn severity alone did not have a significant effect on the species richness, but the interaction between burn severity and logging treatments was significant (p = 0.018). The major differences were found between the NB and NBL plots, and the MB and MBL plots of both logging treatments (Tables 6.1 and 6.2) indicating that logging has a significant effect on the plant communities between the burn severities. A complete list of all species recorded and the frequency at which they occur within the logging treatments and burn severities can be found in Appendix 1.

Species diversity, which estimates a combination of composition and quantitative differences within sample plots, was also found to be higher within the leave stands (Table 6.1). A difference in diversity between burn severities was found to be significant ($p \leq 0.001$), indicating that unique species compositions have developed between the burn severities. Diversity between logging treatments did not show a significant result, while the interaction of burn severity and the logging treatment was significant (p = 0.009; Table 6.2).

Total species cover was not affected by burn severity ($p = 0.221$), but differences in total cover between logging treatments were significant ($p \leq 0.001$) and the interaction of burn severity and the logging treatments was also significant ($p = 0.021$; Tables 6.1 and 6.2) indicating that salvage logging has an effect on total coverage within burn severities. Total cover by regenerating species in the salvage logged sites was sparser and species composition more homogeneous than in the burned sites.

Table 6.1 Species richness and diversity (Shannon`s diversity index *H'*) for all vascular plants within the Candle Lake burn site (1 year post-fire).

Treatment	Burn Severity	# of sites sampled	Mean Species Richness	Total Species	Total Tree	Total Shrub	Total Herb	Total cover (%)	Diversity (*H'*)
	NB	9	26.89	52	4	18	30	100	2.55
Leave	MB	9	27.44	52	4	13	35	100	2.48
	HB	9	21.89	50	4	13	33	90.78	1.96
	NBL	9	19.67	45	4	15	26	38.43	2.50
Salvage	MBL	9	19.78	47	4	14	29	59	2.08
	HBL	9	21.89	42	4	11	27	70.94	2.15
Overall Wildfire		27	25.4	68	6	18	44	96.92	2.33
Overall Salvage		27	20.4	57	4	18	35	56.12	2.24

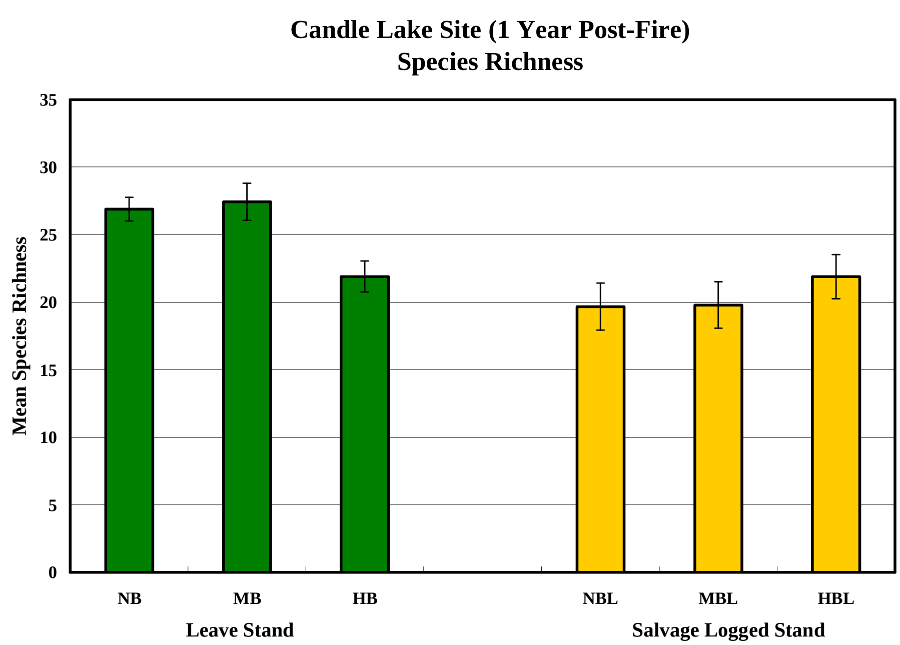

Figure 6.1 Species richness for all vascular plants within the Candle Lake burn site (1 year post-fire).

Table 6.2 ANOVA results for species richness, diversity and total cover on the logging treatment and burn severity classes of the Candle Lake burn site (1 year post-fire). Comparisons found to be significant are shown in bold.

	Total Species Richness			Diversity			Total Cover		
Source	df	F	sig.	df	F	sig.	df	F	sig.
Burn Severity	2	0.792	0.459	2	13.326	**<0.001**	2	1.558	0.221
Logging	1	17.531	**<0.001**	1	1.380	0.246	1	47.994	**<0.001**
Burn Sev. vs. Logging	2	4.394	**0.018**	2	5.187	**0.009**	2	4.185	**0.021**
Error	48			48			48		

6.1.2 Environmental characteristics

Differences in site conditions and stand structure variables such as bryophyte cover, exposed soil and canopy openness were noted between burn severity categories and logging treatments. The removal of standing timber has created very different environments between the salvage logged stands and the wildfire leave stands (Table 6.3 and 6.4). A significant interaction between burn severities and logging treatments was apparent (Table 6.4). The logging treatments alone had a very significant effect on the environmental variables ($\leq$0.001), with one exception found with the lichen species, as a large proportion of the lichen recorded was from the waste debris left from the salvage logging operation.

All salvage logged sites were characterized by a decrease in bryophyte, leaf and exposed soil cover and showed a large increase in the cover of coarse woody debris, lichen and needle litter due to slash and waste created by the salvage logging operations (Table 6.3). Coarse woody debris increased on average by 58% in all burn severities following logging which effectively reduced the amount of exposed soil at these sites; for example, the amount of exposed soil at HBL was reduced by 46.6% compared to the unlogged HB site. The no burn and high burn severity sites showed the largest difference between the wildfire leave stands and the salvage logged stands, with the least amount of disturbance found in the moderate burn severity sites.

As expected, canopy cover declined significantly following salvage logging which removed the majority of the shade producing canopy and resulted in increased light levels within the salvage logged stand; this was particularly significant within NB plots. The residual tree (standing trunk left by fire or harvesting) DBH and heights were similar between all burn severities and logging treatments. The forest environment is altered considerably by salvage logging. The combined effects of increasing the amount of downed woody matter and needle litter, and the removal of the canopy are fully described in chapter 3.4.2 Effects of salvage logging.

Table 6.3 Environmental characteristics of the Candle Lake burn site (1 year post-fire). All values made available are means ± 1 S.E.

Treatment	Leave Stand			Salvage Logged		
Burn Severity	NB	MB	HB	NBL	MBL	HBL
% Ground Cover						
Bryophyte species	47.50 ± 7.53	10.4 ± 4.32	6.94 ± 4.05	4.17 ± 2.23	5.50 ± 2.76	1.32 ± 1.09
Lichen species	4.17 ± 1.10	0.80 ± 0.33	0.06 ± 0.02	2.0 ± 1.04	2.22 ± 1.02	1.07 ± 0.36
Coarse Woody Debris	21.39 ± 4.25	25.83 ± 2.92	12.22 ± 1.47	87.5 ± 0.0	68.89 ± 8.50	76.39 ± 4.39
Leaf Litter	65.28 ± 6.51	35.56 ± 8.62	5.22 ± 2.26	12.61 ± 5.14	11.94 ± 6.62	1.39 ± 0.35
Needle Litter	20.56 ± 5.66	40.83 ± 7.10	13.17 ± 4.80	43.89 ± 5.02	41.1 ± 6.11	53.89 ± 8.51
Exposed Soil	0.01 ± 0.01	16.39 ± 3.09	70.83 ± 7.22	2.78 ± 1.41	13.06 ± 7.36	24.22 ± 6.92
Forest Structure (>10m)						
% Canopy Cover	80.33	35.00	5.11	1.39	8.06	0.67
Residual DBH (cm)	24.09 ± 0.97	25.07 ± 1.15	22.70 ± 1.48	25.30 ± 5.93	21.19 ± 1.52	24.23 ± 5.03
Residual Height (m)	20.56 ± 0.73	20.49 ± 0.78	17.84 ± 0.87	20.77 ± 4.93	19.47 ± 1.44	16.63 ± 3.31
% Dead Snags	8.87	38.81	100.00	33.33	35.71	100.00

Table 6.4 ANOVA results for environmental characteristics of the Candle Lake burn site (1 year post-fire). Significant results are shown in bold type.

	Bryophyte species			Lichen species			Coarse Woody Debris		
Source	df	F	sig.	df	F	sig.	df	F	sig.
Burn Severity	2	15.252	**<0.001**	2	5.427	**0.008**	2	2.703	0.077
Logging	1	27.466	**<0.001**	1	0.020	0.889	1	250.161	**<0.001**
Burn Sev. vs. Logging	2	13.730	**<0.001**	2	3.225	**0.048**	2	4.084	**0.023**
Error	48			48			48		

	Leaf Litter			Needle Litter			Exposed Soil		
Source	df	F	sig.	df	F	sig.	df	F	sig.
Burn Severity	2	19.966	**<0.001**	2	1.112	0.337	2	40.823	**<0.001**
Logging	1	33.388	**<0.001**	1	17.215	**<0.001**	1	13.433	**0.001**
Burn Sev. vs. Logging	2	9.417	**<0.001**	2	5.136	**0.010**	2	13.121	**<0.001**
Error	48			48			48		

6.1.3 Plant community comparisons

Comparisons of species composition between logged and unlogged treatments showed significant differences for all burn severities (Table 6.5) and was especially pronounced between the wildfire leave stands and the salvage logged stands ($p \leq 0.0001$). Salvage logging created a strong difference between the logging treatments, creating unique stands within the same burn severity class. This major division indicates that salvage logging has a major impact on the regeneration of species composition and coverage. Within the wildfire leave stand, all plots were significantly different indicating that the wildfire disturbance has created unique species compositions between the burn severities. Salvage logged stands also showed a significant difference in species composition between all burn severities, showing that the influence of burn severity is still strong enough to create unique species compositions even in the presence of salvage logging.

Table 6.5 Comparisons of species composition between logging treatments and burn severities within the Candle Lake burn site using MRPP. Significant results are shown in bold type.

Comparison	A	*p*
Between Treatments		
Wildfire vs. Salvage	0.1594	**<0.0001**
NB vs. NBL	0.1826	**0.0001**
MB vs. MBL	0.0602	**0.0010**
HB vs. HBL	0.0774	**0.0011**
Within Wildfire		
Wildfire (All)	0.1371	**<0.0001**
NB vs. MB	0.0906	**0.0001**
NB vs. HB	0.1766	**<0.0001**
MB vs. HB	0.0548	**0.0051**
Within Salvage		
Salvage (All)	0.0601	**0.0001**
NBL vs. MBL	0.0358	**0.0095**
NBL vs. HBL	0.0723	**0.0007**
MBL vs. HBL	0.0309	**0.0291**

ISA analysis between the wildfire leave stands and the salvage logged stands resulted in a total of 16 species plus the bryophyte group being identified as significant indicators ($p<0.05$). 15 species plus bryophytes were identified as significant indicators within the wildfire leave stands. Of these, 6 are also listed as indicators within the NB plots of the wildfire leave stand: *Cornus canadensis*, Bryophyte spp., *Picea glauca*, *Viburnum edule*, *Aralia nudicaulis*, and *Lycopodium annotinum* (Tables 6.6 and 6.7). Only *Equisetum arvense* was identified as an indicator species in the salvage logged stands. Salvage logging has increased the disturbance across the burn severities, making them more similar in regenerating species composition.

Table 6.6 Indicator Species Analysis for the Candle Lake burn site between logging treatments.

Species Name or Group	Treatment	IV	*p*
Populus tremuloides	Wildfire	82.1	0.0001
Cornus canadensis	Wildfire	82.1	0.0001
Bryophyte spp	Wildfire	85.5	0.0002
Picea glauca	Wildfire	48.7	0.0005
Viburnum edule	Wildfire	75.1	0.0008
Trientalis borealis	Wildfire	75.3	0.0009
Maianthemum canadens	Wildfire	73.4	0.0010
Linnaea borealis	Wildfire	74.7	0.0014
Aralia nudicaulis	Wildfire	75.0	0.0023
Viola renifolia	Wildfire	54.3	0.0049
Viola canadensis	Wildfire	34.6	0.0057
Lathyrus ochroleucus	Wildfire	56.1	0.0065
Vicia americana	Wildfire	45.6	0.0070
Alnus crispa	Wildfire	48.2	0.0171
Pinus banksiana	Wildfire	22.2	0.0240
Lycopodium annotinum	Wildfire	33.0	0.0324
Equisetum arvense	Salvage Logging	23.8	0.0465

Burn severity categories within the wildfire leave stands show 11 species plus lichens and bryophytes with significant indicator values ($p<0.05$; Table 6.7). Ten of these were indicators of NB plots. The MB plots listed only *Petasites palmatus*, while *Geranium bicknellii* and *Dracocephalum parviflorum*, species commonly associated with early successional stands, were listed as indicators for the HB plots. Indicator species were found in each burn severity category indicating that unique species compositions were occurring due to the varying levels of burn severity disturbance. All species had an indicator value (IV) greater than 50, identifying them as strong species indicators for those burn severities.

Table 6.7 Indicator Species Analysis for the Candle Lake burn site between burn severities within the wildfire leave stands.

Species Name or Group	Burn Severity	IV	*p*
Aralia nudicaulis	No Burn	76.3	0.0001
Lichen spp.	No Burn	83.0	0.0001
Bryophyte spp.	No Burn	73.3	0.0002
Picea glauca	No Burn	71.9	0.0005
Betula papyrifera	No Burn	68.3	0.0023
Rubus pubescens	No Burn	64.1	0.0034
Pyrola secunda	No Burn	57.1	0.0055
Lycopodium annotinum	No Burn	63.6	0.0068
Cornus canadensis	No Burn	53.1	0.0210
Viburnum edule	No Burn	57.6	0.0462
Petasites palmatus	Light/Medium Burn	72.7	0.0026
Geranium bicknellii	High Burn	78.8	0.0018
Dracocephalum parviflorum	High Burn	50.5	0.0404

Burn severity categories within the salvage logged stands identified 4 species as significant indicators ($p<0.05$; Table 6.8). All species were listed within the HBL plots and have an IV >50. These species include: *Epilobium angustifolium,* Aster spp., *Petasites palmatus,* and *Mertensia paniculata*. No species were identified as significant indicators within the NBL and MBL plots. Since indicator species were identified only for the high severity burn sites, salvage logging has created a more homogenous species composition between the burn severities, losing the vegetative range found within the wildfire leave stands.

Table 6.8 Indicator Species Analysis for the Candle Lake burn site between burn severities within the salvage logged stands.

Species Name or Group	Burn Severity	IV	*p*
Epilobium angustifolium	High Burn	75.1	0.0018
Aster spp.	High Burn	56.7	0.0174
Petasites palmatus	High Burn	61.4	0.0176
Mertensia paniculata	High Burn	61.0	0.0340

The cluster analysis of burn severity and logging treatment on stand similarity at Candle Lake showed a strong division between the wildfire leave stands and the salvage logged areas (Figure 6.2). The MB and HB leave plots displayed a high degree of similarity in terms of species composition due to the influence of a fire disturbance. These sites were noticeably different from NB plots. The salvage logged plots showed varying levels of dissimilarity between the burn severities and overall differences were less pronounced than the wildfire leave stands, with the HBL plot shown to be the most dissimilar of the group. NBL plots are more similar in composition to the MBL and HBL plots, indicating a more homogenous regeneration within the salvage logged areas. The separation of the two clusters indicates that post-fire salvage logging does influence stand composition.

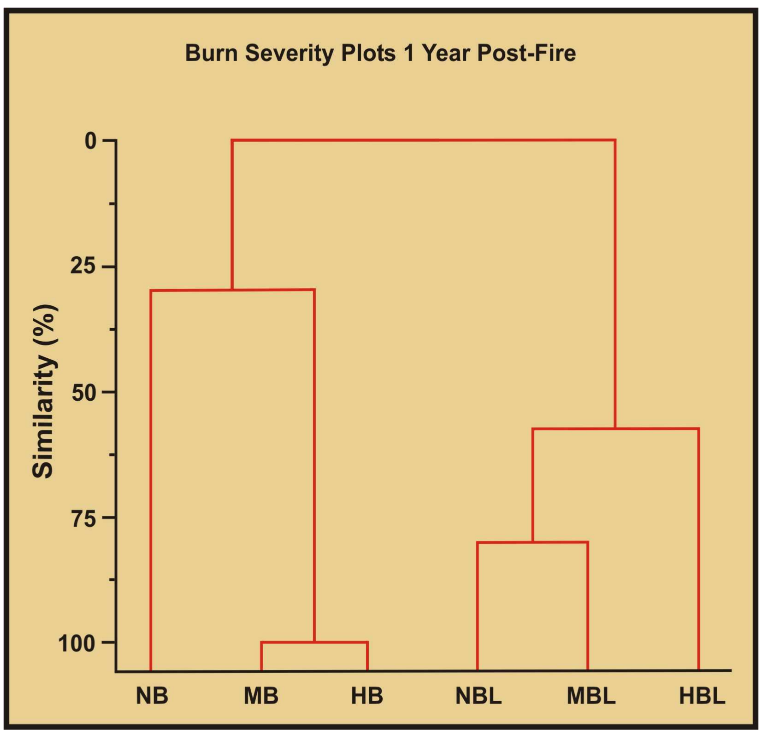

Figure 6.2 Association analysis of burn severity stand similarity for Candle Lake burn site - 1 year post-fire. NB, MB, HB indicate wildfire leave stands while NBL, MBL, HBL indicate salvage logged stands.

The summary results of the Canonical Correspondence Analysis (CCA) for all burn severity and logging combinations as related to environmental variables are shown in Table 6.9. Axis 1 shows a strong negative correlation with leaf litter and cover of bryophytes and lichens, and a positive correlation with the amount of exposed soil. Axis 2 shows a positive correlation with needle litter cover and a negative correlation with exposed soil. No variables were strongly related to Axis 3. The total variance in species data explained by each axis is shown in Table 6.9.

Table 6.9 Correlations on three axes for six variables using CCA on logging treatment and burn severity plots within the Candle Lake burn site (1 year post-fire).

Variables	Correlations		
	Axis 1	Axis 2	Axis 3
Wood Matter Cover	0.219	0.320	0.237
Leaf Litter Cover	-0.870	-0.089	-0.020
Needle Litter Cover	0.255	0.546	0.023
Exposed Soil Cover	0.675	-0.616	0.098
Bryophyte spp. Cover	-0.805	-0.048	0.128
Lichen spp. Cover	-0.594	0.207	-0.150
Total Variance (%)	11.6	5.6	3.8

The CCA ordination visually separated the burn severities between the logging treatments (Figure 6.3). NB plots are strongly separated from the HB and all salvage logged plots by axis 1. NB plots are associated with leaf litter, lichen, and bryophyte cover which increases from the right to the left within the ordination. The first axis placed the MB (light to medium burn severity) plots between NB and HB plots. MB plots contain characteristics of both classes which differ in the amount of disturbance as shown through the dispersal across the ordination. HB plots are associated with exposed soil cover as the organic layer has been consumed by the high severity wildfire, opening up the forest floor. HB plots were closer to the composition and environment of the salvage logged plots but remained significantly different on Axis 2. All burn severities within the salvage logged plots, NBL, MBL, and HBL, are associated with needle litter cover indicating the larger amount of debris and slash which occurred due to the harvesting methods used for the salvage logging operation.

MB and MBL plots tend to occupy the same ordination space indicating that species composition and environment variables of moderately burned forest stands are not drastically affected by salvage logging. The major disturbance occurs within the high burn and low burn areas as they contract to the moderately burned ordination space when salvage logging is applied. The high level of disturbance of the environmental variables of the salvage logging operation within the high burn and low burn areas makes them more similar to the moderately burned areas, decreasing the range of the vegetation communities and creating a more homogenous forest stand.

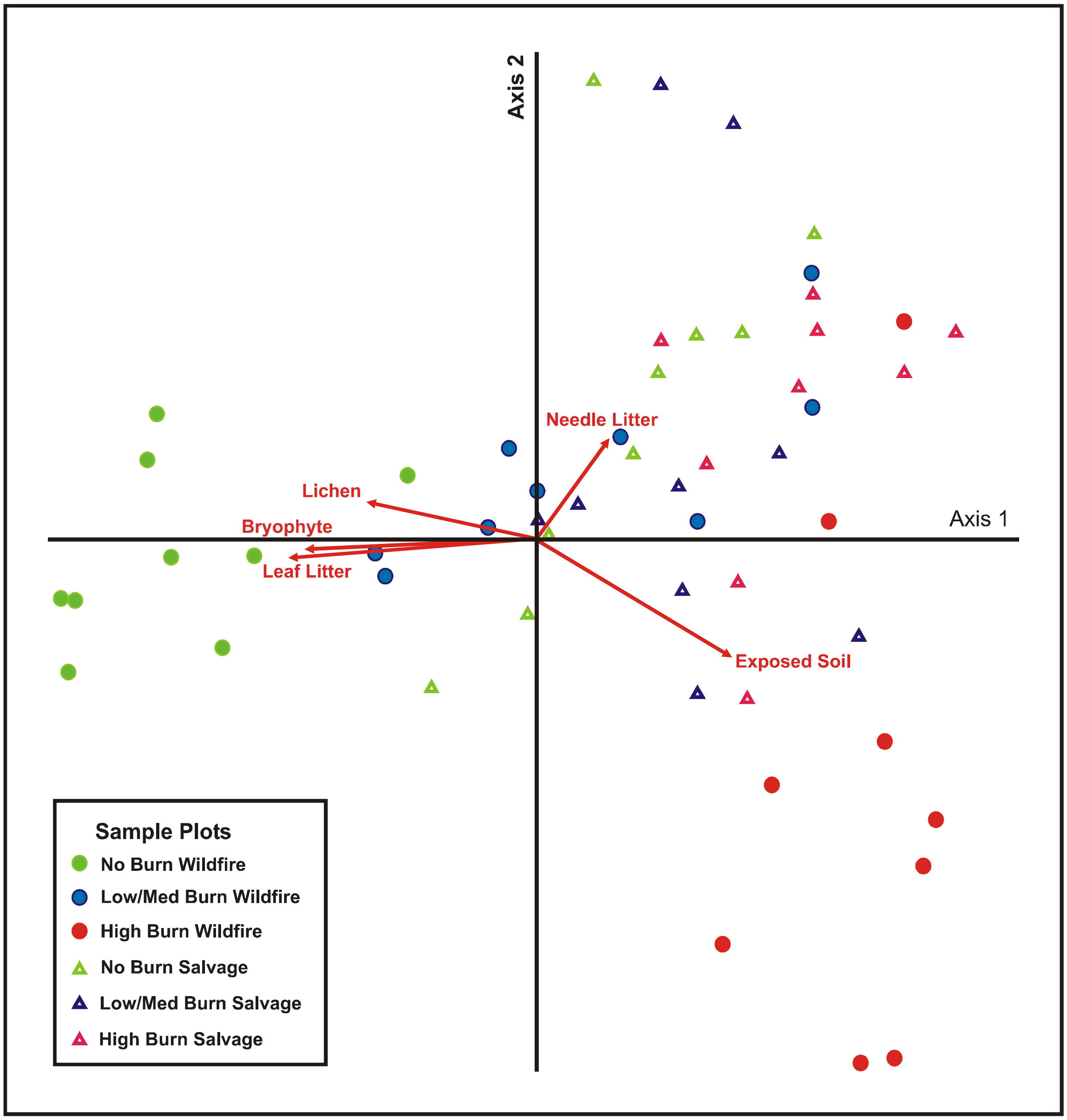

Figure 6.3 Canonical Correspondence Analysis (CCA) ordination plot of burn severity between logging treatments in the mixedwood boreal forest stands of the Candle Lake burn site (1 year post-fire).

6.2 Mahigan burn sites (10 years post-fire)

6.2.1 Species richness and diversity

A total of 73 species were catalogued in salvage logged and wildfire leave stands at the Mahigan Burn Site. Seventy-two species were recorded within the wildfire leave stand and 54 within salvage logged stand (Table 6.10). A total of 18 species found within the wildfire leave stand were not found within the salvage logged stand. Overall species richness was found to be marginally higher within the salvage logged stand (Figure 6.4), but this may be influenced by a smaller sample size of 6 plots and was not found to be significant between the logging treatments (Table 6.11). A significant difference in total species richness between burn severities was found ($p \leq 0.001$; Table 6.11); all burn severities within salvage logged stands were found to have higher values (Table 6.10). The wildfire leave stands recorded a higher amount of shrub and herb species between all of the burn severities than the salvage logged areas. A complete list of all species recorded and the frequency they occur between the logging treatments and burn severities is found in Appendix 2.

Species diversity at the treatment level and between burn severities was found to be higher within the salvage logged stands (Table 6.10). A significant difference in diversity between burn severities ($p \leq 0.001$) and between logging treatments ($p \leq 0.001$) was found in both cases, while the interaction between burn severity and logging treatments did not prove significant (Table 6.11). No difference in total cover of species between the burn severities was found, but total cover differences between logging treatments were shown to be significant ($p = 0.016$). The regeneration of the young tree and shrub species created a low thick canopy which can account for a large total coverage within the salvage logged plots. The difference in diversity and total cover between the logged and unlogged treatments is probably connected to the removal of residual trees and disturbance of the forest floor during the salvage logging operation.

Table 6.10 Species richness and diversity (Shannon`s diversity index *H'*) for all vascular plants within the Mahigan burn site (10 years post-fire).

Treatment	Burn Severity	# of sites sampled	Mean Species Richness	Total Species	Total Tree	Total Shrub	Total Herb	Total cover (%)	Diversity (*H'*)
	NB	6	26.83	52	3	14	35	88.7	2.10
Leave	MB	6	28.00	60	7	17	36	84.33	2.30
	HB	6	17.67	43	5	10	28	80.3	1.58
	NBL	4	31.00	47	6	12	29	100	2.75
Salvage	MBL	4	27.00	42	6	9	27	100	2.71
	HBL	4	20.50	34	6	9	19	100	2.21
Overall Wildfire		18	24.17	72	7	19	46	84.44	1.99
Overall Salvage		12	26.17	54	6	16	32	100	2.56

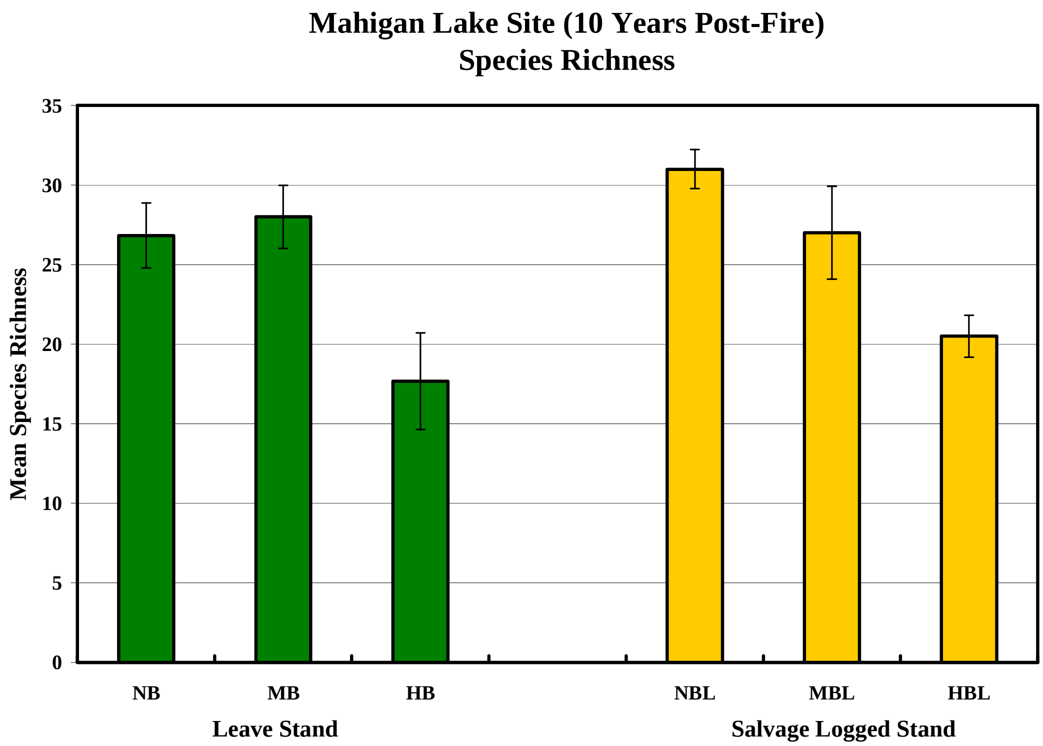

Figure 6.4 Species richness for all vascular plants within the Mahigan burn site (10 years post-fire).

Table 6.11 ANOVA results for species richness, diversity and total cover on the logging treatment and burn severity classes of the Mahigan burn site (10 years post-fire). Significant results are shown in bold type.

	Total Species Richness			Diversity			Total Cover		
Source	df	F	sig.	df	F	sig.	df	F	sig.
Burn Severity	2	9.847	**0.001**	2	1.069	**<0.001**	2	0.612	0.851
Logging	1	1.045	0.317	1	2.283	**<0.001**	1	6.666	**0.016**
Burn Sev. vs. Logging	2	0.627	0.543	2	0.045	0.619	2	0.612	0.851
Error	24			24			24		

6.2.2 Environmental characteristics

Environmental differences between the two logging treatments are still evident 10 years after the wildfire and salvage logging operation. After removing the standing timber, the surface area of the salvage logged stand was tilled and replanted with *Pinus banksiana*; large trenches and berms are found throughout the site. Comparative forest structure was not measured within the salvage logged stands because there were insufficient trees and snags due to the clear cutting method utilized. The major differences in the environmental variables found at the Candle Lake site (1 year post-fire) are not as prominent 10 years post-fire between the salvage logged and wildfire leave stands (Table 6.4 and Table 6.13).

Between the NB and NBL sites there was a noticeable decline in bryophyte cover, whereas the MBL and HBL had a considerably higher bryophyte cover compared to their respective leave stands (Table 6.12). This is shown in Table 6.13 as the interaction between the burn severity and the logging treatment was significant (<0.001). Lichen species were found to have no significant difference across the logging treatments and burn severities. Coarse woody debris was slightly higher in the MB and HB leave stands due to the large amount of fallen snags which have tipped over since the fire disturbance

(Table 6.12). The coarse woody debris coverage found no significant difference across the logging treatments, burn severity or their interaction. This evenness in CWD between the wildfire leave stand and the salvage logged stand is predicted to change as more standing snags within the leave stand fall due to decay, increasing the input of CWD over a longer time period. Both leaf litter and needle litter had higher total coverage within the salvage logged stands due to the high regeneration of *Populus tremuloides* and the planted *Pinus banksiana*. Leaf litter was found to be significant within the burn severity and the logging treatments due to the unique species compositions found between the burn severities and the very high regeneration rate of *Populus tremuloides* within the salvage logged stand. Needle litter was significantly different in the burn severity due to the increased presence of *Pinus banksiana* in the high severity burn areas. Only the HBL treatment had an increased amount of exposed soil and it was not significantly different at any level. Comparative forest structure was not measured because there were insufficient trees and snags after the sites had been clear-cut during salvage logging.

Table 6.12 Environmental characteristics of the Mahigan burn site (10 years post-fire). All values made available are means ± 1 S.E.

Treatment	Leave Stand			Salvage Logged		
Burn Severity	NB	MB	HB	NBL	MBL	HBL
% Ground Cover						
Bryophyte species	35.42 ± 9.29	5.92 ± 1.85	2.75 ± 1.5	10.63 ± 3.59	23.75 ± 7.94	28.75 ± 5.05
Lichen species	2.42 ± 1.55	0.50 ± 0.0	0.43 ± 0.07	0.30 ± 0.11	1.00 ± 0.5	0.80 ± 0.57
Coarse Woody Debris	16.67 ± 2.11	24.17 ± 4.50	18.33 ± 1.67	15.0 ± 2.89	16.88 ± 6.88	12.5 ± 2.5
Leaf Litter	34.17 ± 7.35	25.17 ± 7.80	19.67 ± 6.58	62.5 ± 10.2	56.25 ± 11.98	21.86 ± 5.72
Needle Litter	2.42 ± 1.55	4.42 ± 3.14	41.25 ± 8.00	6.25 ± 2.17	13.13 ± 8.32	50.0 ± 7.22
Exposed Soil	0.00	0.08 ± 0.08	0.00	0.00	0.00	10.63 ± 8.98
Forest structure (>10m)						
% Canopy Cover	51.75	18.00	8.75	--	--	--
Residual DBH (cm)	23.95 ± 1.80	24.23 ± 1.86	16.36 ± 0.99	--	--	--
Residual Height (m)	12.37 ± 0.89	13.05 ± 1.23	12.58 ± 0.76	--	--	--
% Dead Snags	10.81	25.00	100.00	--	--	--

Table 6.13 ANOVA results for environmental characteristics of the Mahigan burn site (10 years post-fire). Significant results are shown in bold type.

	Bryophyte species			Lichen species			Coarse Woody Debris		
Source	df	F	sig.	df	F	sig.	df	F	sig.
Burn Severity	2	1.165	0.329	2	0.453	0.641	2	1.181	0.324
Logging	1	1.749	0.198	1	0.378	0.545	1	2.680	0.115
Burn Sev. vs. Logging	2	10.765	**<0.001**	2	1.574	0.228	2	0.313	0.734
Error	48			48			48		

	Leaf Litter			Needle Litter			Exposed Soil		
Source	df	F	sig.	df	F	sig.	df	F	sig.
Burn Severity	2	5.758	**0.009**	2	31.144	**<0.001**	2	2.223	0.130
Logging	1	8.996	**0.006**	1	2.290	0.143	1	2.206	0.151
Burn Sev. vs. Logging	2	1.805	0.186	2	0.121	0.887	2	2.258	0.126
Error	48			48			48		

6.2.3 Plant community comparisons

MRPP comparisons between the salvage logged stand and wildfire leave stand showed that the species composition between logged and unlogged treatments 10 years post-fire are still significantly different ($p \leq 0.001$) for all burn severities, with the exception of the HB and HBL sites (Table 6.14). Differences are still evident in the species compositions between the no burn and moderate burn severities. The similarity between the HB and HBL sites signifies that the effects of salvage logging do not have long lasting effects in areas of high severity burns. Within the wildfire leave stand all burn severities were significantly different, indicating that separate plant communities have developed since disturbance. The varying levels of disturbance caused by the burn severity have allowed different vegetative communities to develop in close proximity to one another. Within the salvage logged stand, high burn severity plots were significantly different from both the NBL and MBL plots. There was no significant difference found between the NBL and MBL sites indicating that the sites have become similar in the ten years since the salvage logging disturbance. The removal of the standing timber and the major tillage of the forest soils have caused the no burn and moderate burn severity sites to become similar in species composition, with salvage logging erasing the signs of burn activity and the unique species compositions that follow.

Table 6.14 Comparisons of species composition between logging treatments and burn severities within the Mahigan Burn Site using MRPP. Significant results are shown in bold type.

Comparison	A	*p*
Between Treatments		
Wildfire vs. Salvage	0.2205	**<0.0001**
NB vs. NBL	0.1434	**0.0022**
MB vs. MBL	0.1130	**0.0014**
HB vs. HBL	0.0493	0.1172
Within Wildfire		
Wildfire (All)	0.1895	**<0.0001**
NB vs. MB	0.0977	**0.0005**
NB vs. HB	0.2284	**0.0005**
MB vs. HB	0.1289	**0.0019**
Within Salvage		
Salvage (All)	0.1667	**0.0039**
NBL vs. MBL	0.0072	0.3833
NBL vs. HBL	0.2089	**0.0087**
MBL vs. HBL	0.1742	**0.0114**

ISA analysis between the logging treatments resulted in a total of 12 species plus the *Salix* spp. group being identified as significant indicators ($p<0.05$) within the salvage logged stands (Table 6.15). Of the species listed, *Pinus banksiana* is also considered as an indicator species for both the HB and HBL plots within the wildfire leave stand and the salvage logged leave stand (Tables 6.16 and 6.17). At the logging treatment level no species was identified as an indicator for the wildfire leave stands; this relates to the loss of distinctive community structures between the burn severity classes within the salvage logged area. Tillage of the forest soil within the salvage logged area may have produced a more hospitable environment for species regeneration, resulting in a higher abundance of herbaceous species. As the salvage logged area have become more homogenous, the burn severity classes are of similar species compositions, increasing the likelihood for individual species to be counted as an indicator for that logging treatment.

Table 6.15 Indicator Species Analysis for the Mahigan burn site between logging treatments.

Species Name or Group	Treatment	IV	*p*
Cornus canadensis	Salvage Logging	91.5	0.0001
Linnaea borealis	Salvage Logging	80.4	0.0019
Epilobium angustifolium	Salvage Logging	82.9	0.0020
Lathyrus ochroleucus	Salvage Logging	72.0	0.0020
Alnus crispa	Salvage Logging	71.4	0.0039
Vaccinium vitis-idaea	Salvage Logging	63.1	0.0060
Achillea millefolium	Salvage Logging	56.7	0.0089
Populus balsamifera	Salvage Logging	46.8	0.0143
Pinus banksiana	Salvage Logging	62.3	0.0277
Ledum groenlandicum	Salvage Logging	65.5	0.0289
Salix spp.	Salvage Logging	59.2	0.0369
Rubus idaeus	Salvage Logging	62.3	0.0431
Larix laricina	Salvage Logging	31.6	0.0437

Burn severity categories within the leave stands show 10 species plus bryophytes, *Salix* spp. and grasses with significant indicator values ($p<0.05$; Table 6.16). Nine of these were indicators of NB severity. The MB severity listed only grass species, while *Pinus banksiana* and *Salix* spp. were listed as indicators for the HB plots. All species had an indicator value greater than 50, identifying them as strong species indicators for distinguishing between burn severities which have developed unique stand characteristics since the fire disturbance. The no burn plots were untouched by fire and are characterized by species such as *Picea glauca* and bryophytes which are commonly found in more mature undisturbed forests. The high burn plots developed a strong association with *Pinus banksiana* which tends to regenerate in large abundance after high severity burns due to the large amount of mineral soil exposed after the fire.

Table 6.16 Indicator Species Analysis for the Mahigan burn site between burn severities within the wildfire leave stands.

Species Name or Group	Burn Severity	IV	*p*
Picea glauca	No Burn	92.5	0.0003
Bryophyte spp.	No Burn	80.3	0.0009
Alnus crispa	No Burn	82.1	0.0030
Aralia nudicaulis	No Burn	85.4	0.0065
Rubus pubescens	No Burn	56.6	0.0158
Ribes lacustre	No Burn	79.6	0.0184
Galium triflorum	No Burn	68.2	0.0275
Ribes triste	No Burn	67.7	0.0346
Cornus stolonifera	No Burn	62.6	0.0438
Grass spp.	Light/Medium Burn	83.4	0.0140
Pinus banksiana	High Burn	99.5	0.0002
Salix spp.	High Burn	67.3	0.0273

Burn severity categories within the salvage logged stands identified 2 species as significant indicators (p<0.05; Table 6.17). The no burn plots listed *Mertensia paniculata* as a strong indicator species (IV = 83.2); high burn severity listed *Pinus banksiana* as a strong indicator (IV = 62.8). No species were identified as significant indicators within the MBL plots. The lack of indicator species found between the burn severity classes indicates a loss of heterogeneity within the salvage logged area as the regenerating species composition becomes similar. The loss of distinctive stand structure between the burn severities is an indication of a decrease in diversity and a loss of species richness within the salvage logged areas ten years post-fire. The only indicator species found within both logging treatments are *Pinus banksiana* and *Salix* spp. and both species are identified with high burn severity signifying that salvage logging within high severity areas does not have long lasting effects.

Table 6.17 Indicator Species Analysis for the Mahigan burn site between burn severities within the salvage logged stands.

Species Name or Group	Burn Severity	IV	*p*
Mertensia paniculata	No Burn	83.2	0.0361
Pinus banksiana	High Burn	62.8	0.0341

The cluster analysis of burn severity and logging treatment on stand similarity at the Mahigan burn site indicated that the effects of salvage logging are still evident 10 years post-fire (Figure 6.5). Since the NB plots were undisturbed they showed a strong dissimilarity to the other treatments while the greatest similarity was found between the HB and HBL plots. This indicates that the residual effects of salvage logging do not persist over a long period of time in areas of high burn severity. Differences were still detected between the NBL and MBL plots and they have formed a weak cluster with the MB plots. Whereas initial post-fire regeneration was clearly divided by salvage logging (Figure 6.3), over a ten year time period three regrowth cover types have developed, characterised by no disturbance, moderate disturbance either by fire or salvage logging, and severe disturbance.

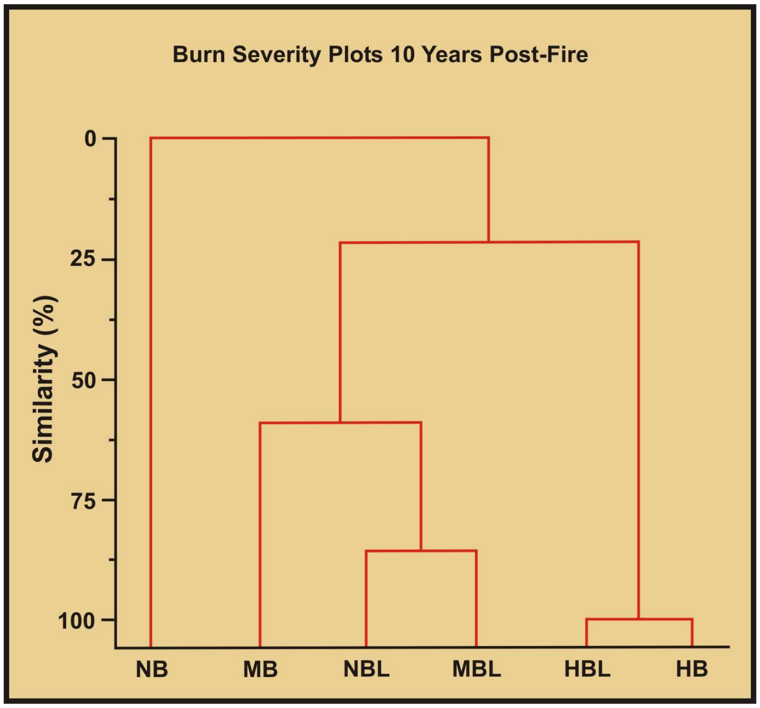

Figure 6.5 Association analysis of burn severity stand similarity for the Mahigan burn site - 10 years post-fire. NB, MB, HB indicate wildfire leave stands while NBL, MBL, HBL indicate salvage logged stands.

The summary results of the Canonical Correspondence Analysis (CCA) for all burn severity and logging combinations as related to environmental variables are shown in Table 6.18. Axis 1 shows a strong negative correlation with needle litter. Axis 2 shows a negative correlation with the amount of bryophyte cover recorded. No variables were strongly related to Axis 3. The total variance in species data explained by each axis is shown in Table 6.18.

Table 6.18 Correlations on three axes for six variables using CCA on logging treatment and burn severity plots within the Mahigan burn site (10 years post-fire).

Variables	Correlations		
	Axis 1	Axis 2	Axis 3
Wood Matter Cover	0.098	0.036	-0.151
Leaf Litter Cover	0.371	0.338	-0.352
Needle Litter Cover	-0.912	-0.097	0.085
Exposed Soil Cover	-0.285	-0.051	-0.052
Bryophyte spp. Cover	-0.006	-0.743	0.051
Lichen spp. Cover	0.188	-0.204	0.161
Total Variance (%)	15.0	7.5	6.4

The CCA ordination visually separated the burn severities between the logging treatments (Figure 6.6). NB plots are associated with bryophyte species cover which increases from the centre to the bottom of the ordination. HB and HBL plots are associated with needle cover due to the high density regeneration of *Pinus banksiana* found within both burn severities. The remaining environmental variables did not significantly correlate with any of the burn severities.

The ordination has separated the plots into three groups with similar species composition and environmental variables. NB plots were grouped together on the bottom right of the axis with a second group of MB, NBL and MBL plots together on the centre of the axis and a third group of HB and HBL plots to the left side of the axis. The NB plots were undisturbed and are grouped together showing a separate species composition unique to that of the disturbed plots. MB, NBL, and MBL are clustered together indicating that in ten years post-fire the MBL and NBL plots are becoming similar in both vegetative and environmental structure to the MB plots. HB and HBL plots have become quite similar in composition 10 years post-fire indicating that high severity burn areas show little long lasting effects to salvage logging.

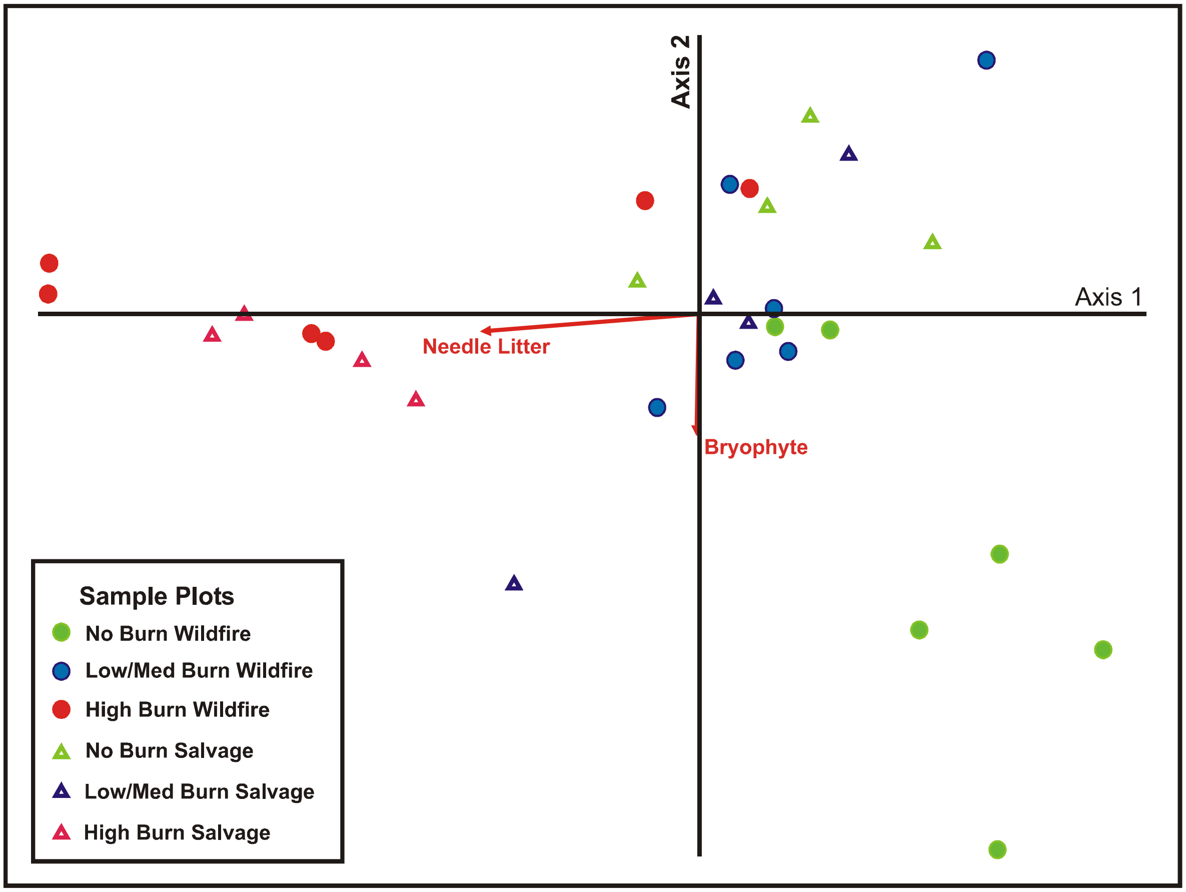

Figure 6.6 Canonical Correspondence Analysis (CCA) ordination plot of burn severity between logging treatments in the mixedwood boreal forest stands of the Mahigan Burn site (10 year post-fire).

6.3 Comparison of the Mahigan and Beaupré burn sites (10 years post-fire)

6.3.1 Species richness and diversity

A total of 62 species were identified at the Beaupré Burn Site, while the Mahigan site catalogued a total of 72 species (Table 6.19). Species richness within the burn severity classes at the Mahigan and Beaupré sites was similar for the NB and MB plots. However, the Beaupré site had much higher species richness in the HB severity class; this is possibly due to a higher density of *Populus tremuloides* within the pre-fire stand which resulted in a less severe burn. Species richness and diversity was significantly different between the burn severity classes and between sites, and also between burn severities within the sites (Tables 6.20). These significant differences may be due to the Mahigan site being located in a moister low lying area (personal observation) which would create the habitat for a wider range of plant species. A complete list of all species recorded and their frequency at the Beaupré burn is found in Appendix 3.

Diversity was slightly higher within the Beaupré site (Table 6.19). The difference in diversity between the two sites was found to be significant between burn severity classes and between sites, as well as the interaction between the burn severities and the sites (Table 6.20). The species compositions were all significantly different between the two sites. Total species cover was not significantly affected by burn severity or by the interaction between burn severity and the sites, but total cover between the two sites was significantly different (p = 0.035) indicating that there is a difference in the species composition between the two representative upland mixedwood boreal forest stands.

Table 6.19 Species richness and diversity (Shannon's diversity index *H'*) for all vascular plants within the Beaupré burn site (10 years post-fire).

Treatment	Burn Severity	# of sites sampled	Mean Species Richness	Total Species	Total Tree	Total Shrub	Total Herb	Total Cover (%)	Diversity (*H'*)
Beaupré	NB	6	26.67	44	5	12	27	93.92	2.14
	MB	6	28.50	50	5	14	31	93.67	2.39
	HB	6	27.50	52	5	10	37	100	2.22
Mahigan	NB	6	26.83	52	3	14	35	88.70	2.10
	MB	6	28.00	60	7	17	36	84.33	2.30
	HB	6	17.67	43	5	10	28	80.30	1.58
Overall Beaupré		18	27.56	62	6	17	39	95.86	2.25
Overall Mahigan		18	24.17	72	7	19	46	84.44	1.99

Table 6.20 ANOVA results for species richness, diversity and total cover on the effect of burn severity classes between the Mahigan and Beaupré burn sites (10 years post-fire). Significant results are shown in bold type.

	Total Species Richness			Diversity			Total Cover		
Source	df	F	sig.	df	F	sig.	df	F	sig.
Burn Sev.	2	4.405	**0.021**	2	6.634	**0.004**	2	0.067	0.936
Site	1	4.401	**0.044**	1	6.635	**0.015**	1	4.901	**0.035**
Burn Sev. vs. Site	2	3.993	**0.029**	2	3.803	**0.034**	2	0.698	0.505
Error	30			30			30		

6.3.2 Environmental characteristics

Differences in site conditions and stand structure between the two sites are minimal (Table 6.21). Bryophyte cover is significantly different between the burn severities, the sites and the interaction between the burn severities and the sites (Table 6.22). The significant difference in bryophyte cover between the two sites may be explained by the forest canopy difference as the Beaupré canopy is dominated by *Populus tremuloides* which tend to grow in drier soils; this may lead to a lesser abundance of bryophyte cover on the forest floor. Coarse woody debris, lichen and exposed soil coverage all did not show a significant difference between either the burn severities of the site difference. The Beaupré site had a much higher cover of leaf litter associated with the dense regeneration of *Populus tremuloides* in the high burn severity plots which is indicated by the significant difference ($p = 0.002$) between the two sites. The Mahigan site has a much higher needle litter cover within the high burn severity plots due to the greater density of conifers. A difference in needle litter was found significantly different across all of the categories. The forest structure between the two sites does not differ greatly, indicating similar post-fire structure between the burn severities and sites.

Table 6.21 Environmental characteristics of the Beaupré burn site (10 Years Post-Fire). All values made available are means ± 1 S.E.

Treatment	Beaupré Leave Stand			Mahigan Leave Stand		
Burn Severity	NB	MB	HB	NB	MB	HB
% Ground Cover						
Bryophyte species	7.92 ± 2.84	1.83 ± 0.42	1.50 ± 0.45	35.42 ± 9.29	5.92 ± 1.85	2.75 ± 1.5
Lichen species	2.08 ± 1.58	0.50 ± 0	0.50 ± 0	2.42 ± 1.55	0.50 ± 0.0	0.43 ± 0.07
Coarse Woody Debris	17.91 ± 6.31	26.67 ± 8.26	28.33 ± 5.80	16.67 ± 2.11	24.17 ± 4.50	18.33 ± 1.67
Leaf Litter	54.17 ± 5.27	37.08 ± 9.63	53.75 ± 10.87	34.17 ± 7.35	25.17 ± 7.80	19.67 ± 6.58
Needle Litter	3.75 ± 1.25	10.83 ± 10.8	4.08 ± 3.20	2.42 ± 1.55	4.42 ± 3.14	41.25 ± 8.00
Exposed Soil	0.00	0.00	0.00	0.00	0.08 ± 0.08	0.00
Forest structure (>10m)						
% Canopy Cover	69.25	10.83	2.25	51.75	18.00	8.75
Residual DBH (cm)	22.96 ± 1.28	24.09 ± 2.03	22.60 ± 1.29	23.95 ± 1.80	24.23 ± 1.86	16.36 ± 0.99
Residual Height (m)	13.81 ± 0.63	11.79 ± 1.66	13.13 ± 0.91	12.37 ± 0.89	13.05 ± 1.23	12.58 ± 0.76
% Dead Snags	9.86	42.11	100.00	10.81	25.00	100.00

Table 6.22 ANOVA results for environmental characteristics of the Mahigan and Beaupré burn sites (10 years post-fire). Significant results are shown in bold type.

	Bryophyte species			Lichen species			Coarse Woody Debris		
Source	df	F	sig.	df	F	sig.	df	F	sig.
Burn Severity	2	13.949	**<0.001**	2	2.539	0.096	2	1.264	0.297
Site	1	10.718	**0.003**	1	0.014	0.905	1	1.118	0.299
Burn Sev. vs. Site	2	6.191	**0.006**	2	0.028	0.972	2	0.397	0.676
Error	30			30			30		

	Leaf Litter			Needle Litter			Exposed Soil		
Source	df	F	sig.	df	F	sig.	df	F	sig.
Burn Severity	2	1.295	0.289	2	6.468	**0.005**	2	1.000	0.380
Site	1	10.977	**0.002**	1	4.439	**0.044**	1	1.000	0.325
Burn Sev. vs. Site	2	0.951	0.398	2	8.741	**0.001**	2	1.000	0.380
Error	30			30			30		

6.3.3 Plant community comparisons

MRPP comparisons within the wildfire leave stands at the Beaupré site showed significant differences for all combinations of burn severity (Table 6.23) as well as for the overall stand analysis. This reflects the distinctive community structures between burn severity classes within the wildfire leave stands. Comparisons between the Mahigan and Beaupré burn severities show significant differences at all levels (Table 6.24), indicating a difference in species composition. This difference is potentially due to a higher frequency of conifer species found throughout the Mahigan site and a higher frequency of deciduous species found throughout the Beaupré site (Appendices 2 and 3). Both the Mahigan and Beaupré sites show development of distinct species compositions among the burn severities in the 10 years since the wildfire disturbance. Even though the two sites differ in species composition between burn severity classes (Table 6.24), they both show a similar trend in unique species composition among burn severities.

Table 6.23 Comparisons of species cover between burn severities within the Beaupré burn site using MRPP. Significant results are shown in bold type.

Comparison	A	*p*
Within Wildfire		
Wildfire (All)	0.1704	**<0.0001**
NB vs. MB	0.1461	**0.0005**
NB vs. HB	0.2082	**0.0005**
MB vs. HB	0.0565	**0.0131**

Table 6.24 Comparisons of species cover within burn severities between the Mahigan and Beaupré burn sites using MRPP. Significant results are shown in bold type.

Comparison	A	*p*
Within Wildfire		
Wildfire (All)	0.2104	**<0.0001**
Mahigan NB vs. Beaupré NB	0.1309	**0.0030**
Mahigan MB vs. Beaupré MB	0.0535	**0.0034**
Mahigan HB vs. Beaupré HB	0.1735	**0.0013**

ISA analysis of the Beaupré leave stands resulted in a total of 8 species plus *Salix* spp. and bryophyte groups being identified as significant indicators (p<0.05; Table 6.25) of the wildfire treatments. Of these species, three are identified as indicators of the NB treatment - *Abies balsamea*, bryophytes, and *Aralia nudicaulis*. Only *Rubus idaeus* was identified as an indicator species for the MB treatment. Within the HB treatment 6 indicator species are listed - *Taraxacum officinale*, *Epilobium angustifolium*, *Populus tremuloides*, *Salix* spp., *Populus balsamifera*, and *Fragaria virginiana*. This reflects the high regeneration of broadleaf tree species found throughout the HB severity plots at the Beaupré site (Appendix 3). Indicator species were found in each burn severity category indicating that unique species compositions were occurring due to the varying levels of burn severity disturbance. All species had an indicator value (IV) greater than 60, identifying them as very strong species indicators for those burn severities. The Mahigan and Beaupré wildfire leave stands share some indicator species between the burn severities. Within the NB treatment both sites list Bryophyte spp. and *Aralia nudicaulis* as significant indicators. Within the HB treatment only *Salix* spp. was listed as significant between both sites.

Table 6.25 Indicator species analysis for the Beaupré burn site between burn severities within the wildfire leave stands.

Species Name or Group	Burn Severity	IV	*p*
Abies balsamea	No Burn	94.4	0.0005
Bryophyte spp.	No Burn	70.4	0.0175
Aralia nudicaulis	No Burn	73.9	0.0228
Rubus idaeus	Light/Medium Burn	71.1	0.0136
Taraxacum officinale	High Burn	90.9	0.0007
Epilobium angustifolium	High Burn	87.5	0.0017
Populus tremuloides	High Burn	64.1	0.0064
Salix spp.	High Burn	76.4	0.0091
Populus balsamifera	High Burn	62.9	0.0288
Fragaria virginiana	High Burn	61.1	0.0482

6.4 Microclimate variation between logging treatments within the Candle Lake burn site (1 year post-fire)

6.4.1 Microclimate

Available energy for each microclimatic system varied strongly between micro-sites (Figure 6.7). Compared to the NB site, average incoming radiation increased by a factor of 3 within the NBL site, with more than a fourfold increase in the MBL site compared to the MB site. However, average radiation increased only by a factor of 1.2 between the HBL and HB sites due to the smaller overall change in structure.

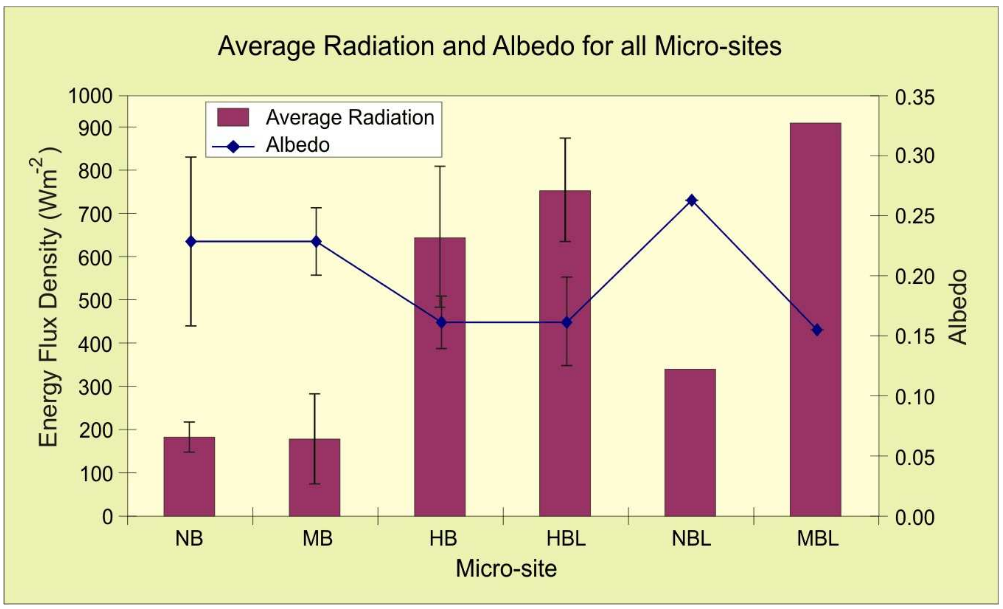

Figure 6.7 Average radiation and albedo at the Candle Lake micro-sites.

Albedo values were generally consistent within the MB and HB sites, averaging about 0.17 (Figure 6.7). Albedo averaged 27% in the three NB sites, and values typically were more variable within each site. The HBL sites showed the most within-site variation with albedos ranging from 12 to 24%. The high albedo associated with the NBL sites can be attributed to the reflectivity of branches and foliage on the ground and the absence of blackened, fire-charred materials which provides a surface that is comparable to the NBL site.

Air temperatures differed significantly between sites and were highest in the salvage logged treatments MBL and HBL where mean monthly maximum temperatures at a height of 50 cm exceeded 33 °C in July (Figure 6.8). Mean maximum temperature in July for HB was 32 °C which was similar to the NB control stand. The 50 cm mean July temperature at MB was lower than HB by 3 ° C and by 7° C compared to MBL. Unfortunately, the datalogger at NBL failed. Mean monthly air temperatures at 150 cm were less variable and in July ranged from 29 °C at MB to 34 °C at HBL.

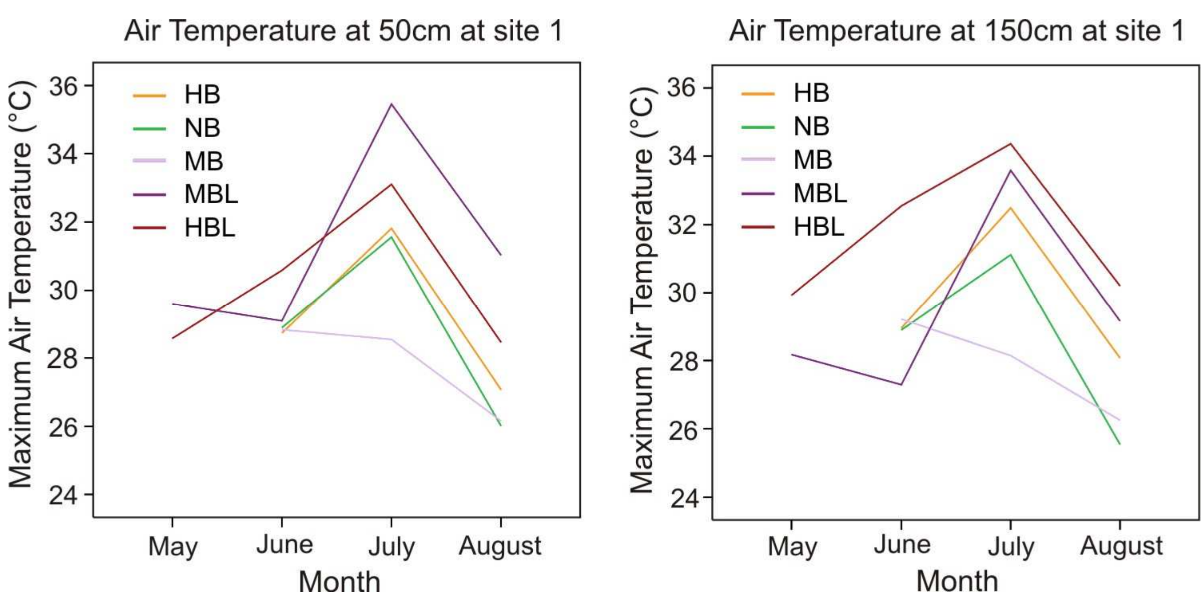

Figure 6.8 Mean monthly maximum air temperatures (°C) at 50 cm and 150 cm.

Air temperature gradients calculated from 50 and 150 cm sensor heights indicate the direction of sensible heat flux and show how energy is transferred within the different micro-sites (Figure 6.9). Negative values denote energy transfer away from the surface and positive values denote energy transfer towards the surface. For the logged sites

(MBL and HBL) heat is generally moved away from the surface. A similar effect was noted in the MB site. However, in the case of the NB and HB sites, the heat flux was downwards.

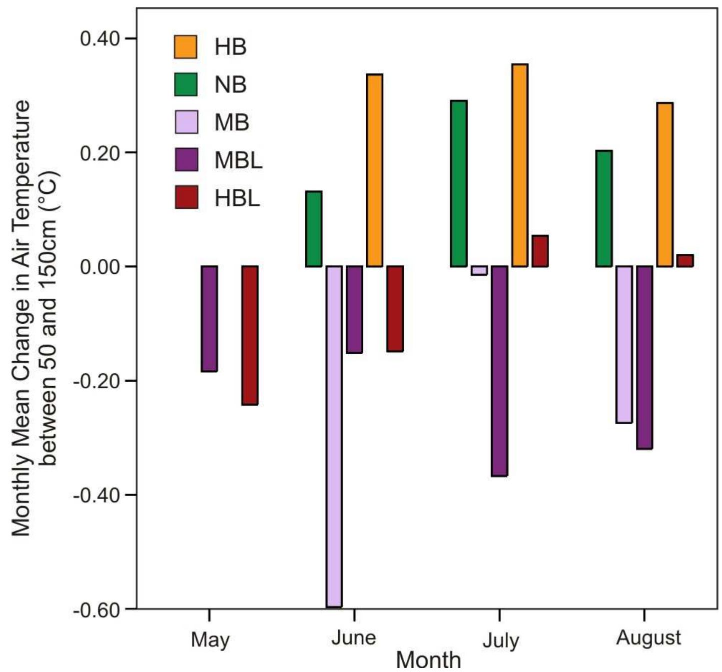

Figure 6.9 Air temperature gradients at treatment sites at Candle Lake based on difference between 50 cm and 150 cm. Negative values denote an upward flux to the atmosphere. Positive values denote a downward flux toward the surface.

Rainfall during the summer of 2004 was higher than average for the region. The nearest weather station operated by Environment Canada was located at Waskesiu Lake, approximately 100 km NW of the Candle Lake study area. A total of 350 mm of rainfall was recorded from May to August at Waskesiu Lake compared to the normal amount of 275 mm (Figure 6.10).

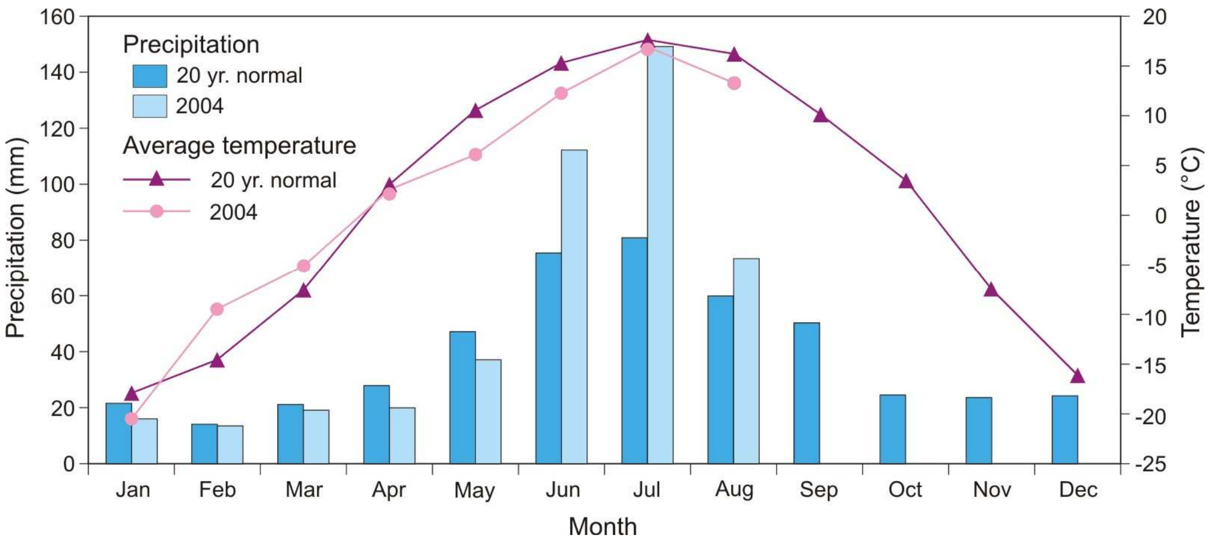

Figure 6.10 Waskesiu Lake climograph showing 20 year normal monthly temperatures and precipitation vs. conditions during 2004.

Short term measurements following periodic wet spells showed that noticeable variations occurred between the research sites (Figure 6.11). In the wildfire leave stands rainfall values increased with burn severity and totaled 57 mm in the NB site, 71 mm in the MB site and 88 mm in the HB site. Salvage logging further increased rainfalls of 90, 95 and 94 mm recorded at NBL, MBL and HBL respectively. The difference in precipitation noted between NB and MB is due to the reduced rainfall interception caused by loss of foliage and the more open canopy at MB. More complete canopy removal in HB further reduces interception and makes the site similar to the areas that have been salvaged logged.

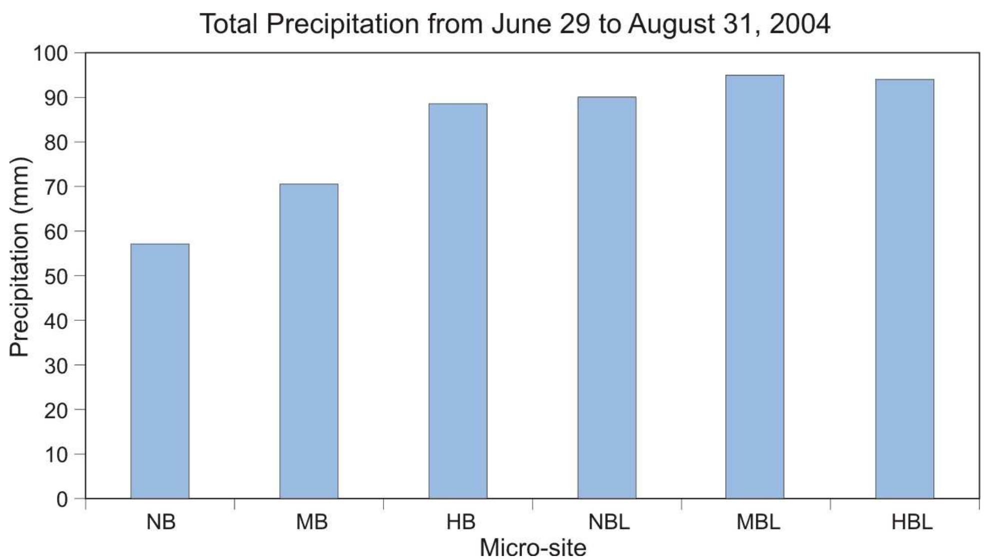

Figure 6.11 Total precipitation at treatment sites at Candle Lake.

Mean relative humidity (RH) values are presented in Figure 6.12. Conditions were comparatively dry in May and June and RH at 50 cm was especially variable between sites during these months. With higher rainfalls during July and August mean RH was uniformly high at all sites and increased from 60% in the early summer to 80% later in the growing season. Mean RH values at 150 cm ranged from 65% in May to about 80% in August and, with the exception of MB, showed little variation between sites. The low values at MB probably are caused by a defective sensor. HB and HBL showed similar trends over the course of the summer, but HB displayed consistently more humid conditions than HBL. HB had a denser vegetation cover than HBL and transpiration could attribute to the ~10% difference between these sites.

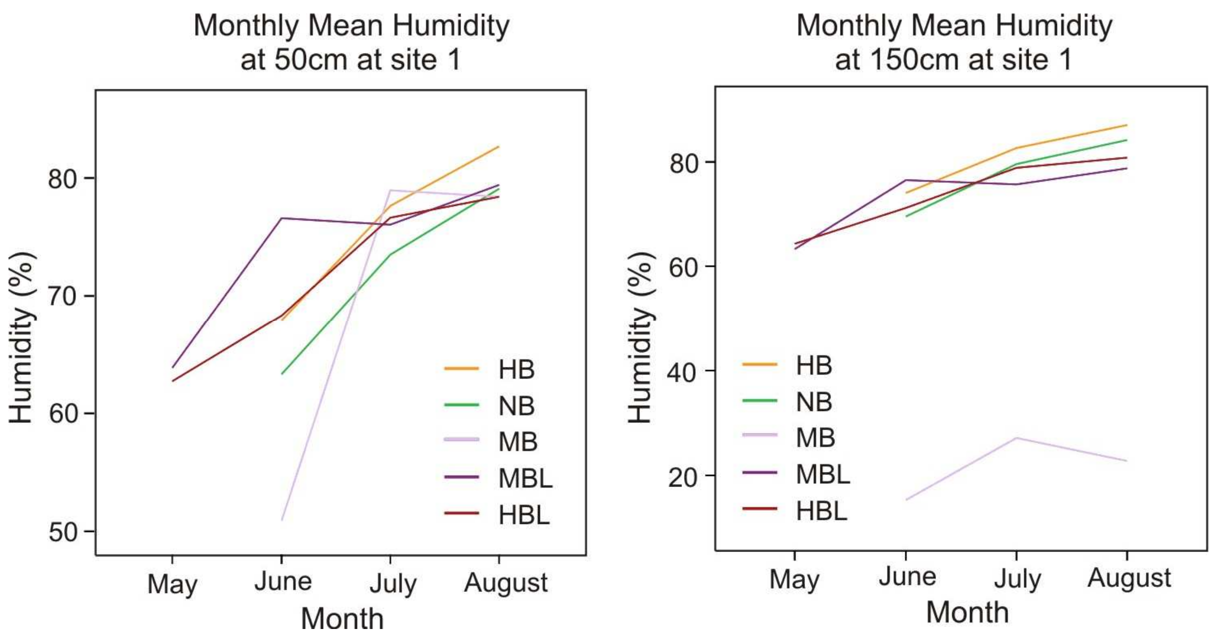

Figure 6.12 Monthly mean relative humidity at 50 cm and 150 cm at treatment sites at Candle Lake.

A small RH gradient from the 50 cm to the 150 cm height occurred at HB, HBL, and NB throughout the growing season, while at MB there was a positive gradient (Figure 6.13). MBL is considered to be spurious and should be ignored. The NB site displayed the largest gradient moving from the surface to the atmosphere which may be associated with transpiration from the undisturbed ground cover. Similarly, the rapid establishment of fast growing aspen and other early seral species at HBL may account for the negative RH gradient that develops in June and persists through the remainder of the growing season. However, the negative RH gradient declined at NB, HB and HBL as the summer progressed and perhaps because of reduced available soil moisture later in August or slower growth and senescence.

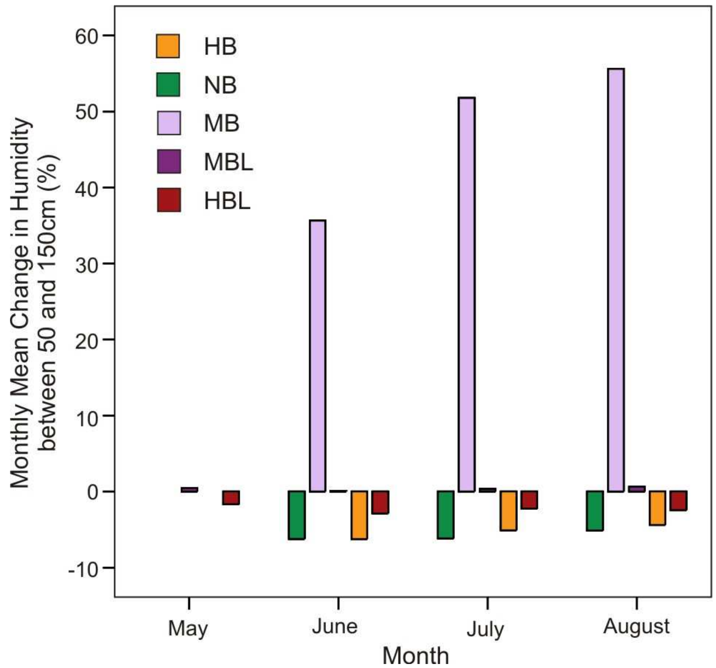

Figure 6.13 Humidity gradients at treatment sites at Candler Lake: negative values denote movement of water upwards to the 150 cm height and positive values denote movement downwards to the 50 cm height.

Minimum soil temperatures at 5cm depth in the treatment sites are shown in Figure 6.14. HBL is nearly always the hottest site with near-surface soil temperatures typically 1 to 5° C warmer than other sites. The difference appears to be most marked in the mid season period, and becomes less apparent later in the year. The NBL and MB sites were the coolest at the start of the growing season, but by mid season the near-surface soils were coolest in the NB site, a condition that was essentially maintained with until the end of the season. Maximum soil temperatures plotted at each of four depths for the NB are presented in Figure 6.15. A fairly regular decrease in maximum soil temperatures was noted with depth with the range in temperatures increasing at mid season. At this time the difference in temperature between the 5 cm and 50 cm depths was about 5° C compared to about 3° C in May and less than 2° C in August. The highest temperature at 5 cm at the NB site was 17° C.

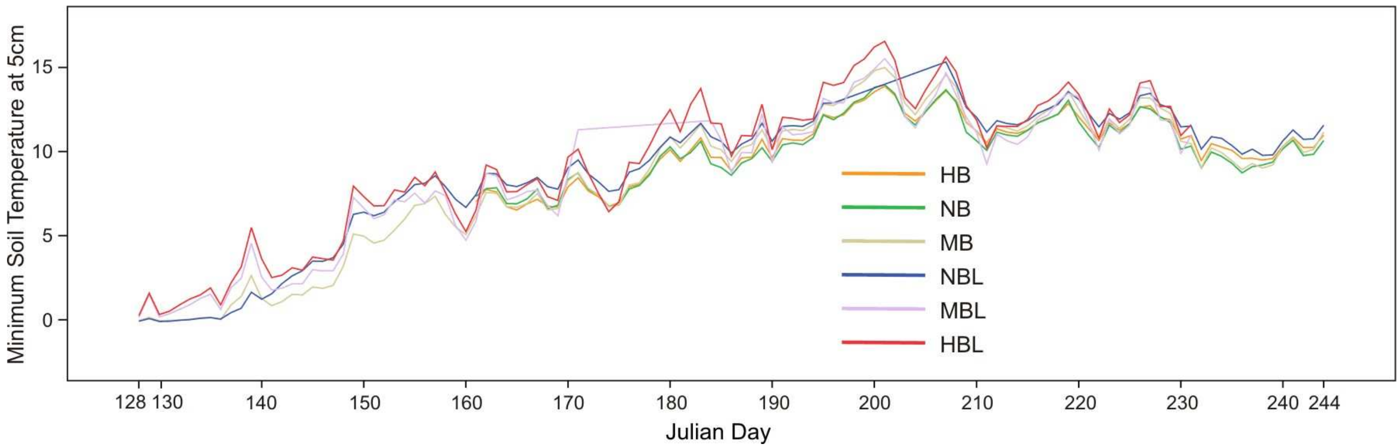

Figure 6.14 Minimum soil temperatures at 5cm depth in treatment sites at Candle Lake.

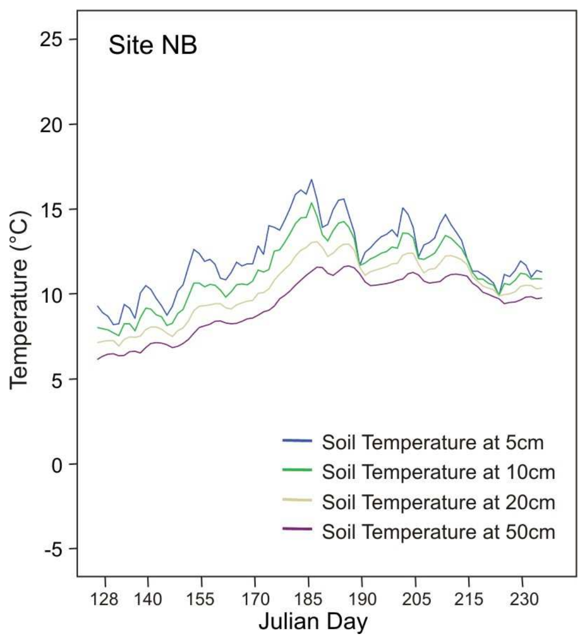

Figure 6.15 Maximum soil temperatures plotted at four depths for the NB site at Candle Lake.

Similar soil temperatures were noted at the MB site (Figure 6.16) although here the temperatures at the 5 and 10 cm depths were quite similar and noticeably warmer than at 20 and 50 cm depth. This dichotomy was even more pronounced in the MBL site where the upper soil layers were more than 7° C warmer than the deeper soils. This presumably was caused by the two-fold effect of the charred debris that was left on the soil surface following salvage logging. The blackened material would increase absorption of solar energy near the surface, but at the same time afford some insulating effect against energy transfer to the deeper soil layers. The highest temperature recorded at the MBL site was 22° C compared to 17° C at the MB site.

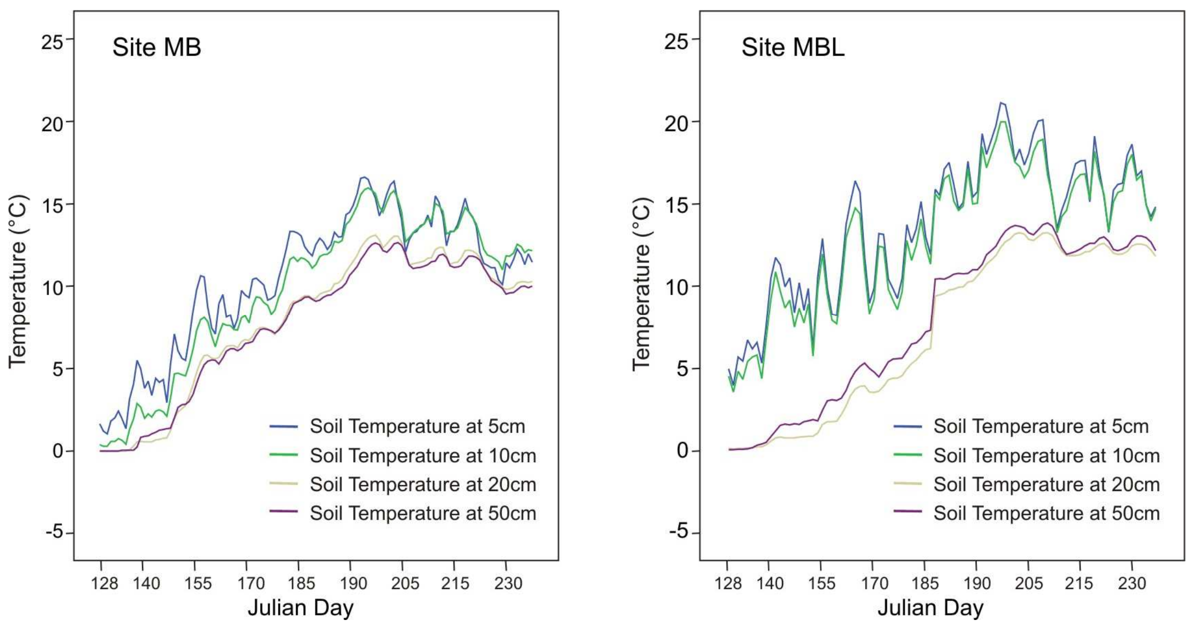

Figure 6.16 Maximum soil temperatures plotted at four depths for the MB and MBL sites at Candle Lake.

A different pattern was seen at HB and HBL (Figure 6.17). At the HB site maximum soil temperatures at 5 cm were typically 2 degrees warmer than at 10 cm, presumably due to increased energy absorption by dark ash and charred material on the surface. Temperatures 10 and 20 cm were almost identical and were about 1° C warmer than at 50 cm. Temperatures at HB were comparable to those at NB and the warm soils at the start of the growing season distinguished HB from the other burned and logged sites. Soil temperatures at HBL are similar to those at MBL and both fluctuate markedly throughout the growing season. In both cases soil temperatures appear to follow daily radiation levels quite closely. The differences noted at depth between these sites likely reflect moisture levels with wetter conditions prevailing at MBL.

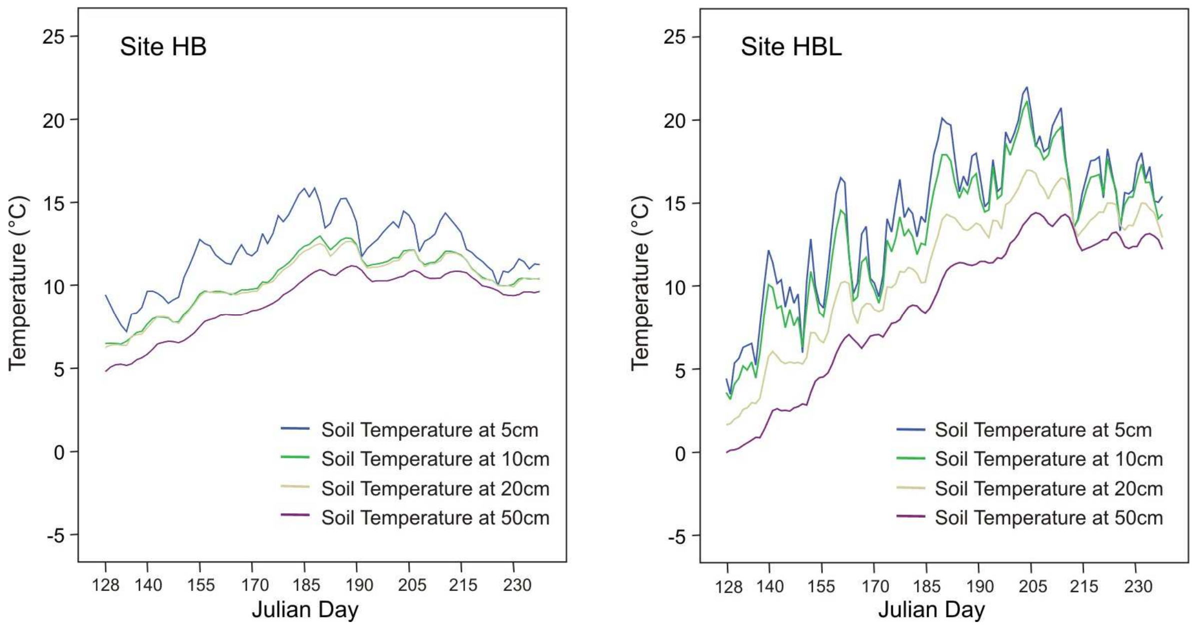

Figure 6.17 Maximum soil temperatures plotted at four depths for the HB and HBL sites at Candle Lake.

Wind speed was measured at NB, HB, and HBL and illustrates the extreme range of site conditions (Figures 6.18 and 6.19). Comparison of conditions at 50 cm at the NB and HB sites showed that HB had consistently higher wind speeds until the end of June at which time the regrowth aspen suckers and other vegetation were sufficiently tall to interfere with air movement (Table 6.18). For the rest of the growing season the 50 cm wind speeds at both sites were steady at 0.45 m s^{-1}. This compares to values peaking of 0.46 m s^{-1} at NB and 0.62 m s^{-1} at HB at the start of the growing season.

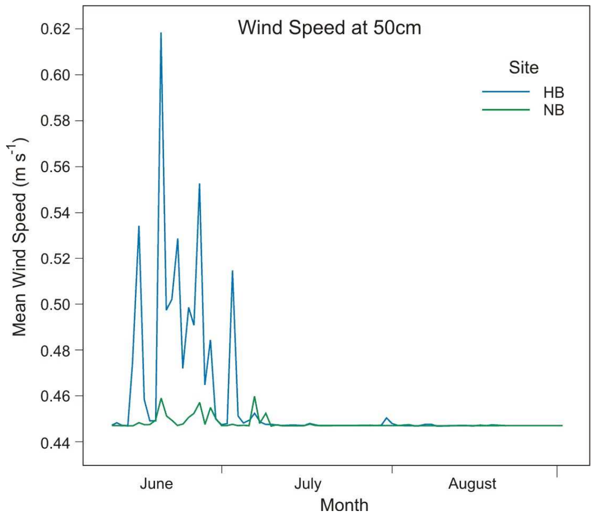

Figure 6.18 Mean wind speed at 50 cm. for NB and HB sites at Candle Lake.

Wind speeds at 150 cm were more variable throughout the growing season at all sites and were generally highest in the disturbed sites (Table 6.19). Wind speed at HBL ranged from 0.25 to 1.6 m s^{-1} and was the most variable with both the lowest and highest speeds recorded for any site. The complete removal of standing timber opens up the forest environment and takes away all shade, creating an extreme environment not found when a canopy is present. At HB the range in wind speed was 0.75 to 1.3 m s^{-1} compared to 0.6 to 1.15 m s^{-1} at NB.

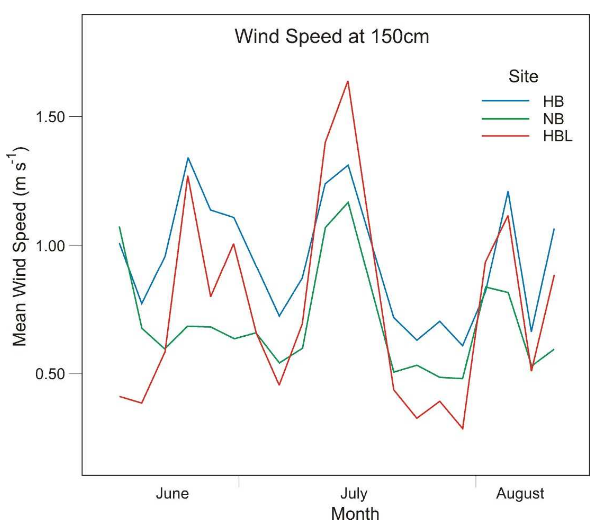

Figure 6.19 Mean wind speed at 150 cm for NB, HB, and HBL sites at Candle Lake.

6.4.2 Microenvironment

The most modified structural feature of the micro-environment was the canopy cover. All three logged sites showed high canopy openness ranging from 72% in NBL to 93% in MBL (Figure 6.20). The lower value of canopy openness in NBL is due to the occurrence of many small aspen stems throughout the cut area and occasional short trees that were left standing. The wildfire leave stand sites showed increasing canopy openness from NB, MB and HB respectively. Canopy openness in the MB sites averaged 43% as not all tree cover had been killed by fire and 70% in the HB sites where remnant dead snags provided some shade. This compared to 30% in the undisturbed NB sites.

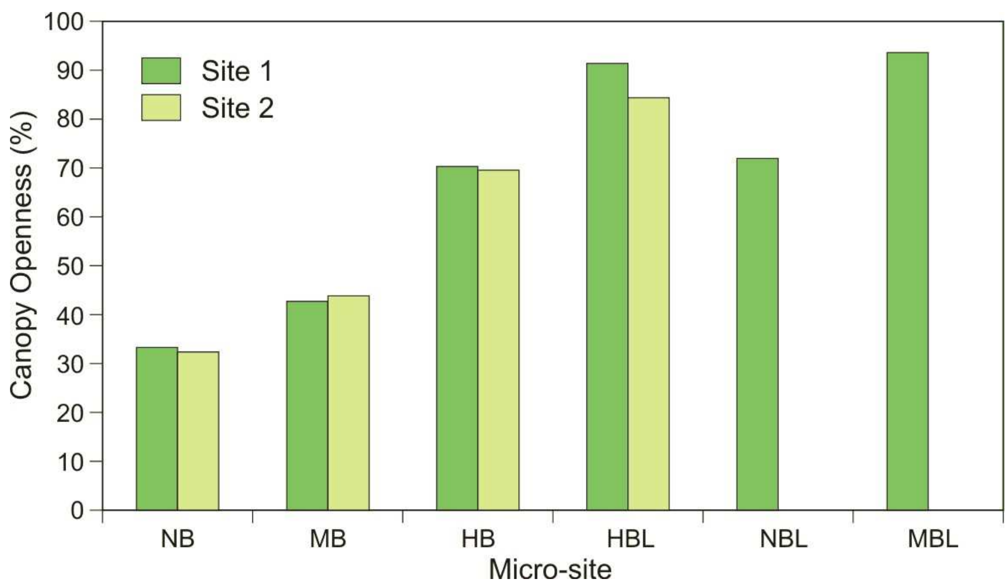

Figure 6.20 Canopy openness between micro-sites at Candle Lake.

Canopy openness was found to be significantly correlated to radiation received at 1.3 m height on a cloudless day (r^2 = 0.87 for Candle Lake site 1 and 0.81 for site 2, $p \leq 0.05$; Figure 6.17). Canopy openness was also found to be significantly correlated to the amount of precipitation received at each micro-site ($r^2 = 0.92$ for site 1 and 0.73 for site 2, p≤0.05; Figure 6.21).

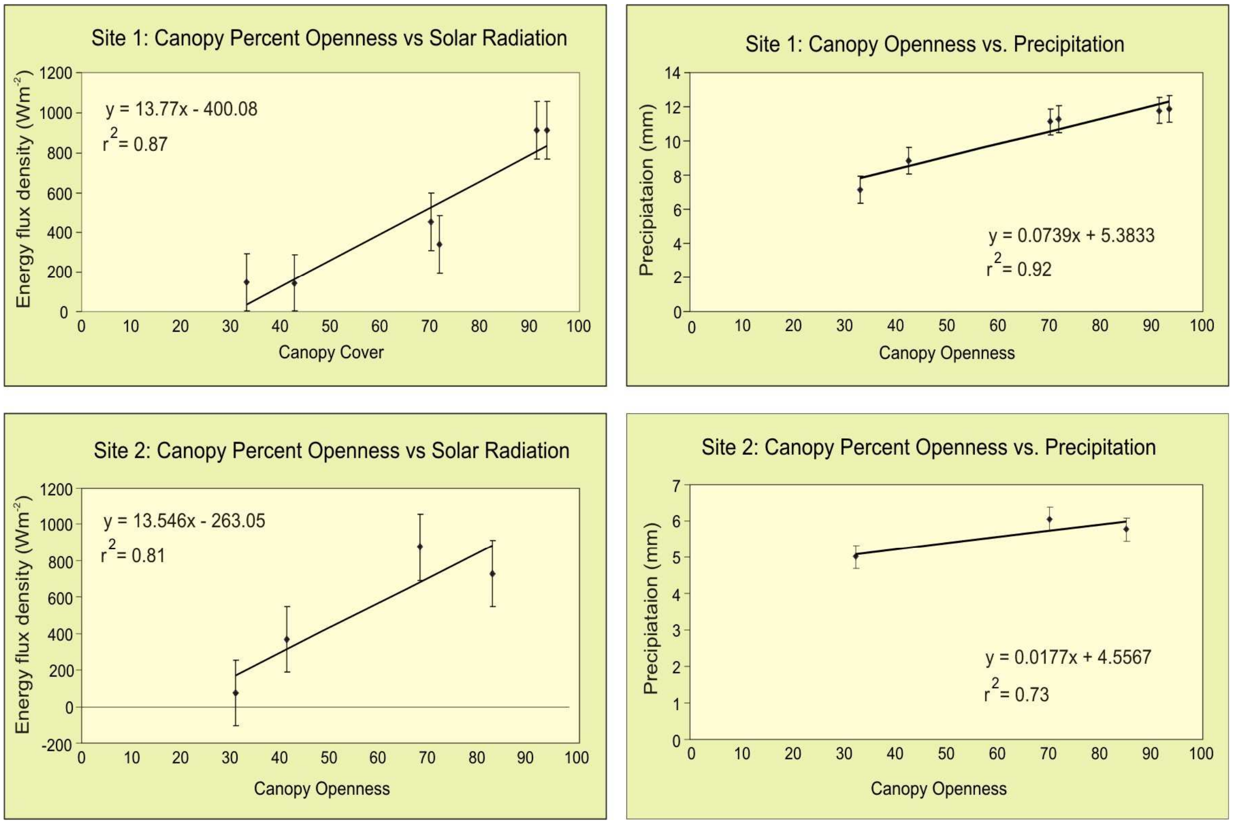

Figure 6.21 Canopy cover (% openness) versus solar radiation (left) and versus precipitation (right) for all treatments at sites 1 and 2 at Candle Lake.

Litter depth generally was negatively correlated to maximum soil temperatures at 5 cm and 10 cm depths (Figure 6.22), with increase in litter depth producing a corresponding decrease in temperature. The exception was site 1 where the reverse trend was noted; this was likely caused to the topographic position of the site which maintained relatively high soil moisture levels. Higher soil moisture levels increase soil thermal conductivity and energy storage allowing the top soil layer to attain higher soil temperatures even with an increased litter depth (Al Nakshabandi and Kohnke 1965).

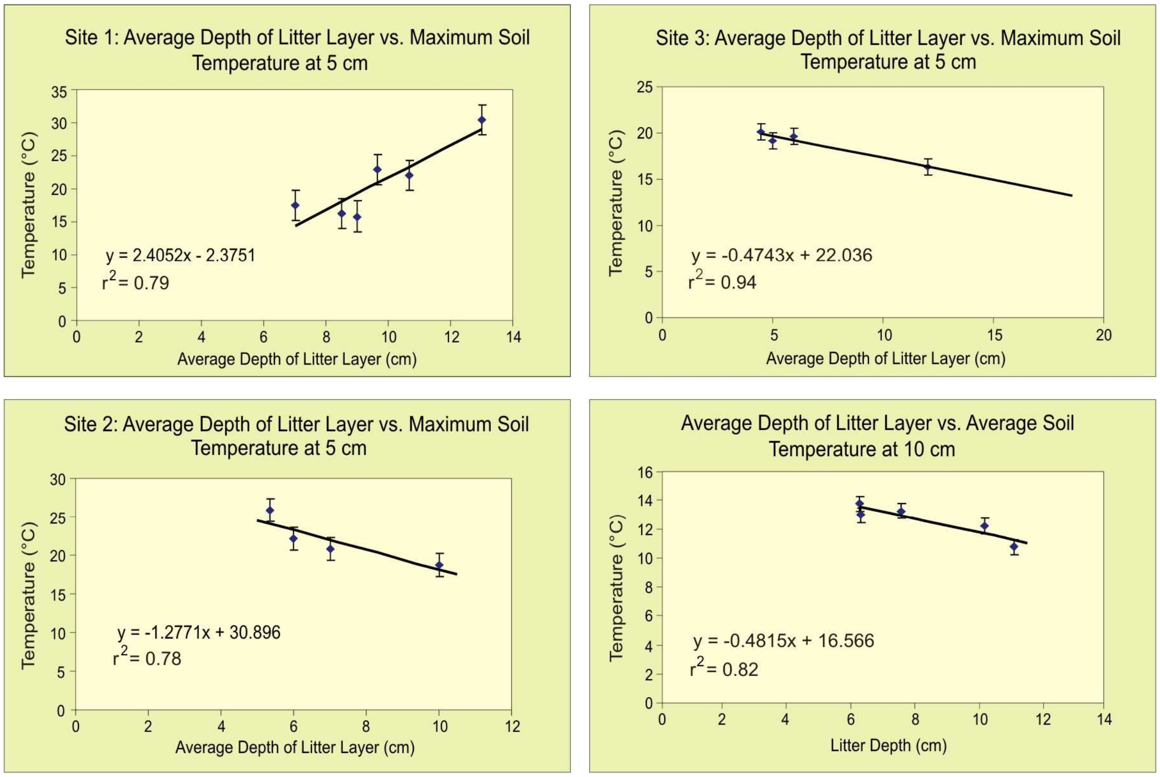

Figure 6.22 Average litter depth vs. maximum soil temperature at 5 cm at three sites and overall average for the study area at Candle Lake.

Analysis of Variance (ANOVA) was used to quantify differences between treatment sites (Table 6.26). Comparison of the burned and logged counterparts indicated that significant differences ($p \leq 0.05$) occurred between MB and MBL for canopy openness, albedo, minimum soil temperatures and precipitation. HB and HBL showed significant differences only for canopy openness and minimum soil temperatures. NB and NBL showed significant differences for canopy openness maximum, minimum soil temperatures and precipitation received. Comparison of non-logged sites showed that NB and HB differed significantly for all variables except minimum soil temperatures at 5 cm and precipitation. NB and MB showed significant differences in maximum soil temperature at 5 cm and albedo. For the salvage-logged sites no significant differences were noted between MBL and HBL.

Table 6.26 ANOVA results between sites for environmental variables. Values provided are *p*-values with significant differences shown in bold type.

Site Comparison	Soil Temp. (°C) at 5 cm		Avg. Soil Temp. (°C) at 5 cm	Canopy Openness (%)	Precip. (mm)	Albedo
	Min.	Max.				
NB vs. NBL	**<0.001**	**0.022**	**0.005**	**0.002**	**0.018**	0.765
MB vs. MBL	0.151	**<0.001**	0.128	**0.023**	**<0.001**	**0.002**
HB vs. HBL	0.715	**0.035**	0.096	**0.022**	0.162	0.763
NB vs. MB	**0.023**	0.396	0.101	0.191	0.159	**<0.001**
NB vs. HB	**0.020**	0.169	**0.028**	**<0.001**	0.320	**<0.001**
MB vs. HB	0.194	0.591	0.211	**0.018**	0.732	**0.005**
MBL vs. HBL	0.632	0.365	0.487	0.580	0.314	0.475

7. Discussion

The results of this study agree with other authors in affirming that salvage logging immediately after a wildfire disturbance significantly alters early post-fire plant communities (Martinez-Sanchez *et al*. 1999; Fraser *et al*. 2004; Kurulok 2004; Purdon *et al*. 2004; Hanson and Stuart 2005). Early post-fire salvage logging (1 year post-fire) tends to remove the boundaries between burn severities; creating similar patterns of species composition through the removal of the forest canopy and disruption of the forest floor. The wildfire leave stands showed unique species composition among the burn severities as boreal forest species have developed different reproductive strategies in response to varying degrees of burn severity (Rowe 1983; Schimmel and Granström 1996). Salvage logged forest stands in my study showed a greater degree of homogenous plant communities among burn severities. Logging appears to truncate the broader range of plant community characteristics found in plant communities of unlogged post-fire forest stands.

The effects of salvage logging were less pronounced ten years post-fire, with plant communities converging between the salvage logged and unlogged sites. The early distinct differences found between salvage logged and unlogged leave stands, developed into three plant community types described as no disturbance, moderate disturbance either by fire or salvage logging, and severe disturbance early succession communities. I found that the effects of salvage logging do not persist over a long period of time in areas of high burn severity, but continue to be apparent in areas of low to moderate burn severity ten years after disturbance. The effects of salvage logging on plant community development were still evident ten years post-fire causing a decrease in the range of boreal plant community composition and structure among the no burn and moderate burn severities.

7.1 The effects of salvage logging on species regeneration

Within the very early succession wildfire leave stands (1 year post-fire) the variability in species richness, and diversity of the post-fire environment, is influenced by the structural and environmental characteristics at the sites. The formation of distinctive species compositions between burn severities within the wildfire leave stands was typical of mixedwood boreal forest after a wildfire disturbance (Dix and Swan 1971; Rowe 1983; Bonan and Shugart 1989, Schimmel and Granström 1996). The fire disturbance affected the microclimate and availability of exposed mineral soil germination sites via the removal of forest canopy and the creation of residual snags. Through the variation in burn severity and light availability, which taken together created unique plant regeneration sites, lead to differences in plant communities across the burnt areas.

Although the salvage logged stands were established within the same range of post-fire conditions as the leave stands, the additive effects of the secondary logging disturbance resulted in significant differences in species composition. Early successional regeneration in the salvage logged stands showed an overall loss in species richness and a drop in species diversity compared to stands disturbed by wildfire alone. Overall vascular vegetative cover within salvage logged stands was 40.8% lower than for similar burn severities in the leave stands with the largest difference seeing a 41% decrease between the moderately burned (MBL) areas. The salvage logged stands created a more simplified and sparse vegetative community. These findings are similar to Purdon *et al*.

(2004) where they found a more homogenous understory composition with a decrease in species diversity and abundance among burn severities in salvage logged stands.

The most noticeable effect of salvage logging is the removal of the residual forest canopy within all burn severities. Removing the standing timber through salvage logging created substantial differences in the structural and environmental characteristics at the sites. The decrease in the abundance of standing trees and snags created significant differences in canopy structure and the micro-environment. At the Candle Lake burn site, changes such an increase in incoming radiation, air temperature, wind speed and soil temperature alter the growing conditions in the salvage logged stands. Within the moderate to high burn severity salvage stands, the loss in shade and increase in wind speeds produced increased fluctuations in daily temperatures and humidity, which enhance like likeliness of drying out the top soil layer and increasing the potential for water stress in the regenerating plants. The lower species richness and sparser plant cover found in the salvage logged stands is evidence of this effect. Modification of the micro-climate of the salvage logged environment was most pronounced between the leave stands and salvage logged stands of the no burn areas as an undisturbed forest is vastly different in structure than a disturbed area. As salvage logging encompasses areas which were not directly affected by the wildfire event, these areas of no burn are essentially clear-cut and the changes in species composition and environmental variables were similar to results described by Franklin *et al*. (2002). Differences between the unlogged and salvage logged areas were progressively less noticeable as burn severity increased in the environments being compared.

In addition to modifying site micro-climate, the removal of standing snags and the residual live canopy also disturbed the forest floor by leaving behind a large amount of woody material and needle litter (i.e. logging slash). Coarse woody debris left on the forest floor showed an overall increase of 58% in salvage logged areas with the largest increase of 64.2% occurring within the high severity burn (HBL) areas. Salvage harvesting the burnt forest stands increased the amount of coarse woody debris on the forest floor inhibiting forest regeneration as documented in studies by Purdon *et al*. (2004), Kurulok (2004) and Donato *et al*. (2006). This increase in coarse woody debris and disturbance of the forest floor caused a decrease in the amount of exposed mineral soil found between the burn severities. Salvage logged stands showed an overall decrease in exposed mineral soil by 15.7% with the largest decrease of 46.6% occurring in high severity burn (HBL) areas. The loss of the canopy also increased solar radiation, increasing the surface temperature of the forest floor and making it more susceptible to drying out. The moderate and high burn severity areas within the salvage logged stands produced an average temperature 5°C higher within the top 5 cm of the soil layer. The disturbance of the forest floor by the salvage logging operation has been found to inhibit the regeneration of plant species, specifically lowering the successful germination rate of tree seedlings (Martinez-Sanchez *et al*. 1999; Donato *et al*. 2006; Greene *et al*. 2006).

Similar to the Candle Lake burn site (1 year post-fire), the variability in species richness and diversity at the Mahigan site wildfire leave stands (ten years post-fire) is influenced by the structural and environmental characteristics. Ten years after the wildfire disturbance, the formation of distinctive species compositions between burn severities within the wildfire leave stands is typical of mixedwood boreal forest (Dix and

Swan 1971; Rowe 1983; Bonan and Shugart 1989, Schimmel and Granström 1996). The variation in fire severity is important in determining the ability for species to recolonize after the wildfire event. Areas affected by lower burn severities have a higher success rate of regenerating species which were present prior to the wildfire disturbance, while areas of high burn severities rely on recolonization to take place through aerial seed bank input and seed from surviving sources at the edges of the burn (Greene *et al*. 2004; Barnes *et al*. 1998).

Species richness at the Mahigan site ten years post-fire was not significantly different between the logging treatments, but there were 18 fewer species recorded within the salvage logged stands compared to the wildfire leave stands. This large decrease in the amount of individual species found in the salvage logged stand indicates that there is a long lasting effect on the species composition of salvage logged stands. The wildfire leave stands recorded a higher amount of shrub and herb species between all of the burn severities than the salvage logged areas. A reduction of species post-salvage logging was first seen in the loss of vegetative range recorded at the Candle Lake burn sites one year post-fire. The loss in the number of boreal species is primarily associated with herbaceous species largely found in older mixedwood stands such as wintergreens (*Pyrola secunda*) and orchids (*Goodyera repens*). Salvage logged stands also showed a loss of shrub species, particularly within the moderate burned plots. This loss of understory shrub species may be due to the disturbance of the forest floor during the salvage logging operation, removing the residual shrub species which would have normally recolonized the area after surviving the exposure to a moderate burn. Overall diversity was significantly higher within the salvage logged stands compared to the leave stands. This increase in diversity is possibly due to a smaller sample size, ground preparation, tillage of the soil, and the planting of *Pinus banksiana* seedlings post-salvage harvest. Vegetation cover was also higher by 15.5% in the salvage logged stand due to the dense canopy cover by young regenerating trees, specifically *Populus tremuloides*. However, differences in composition between logged and unlogged sites became less pronounced with increasing burn severity.

The effects of salvage logging on environmental variables were less pronounced at the Mahigan burn site. The division between the wildfire leave stand and the salvage logged stand has lessened after ten years post-fire with no significant differences being found other than within the leaf litter coverage; this can be explained by the high regeneration rate of aspen species, specifically throughout the no burn to moderate burn severity salvage logged plots. The large division in the abundance of coarse woody debris between wildfire leave stands and salvage logged stands displayed one year after the salvage operation has diminished and no significant difference was found between the post-fire sites ten years afterwards. Within the Mahigan burn site, the increased coarse woody debris coverage after salvage logging has decreased since the salvage logging operation as there has been no long term input from standing snags. Conversely, the wildfire leave stand has an increasing rate of coarse woody debris due to the natural collapse of snags which were killed by the wildfire disturbance. The snags present within the wildfire leave stand provide a long term input of nutrients, shade, animal habitat (both standing and fallen), and the availability of nurse logs for the germination of tree seedlings. This was most apparent in the moderately burned areas which have a mix of dead and living trees which were not completely consumed by the fire disturbance and are dying and falling at a slower rate than seen in the high severity burn areas (Greif *et al*. 1999; Lee and Crites 1999; Morissette *et al*. 2002; Nappi *et al*. 2004; Russell *et al*. 2006).

7.2 Effects of salvage logging on plant communities

Fires are important processes for maintaining the biodiversity within boreal forest communities (Wein and MacLean 1983; Johnson 1992). Fire severity at the local level is important in determining the process of species recolonization after a wildfire disturbance. Boreal forest species have developed different reproductive strategies in response to varying degrees of burn severity that create unique species compositions within the post-fire environment (Rowe 1983; Schimmel and Granström 1996). Results of this research have found that significant differences in species composition between burn severities is common in the wildfire leave stands, while salvage logged stands tended to show similarity in species composition between the burn severities. The negative influences to species composition by salvage logging can be attributed to the increase of forest floor disturbance and removal of the forest canopy. It was found that salvage logging increased the ground cover of coarse woody debris and needle litter while decreasing the amount of exposed soil, resulting in reduced species richness and abundance, with similar findings by Purdon *et al*. (2004). Removal of the forest canopy alters the post-fire micro-climate by increasing fluctuations in wind, temperature and moisture gradients; this has been shown to dry out the forest floor and topsoil, increasing stress on the emerging plant community and induces higher rates of mortality among seedlings in the post-fire environment (Kurulok 2004; Greene *et al*. 2006).

Although the logging treatments within the Candle Lake burn site were disturbed the same range of fire severity, the results have shown that the species composition between the logging treatments were significantly different (Table 6.5, Figure 6.2, Figure 6.3) and this is substantiated by the indicator species analysis. Indicator species of the leave stand were typical of those described by Rowe (1983), with early successional species such as *Geranium bicknellii* and *Dracocephalum parviflorum*, associated with the high burn severity, while late successional species, such as *Picea glauca*, were indicators of no disturbance. Significant indicator species within the salvage logged stands were only identified within the high burn severity, indicating that secondary disturbance through salvage logging had altered the areas of no disturbance and moderate burn severity such that they showed similar species composition. Complementing these results is the analysis from the ordination which indicated that the high level of disturbance caused by salvage logging one year post-fire has tended to homogenize the species composition towards that of the moderate burn severity plots and in doing so has decreased the range of the vegetative communities.

The composition of plant community structure at the Mahigan burn site still shows the effects of salvage logging ten years post-fire. In comparison to the logging treatments one year post-fire, where there was a distinct division between the salvage logged and unlogged stands, the Mahigan site ten years post-fire shows several groupings between the logging treatments (Table 6.14, Figure 6.5, and Figure 6.6). Results from the indicator species analysis between logging treatments at the Mahigan burn site identified 12 species, all of which were significant indicators of salvage logged stands. This may be explained by the general loss of community structure between burn severities at the stand level, tillage of the forest floor, and the replanting of *Pinus banksiana*, allowing for species to regenerate in a large abundance. As witnessed within the leave stands one year post-fire, indicator species of the leave stand ten years post-fire were typical of those described by Rowe (1983). Identified were endurer species, such as *Pinus banksiana* associated with high regeneration rates within high burn severity areas while areas of no disturbance were again indicated by late successional species such as *Picea glauca*. Within the salvage logged stands only two species were identified as significant indicators of burn severity, with *Pinus banksiana* being an indicator of high burn severity again. There has been a loss of distinctive species assemblages normally associated with burn severity. Initial post-fire regeneration one year post-fire was clearly divided into two groups composed of the salvage logged stand and the wildfire leave stand. Over a ten year time period three regrowth cover types have developed, characterised by no disturbance, moderate disturbance either by fire or salvage logging, and severe disturbance. The merging of the high severity burns between the logging treatments indicates that the effects of salvage logging do not have long lasting effects within areas of high burn severity.

8. Conclusions

8.1 Summary

The principal objective of this study was to determine if salvage logging within areas of different forest fire burn severities has an effect on species regeneration and plant community composition in a mixedwood boreal forest community. Results indicated that salvage logging had a significant impact on the composition of early succession plant communities in burned mixwood boreal forests across different burn severities. This effect was still evident in forest stands ten years post-fire, indicating that salvage logging had longer lasting residual effects on boreal forest community development. The initial impact of salvage logging was to reduce species richness, diversity, and cover within all burn severities, creating a less abundant and more simplified plant community. It was shown that salvage logging one year post-fire tended to create more homogenous plant communities similar to those communities found in an area of moderate burn severity, contracting the effects of burn severity and decreasing the range of the vegetative communities. Such distinctions remained apparent over the course of the ten year regrowth period encompassed by this study. As salvage logging becomes more prevalent within fire disturbed boreal forest communities, there will be an increase in the regenerating forest stands and understory compositions that have been altered by salvage logging. These stands tend to be more homogenous, with a distinct loss of species and vegetative range, simplifying the successional pathways.

The regeneration of plant communities after a fire disturbance is dependant on the plant community prior to the fire event, the intensity and severity at which the fire burns, and the presence of viable vegetative banks and seed banks, *in situ* or above ground. As salvage logging removes the forest canopy, the main source for aerial seed input is also removed, requiring the salvage logged stand to depend on seed to be dispersed from the cut-block edge for seed input. Increased disturbance of the forest floor, such as a large input of coarse woody debris, inhibits the regeneration of early post-fire species. The initial effects of salvage logging on the number of species regenerating and their abundance within the post-salvage logging environment have influence on the long term effect of the regenerating forest structure and understory component.

One of the most distinct features of a salvage logged stand is the removal of the forest stand itself. By harvesting the standing timber, the salvage logged area is left open and bare. The removal of the standing timber and snags created a large increase of coarse woody debris on the forest floor, insulating the ground and potentially causing fuel loads to increase and in case of a re-burn, would create a more intense fire to occur. The large coverage of coarse woody debris found within the salvage logged plots at the Candle Lake site (one year post-fire) has decreased in total coverage when compared to the Mahigan salvage logged stand ten years later. In contrast to the salvage logged stand, the wildfire leave stand ten years later is receiving higher amounts of coarse woody debris due to the natural collapse of snags, receiving a long term input of nutrients, shade, animal habitat (both standing and fallen), seed bank input, and the availability of nurse logs for the germination of tree seedlings. This division in coarse woody debris allows the wildfire leave stand a long term input of coarse woody debris while the salvage logged stands ten years after the salvage logging operation are starting to show a shortfall in coarse woody debris.

8.2 Recommendations

Areas of the boreal forest affected by wildfire are of high ecological value for the range of vegetation that develops, the unique plant communities forged by burn severities, and the turnover of the forest structure leaving large amounts of snags. Salvage logging disrupts the post-fire ecological value of the forest structure by causing a secondary disturbance, removing the standing timber and disrupting plant community succession. The use of logging roads and large cut blocks create major disturbances which are unnatural to the post-fire environment. Salvage logging should emulate wildfire disturbances more, with larger blocks of standing trees, dead and alive to act as seed banks for post-fire regeneration, habitat for post-fire invaders, and to keep the large range of vegetation. Based on the findings in this study, the author recommends that forest managers take measures to decrease the negative ecological effects of salvage logging. To minimize the loss of species, vegetative range, and disturbance to the forest floor that occurs within salvage logged burned forest stands, it is suggested that:

1. Large blocks of residual burned forest should be left un-salvaged to safeguard species diversity in the post-fire environment. These large blocks of residual burned forest should contain large areas of all burn severity classes to ensure of a wide range of plant communities.

2. Standing residual trees and coarse woody debris should be left on salvage logged sites to provide shade and a potential long term source of nutrients from tree decomposition.

It has been shown that salvage logging reduces the species richness and abundance of the boreal plant community. These effects were noticed across all burn severities but were the most prominent in the moderate burn sites. Salvage logging these areas tends to create longer lasting effects on the successional growth. This is a concern as forest managers target these sites as the main areas for salvage as they are the most valuable for the production of pulp and saw timber (Pshebnicki per. comm. 2004). There is a lack of reliable research on the long term effects of salvage logging within the boreal forest. Many questions still need to be looked at to determine the long term effects salvage logging has on the loss of species, vegetative range between burn severities, and other important issues such as seed input. Salvage logging operations will continue to occur and there is a need to define what the consequences are and how to better manage the post-fire forest ecosystem.

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Appendix 1 Frequency of all species within the Candle Lake burn site (1 year post-fire) between logging treatments and burn severities. Frequency is shown as the percentage of plots in which a species occurs. Wildfire and Salvage *n* = 54 plots. x = species found only within the wildfire leave stands.

		Wildfire			Salvage Logged			
Tree Species:		**NB**	**MB**	**HB**	**NBL**	**MBL**	**HBL**	**Species Code**
Abies balsamea	x	0.22	0.00	0.00	0.00	0.00	0.00	Abie bal
Betula papyrifera		0.89	0.33	0.08	0.78	0.33	0.22	Betu pap
Picea glauca		1.00	0.56	0.00	0.22	0.11	0.11	Pice gla
Pinus banksiana	x	0.00	0.22	0.15	0.00	0.00	0.00	Pinu ban
Populus balsamifera		0.00	0.00	0.04	0.11	0.11	0.11	Popu bal
Populus tremuloides		1.00	1.00	0.35	0.89	1.00	1.00	Popu tre
Shrub Species:								
Alnus crispa		0.78	0.56	0.15	0.22	0.56	0.33	Alnu cri
Amelanchier alnifolia		0.11	0.11	0.04	0.11	0.11	0.00	Amel aln
Cornus stolonifera		0.11	0.11	0.00	0.00	0.11	0.00	Corn sto
Corylus cornuta		0.33	0.44	0.08	0.22	0.11	0.22	Cory cor
Ledum groenlandicum		0.56	0.44	0.15	0.44	0.67	0.22	Ledu gro
Lonicera dioica		0.11	0.00	0.04	0.22	0.11	0.22	Loni dio
Prunus pensylvanica		0.11	0.00	0.08	0.00	0.11	0.00	Prun pen
Ribes hudsonianum		0.11	0.00	0.00	0.11	0.00	0.00	Ribe hud
Ribes lacustre		0.11	0.11	0.00	0.33	0.00	0.22	Ribe lac
Ribes oxyacanthoides		0.11	0.00	0.04	0.11	0.00	0.22	Ribe oxy
Ribes triste		0.67	0.56	0.08	0.44	0.67	0.44	Ribe tri
Rosa acicularis		0.89	0.78	0.23	0.89	0.78	0.56	Rosa aci
Rubus idaeus		0.33	0.56	0.04	0.22	0.33	0.67	Rubu ida
Salix spp.		0.44	0.67	0.23	0.56	0.56	0.44	Sali spp
Shepherdia canadensis		0.33	0.11	0.00	0.00	0.11	0.00	Shep can
Vaccinium myrtilloides		0.22	0.00	0.04	0.11	0.00	0.00	Vacc myr
Vaccinium vitis-idaea		0.33	0.56	0.00	0.33	0.22	0.00	Vacc vit
Viburnum edule		1.00	0.89	0.31	0.56	0.67	0.78	Vibu edu
Forb & Graminoid Species:								
Actaea rubra		0.11	0.11	0.00	0.11	0.00	0.22	Acta rub
Apocynum androsaemifolium	x	0.11	0.11	0.00	0.00	0.00	0.00	Apoc and
Aquilegia brevistyla	x	0.00	0.00	0.04	0.00	0.00	0.00	Aqui bre
Aralia nudicaulis		1.00	0.89	0.27	0.89	0.89	0.67	Aral nud
Aster conspicuus		0.00	0.11	0.08	0.00	0.00	0.00	Aste con
Aster spp.		0.67	0.67	0.19	0.44	0.11	1.00	Aste spp
Cirsium arvense		0.00	0.00	0.04	0.00	0.00	0.11	Cirs arv
Coptis trifolia	x	0.00	0.11	0.00	0.00	0.00	0.00	Copt tri
Cornus canadensis		1.00	1.00	0.35	1.00	0.89	1.00	Corn can
Corydalis aurea		0.00	0.33	0.12	0.00	0.00	0.22	Cory aur
Corydalis sempervirens		0.00	0.44	0.12	0.00	0.11	0.22	Cory sem
Disporum trachycarpum		0.11	0.00	0.04	0.33	0.11	0.11	Disp tra
Dracocephalum parviflorum		0.00	0.67	0.27	0.11	0.33	0.78	Drac par
Epilobium angustifolium		0.67	1.00	0.35	0.89	1.00	1.00	Epil ang
Epilobium glandulosum	x	0.00	0.00	0.04	0.00	0.00	0.00	Epil gla
Equisetum arvense		0.00	0.00	0.04	0.11	0.11	0.56	Equi arv
Equisetum pratense	x	0.00	0.11	0.04	0.00	0.00	0.00	Equi pra
Fragaria vesca		0.44	0.44	0.00	0.11	0.56	0.22	Frag ves
Fragaria virginiana		0.44	0.33	0.12	0.44	0.44	0.56	Frag vir
Galium boreale		0.22	0.22	0.12	0.33	0.00	0.33	Gali bor
Galium triflorum		0.11	0.00	0.00	0.00	0.11	0.00	Gali tri

Geranium bicknellii		0.11	1.00	0.35	0.22	0.89	1.00	Gera bic
Goodyera repens	x	0.11	0.00	0.00	0.00	0.00	0.00	Good rep
Grass spp.		0.89	1.00	0.31	1.00	1.00	0.89	Gras spp
Lathyrus ochroleucus		0.89	0.78	0.19	0.67	0.44	0.44	Lath och
Linnaea borealis		0.78	1.00	0.27	0.44	0.56	0.56	Linn bor
Lycopodium annotinum		0.67	0.56	0.00	0.22	0.22	0.00	Lyco ann
Lycopodium complanatum		0.22	0.44	0.00	0.00	0.11	0.00	Lyco com
Lycopodium obscurum		0.00	0.33	0.08	0.11	0.22	0.00	Lyco obs
Maianthemum canadens		1.00	1.00	0.31	0.78	0.89	0.89	Maia can
Mertensia paniculata		0.89	0.56	0.15	0.67	0.44	0.78	Mert pan
Mitella nuda		0.78	0.67	0.12	0.33	0.44	0.67	Mite nud
Petasites palmatus		1.00	1.00	0.27	0.89	1.00	1.00	Peta pal
Petasites sagittatus		0.00	0.33	0.15	0.00	0.11	0.22	Peta sag
Pyrola asarifolia	x	0.11	0.00	0.00	0.00	0.00	0.00	Pyro asa
Pyrola secunda		0.67	0.11	0.00	0.22	0.00	0.00	Pyro sec
Pyrola virens		0.33	0.11	0.00	0.00	0.11	0.00	Pyro vir
Rubus pubescens		1.00	0.89	0.23	1.00	0.89	0.89	Rubu pub
Solidago spathulata		0.00	0.22	0.04	0.00	0.11	0.00	Soli spa
Trientalis borealis		1.00	1.00	0.31	0.89	0.67	0.78	Trie bor
Vicia americana		0.33	0.67	0.23	0.00	0.11	0.44	Vici ame
Viola canadensis		0.44	0.44	0.08	0.11	0.00	0.00	Viol can
Viola renifolia		1.00	0.78	0.15	0.44	0.22	0.56	Viol ren

Appendix 2 Frequency of all species within the Mahigan burn site (10 years post-fire) between logging treatments and burn severities. Frequency is shown as the percentage of plots in which a species occurs. Wildfire and Salvage *n* = 30 plots. x = species found only within wildfire leave stands or salvage logged stands as indicated.

		Wildfire				Salvage Logged			
Tree Species:		**NB**	**MB**	**HB**		**NBL**	**MBL**	**HBL**	**Species Code**
Betula papyrifera		0.50	0.67	0.67		0.50	0.75	0.50	Betu pap
Larix laricina		0.00	0.17	0.00		0.50	0.25	0.50	Lari lar
Picea glauca		1.00	0.83	1.00		1.00	1.00	1.00	Pice gla
Picea mariana	x	0.00	0.17	0.00		0.00	0.00	0.00	Pice mar
Pinus banksiana		0.00	0.33	1.00		1.00	1.00	1.00	Pinu ban
Populus balsamifera		0.00	0.17	0.17		0.75	0.75	0.25	Popu bal
Populus tremuloides		0.83	1.00	1.00		1.00	1.00	1.00	Popu tre
Shrub Species:									
Alnus crispa		0.83	0.33	0.00		0.75	1.00	1.00	Alnu cri
Alnus rugosa	x	0.00	0.17	0.00		0.00	0.00	0.00	Alnu rug
Arctostaphylos uva-ursi		0.00	0.17	0.00		0.00	0.00	0.25	Arct uva
Cornus stolonifera	x	0.67	0.33	0.00		0.00	0.00	0.00	Corn sto
Gaultheria hispidula		0.00	0.00	0.17		0.00	0.00	0.25	Gaul his
Ledum groenlandicum		0.50	0.50	0.83		0.50	1.00	1.00	Ledu gro
Lonicera dioica		0.33	0.00	0.17		0.50	0.00	0.00	Loni dio
Lonicera involucrata		0.50	0.50	0.17		0.75	0.25	0.00	Loni inv
Prunus pensylvanica	x	0.17	0.17	0.00		0.00	0.00	0.00	Prun pen
Ribes hudsonianum	x	0.50	0.17	0.00		0.00	0.00	0.00	Ribe hud
Ribes lacustre		0.83	0.33	0.00		0.25	0.00	0.25	Ribe lac
Ribes oxyacanthoides		0.17	0.17	0.00		0.50	0.50	0.00	Ribe oxy
Ribes triste		0.83	0.50	0.00		1.00	0.75	0.00	Ribe tri
Rosa acicularis		0.67	1.00	0.17		0.75	1.00	0.00	Rosa aci
Rubus idaeus		0.50	0.83	0.50		1.00	1.00	0.50	Rubu ida
Salix spp.		0.00	0.67	1.00		0.75	0.75	1.00	Sali spp
Shepherdia canadensis		0.00	0.00	0.00	x	0.25	0.00	0.00	Shep can
Vaccinium myrtilloides		0.00	0.33	0.67		0.00	0.00	0.25	Vacc myr
Vaccinium vitis-idaea		0.17	0.33	0.50		0.50	0.75	0.75	Vacc vit
Viburnum edule		0.67	0.83	0.33		0.75	0.50	0.00	Vibu edu
Forb & Graminoid Species:									
Achillea millefolium		0.17	0.33	0.17		0.75	0.75	0.50	Achi mil
Actaea rubra		0.33	0.33	0.17		0.50	0.25	0.00	Acta rub
Aquilegia brevistyla	x	0.00	0.00	0.17		0.00	0.00	0.00	Aqui bre
Aralia nudicaulis		1.00	0.67	0.17		1.00	0.50	0.00	Aral nud
Aster spp.		0.83	0.83	0.17		1.00	1.00	0.50	Aste spp
Astragalus canadensis	x	0.17	0.00	0.00		0.00	0.00	0.00	Astr can
Carex spp.		0.17	0.00	0.00		0.00	0.25	0.00	Carx spp
Circaea alpina		0.33	0.00	0.00		0.25	0.00	0.00	Circ alp
Coptis trifolia	x	0.00	0.00	0.17		0.00	0.00	0.00	Copt tri
Cornus canadensis		0.83	0.83	0.83		1.00	1.00	1.00	Corn can
Disporum trachycarpum	x	0.17	0.00	0.00		0.00	0.00	0.00	Disp tra
Epilobium angustifolium		0.50	1.00	0.83		1.00	1.00	1.00	Epil ang
Equisetum arvense		0.33	0.50	0.00		0.75	0.75	0.25	Equi arv
Equisetum pratense		0.67	0.50	0.17		0.75	0.75	0.75	Equi pra
Equisetum scirpoides	x	0.33	0.33	0.17		0.00	0.50	0.00	Equi sci
Equisetum sylvaticum	x	0.17	0.33	0.17		0.00	0.00	0.00	Equi syl
Fragaria vesca	x	0.17	0.50	0.17		0.00	0.00	0.00	Frag ves
Fragaria virginiana		0.33	0.33	0.17		0.50	0.50	0.25	Frag vir

Galium boreale		0.17	0.33	0.50	0.00	0.25	0.50	Gali bor
Galium triflorum		0.83	0.33	0.00	0.50	0.25	0.00	Gali tri
Goodyera repens	x	0.17	0.00	0.00	0.00	0.00	0.00	Good rep
Grass spp.		0.83	1.00	0.83	1.00	0.75	1.00	Gras spp
Gymnocarpium dryopteris	x	0.17	0.17	0.00	0.00	0.00	0.00	Gymn dry
Habenaria hyperborea		0.00	0.33	0.00	0.25	0.00	0.00	Habe hyp
Lathyrus ochroleucus		0.33	0.33	0.67	1.00	1.00	0.50	Lath och
Lathyrus venosus		0.00	0.33	0.00	0.75	0.00	0.00	Lath ven
Linnaea borealis		0.67	0.67	0.50	1.00	1.00	0.75	Linn bor
Lycopodium annotinum		0.33	0.17	0.00	0.25	0.00	0.00	Lyco ann
Lycopodium complanatum		0.00	0.17	0.17	0.00	0.25	0.50	Lyco com
Lycopodium obscurum	x	0.00	0.00	0.50	0.00	0.00	0.00	Lyco obs
Maianthemum canadens		0.67	0.67	0.17	0.50	0.25	0.00	Maia can
Mertensia paniculata		1.00	0.83	0.17	1.00	0.25	0.50	Mert pan
Mitella nuda		0.83	0.83	0.00	0.50	0.50	0.00	Mite nud
Petasites palmatus		1.00	1.00	0.67	1.00	1.00	0.75	Peta pal
Pyrola secunda	x	0.00	0.17	0.00	0.00	0.00	0.00	Pyro sec
Pyrola virens	x	0.00	0.17	0.33	0.00	0.00	0.00	Pyro vir
Rubus pubescens		1.00	1.00	0.17	1.00	0.50	0.50	Rubu pub
Rumex occidentalis	x	0.00	0.17	0.00	0.00	0.00	0.00	Rume occ
Smilacina stellata	x	0.17	0.00	0.00	0.00	0.00	0.00	Smil ste
Stellaria longifolia		0.00	0.17	0.33	0.25	0.00	0.25	Stel lon
Taraxacum officinale		0.00	0.17	0.17	0.25	0.25	0.00	Tera off
Trientalis borealis		0.67	0.33	0.17	0.25	0.50	0.50	Trie bor
Urtica dioca		0.17	0.00	0.00	0.00	0.00	0.00	Urti dio
Vicia americana		0.50	0.83	0.50	0.50	0.50	0.50	Vici ame
Viola canadensis		0.50	0.17	0.00	0.00	0.00	0.00	Viol can
Viola renifolia		0.67	0.50	0.00	0.50	0.25	0.50	Viol ren

Appendix 3 Frequency of all species within the Beaupre burn site (10 years post-fire) between burn severities. Frequency is shown as the percentage of plots in which a species occurs. Wildfire and Salvage n = 18 plots.

	Wildfire			
Tree Species:	**NB**	**MB**	**HB**	**Species Code**
Abies balsamea	1.00	0.17	0.00	Abie bal
Betula papyrifera	0.17	0.83	1.00	Betu pap
Picea glauca	1.00	1.00	1.00	Pice gla
Pinus banksiana	0.00	0.00	0.17	Pinu ban
Populus balsamifera	0.17	0.67	1.00	Popu bal
Populus tremuloides	1.00	1.00	1.00	Popu tre
Shrub Species:				
Alnus crispa	0.50	0.17	0.00	Alnu cri
Amelanchier alnifolia	0.17	0.00	0.00	Amel aln
Cornus stolonifera	0.50	0.33	0.17	Corn sto
Ledum groenlandicum	0.00	0.17	0.00	Ledu gro
Lonicera dioica	0.17	0.17	0.17	Loni dio
Lonicera involucrata	0.67	0.67	0.33	Loni inv
Prunus pensylvanica	0.00	0.17	0.17	Prun pen
Ribes glandulosum	0.00	0.17	0.00	Ribe gla
Ribes hudsonianum	0.33	0.00	0.00	Ribe hud
Ribes lacustre	0.17	0.17	0.17	Ribe lac
Ribes oxyacanthoides	0.17	0.00	0.00	Ribe oxy
Ribes triste	0.83	0.67	0.00	Ribe tri
Rosa acicularis	1.00	0.83	0.50	Rosa aci
Rubus idaeus	0.33	1.00	1.00	Rubu ida
Salix spp.	0.00	0.83	1.00	Sali spp
Vaccinium myrtilloides	0.00	0.17	0.17	Vacc myr
Viburnum edule	1.00	0.83	0.50	Vibu edu
Forb & Graminoid Species:				
Actaea rubra	0.33	0.33	0.17	Acta rub
Aralia nudicaulis	1.00	0.83	0.83	Aral nud
Aster conspicuus	0.00	0.00	0.33	Aste con
Aster spp.	0.83	0.83	1.00	Aste spp
Cirsium arvense	0.00	0.17	0.67	Cirs arv
Cornus canadensis	1.00	1.00	0.83	Corn can
Disporum trachycarpum	0.67	0.50	0.00	Disp tra
Epilobium angustifolium	0.00	0.67	1.00	Epil ang
Equisetum arvense	0.17	0.17	0.33	Equi arv
Equisetum pratense	0.17	0.17	0.50	Equi pra
Equisetum scirpoides	0.00	0.00	0.17	Equi sci
Equisetum sylvaticum	0.00	0.00	0.17	Equi syl
Fragaria vesca	0.67	0.67	0.50	Frag ves
Fragaria virginiana	0.83	0.83	1.00	Frag vir
Galium boreale	0.83	0.33	0.17	Gali bor
Galium triflorum	0.83	0.83	0.67	Gali tri
Grass spp.	1.00	0.83	0.83	Gras spp
Lathyrus ochroleucus	0.17	0.83	0.50	Lath och
Lathyrus venosus	0.50	0.67	0.50	Lath ven
Linnaea borealis	0.83	0.83	0.83	Linn bor
Lycopodium annotinum	0.17	0.00	0.17	Lyco ann
Lycopodium complanatum	0.00	0.00	0.17	Lyco com
Maianthemum canadens	1.00	0.83	0.67	Maia can

Mertensia paniculata	1.00	1.00	0.83	Mert pan
Mitella nuda	1.00	1.00	0.50	Mite nud
Monotropa uniflora	0.00	0.17	0.00	Mono uni
Petasites palmatus	1.00	1.00	1.00	Peta pal
Petasites sagittatus	0.00	0.00	0.17	Peta sag
Pyrola asarifolia	0.33	0.33	0.17	Pyro asa
Pyrola secunda	0.17	0.17	0.33	Pyro sec
Pyrola virens	0.33	0.17	0.17	Pyro vir
Rubus pubescens	1.00	1.00	0.83	Rubu pub
Stellaria longifolia	0.00	0.00	0.17	Stel lon
Taraxacum officinale	0.00	0.17	1.00	Tera off
Trientalis borealis	0.67	0.50	0.33	Trie bor
Trifolium hybridum	0.00	0.00	0.17	Trif hyb
Vicia americana	0.17	0.83	0.83	Vici ame
Viola canadensis	0.00	0.17	0.17	Viol can
Viola renifolia	0.83	0.67	0.50	Viol ren