Impact of Slash Loading on Soil Temperatures and Aspen Regeneration

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Abstract

Natural regeneration is used to restock trembling aspen (*Populus tremuloides* Michx.) cutblocks and factors controlling regeneration are areas of interest and concern to the forest industry. Harvest operations in Manitoba require that coarse woody debris, or slash, be left and distributed in cutblocks. The objective of this study was to investigate the effects of slash loading on soil temperatures and aspen regeneration, and implications for harvest operations in the Duck Mountain area. Early sucker growth, initiation, and soil temperatures were surveyed in six winter and six summer cutblocks under different levels of slash loadings. A growth chamber study, using field temperature data as a guideline, examined the effects of diurnal temperature variation on sucker initiation and production. In winter and summer cutblocks, mean depths to sucker initiation from the parent root were 4.6 ± 2.4 cm and 3.4 ± 2.1 cm, respectively, and initiation of suckers occurred mainly from parental roots located in the LFH layer. Daily mean soil temperatures during the growing season were significantly lower under higher levels of slash (difference of 3.6 ^{o}C during May). Higher amounts of slash also significantly shortened the length of the growing season (89 fewer days above 0 ^{o}C in one season) and decreased the number of suckers produced (150 000 ha^{-1} decreased to 14 000 ha^{-1}), sucker volume (decreased by 256 cm^{3}m^{-2}) and leaf area index (decreased by 0.9). There was no difference in sucker production between any diurnal temperature treatments in the growth chamber study. Shallow depth to sucker initiation has important implications for harvest operations using heavy machinery especially those occurring during the summer season. Moderate levels of slash in summer cutblocks, and heavy levels of slash in winter cutblocks limit sucker growth. Although slash decreases diurnal

temperature amplitudes, this may not be the reason for the decrease in sucker production associated with increased levels of slash. Both soil temperature and early sucker growth are strongly affected by slash loading; by monitoring harvest operations and the distribution of slash within cutblocks, the negative effect of heavy machine traffic and heavy piles of slash can be reduced and ensure successful forest regeneration.

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1 GENERAL INTRODUCTION

Trembling aspen (*Populus tremuloides* Michx.) thrives in a broad range of climatic conditions and occurs across the North American continent. In Canada, trembling aspen has become the most commercially important hardwood tree species because of its broad use in the pulp and oriented strand board (OSB) industries (Bates et al., 1991). The geographic region where trembling aspen trees grow large enough to be commercially important occurs in a wide band across the Prairie Provinces (Peterson and Peterson, 1992). In fact, more than 40 % of all the trembling aspen stands in Canada (approximately 2 billion m^3 of wood) occur within the Prairie Provinces (Bella, 1986). This area of harvestable wood is broken up into several forest management land use areas (FML's), which are managed by several different companies. According to Forest Management License Agreement, all stands must be successfully restored or regenerated following harvest operations. For companies primarily harvesting aspen, successful management and regeneration of productive aspen forests is an area of great concern.

Because of aspen's ability to reproduce asexually, natural regeneration is the primary method incorporated to regenerate these hardwood forests after clear cutting. Several factors such as clonal capability, site moisture conditions, soil texture, competition, soil temperature, and apical dominance affect the natural regenerative capability of aspen; however, much research has indicated that apical dominance and soil temperature are the two primary factors controlling aspen suckering (Farmer, 1962;

Maini and Horton, 1966; Zasada and Schier, 1973; Frey et al., 2003). When mature trees are cut during forest operations, the apical dominance control over aspen sucker regeneration is removed and soil temperature becomes the most important issue concerning an aspen stand's ability for reproduction through natural regeneration.

Any imposed fluctuations in soil temperature will affect the ability of aspen clones to produce a reasonable number of viable suckers from their root system (Maini and Horton, 1966). Several environmental factors, especially soil surface conditions, are important in terms of their potential effect on soil temperature and soil temperature fluxes. Because soil temperature is a function of radiation into the soil, radiant heat out of the soil and convective heat flux, the type and density of any material overlying the soil is an area of great importance in terms of aspen regeneration. Harvesting methods most certainly alter soil surface conditions, soil temperature and thus the conditions surrounding aspen sucker initiation, initial growth and regeneration in general. To ensure the establishment of productive forests, harvest operations must be considered in terms of their capacity to alter soil surface conditions.

In the Duck Mountain area of west central Manitoba, Louisiana-Pacific Canada (L-P) harvests 900 000 m^3 of wood each year from FML #3 primarily for the production of OSB. The majority of the wood harvested in this FML is trembling aspen. Present operations in the Duck Mountain area are predominantly tree length harvest operations; trees are harvested and delimbed at the stump and subsequently the entire length of the tree is moved to a central landing area. As trees are cut and prepared for transport from the cutblock, tree tops, branches and other coarse woody debris are left throughout the cutblock according to the harvesting machinery cutting patterns. In order to ensure nutrient return to the soil, the slash is necessarily left on the cutblock. The amount and distribution of slash left after harvest operations is an area of great interest for companies such as L-P since slash may alter aspen reproduction in both softwood stands and hardwood stands (Steneker, 1976; Bella, 1986; McInnis and Roberts, 1995; Navratil, 1996). In addition, as of May 1, 1993, Manitoba Natural Resources Forestry Branch implemented a policy which requires that slash be spread throughout cutblocks. This policy further prohibits the use of landing areas, where harvesting machinery bring harvested wood to a central area adjacent to a roadway, which often result in roadside debris piles. Consequently, there is an increasing awareness and concern regarding the severity of the effects of slash and slash distribution on forest renewal not only in Manitoba but also throughout the continent where the harvest of aspen is commercially important. Although several authors have individually addressed the issues of slash cover, aspen reproduction and soil temperature, no previous studies have been done which concisely quantify the effects of different levels of slash loading on soil temperatures and on aspen suckering, especially under field conditions (Farmer, 1963; Maini and Horton, 1966; Zasada and Schier, 1973; Bella, 1986; Hungerford, 1988; Johansson and Lundh, 1988; Hogg and Lieffers, 1991).

The influence of slash loading on soil temperatures is of great concern for the reproduction of healthy hardwood forests throughout the continent. The hypothesis of this study was that by increasing the levels of slash, the process of harvesting forests would decrease soil temperatures, alter the daily temperature cycle, decrease aspen regeneration, and alter the pattern of sucker initiation. This project attempts to clarify the effects of slash loading on soil temperature and aspen regeneration in the Duck Mountain area by investigating several important relationships. The study objectives were to:

1. Examine the effect of different levels of slash loading on field soil temperature conditions;
2. Examine the effect of different levels of slash loading on aspen regeneration parameters;
3. Examine the relationship between slash loading and the pattern of sucker initiation;
4. Examine the effects of diurnal temperature fluctuations similar to those found in field conditions on aspen regeneration parameters.

The following thesis consists of six chapters: a general introduction; a literature review; three chapters which detail the research conducted in the Duck Mountain area and in controlled environment chambers; and a concluding chapter. The material contained in each of these chapters is briefly outlined below.

Chapter 2 is a basic literature review of the factors influencing aspen reproduction and the mechanism of their influence. This includes a brief overview of aspen root systems, aspen sucker initiation and factors that significantly influence early aspen sucker production. As well, this chapter examines the debris left behind during harvest operations and the difficulty in measuring and describing this slash material. Present knowledge regarding the effects of season of harvest and diurnal temperature variation on aspen reproduction is also discussed.

Chapter 3 introduces the techniques used to quantify slash and the study of the effects of slash on both soil temperature and aspen regeneration. Two different slash quantification methods were compared.

Chapter 4 describes a field study where, using one of the quantification methods, soil temperature regimes under three levels of slash loading were examined with the use of Hobo temperature probes installed in both winter and summer cutblocks (Objective 1). Additionally, the success of aspen regeneration under different levels of slash loading was addressed by measuring sucker density, sucker volume, and leaf area index (Objective 2).

In Chapter 5, the pattern of sucker initiation is examined (Objective 3). This chapter follows the results of a field study conducted in the Duck Mountain area where aspen suckers under varying levels of slash were excavated and described. The location of sucker initiation and depth of root from which the suckers initiate was collected and analyzed.

Chapter 6 explores the effects of diurnal temperature variation on aspen sucker regeneration through the use of a controlled environment chamber (Objective 4). Three temperature conditions were imposed on aspen roots collected from the Duck Mountain area and success of regeneration was measured following an eight week growth period.

Chapter 7 summarizes the results of the field and controlled environment chamber studies and discusses implications of these studies in the forest industry.

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2 LITERATURE REVIEW

2.1 Aspen reproduction

Aspen, a relatively common tree species across the Canadian prairie provinces, is able to reproduce both sexually and asexually (Peterson and Peterson, 1992). Sexual reproduction is accomplished through the production, germination and establishment of seeds from mature trees. Seeds are successfully produced in large numbers from aspen trees; however, these seeds need moist seedbed conditions with an abundance of light in order to germinate (Steneker, 1976; Bates et al., 1991). If seedbed conditions are appropriate, sexual reproduction has the potential to contribute to forest regeneration; however, sexual reproduction is often limited because appropriate microclimate conditions are rare and seeds quickly lose viability (Steneker, 1976; Bates et al., 1991; Peterson and Peterson, 1992).

Asexual reproduction involves the stimulation of suppressed buds, newly initiated buds, or root meristems which results in the production of numerous new root sprouts or “suckers” from one extensive root system of a group of mature trees (Schier, 1973; Bates et al., 1991). Aspen forests are supported by these intertwining root systems since the large root systems are able to provide the mature forests with necessary nutrient and moisture resources. When mature trees from these forests die as a result of natural disturbance or are removed by harvest operations, root suckers proliferate (Peterson and Peterson, 1992; Shepperd, 1996). Because of this potential for successful and prolific reproduction, most companies depend on the asexual reproduction of aspen after harvest. Since natural regeneration is the primary method used to regenerate aspen in the boreal forest, the present research has focused on factors controlling aspen suckering.

2.1.1 Sucker origin and distribution

The extensive root system of mature aspen trees is interconnected. The numerous suckers which develop from the same mother root are genetically identical and are called clones (Ford-Robertson, 1971; Steneker, 1976). The size of each clone varies but may reach up to several hectares and may include hundreds of mature trees with the same genetic makeup. Shoots that are produced from this below –ground root system are called ramets or suckers (Ford-Robertson, 1971). Steneker (1973) indicates that typical aspen clones in the Duck Mountain Forest Reserve are approximately 0.08 ha in size. This ample system of roots can support thousands of aspen suckers after harvest operations. Typical stocking density after harvest operations can be as high as 80 000 suckers ha^{-1} but varies substantially (Steneker, 1976; Huffman et al., 1999).

Although hardwood stocking standards have historically not been well defined, because of the rapid self-thinning process, 20 000 to 25 000 suckers ha^{-1} is an accepted minimum initial number of suckers for successful stand regeneration (Farmer, 1963; Bates et al., 1991; Navratil et al., 1994; Huffman et al., 1999). Contrary to the high estimates of stand regeneration densities found commonly in the literature, Manitoba’s current forest renewal standard requires densities ranging from 2 500 to 6 000 suckers

ha^{-1} (Delaney, 1995). Although the standards are based on densities necessary for successful regeneration of mixedwood forests and not pure hardwood stands, they still are astonishingly low in comparison with literature values. Although initial sucker densities do vary widely, within several years, they have been noted to converge to similar densities, creating a commonly held belief that low initial sucker densities are not an area for concern (Peterson and Peterson, 1992; Delaney, 1995). However, higher initial densities have significantly higher total leaf area and consequently better maintain and support the underlying clonal root system (DesRochers, 2000; DesRochers and Lieffers, 2001). The use of such exceptionally low regeneration standards in Manitoba may be inadequate for successful regeneration in aspen dominated stands.

The origin of aspen suckers and the distribution of aspen root systems range according to site conditions and clonal capabilities. The distribution of suckers within the soil profile displays the versatility of aspen roots to respond to different environmental conditions. Aspen suckers typically originate from lateral roots ranging from 0.5 to 2.5 cm in diameter (Peterson and Peterson, 1992). However, Perala (1991) indicated that in the Lake States most suckers are initiated on lateral roots less than 1 cm in diameter. In field conditions, most of these suckers originate on the upper side of lateral roots. Aspen roots have been found to extend to depths of 1.2 m and radially they can extend up to 30 m (Stone and Kalisz, 1991; Van Rees, 1997). Perala (1991) and Peterson and Peterson (1992) indicate that the majority of suckering occurs on aspen roots located in the upper 12 cm of soil while Strong and La Roi (1983) point out that most suckers are produced by roots at 5 to 20 cm depth. Navratil (1996) similarly showed that sucker initiation occurred at depths of 8 to 15 cm in the field. Both Gifford (1966) and Strong and La Roi (1983) found suckering at increased depth in coarse-textured soils. Farmer (1962*b*) and Kemperman (1978) indicate that in field conditions, most suckers occur at 1 to 3 cm root depth. Clearly there is immense variability among aspen clones and aspen suckering responses. Considering this immense variability, characterization of aspen sucker responses to differing environmental situations may be very problematic unless the individual effects of altered environmental conditions are significant.

2.1.2 Factors controlling aspen sucker reproduction

Several factors may affect aspen suckering. Peterson and Peterson (1992) summarized several studies that highlight the key factors controlling aspen suckering: apical dominance, soil temperature, growth regulators, root carbohydrate reserves, root size, the inherent ability of each clone to sucker, root depth, degree of disturbance, and soil moisture levels. A similar summary by Frey et al. (2003) included these factors as well as: season of logging, wounding of roots, severing of roots, and predisturbance stand conditions. Although all of these factors are involved in sucker production, in most situations the two most influential factors are apical dominance and soil temperature (Peterson and Peterson, 1992).

The phenomenon of apical dominance results from the flow of auxin, indoleacetic acid and several other growth hormones within mature trees and the supporting root system, which collectively inhibit sucker formation (Farmer, 1962*a*;

Eliasson, 1971). Only when the flow of these hormones between mature trees and the root system is discontinued or decreased is apical dominance broken and can sucker initiation begin to take place. The cutting of mature trees during harvest operations ensures that root systems are no longer inhibited from sucker formation and thus soil temperature becomes the dominant factor controlling aspen suckering in cutblocks. In most instances, harvest operations not only break apical dominance, but they also result in increased soil temperatures due to increased incident radiation.

2.2 Soil Temperature

Soil temperature plays a substantial role in aspen sucker initiation and growth; however, the consideration of the specific effects of soil temperature on root growth is complex (Maini and Horton, 1966; Johansson and Lundh, 1988). Soil temperatures, typically lower than air temperatures, fluctuate throughout the growing season, throughout the day, throughout the soil profile, and with different management practices (Glinski and Lipiec, 1990; Rendig and Taylor, 1989; McMichael and Burke, 1996). Because of these differences, each area of the extensive root system can experience very different growing conditions at the same time (Rendig and Taylor, 1989). Soil temperature also influences soil physical properties such as moisture, aeration, structure, microbial and enzyme activity, and plant residue decomposition, which in turn can alter plant root growth (Kohnke, 1968). In addition to the complexity of heat absorption and transfer within soils, plant physiology is complex and may be altered by several different and interacting environmental conditions.

2.2.1 Physical processes related to changes in soil temperature

Soil temperature is affected by forces that are either internal (within the soil) or external (environmental). The combination of internal and external factors determines soil temperature fluxes and the equilibrium soil temperature. The main environmental factors affecting soil temperature are solar radiation, radiation from the sky, heat conduction from the atmosphere, condensation, evaporation, rainfall, insulation, and vegetation (Kohnke, 1968). Short-wave radiation from the sun and long-wave radiation from the atmosphere are the most important components contributing to soil heat. Soil heat is most easily lost by long-wave radiation from the soil surface back into the atmosphere (Glinski and Lipiec, 1990).

Because the largest input of heat to soil is from environmental inputs, internal factors have their principal influence on soil temperature by affecting soil temperature movement and gradients. Internal factors mainly affect soil temperature conductance by altering soil heat capacity and soil thermal conductivity. Heat capacity is a measure of the quantity of heat required to change the temperature of a given mass of a substance by a certain amount. Thermal conductivity is a measure of how well a substance is able to transfer heat between molecules. The movement of heat in soils depends on both of these variables. Thermal diffusivity combines these two terms and is used to measure the rate at which a substance heats up when introduced to a temperature gradient. Thermal diffusivity is proportional to thermal conductivity and inversely proportional to heat capacity (Kohnke, 1968; Wood, 1981; Glinski and Lipiec, 1990). Physical soil factors such as bulk density, texture, soil albedo, porosity and water content greatly affect soil thermal diffusivity (Wood, 1981). These internal factors have a strong influence on the nature of heat transfer in soils and the resulting soil temperature.

2.2.2 Effect of soil temperature on plant and root growth

In recently harvested cutblocks, soil temperature is the environmental factor which has the strongest influence on root growth, root development, and ultimately aspen sucker productivity. Soil temperature largely controls aspen productivity by affecting major plant processes such as nutrient uptake, nutrient utilization, photosynthetic rates, and even carbon partitioning (McMichael and Burke, 1996). Temperature changes in the soil result in a change in the physiological response of roots and thus a change in root growth, anatomy, and root differentiation (Glinski and Lipiec, 1990; Kaspar and Bland, 1992). Observed root growth rates and root anatomy at different temperatures demonstrate that plant roots have an optimal temperature for growth. Aspen root growth may be limited or even cease altogether when exposed to extremely high or low soil temperatures (Kaspar and Bland, 1992). For most plant species, optimal root growth temperature is around 20 to 25 °C; however, the process of aspen sucker initiation appears to be inhibited at soil temperatures less than 15 °C and optimal suckering occurs at approximately 20 °C (Maini and Horton, 1966; Navratil, 1991; Kaspar and Bland, 1992). Because plant roots are typically more sensitive to changes in temperature than plant shoots, creating less than optimal soil temperatures could affect aspen sucker initiation (Kaspar and Bland, 1992). Aspen root sucker initiation, especially in cool soil conditions, may be drastically affected by environmental conditions and the potential ramifications for successful forest regeneration are significant.

2.3 Slash debris in cutblocks

In field conditions, numerous environmental situations alter soil temperatures and soil temperature fluxes. Presently, tree length harvest operations often exercise delimbing adjacent to the tree stump; trees are felled, limbed and topped at the stump and then the whole length of the tree is moved to the roadside for transport. As trees are harvested in this manner across cutblocks, treetops, branches and other coarse woody debris are distributed throughout the area according to the feller buncher (harvesting equipment) cutting pattern. In Manitoba, according to policies implemented in Timber Sale Agreements made between L-P and timber operators, all logging debris must be distributed so that it lays as close to the ground as possible and no roadside debris piles or in-bush debris piles are permitted. In addition, as of May 1, 1993, Manitoba Natural Resources Forestry Branch has put into place a policy which requires that slash be spread out in the cutblock. This policy further prohibits the incidence of landing areas with roadside debris piles. Consequently, there is an increasing awareness and concern regarding the range and severity of effects of slash and slash distribution on forest renewal.

2.3.1 Effects of slash on soil temperatures and aspen regeneration

Increased levels of vegetation cover and litter have been shown to significantly delay spring thaw and decrease summer soil temperatures (Hogg and Lieffers, 1991). Because slash effectively decreases the amount of radiation intercepted by the soil surface and the flow of radiative heat into and out of the soil, slash loadings effectively decrease soil temperatures in the same manner as vegetation cover and litter. McInnis and Roberts (1995) found that slash loadings from tree length harvesting of spruce and fir stands in New Brunswick resulted in 34% less solar radiation reaching the soil surface and lower maximum soil temperatures than control plots. Decreased soil temperatures and late spring thaw could have serious implications for aspen sucker initiation and regeneration. Navratil (1996) and Bella (1986) indicated that the numbers of suckers produced under conditions of heavy slash loading substantially decreased. Bella (1986) demonstrated that slash cover on Chernozemic soils in Saskatchewan reduced both aspen regeneration and growth.

Despite these findings, some authors dispute the importance of the effects of slash loading on soil temperatures and aspen regeneration. Bates et al. (1991) indicated that logging slash generally does not decrease regeneration success and emphasized the importance of leaving slash on cutblocks to ensure nutrient return to soil reserves. Shepperd (1996) suggested that the effects of slash on aspen suckering were marginal even when heavier slash loads than normal were applied. Steneker (1976) proposed that slash does not significantly affect sucker formation and growth on fresh or moist sites but on wet sites, slash may depress soil temperatures below the optimal levels for sucker initiation. The controversy regarding the severity of effects of slash loading on soil temperatures and aspen suckering stems from the lack of detailed and quantitative description of the amounts of slash cover and the specific effects of slash loading on soil temperatures. In these aforementioned studies, continuous soil temperature values were not monitored and no consistent method of measuring the actual amount of slash present was used. This lack of parallel methodology and precision in measurement prohibits tangible comparison or synopsis of the amounts of slash present and their quantifiable effects on both soil temperature and aspen regeneration.

2.3.2 Diurnal temperature variation

Not only does slash have a measurable effect on mean daily soil temperatures in cutblocks, it also has an impact on the diurnal temperature variation. Initial soil temperature/aspen regeneration experiments conducted by Maini and Horton (1966) investigated aspen suckering at constant temperatures in incubators, however, field conditions are significantly different since there are notable diurnal temperature fluctuations. Diurnal temperature fluctuations present in natural conditions are believed to play a favourable role in sucker initiation (Zasada and Schier, 1973). Maini and Horton (1966) indicated that aspen have poor suckering potential during hot days and increased suckering potential associated with cool nights. High daytime temperatures following harvest may inhibit suckering while high nighttime temperatures may produce a more favourable regime for suckering.

More recent studies examining the differences that night and day temperatures have on aspen regeneration and growth in controlled environments have simply used a mean day and a mean night temperature alternating cycle (Farmer, 1963; Bate and Canvin, 1971; Zasada and Schier, 1973; Fraser et al., 2002). These studies have failed to consider that in field conditions, temperature change is gradual. Considering the effect of soil temperatures on plant growth by only implementing the mean day and night temperatures or by using one mean temperature for one 24 hour period is not an effective way to replicate real life conditions. Examining the effects of regular and realistic variations in the daily soil temperature may significantly alter the early findings of the relationships between soil temperature and aspen regeneration and the study of the effects of slash loading on soil temperature and aspen regeneration.

The examination of the effects of diurnal temperature variations on aspen regeneration may not only affect accepted knowledge regarding the ability of aspen roots to sucker at various temperatures, but also introduces another variable to consider in natural environmental conditions. By altering the surface layer above the aspen roots in the field, not only the timing of soil temperature cycles but also the daily maximum and minimum temperatures may be affected. Hogg and Lieffers (1991) indicated that a litter layer over the soil surface influences soil temperature fluxes. Specifically, insulative material such as the litter from *Calamagrostis canadensis* can delay the timing of diurnal cycles of soil temperatures. This delay may be up to 3 to 4 hours in plots with a thick insulative layer. Slash, a highly insulative material, also has the potential to significantly alter the diurnal temperature cycles in cutblocks. If daily soil temperatures fail to reach optimal levels because of this insulative layer, there may be a significant decrease in aspen suckering as a result of increased slash loads. Quantification of slash loads and examination of their effects on daily soil temperature dynamics may help to elucidate the factors behind decreased suckering ability associated with decreased soil temperatures.

2.3.3 Slash load determination

Because of the large size and variety of slash found in cutblocks, actual measurement of slash in cutblocks presents a problem in terms of field scale surveys. In order to approach a similar task, Newman (1966) developed a mathematical method to estimate the total length of roots found in soil samples. The line intersection method involves overlaying a sample of roots with a square consisting of random lines. Counting the number of intersections of the lines with the sample roots, measuring the area of the overlaid square, and the total length of the random lines, allows a fairly precise method of determining the total length of root material in a sample, regardless of the shape or orientation of the roots themselves. Newman (1966) demonstrated that both direct measurement and weighing of the sample takes more time and in fact often results in a larger coefficient of variation. Tennant (1975) examined Newman’s method and modified it to provide a slightly improved approach, which used a grid system to determine the length of roots in a given sample.

The line intercept theory has been used numerous times for a variety of ecological sampling purposes ranging from the examination of grassland communities, to estimations of vegetation types, to root length estimation, to forest fuel sampling, to estimations of downed coarse woody material (Hasel, 1941; Van Wagner, 1961; Warren and Olsen, 1964; Newman, 1966; McRae et al., 1979). The basis of this theory lays in the expectation that in a given area, within which some straight lines lie, the larger a given object is, the more intersections with the straight lines will occur (Newman, 1966).

Extension of the line intercept theory has been used to create several mathematically based systems to measure and describe slash and fuel loads in both forests and cutblocks (Warren and Olsen, 1964; Bailey, 1970; McRae et al., 1979; Brown et al., 1982). McRae et al. (1979) developed a mathematical model to estimate fuel loads for predicting fire spread. This method entails tallying intersections of slash with a sample line representing a vertical plane. Slash pieces are tallied according to diameter size classes. Sample lines are laid out in equilateral triangles (30 m on each side) in the area to be measured. The number of woody pieces which intersect the sample line (vertical plane) are tallied for different lengths along each 30 m sample line according to diameter size; 0.0 to 0.49 cm category, 0.5 to 0.99 cm category, 1.0 to 2.99 cm category, 3.0 to 4.99 cm category, 5.0 to 6.99 cm category and greater than 7.0 cm category are counted for 5 m, 10 m, 15 m, 20 m, 25 m, and 30 m respectively. The diameters of all pieces 7.0 cm and greater are measured and identified by tree species. Using average species composition values and multiplication factors for these species in conjunction with the tally and a slope correction factor, a total slash loading can be determined for large scale areas.

These procedures created to measure slash in cutblocks involve surveying on a relatively large scale thus making it difficult to measure accurately and precisely the amount of slash in a small area. Because of the highly variable distribution of slash throughout cutblocks, it is necessary to examine the effects of slash on a small scale. In order to facilitate the replication necessary in field studies, new methods must be developed to measure the amounts of slash in a given small area.

2.4 Season of forest harvest operations

Seasonal forest operations may also affect aspen suckering. Summer logging creates more disturbance to soil profiles (organic layers and vegetation cover) than winter logging, which takes place when the ground is frozen (Navratil, 1996). It is likely that summer logging may increase soil temperatures by increased disturbance to the forest floor. However, because the mature trees are actively growing right before harvest, parental root systems have decreased levels of non-structural carbohydrates and thus decreased suckering capacity (Zasada and Schier, 1973; Bates et al., 1991; Genoway, 1999). There is also an increased chance that machine traffic will cause injury to aspen root systems.

Winter harvesting occurs during the winter season when the soil profile is frozen resulting in a decreased level of disturbance on a large scale. Winter harvesting is especially successful where cutblocks are likely to contain higher levels of soil moisture. Higher levels of soil moisture make the underlying aspen roots more susceptible to injury due to machine traffic during summer months and poor growing conditions such as those caused by soil compaction. Those cutblocks harvested in the winter will likely have less disturbance to the soil profile, compared to summer cutblocks, and the majority of the vegetative cover will be intact. Slash residues, vegetative cover, and low disturbance associated with winter logging likely delay the initial spring thaw after the harvest and reduce mid-summer soil temperatures in a similar manner to vegetation cover and litter studied by Hogg and Lieffers (1991).

Although the winter cutblocks may have lower soil temperatures than those in summer cutblocks, suckers which initiate will likely have higher levels of available carbohydrate reserves than those in summer cutblocks. Bella (1986) reported that sucker density was initially higher in summer cutblocks than in winter cutblocks. Sucker density appeared to differ more under different slash loading conditions in the summer cutblocks than in the winter cutblocks (Bella, 1986). In contrast, Bates et al. (1991) indicated that spring and early summer harvest often result in a decreased number of initial suckers as well as slow initial sucker growth as compared to suckers in winter harvested cutblocks. They hypothesize that this is related to a decreased amount of available carbohydrates available for suckering where carbohydrate reserves are used for bud break and leaf expansion.

The effects of the season of harvest appear to vary widely due to the large variation in site conditions. The severity of the effects of lower soil temperatures imposed in winter cutblocks is difficult to isolate due to the confounding effects of carbohydrate reserve availability and the imposition of harvest season on different locations because of environmental conditions. Although the season of harvest clearly affects the soil temperatures imposed on parental roots, the relationship between suckering response during different seasons of harvest and soil temperatures is unclear.

2.5 Summary

Although several environmental factors can potentially affect aspen regeneration, soil temperature may in fact largely control the success of aspen reproduction both in the Duck Mountain area and throughout Canada. Slash loading, a factor which appears to influence aspen stand initiation and development, may act through significant alterations to average soil temperature, length of growing season and average diurnal temperatures. Management of slash loading is critical to ensure that the number of aspen suckers reproduced in cutblocks results in a sustainable forest resource for future generations. Research about the effects of slash loading and soil temperatures on aspen initiation and regeneration in both summer and winter harvested cutblocks is necessary to clarify the effects of harvest operations on hardwood and mixedwood forests.

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3 EXTENT OF SLASH LOADING IN WINTER AND SUMMER CUTBLOCKS

3.1 Introduction

Because slash acts as an insulative layer over the exposed soil following forest harvest, this is likely to cause significant alterations to soil temperature profiles. Factors such as slash loading, which can alter soil temperature, have a potentially detrimental effect on the successful regeneration of trembling aspen. These induced changes may negatively affect both aspen sucker initiation and development if soil temperatures increase or decrease to levels that alter physiological processes within the root system (Maini and Horton, 1966; Hogg and Lieffers, 1991; McInnis and Roberts, 1995; McMichael and Burke, 1996; Navratil, 1996). Although initial growth of aspen suckers has been thought to be of little significance as an indicator of long term survival and ability to thrive, recent research indicates that early sucker growth may be strongly linked with the long-term maintenance of healthy mother root systems and thus stand survival and success (Desrochers and Lieffers, 2001). Due both to the nature of forest harvest techniques and forest harvest regulations, the amount and distribution of slash varies widely throughout both winter harvested and summer harvested cutblocks. This scattered distribution of slash makes it difficult not only to determine the actual amount and distribution of slash but also to quantify the extent of the effects of slash loading on both soil temperatures and aspen regeneration.

Using the line-intercept theory as a basis, several methods have been developed which fairly accurately estimate the amount of downed coarse woody material in a large area (Warren and Olsen, 1964; Bailey, 1970; Rothermel, 1972; McRae et al., 1979; Brown et al., 1982). These methods may appropriately be further applied to estimate the average amount of slash found across an entire cutblock following harvest. McRae et al. (1979) developed such a mathematical model to estimate fuel loads for predicting fire spread. This method entails tallying intersections of slash with a sample line representing a vertical plane. Slash pieces are tallied according to diameter size classes. Using average species composition values and multiplication factors for these species in conjunction with the tally and a slope correction factor, a total slash loading can be determined for large scale areas.

Accurate estimation of the amounts of slash loading across both winter and summer cutblocks is necessary to determine the magnitude of effects of slash loading on both soil temperatures and aspen regeneration. The large scale fuel loading estimation method outlined by McRae et al. (1979) seems appropriate to estimate and compare the amounts of slash found in both winter and summer cutblocks at a cutblock level. However, since the slash distribution is so varied and the average may not appropriately describe the range of slash conditions across the cutblock, the use of small plots for estimation of slash load distribution in conjunction with a frequency distribution type analysis may be more appropriate when considering the effects of slash load across winter and summer cutblocks.

Because of the diversity of slash distribution throughout cutblocks, critical examination of the specific effects of slash loading on soil temperature and aspen regeneration in field conditions must necessarily be considered on a smaller scale. To determine the individual effect of a large pile of slash on the soil temperature directly below the pile, it is necessary to estimate the amount of slash directly above that area of soil. Newman (1966) developed a mathematical method to estimate the total length of roots found in soil samples. This line intersection method allowed for a fairly precise method of determining the total length of root material in a sample, regardless of the shape or orientation of the roots themselves. Tennant (1975) examined Newman's method and modified it to provide a slightly improved approach, which used a grid system to determine the length of roots in a given sample. Extension of this model may be used to estimate slash load in smaller areas within cutblocks.

The hypothesis of this study was that a modified version of the Newman method would produce similar slash estimates as fuel loading estimates. The objectives therefore of this study were to obtain a description of slash distribution in both winter and summer cutblocks in the Duck Mountain area, to determine whether an extension of the Newman method will produce comparable slash load estimates to an established large scale estimation method and to compare the utility of two methods of slash load estimation.

3.2 Methods

3.2.1 Study area

The study area was located in the Duck Mountain region of west-central Manitoba ($57^{o}02'$ to $57^{o}48'$ north and 350^{o} to 385^{o} east). The forests of this area are predominantly deciduous with mixed deciduous and coniferous forests at higher elevations. The lower elevations of the Duck Mountain area (300 to 400 m) primarily consist of Chernozemic soils, while soils at higher elevations (400 to 700 m) are largely composed of Gray Luvisolic soils (Zoladeski et al., 1995). A summary of soil characteristics is presented in Appendix A.

The Duck Mountain area is composed of hardwood stands at the lower elevations and some conifer dominated stands at the higher elevations. Tree length harvesting is the conventional harvest operation used in this FML, resulting in the slash being retained at the tree stump and thus distributed across the cutblock according to the movement pattern of the harvesting machinery. According to policies implemented in Timber Sale Agreements, made between L-P and timber operators, all logging debris must be distributed so that it lies as close to the ground as possible and no roadside debris piles or in-bush debris piles are permitted. Harvest operations in FML #3 occur during both the winter and summer seasons and are applied to different blocks of land according to site conditions.

To examine the effects of slash loading on soil temperature regimes, aspen regeneration, and depth to sucker initiation, twelve newly harvested hardwood cutblocks located within FML #3 were chosen as sample study areas. Six of these cutblocks were harvested during the 1998/1999 winter season, while the other six were harvested during the 1999 summer season. Before harvesting, all 12 of these cutblocks were composed of mature, well stocked, aspen dominated stands (Table 3.1).

Table 3.1 Pre-harvest stand characteristics of field study sites located throughout the Duck Mountain area.

Site	Harvest Season	Soil Type†	Vegetation Type‡	Species Composition§	Area (ha)
Madge Lake	Winter	6	5	TA10	3.55
				TA8WB2	4.83
				TA6BA2BS1BF1	44.51
Arm Lake	Winter			TA7WS2BA1	37.3
				TA8WS1BS1	10.6
				TA7BF3	0.4
Route H	Winter	10	5, 1, 0	TA8WB1WS1	25.6
				TA8WB2	6.1
West Favel	Winter			TA8WS1BF1	35.2
				TA10	3.6
				WS6TA4	0.3
Minnitonas Creek 1	Winter	6, 10	5, 1	TA9WS1	27.8
				TA8WB2	5.2
				TA8BF1BS1	12.3
Minnitonas Creek 2	Winter	4, 10	4, 5, 1, 0	TA8BA1WB1	2.5
				TA8BF2	20.4
				TA9WS1	3.0
				TA8WB2	2.4
				TA9WS1	9.8
Watjask	Summer	10	8, 5	TA8WS2	33.1
Cryderman's Pit	Summer	4	5	TA6BA1WB1WS1BF1	33.4
Route W	Summer	10, 6	5	TA8WS2	19.5
				TA8WS2	7.9
Wine Lake	Summer	5, 8, 1	5, 1	TA7WB2BF1	34.0
				TA8BA2	5.9
				TA7BA1WS1BF1	26.0
				TA6WS4	0.9
Ethelbert Trail	Summer	10	5	TA8BA2	42.6
Upper Dam	Summer	4, 5	5, 8	TA7BS1WS1BF1	87.1

†Soil Type classification according to Forest Ecosystem Classification for Manitoba: Field guide (Zoladeski et al., 1995).

‡ Vegetation Type classification according to Forest Ecosystem Classification for Manitoba: Field guide (Zoladeski et al., 1995).

§TA is Trembling aspen, WB is White birch, BA is Balsam poplar, BS is Black Spruce, BF is Balsam fir, WS is White spruce; numbers following tree species denote portion of forest composed by that species on a scale of 10.

3.2.2 Sampling methods

To examine the extent and distribution of slash in both winter and summer cutblocks, two slash load estimation methods were used and compared. The first method used was the fuel load description method discussed by McRae et al., (1979). The second method used was a modified version of the line transect method developed by Newman (1966). The second method was developed in this study in order to allow for estimation of slash for small scale studies.

3.2.2.1 Fuel loading method

McRae et al. (1979) created a handbook to aid in estimating and describing fuel loads and fuel characteristics in areas selected for prescribed burns in northern Ontario. The method described in this handbook was used to determine the amount of slash in the six selected winter cutblocks and the six selected summer cutblocks.

Three equilateral triangles measuring 30 m on each side were sampled in each cutblock. To effectively estimate the mean level of slash left behind in each cutblock, these triangles were chosen so as not to cross any roadways or landing areas. Line intersect pins were located every 5 m along each side of each triangle and intersections of slash pieces which crossed the sample triangle line between the pins were tallied according to diameter size classes of 0.00 to 0.49 cm, 0.50 to 0.99 cm, 1.00 to 2.99 cm, 3.00 to 4.99 cm, and 5.00 to 6.99 cm. For all slash pieces with a diameter greater than 7.00 cm, the actual diameters were measured independently, and for each of these slash pieces, tree species was noted. The 0.00 to 0.49 cm category, 0.50 to 0.99 cm category, 1.00 to 2.99 cm category, 3.00 to 4.99 cm category, 5.00 to 6.99 cm category and greater than 7.00 cm category were measured along each line transect for 5 m, 10 m, 15 m, 20 m, 25 m, and 30 m respectively. Using the mathematical method and multiplication factors described in the handbook, an estimate of the fuel load was determined for each triangle.

3.2.2.2 Line transect method

The second method used to estimate and describe the amount and distribution of slash in winter and summer cutblocks was based on the line intercept method developed by Newman (1966). For each individual "point" surveyed, an estimation of the amount of slash in an area 1 m^2 surrounding the point was determined. First, the total length of slash on each plot was quantified using the line intercept method developed by Newman (1966). The 1 m^2 plot area was surveyed using vertical lines and horizontal lines spaced every 20 cm. Since both ends of the quadrat were included, six vertical lines and six horizontal lines were used. Similar to the fuel loading method, intersections of slash pieces that crossed each horizontal and vertical sample line were tallied according to diameter size classes. Slash in each of the 1 m^2 plots was counted separately based on the following diameter classes: <1.0 cm, 1.0 to 4.9 cm, 5.0 to 9.9 cm, 10.0 to 20.0 cm and >20.0 cm. Using the formula developed by Newman (1966) these tallies were converted to a total length of slash. The formula is as follows:

$$R = (\pi NA)/(2H) \qquad [\text{ Eq. 3.1}]$$

where R is the total length of slash, N is the number of intersections between the slash and the straight lines, A is the area of the plot, and H is the total length of the straight lines.

The total length of slash was converted to mass by determining a unit biomass estimate for each diameter class and multiplying by the total length values. To determine the unit biomass, fresh samples of slash from each diameter class were collected from cutblocks, dried and measured for length and mass (unit biomass table in Appendix B). This unit biomass, or density measurement, in combination with the total length estimated with the line intercept method, was used to calculate the total dry biomass in each of the 1 m^2 areas surveyed. The unit biomass for the slash pieces < 1.0 cm, 1.1 cm to 5.0 cm, 5.1 cm to 10.0 cm, 10.1 cm to 20.0 cm and >20 cm were 0.016 kg m^{-2}, 0.314 kg m^{-2}, 2.639 kg m^{-2}, 7.720 kg m^{-2}, and 21.299 kg m^{-2}, respectively. Although the modified Newman line intercept method allowed for a slash estimate on a smaller scale, the total length of lines sampled separately in each quadrat for each diameter class was 12 m, resulting in a very time consuming method.

To obtain an estimate of the mean amount of slash within the cutblock twenty quadrats were sampled. In each of the six winter and six summer cutblocks two 100 m line transects were located so as not to cross any roadways or landing areas. Every 10 m along these line transects a 1 m^2 quadrat was placed and the number of slash intersections counted. These counts were converted to biomass estimates according to the modified Newman line intercept method.

3.2.3 Statistical analysis

For the fuel loading method an average level of slash was determined for both the winter and summer cutblocks. Using the estimate of the three triangles an average load was determined for each cutblock, and from these values, the average amount of slash in winter and summer cutblocks was calculated. Similarly, for the modified Newman line intercept method, a mean level of slash was determined by averaging the twenty sample estimates for each cutblock and from these cutblock means, the average amounts of slash in winter and summer cutblocks were calculated. A Student's t-test (α=0.05) assuming equal variances was performed to compare the winter and summer slash means (SAS)(Version 8.0, SAS Institute Inc. Cary, NC, USA).

The point estimates determined using the modified Newman line intercept method were further sorted and examined using a frequency distribution analysis to better consider not only the extent of slash but also the distribution of different levels of slash within cutblocks .

Because both methods allowed for the calculation of the amount of slash in each sample according to diameter size, the point estimates in each cutblock were also broken down and examined according to the mean amount of slash by diameter size. These means were used to determine the mean amount of slash in each diameter size category in winter and summer cutblocks. A Student's t-test (α=0.05) assuming equal variances was used to determine whether a difference existed between diameter size distribution in winter and summer cutblocks (SAS)(Version 8.0, SAS Institute Inc. Cary, NC, USA).

3.3 Results

Although the modified Newman line intercept method produced slightly higher estimates of mean slash loads than the fuel loading method (Table 3.2), both slash estimation methods consistently indicated that summer cutblocks had a significantly lower amount of slash left on the cutblocks after harvest than winter cutblocks (p=0.01 and p<0.001, respectively).

To better evaluate the distribution of slash, the point estimates from the modified Newman line intercept method of slash estimation were examined in terms of the frequency of different levels of slash loading in winter and summer cutblocks (Figure 3.1). In winter cutblocks, the highest frequency of slash was found in the 0.00 to 4.99 kg m^{-2} and 5.00 to 9.99 kg m^{-2} categories. However, although the slash loads occurred in the 0.00 to 4.99 kg m^{-2} category at nearly the highest frequency, 68% of the plots in fact had slash loads greater than 5.00 kg m^{-2}. Maximum slash loads in these winter cutblocks were in excess of 40.00 kg m^{-2}. In summer cutblocks, the mean slash load was estimated to be 6.96 kg m^{-2} and the slash appeared in the highest frequency in the 0.00 to 4.99 kg m^{-2} category. In the summer cutblocks, 49% of the plots examined had slash loads greater than 5.00 kg m^{-2}. The distribution of slash in the summer cutblocks indicated that the slash was spread out more and that the piles of slash that were created did not frequently reach levels exceeding the 25.00 to 29.99 kg m^{-2} category.

Table 3.2 Average biomass of slash (kg m^{-2}) in winter and summer cutblocks.

Cutblock	**Slash Biomass as Determined by Fuel Loading Method**	**Slash Biomass as Determined by Modified Newman Line Intercept Method**
	kg m^{-2}	kg m^{-2}
	Winter Cutblocks	
Madge Lake	4.66	8.05
Arm Lake	8.81	13.34
Route H	7.74	14.69
West Favel	6.02	7.87
Minnitonas Cr. 1	6.07	11.20
Minnitonas Cr. 2	6.80	7.34
Mean	**6.68**	**10.42**
	Summer Cutblocks	
Watjask	4.63	6.70
Cryderman's Pit	4.70	7.21
Route W	4.81	9.53
Wine Lake	3.66	5.73
Ethelbert Trail	5.04	5.54
Upper Dam	4.60	7.05
Mean	**4.58**	**6.96**

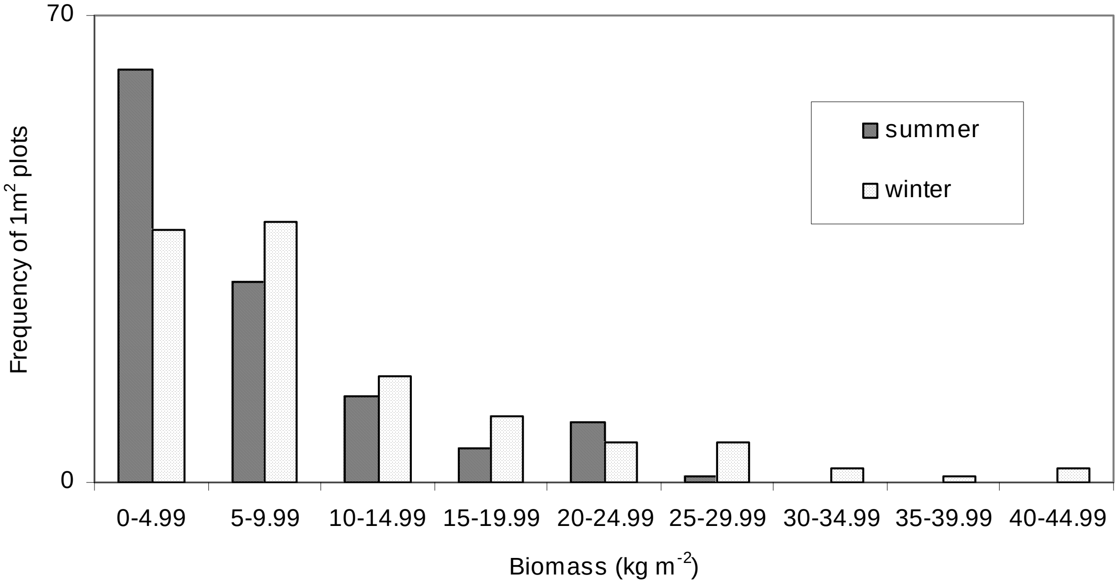

Figure 3.1 Frequency distribution of slash load in winter and summer cutblocks in the Duck Mountain area (estimated using the modified Newman line intercept method).

Breakdown of the estimated amounts of slash within each individual plot according to diameter size, using the modified Newman line intercept method, indicated that on average, the 1.0 to 4.9 cm diameter category was represented in the largest amount and that the 10.0 to 20.0 cm category was represented in the second largest amount on both winter and summer cutblocks (Table 3.3). In contrast, the fuel loading method indicated that it was the slash pieces greater than or equal to 7.00 cm which were represented in the largest amount in triangles surveyed in both winter and summer cutblocks (Table 3.4). The amount of slash in the smaller diameter categories occurred in a much smaller amount when surveyed with the fuel loading method.

Table 3.3 Average biomass of slash (kg m^{-2}) in each of the five diameter classes in winter and summer cutblocks in the Duck Mountain area using the modified Newman line intercept method of slash estimation.

	Slash diameter size class					
	<1.0 (cm)	**1.0 - 4.9** (cm)	**5.0 – 9.9** (cm)	**10.0 – 20.0** (cm)	**>20.0** (cm)	**Total**
			Mean slash biomass (kg m^{-2})			
Winter cutblocks	0.32a†	3.39a	1.79a	3.31a	1.62a	10.42a
Summer cutblocks	0.42b	2.11b	1.64a	1.85b	0.94a	6.96b

† Values in a column with the same letter are not significantly different at $p = 0.05$.

Table 3.4 Average biomass of slash (kg m^{-2}) in each of the six diameter classes in winter and summer cutblocks in the Duck Mountain area using the fuel loading method of slash estimation.

	Slash diameter size class						
	0.00 - 0.49 (cm)	**0.50 - 0.99** (cm)	**1.00 - 2.99** (cm)	**3.00 - 4.99** (cm)	**5.00 - 6.99** (cm)	**≥7.00** (cm)	**Total**
				Mean slash biomass (kg m^{-2})			
Winter cutblocks	0.05a†	0.08a	0.75a	0.66a	0.75a	4.39a	6.68a
Summer cutblocks	0.04a	0.06a	0.65a	0.55a	0.68a	2.60b	4.58b

† Values in a column with the same letter are not significantly different at $p = 0.05$.

The fuel loading method of slash estimation indicated that there was little difference between the amount of slash in the winter and summer cutblocks except in the slash pieces greater than or equal to 7.00 cm. In this category the winter cutblocks had significantly more slash than the summer cutblocks (p = 0.01). The modified Newman line intercept method indicated that there was a significantly different distribution of slash between the winter and summer cutblocks: winter cutblocks had significantly less slash than summer cutblocks in the less than 1.0 cm category (p=0.00), winter cutblocks had significantly more slash than summer cutblocks in both the 1.0 - 4.9 cm category (p=0.00) and 10 to 20 cm category (p=0.01). There were no significant differences between slash load in winter and summer cutblocks in both the 5.0 to 9.9 cm category (p=0.29) and the greater than 20 cm category (p=0.14).

Estimates from both methods were summarized according to similar slash loading categories and the two methods estimated relatively similar levels of slash (Table 3.5 and Table 3.6). The modified Newman line intercept method produced slightly higher levels of slash in all three slash load categories than the fuel loading method.

Table 3.5 Average biomass of slash (kg m^{-2}) in grouped diameter classes in winter and summer cutblocks in the Duck Mountain area using the modified Newman line intercept method of slash estimation.

	Slash diameter size class			
	<1.0 (cm)	**1.0 – 4.9** (cm)	**>5.0** (cm)	**Total**
	Mean slash biomass (kg m^{-2})			
Winter cutblocks	0.32a†	3.39a	6.72a	10.42a
Summer cutblocks	0.42b	2.11b	4.43b	6.96b

† Values in a column with the same letter are not significantly different at p = 0.05.

Table 3.6 Average biomass of slash (kg m^{-2}) in grouped diameter classes in winter and summer cutblocks in the Duck Mountain area using the fuel loading method of slash estimation.

	Slash diameter size class			
	<1.0 (cm)	**1.0 – 4.9** (cm)	**>5.0** (cm)	**Total**
	Mean slash biomass (kg m^{-2})			
Winter cutblocks	0.13a†	1.41a	5.14a	6.68a
Summer cutblocks	0.10a	1.20a	3.28b	4.58b

† Values in a column with the same letter are not significantly different at $p = 0.05$.

3.4 Discussion

Examination of the frequency distribution of slash levels revealed that both moderate and high levels of slash do occur within cutblocks. Although the mean load of slash surveyed is relatively low (10.42 kg m^{-2} in winter cutblocks and 6.96 kg m^{-2} in summer cutblocks using the modified Newman line intercept method), considering that 68 % of plots surveyed in winter cutblocks and 49 % of plots surveyed in summer cutblocks had loads of slash greater than 5 kg m^{-2}, the physical area covered by higher loads of slash loads may be considerable. Therefore, there is potential for these moderate and high levels of slash to significantly affect soil temperature and aspen regeneration.

Examination of the total biomass of slash according to each diameter size category differed between the two slash estimation methods. The modified Newman line intercept method indicated that the largest contributor to slash biomass occurred in the 1.0 to 4.9 cm category while the fuel loading method indicated that the largest contributor was the largest diameter pieces of slash ($\leq$ 7.0 cm). However, because the modified Newman line intercept method indicated that the 10.0 to 20.0 cm diameter category contributed the second highest amount of biomass to the total amount of slash left in both the winter and summer cutblocks. This discrepancy between the two methods was in part due to the different diameter class categories as was evident when the categories were summarized according to similar slash loading categories. In both cases, it was clear that slash pieces <1 cm occurred in small amounts and that the large pieces of slash were large contributors to the total biomass of slash in both summer and winter cutblocks. Both methods produced similar estimations of slash loads within cutblocks.

Though a high amount of slash found in one diameter category points to a more substantial effect on soil temperature, the diameter size of the slash in these piles may affect the degree of soil temperature change. Unless large pieces of slash are aligned parallel and lie directly on top and beside one another they cannot create an effective insulative layer over the soil. Olsson and Staaf (1995) indicate that small pieces of slash material often decompose rapidly and do not act as a heavy physical barrier to plant growth; however, they fail to consider the ability of smaller pieces of slash to create a continuous ground cover. Because pieces of slash with large diameter may not cover the ground area as effectively as a continuous layer of fine materials, the effect of large diameter slash on soil temperature may also greatly depend on slash orientation. Depending on the actual distribution of the slash, large pieces of slash may have a similar effect on soil temperature as a continuous layer of fine materials (Greenway, 1998; Bulley, 1999). Even though both the fuel loading method and the modified Newman line intercept method allow for examination of the amount of slash by diameter size category, both are unable to examine or describe the effectiveness of cover layer created. The extent of this effect is difficult to sample and analyze with any method available at present as the distribution of slash after harvesting is so diverse and the fine materials are often mixed with the heavier pieces of slash.

The distribution of slash according to diameter size category provided an interesting evaluation of slash loads which occurred during the different harvest seasons. Although a recent study in the Duck Mountain area examining the effects of harvesting on vegetation dynamics and regeneration indicated that there was no difference in coarse woody debris volume on cutblocks harvested during different harvest seasons (Murray and Kenkel, 2001), both slash estimation methods from this study consistently indicated that the mean amount of slash found in winter cutblocks was greater than that found in summer cutblocks. While the smallest size of slash (<1.0 cm) is present in higher amounts in summer cutblocks than in winter cutblocks, slash pieces of diameter 1.0 to 5.0 cm occur in substantially higher amounts in winter cutblocks than in summer cutblocks according to the modified Newman line intercept method. In addition to this, slash pieces of diameter 10 to 20 cm (and $\geq$ 7.0 cm according to the fuel loading method) also occur in substantially higher amounts in the winter cutblocks as compared to the summer cutblocks. The higher levels of slash found in the winter cutblocks is likely due to the cold temperature conditions producing brittle branches and stems. Smaller levels of impact during the winter harvest season may result in more slash being produced on cutblocks

The fuel loading method was effectively used to describe the mean levels of slash loading on a cutblock level. This method indicates that the mean levels of slash loading are fairly low and are higher in winter cutblocks than in summer cutblocks. However, because of the large transect size, this method is unable to examine the amount or the distribution of slash on a smaller scale which is necessary when considering the direct effects of slash piles on soil temperature and aspen regeneration. The modified Newman line intercept method is a point estimate method which was successfully developed and used to examine the levels of slash found on both a large cutblock scale and on a smaller scale. The mean values of slash at the cutblock level were similar to those estimated using the fuel loading method and they showed the same trend with the winter cutblocks having higher levels of slash loading than the summer cutblocks. The modified Newman line intercept method easily facilitates examination of the incidence of heavier biomass piles of slash within cutblocks and the breakdown of slash by diameter class. However, as with the fuel loading method, the use of diameter size categorical analysis is limited since the biomass of each diameter size category does not easily convert to a measure of the effective surface cover or insulative layer. Though this method was significantly more labour intensive, it is essential in order to examine the effects of an individual pile of slash on the soil temperature directly under and the aspen regeneration in the immediate area above it.

3.5 Summary

Although both methods proved reliable and useful, direct comparison of the two methods and examination of the different amounts of slash according to slash diameter size is difficult as these two methods employed different size categories in their measurements. Both methods underlined the presence of significant amounts of slash biomass within winter and summer cutblocks. The higher amount of slash found in winter cutblocks as well as the distribution of different diameter slash pieces may have important ramifications for the successful regeneration of aspen forests under different harvest techniques. Using different methods to obtain concrete measurement of slash loading and patterns of distribution within cutblocks may help to better understand the effects of slash loads on soil temperatures. The ability to measure and describe slash loading in cutblocks is an invaluable tool when considering the effects of slash on aspen regeneration and ultimately forest sustainability.

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4 SLASH LOADING IMPACTS ON SOIL TEMPERATURE AND ASPEN REGENERATION

4.1 Introduction

To sustainably harvest trembling aspen, forests companies rely on the inherent ability of aspen to asexually reproduce in abundance. Harvest operations effectively result in both the warming of soil temperatures and the elimination of apical dominance. As several studies have shown, the main factor limiting aspen sucker initiation and early growth after mature aspen forests are cut is soil temperature (Maini and Horton, 1966; Schier and Zasada, 1973; Hungerford, 1988; Peterson and Peterson, 1992; Steneker, 1976). Because soil heat is most easily lost by short-wave radiation from the soil surface back into the atmosphere, any factor which alters the soil surface may significantly alter soil temperature profiles and the success of aspen regeneration (Glinski and Lipiec, 1990; Hogg and Lieffers, 1991; Navratil, 1996; Amacher et al., 2001).

In the Duck Mountain area, harvest operations are predominantly tree-length harvest operations with delimbing occurring at the tree stump. This type of harvest operation typically results in tree tops, branches and other coarse woody debris being randomly dispersed across cutblocks. Manitoba Natural Resources Forestry Branch requires that the slash material be left on the cutblocks in order to allow for some nutrient return to the soil. Recent studies examining the effect of increased levels of ground cover on soil temperatures have resulted in some concern regarding the consequences associated with leaving slash material on cutblocks. Increased levels of ground cover may act as an insulative layer over the forest floor and not only negatively affect daily mean soil temperatures and growing season length but also the ability of aspen, a shade intolerant tree species, to successfully reproduce. Consequently, there is increasing awareness and concern regarding the severity of effects of slash on both soil temperatures and aspen reproduction. The hypothesis of this study was that high slash loads would decrease soil temperatures and aspen regeneration.

The objectives of this study were:

1. To quantify the effects of no slash, moderate, and heavy slash loads on soil temperature profiles;
2. To examine the effects of no slash, moderate, and heavy slash loads on aspen regeneration; and,
3. To study the relationship between soil temperatures and the regeneration of aspen observed under different slash load conditions.

4.2 Methods

4.2.1 Study area

The study sites were located within twelve cutblocks throughout the Duck Mountain region of west-central Manitoba (described in Chapter 3, section 3.2.1).

4.2.2 Sampling

4.2.2.1 Soil sampling and analysis

Three 1 m^2 plots were established in each of the six winter and six summer cutblocks. Four soil cores (2.5 cm diameter) were collected from within each of these plots and samples were taken from the LFH, 0 to 15, 15 to 30, and 30 to 45 cm depths and air dried, mixed, ground, and sieved (2 mm). Soil pH was determined only for the 0 to 15 cm depth, using a 1:2 soil to solution ratio and a Corning pH meter (Corning Inc., New York, NY USA) (Kalra and Maynard, 1991). All samples were analyzed for total soil C and N using a LECO CNS-2000 Carbon, Nitrogen and Sulphur Analyzer (LECO Corp., St. Joseph, MI, USA), and for organic C using a LECO CR-12 Carbon Determinator (LECO Corp., St. Joseph, MI USA). A summary of soil characteristics is presented in Appendix A.

4.2.2.2 Plot establishment and slash load determination

In each of the twelve newly harvested cutblocks, one 1 m^2 plot was established in areas with no slash, moderate slash and heavy slash loading. Each of these plots was chosen based on a visual estimation of the three levels of slash loading. These plots were established in the spring of 1999 (winter cutblocks) and in the late summer of 1999 (summer cutblocks) following harvest operations. During the fall of 1999, the amount of slash in each plot was estimated using the modified Newman line intercept method (described in Chapter 3 section 3.2.2), in order to confirm that the visually chosen levels were similar across cutblocks. Once quantified, it was apparent that the visual method used to establish plots was, in most cases, reasonably accurate at delineating distinct slash load categories. In the winter cutblocks, the “no slash” load was less than 5 kg m^{-2} (0 to 50 t ha^{-1}), the “moderate slash” load ranged from 5 to 20 kg m^{-2} (50 to 200 t ha^{-1}) and the “heavy slash” load was approximately 20 to 110 kg m^{-2} (200 to 1100 t ha^{-1}). In the summer cutblocks, the “no slash” load was less than 5 kg m^{-2} (0 to 50 t ha^{-1}), the “moderate slash” load was approximately 5 to 15 kg m^{-2} (50 to 150 t ha^{-1}), and the “heavy slash” load was approximately 15 to 30 kg m^{-2} (150 to 300 t ha^{-1}) (Appendix B).

Quantifying the amount of slash in each plot emphasized the difference between the slash loads in the winter cutblocks and the summer cutblocks. The visually chosen categories in the summer cutblocks had noticeably less slash in them than in the winter cutblocks (Appendix B); therefore, another plot was installed in each summer cutblock under a “very heavy” amount of slash (approximately 30 to 80 kg m^{-2} or 300 to 800 t ha^{-1}) before the second growing season began in order to examine the effects of comparable slash loading conditions on soil temperature and aspen regeneration in both the winter and summer cutblocks. Although the “heavy slash” load in the summer cutblocks was considerably lower than the “heavy slash” load in the winter cutblocks, this smaller level of slash loading was found consistently across all of the summer cutblocks so these values were considered an accurate representation of “heavy slash” loads in summer cutblocks. The difficulty associated with actually finding “heavy” slash loads in summer cutblocks was likely related to the fact that summer cutblocks do in fact contain smaller piles of slash and less slash on average (Chapter 3).

4.2.2.3 Soil temperature measurement

Hobo temperature probes (Hobo H8 Pro Series; 2 channel; Onset) were installed in the centre, underneath each of the slash plots established in the winter and summer cutblocks. In the winter and summer cutblocks, three probes were installed in the spring and fall of 1999, respectively under no slash, moderate slash and heavy slash. One additional soil temperature probe was installed in the summer cutblocks under the very heavy slash load plots during the spring of 2000. Each internal temperature probe was installed at the LFH – mineral soil interface while external temperature probes were inserted 10 cm below the LFH - mineral soil interface; temperature readings were taken every 30 minutes. Temperature data was downloaded three times each year.

4.2.2.4 Aspen regeneration measurement

The 1 m^2 area above each temperature probe was also used as the sampling area for measuring aspen regeneration. To increase the sample size for aspen regeneration determination, an additional plot was selected in each cutblock for each level of slash loading. No soil temperature probes were installed in these plots as they were exclusively used to measure aspen regeneration. The amount of slash above the newly established second plot in each category was estimated using the modified Newman Line Intercept Method. Once two plots under each slash load were established and categorized in each cutblock, the aspen regeneration success was determined by measuring several parameters. Aspen regeneration was quantified in each 1 m^2 plot after the second growing season by measuring the number of suckers, sucker height, root collar diameter (RCD), sucker volume, and Leaf area index (LAI). LAI, one-sided green leaf area per unit ground area, was determined using a LI-COR LI-3050A leaf area meter (LI-COR, Lincoln, NB, USA). In error, during the installation of the second aspen regeneration plots, no plots were selected for the very heavy slash load category in the summer cutblocks; in winter cutblocks there were 6 regeneration plots and in summer cutblocks there were 7 regeneration plots instead of 8.

4.2.3 Statistical analysis

From the soil temperature probe readings, which were taken every thirty minutes, a mean daily soil temperature was calculated. These were summarized by calculating a monthly average of daily mean soil temperatures for each of the two depths with each probe. Winter and summer cutblocks were evaluated separately from each other due to different locations, different levels of slash loading, site differences, and time of harvest during the growing season, which all have the potential to significantly alter both soil temperature and aspen sucker response. Both the winter and summer cutblocks had a randomized complete block (RCB) experimental design. In the winter cutblocks statistical analysis was performed using a general linear model to perform an analysis of variance (SAS)(Version 8.0, SAS Institute Inc. Cary, NC, USA) on daily mean soil temperatures under three treatments (three slash loads) with six blocks (six cutblocks). A similar analysis was performed for daily mean soil temperatures in summer cutblocks; however, as a fourth soil temperature probe was installed under very heavy slash loads during the early part of second growing season, this analysis had four treatments with six blocks during the second growing season. To illustrate the magnitude of variation within the means, standard deviations were also calculated for monthly summaries of daily mean soil temperatures.

In order to briefly examine the diurnal fluctuations, daily maximum and minimum soil temperatures were determined from the temperature probe data. Determining a monthly mean of both daily maximum and daily minimum soil temperatures summarized these values.

The length of the growing season was measured in three ways: 1) the total number of days when the ground was frozen over the winter (daily mean soil temperatures were negative) at the LFH-mineral soil interface; 2) the first day that daily mean soil temperatures at the LFH-mineral soil interface reached negative values was determined as a measure of the end of the growing season; 3) the first day that daily mean soil temperatures at the LFH-mineral soil interface reached temperatures above zero was determined as a measure of the beginning of the growing season. For the first frost and first thaw data analysis, values were compared using Julian dates. Winter and summer cutblocks were statistically analyzed separately using a general linear model to perform an analysis of variance (SAS)(Version 8.0, SAS Institute Inc. Cary, NC, USA). To further clarify differences in season lengths and daily temperatures, growing degree days using 15 ^{o}C as a base value and the total number of hours each day above 15 ^{o}C were calculated. The base value of 15 ^{o}C was used for these calculations because previous research has indicated that aspen sucker initiation appears to be inhibited at temperatures below 15 ^{o}C (Maini and Horton, 1966; Navratil 1991). For both of these analyses, winter and summer cutblocks were examined separately again using a general linear model to carry out an analysis of variance (SAS)(Version 8.0, SAS Institute Inc. Cary, NC, USA).

Sucker regeneration parameters were examined separately between winter and summer cutblocks. Because each cutblock had two regeneration plots in each slash loading category, these two plots were treated as subsamples within each block; two samples were measured within each experimental unit of the RCB. The effect of slash load on number of suckers, LAI, sucker height, sucker RCD and sucker volume was determined using a general linear model to perform an analysis of variance (SAS)(Version 8.0, SAS Institute Inc. Cary, NC, USA).

4.3 Results

4.3.1 Soil temperature

4.3.1.1 Soil temperature profiles

Initial analysis of the soil temperature data indicated that slash load did have an effect on soil temperature. An average soil temperature profile from all winter cutblocks demonstrated that at the LFH-mineral soil interface, daily mean soil temperatures during the growing season are generally lower under the heavy slash load than under no slash load (Figure 4.1). In addition, daily mean soil temperatures at the LFH-mineral soil interface during the winter season are fairly similar regardless of the slash loading. The LFH-mineral soil interface thawed later in the year under the heavy slash load compared to the no slash load, and soil temperatures at the LFH-mineral soil interface reached 15 ^{o}C earlier in the growing season under the no slash load compared to the heavy slash loads (Figure 4.1).

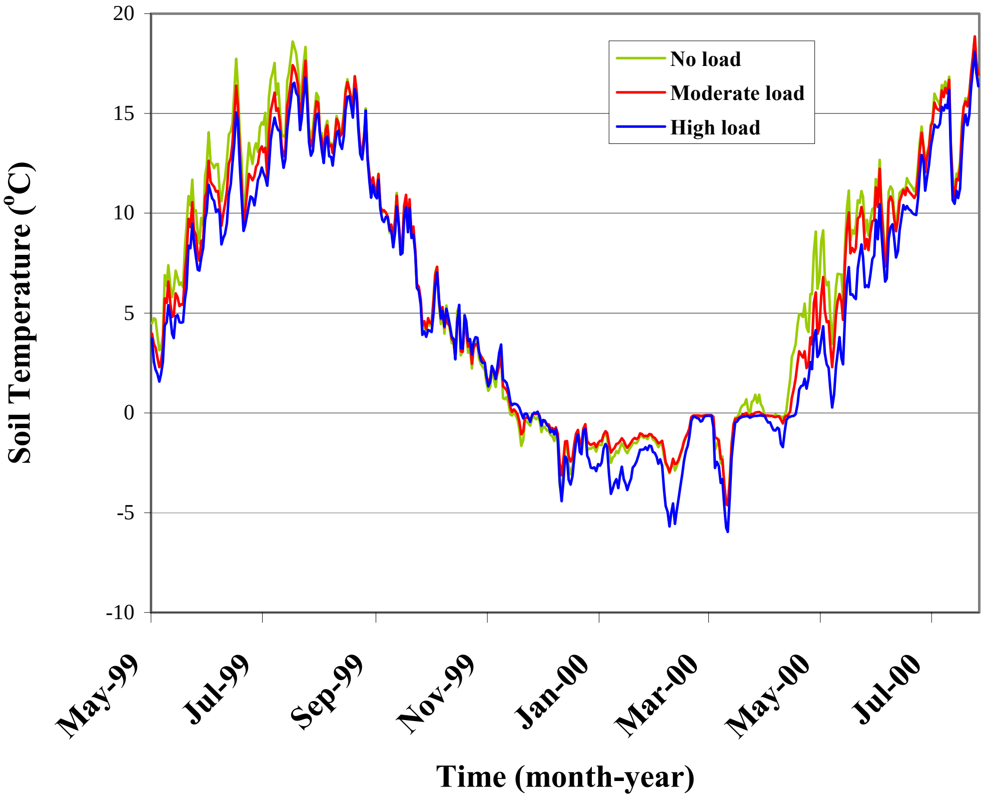

Figure 4.1 Daily mean soil temperature (^{o}C) at the LFH-mineral soil interface under three levels of slash loading over all winter cutblocks.

The average soil temperatures from the probes located 10 cm below the LFH-mineral soil interface in winter cutblocks demonstrated similar trends in soil temperatures as those found at the LFH-mineral soil interface (Figure 4.2). Although these trends were alike, there was less variation in daily mean soil temperatures at 10 cm below the LFH-mineral soil interface as compared to those exhibited at the LFH-mineral soil interface (Figures 4.1 and 4.2). At 10 cm below the LFH-mineral soil interface, soil temperatures were lower under heavy slash loads during the growing season although the difference was not as distinct as that at the LFH-mineral soil interface. Although the 10 cm depth soil temperatures were generally lower under heavy slash loads during the growing season, soil temperatures reached 15 °C at approximately the same time during the growing season regardless of slash load (Figure 4.2).

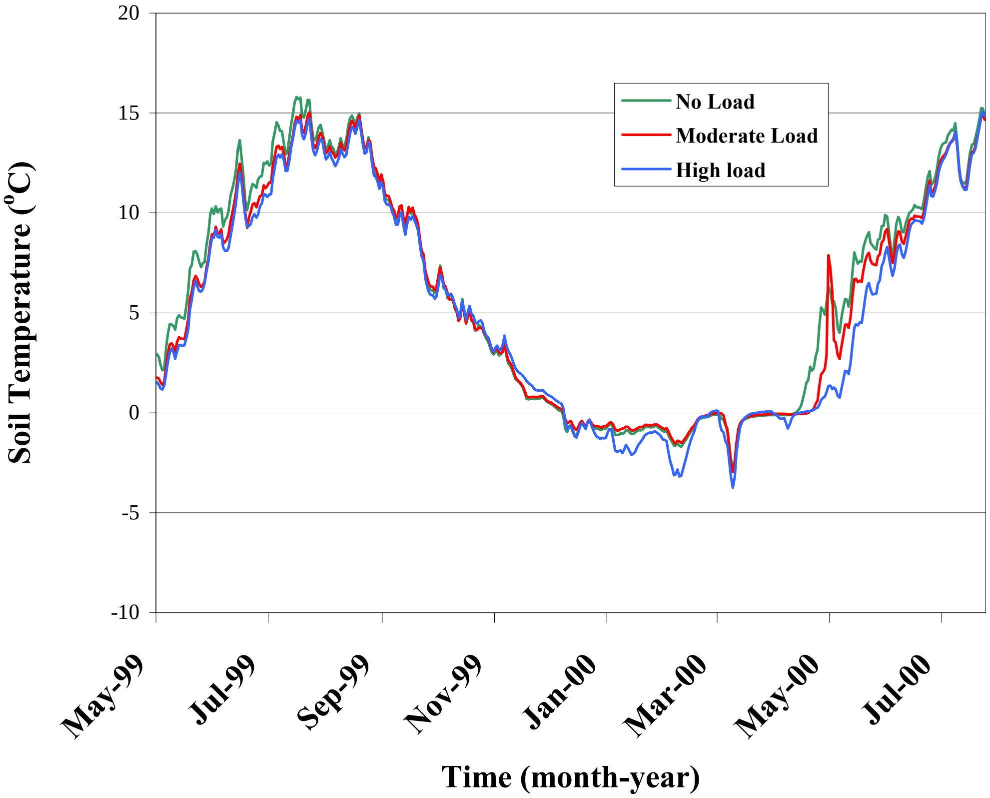

Figure 4.2 Daily mean soil temperature (°C) at 10 cm below the LFH-mineral soil interface under three different levels of slash loading over all winter cutblocks.

To clarify these effects of slash load on soil temperature profiles at the cutblock level, further detailed analysis of the soil temperature profiles was broken down by examining: daily averages summarized monthly, daily maximums, daily minimums, freeze thaw cycles, growing degree days and number of hours each day where soil temperature was above 15 ^{o}C. This examination was done for both the soil temperature profiles at the LFH-mineral soil interface and the 10 cm depth.

4.3.1.2 Daily mean soil temperature

4.3.1.2.1 Growing season

In the winter cutblocks, mean daily soil temperatures decreased significantly under moderate slash loads and decreased further under the high slash load compared to no slash load during the months of May, June and July (Figure 4.3). In the winter cutblocks, the difference in soil temperatures between the different slash categories is most pronounced in the early part of the growing season (May and June) (Figure 4.3). In the summer cutblocks, the mean daily soil temperature during the entire first growing season (July to September) decreased significantly under moderate and heavy slash loads compared to under no slash load (Figure 4.4). However, during the early part of the growing season there were no significant differences between soil temperatures found under moderate and heavy slash loads (Figure 4.4).

In the summer cutblocks the very heavy slash load category was monitored only during the second growing season and second winter season. Similar trends in soil temperature to those seen in the first growing season were noted during the second growing season. Again, in both the winter and summer cutblocks, high slash loads resulted in significantly lower soil temperatures (Figures 4.5 and 4.6). In the winter cutblocks, the differences in soil temperature were not as distinct as they were in the first growing season. In fact, during almost the entire growing season, there were no significant differences in soil temperature under no slash loads and moderate slash loads in the winter cutblocks (Figure 4.5).

In summer cutblocks, again there was a significant decrease in soil temperatures with increasing slash loads during the entire second growing season (Figure 4.6). As before, there was no significant difference in soil temperatures between the moderate and high slash loads. The very high slash load, however, did result in significantly lower soil temperatures than the no slash load, the moderate slash load and the high slash load except during the month of September. These significant differences in soil temperature extending throughout the second growing season, unlike in the winter cutblocks, were unexpected since the summer cutblock slash load categories actually had a lower mean amount of slash than those in the winter cutblocks.

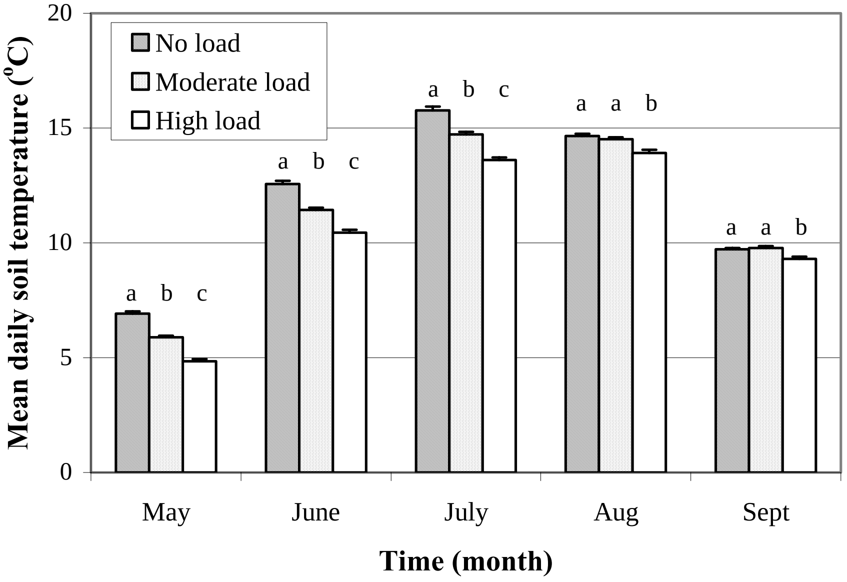

Figure 4.3 Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in winter cutblocks during the first growing season (1999). Bars with the same letter within the same month are not significantly different from each other at p = 0.05. Error bars indicate standard deviation.

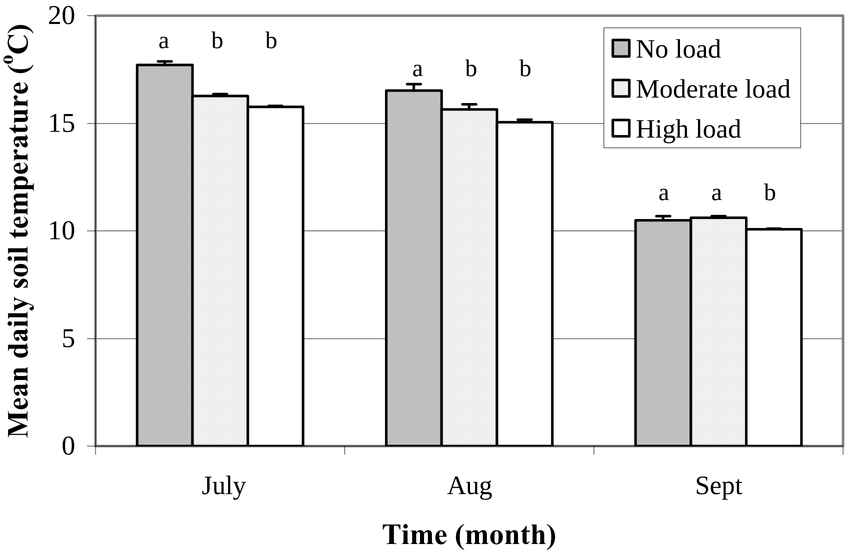

Figure 4.4 Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in summer cutblocks during the first growing season (1999). Bars with the same letter within the same month are not significantly different from each other at p = 0.05. Error bars indicate standard deviation.

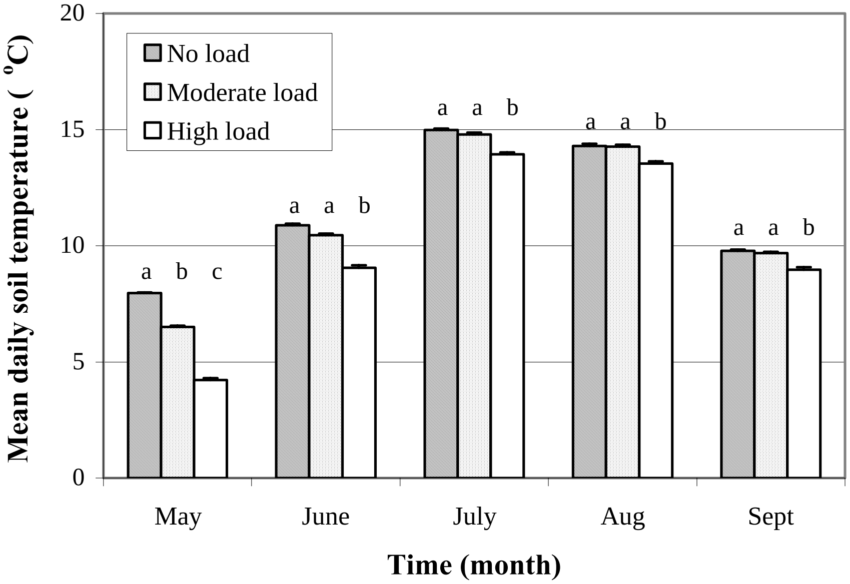

Figure 4.5 Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in winter cutblocks during the second growing season (2000). Bars with the same letter within the same month are not significantly different from each other at *p* = 0.05. Error bars indicate standard deviation.

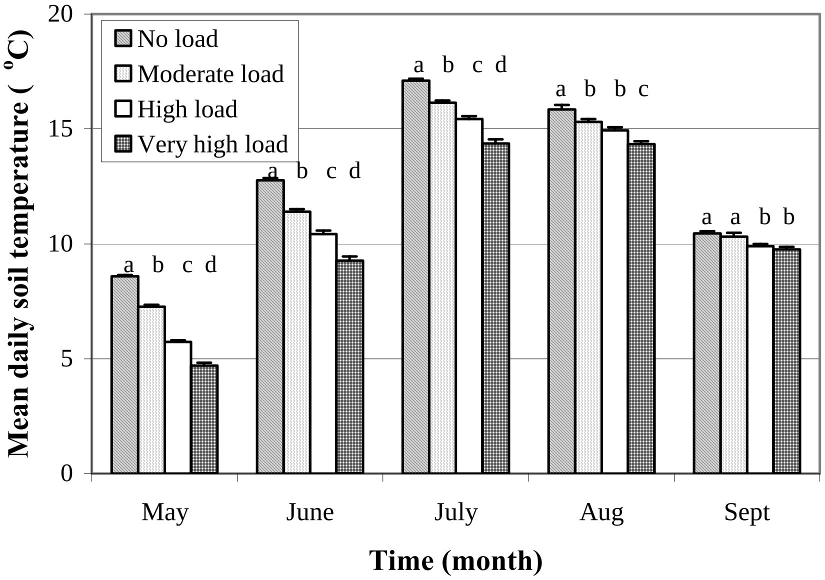

Figure 4.6 Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in summer cutblocks during the second growing season (2000). Bars with the same letter within the same month are not significantly different from each other at *p* = 0.05. Error bars indicate standard deviation.

At 10 cm below the LFH-mineral soil interface, soil temperature trends mimicked soil temperatures at the LFH-mineral soil interface, however, differences were less pronounced (Figures 4.7 to 4.10). In winter cutblocks, the areas with no slash load had lower temperatures than the areas under high slash loads (Figure 4.7). By August however, there were no significant differences in soil temperature under any of the three slash loads (Figure 4.7). Warmest soil temperatures occurred during July and August and ranged from 12.6 ^{o}C to 13.9 ^{o}C (Figure 4.7). In summer cutblocks, the areas under no slash load were significantly warmer than those under both moderate and high slash loads (Figure 4.8). By September, there were no significant differences in temperature under no slash, moderate slash, and high slash loads. In summer cutblocks the warmest soil temperatures again occurred during July and August and ranged from 14.2 ^{o}C to 16.0 ^{o}C (Figure 4.8).

By the end of the second summer there were effectively little or no differences in daily mean soil temperature at 10 cm below the LFH-mineral soil interface in both winter and summer cutblocks (Figures 4.9 and 4.10). During the months of July, August and September, there was no significant difference in daily mean soil temperature (Figure 4.9). In the summer cutblocks at 10 cm below the LFH-mineral soil interface, the high slash load and very high slash loads were significantly lower than those areas under no slash load. In July, the moderate, high, and very high slash load areas were all significantly lower in temperature than those areas under no slash load (Figure 4.10). During August, however, there was no significant difference between soil temperatures for any of the slash loading plots. Comparing the changes between mean daily soil

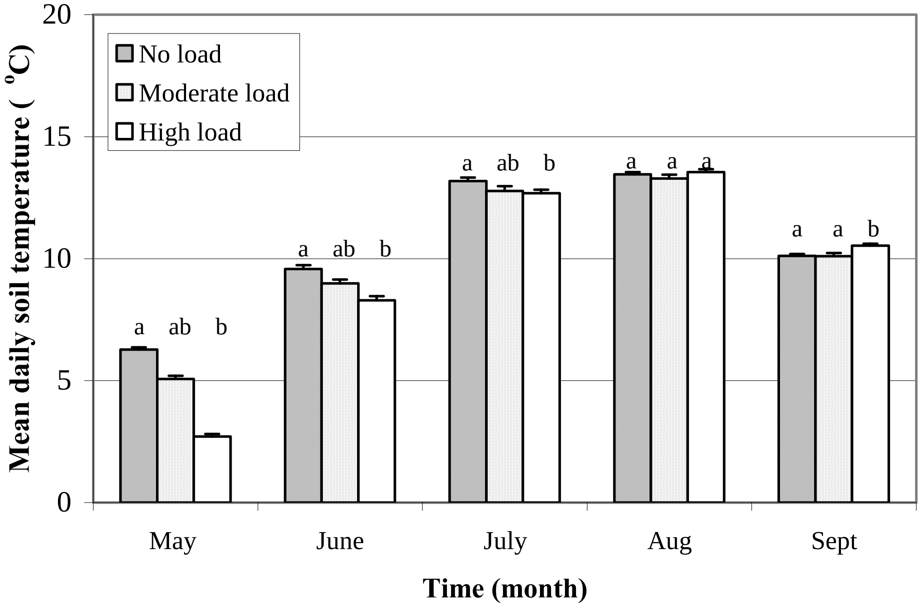

Figure 4.7 Mean daily soil temperature (10 cm below the LFH-mineral soil interface) under varying slash loads in winter cutblocks during the first growing season (1999). Bars with the same letter within the same month are not significantly different from each other at $p = 0.05$. Error bars indicate standard deviation.

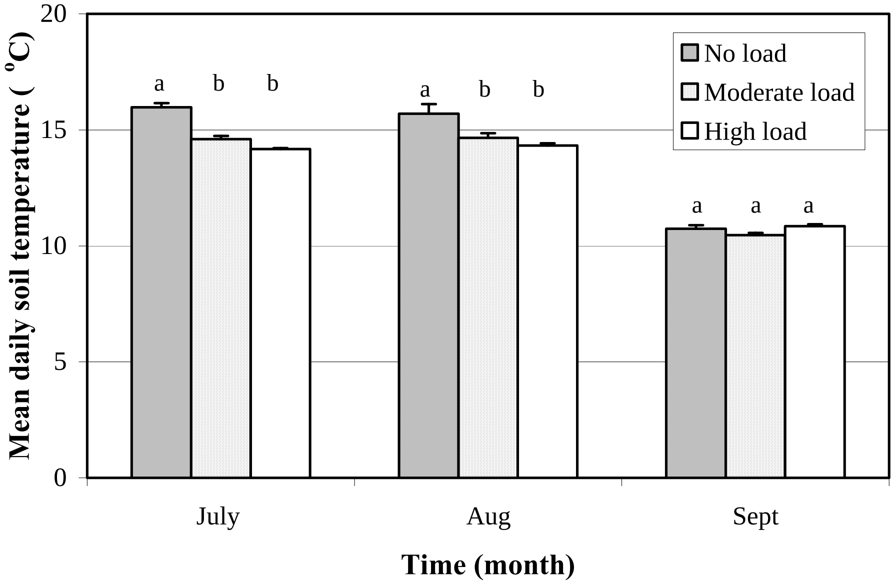

Figure 4.8 Mean daily soil temperature (10 cm below the LFH-mineral soil interface) under varying slash loads in summer cutblocks during the first growing season (1999). Bars with the same letter within the same month are not significantly different from each other at $p = 0.05$. Error bars indicate standard deviation.

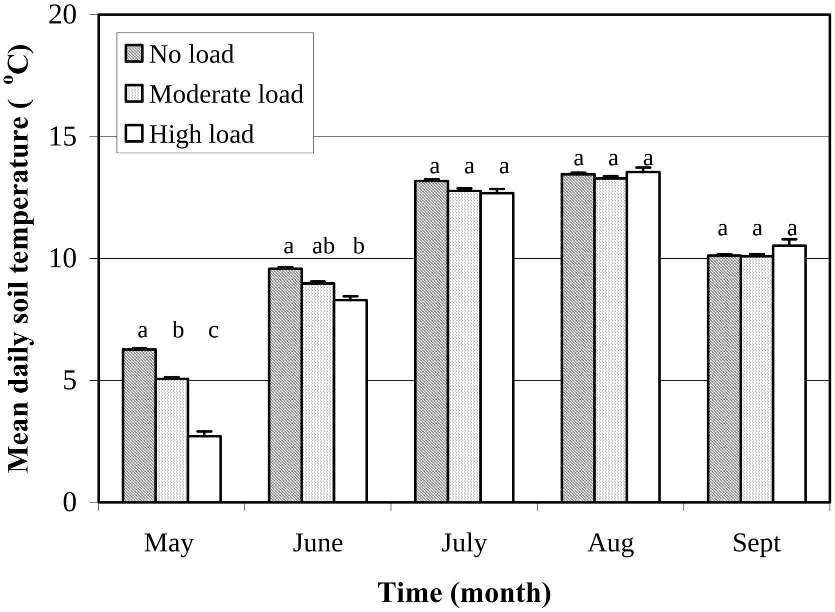

Figure 4.9 Mean daily soil temperature (10 cm below the LFH-mineral soil interface) under varying slash loads in winter cutblocks during the second growing season (2000). Bars with the same letter within the same month are not significantly different from each other at *p* = 0.05. Error bars indicate standard deviation.

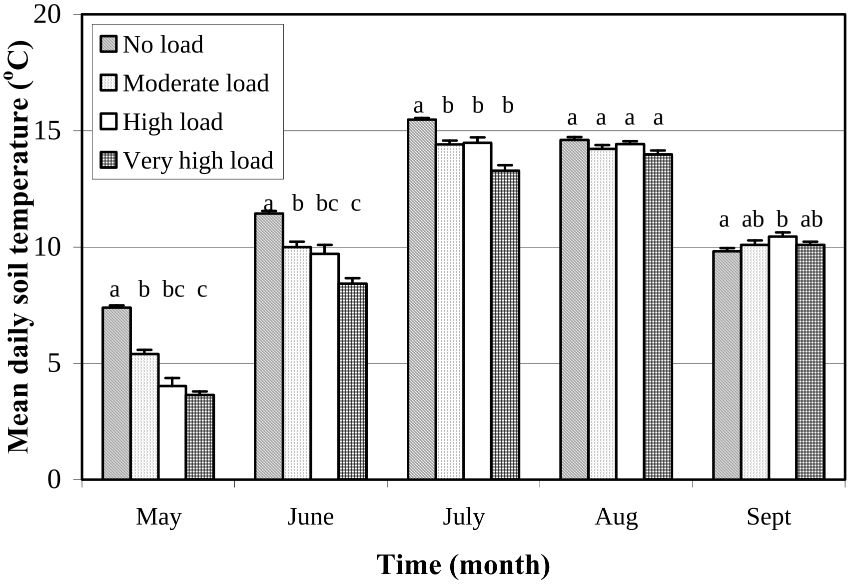

Figure 4.10 Mean daily soil temperature (10 cm below the LFH-mineral soil interface) under varying slash loads in summer cutblocks during the second growing season (2000). Bars with the same letter within the same month are not significantly different from each other at *p* = 0.05. Error bars indicate standard deviation.

temperatures during August and September, except for the area under the very high slash load, the soil temperature under no slash load cools faster than under high slash loads (Figure 4.10).

In both winter and summer cutblocks and during both the first and second growing season, higher levels of slash loading resulted in lower soil temperatures during the growing season, and near the end of the growing season, these soil temperatures became less divergent. Soil temperatures in the summer cutblocks seemed to be warmer than those in the winter cutblocks. The warmest soil temperatures occurred during July and August and the largest difference in soil temperatures under the different slash loads occurred during the spring.

4.3.1.2.2 Winter season

Mean daily soil temperatures, as expected, did not reach extremely cold temperatures during the first or the second winter season under any of the slash loads (Figures 4.11 to 4.14). During the first winter season, in both the winter (Figure 4.11) and summer cutblocks (Figure 4.12), the daily mean soil temperature was not consistently below 0 ^{o}C until December; however, during the second winter season, the soil temperatures were above 0 ^{o}C in some plots as late as January (Figure 4.13 and Figure 4.14). In terms of spring thaw, daily mean soil temperatures were consistently above 0 ^{o}C by April in both winter and summer cutblocks during both the first and second winter season (Figures 4.11 to 4.14).

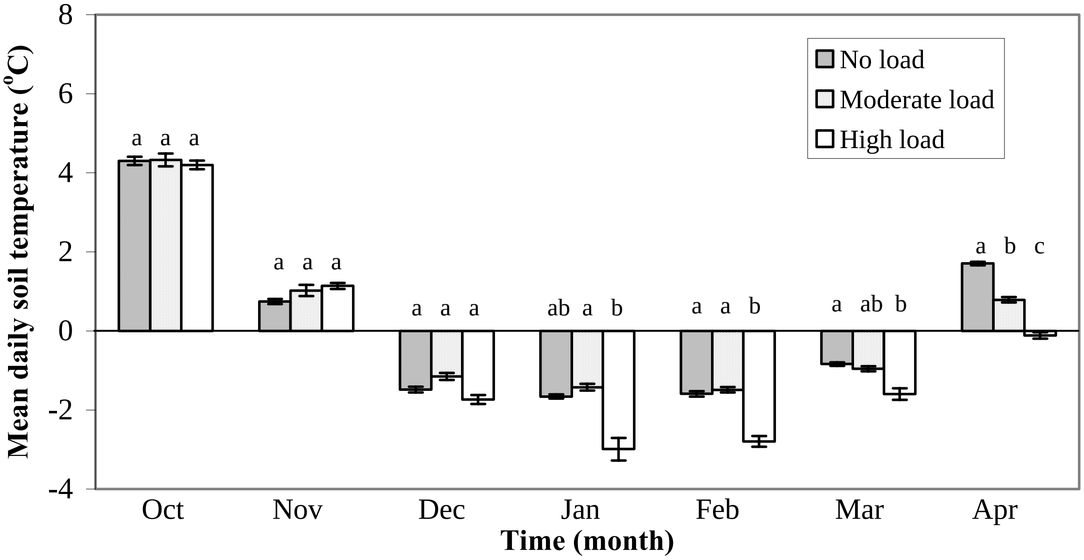

Figure 4.11 Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in winter cutblocks during the first winter season (1999-2000). Bars with the same letter within the same month are not significantly different from each other at p = 0.05. Error bars indicate standard deviation.

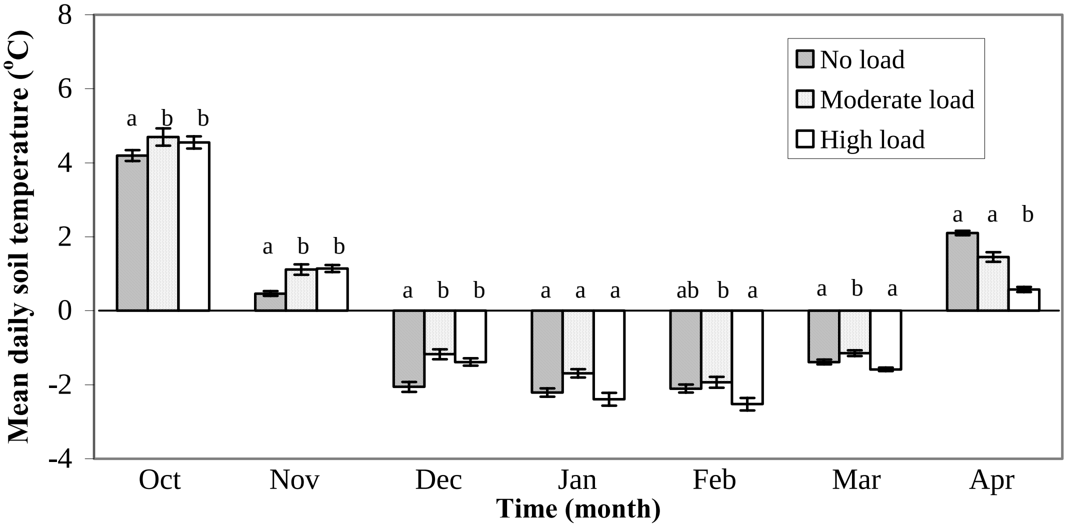

Figure 4.12 Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in summer cutblocks during the first winter season (1999-2000). Bars with the same letter within the same month are not significantly different from each other at p = 0.05. Error bars indicate standard deviation.

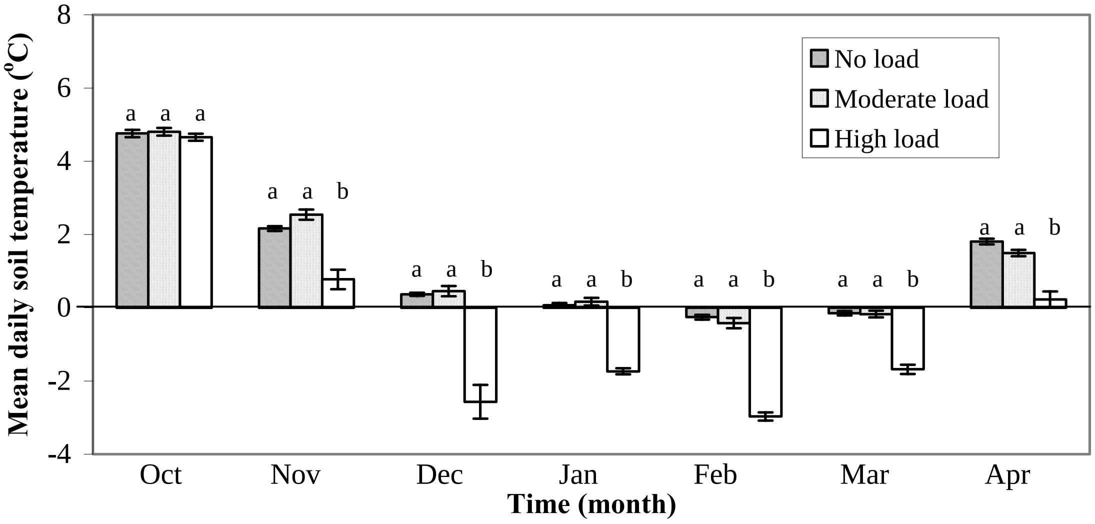

Figure 4.13 Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in winter cutblocks during the second winter season (2000-2001). Bars with the same letter within the same month are not significantly different from each other at $p = 0.05$. Error bars indicate standard deviation.

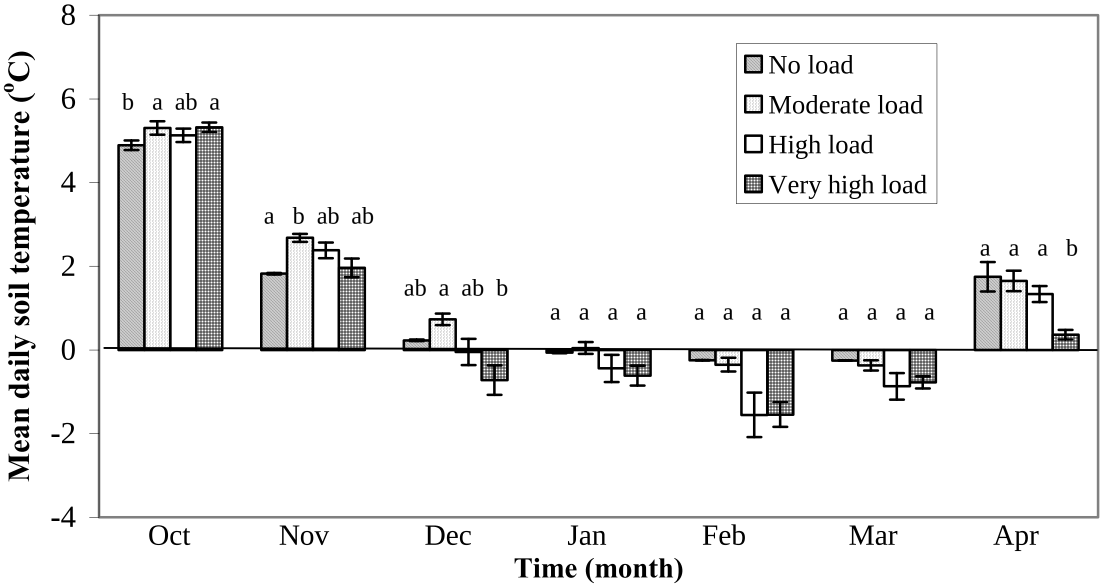

Figure 4.14 Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in summer cutblocks during the second winter season (2000-2001). Bars with the same letter within the same month are not significantly different from each other at $p = 0.05$. Error bars indicate standard deviation.

In winter cutblocks, there were no statistical differences in soil temperatures by the month of October during both the first and second winter season (Figure 4.11 and Figure 4.13). By February during the first winter season, the soil temperature under the heavy slash load in the winter cutblocks was significantly lower than the temperature under no slash and moderate slash loads. The soil under the heavy slash load then took significantly longer to warm up as the relatively lower soil temperature was maintained during the thawing months of March and April (Figure 4.11).

The insulative effect of moderate and heavy slash loads was obvious in summer cutblocks where, during the first winter season, the soil under moderate and heavy slash loads was significantly warmer than under no slash load during the months of October, November, and December (Figure 4.12). Through the second winter season in the summer cutblocks, the effect of the slash loads was unclear (Figure 4.14). Throughout the spring, the soil temperatures were significantly warmer under no slash load in both the winter and summer cutblocks during both the first and second winter season.

At 10 cm below the LFH-mineral soil interface there was little difference in daily mean soil temperatures during the winter seasons in both winter and summer cutblocks (Figures 4.15 to 4.18). During the second winter season, several soil temperature probes stopped taking measurements due to a battery failure therefore some standard deviations were very large during this time (Figure 4.17).

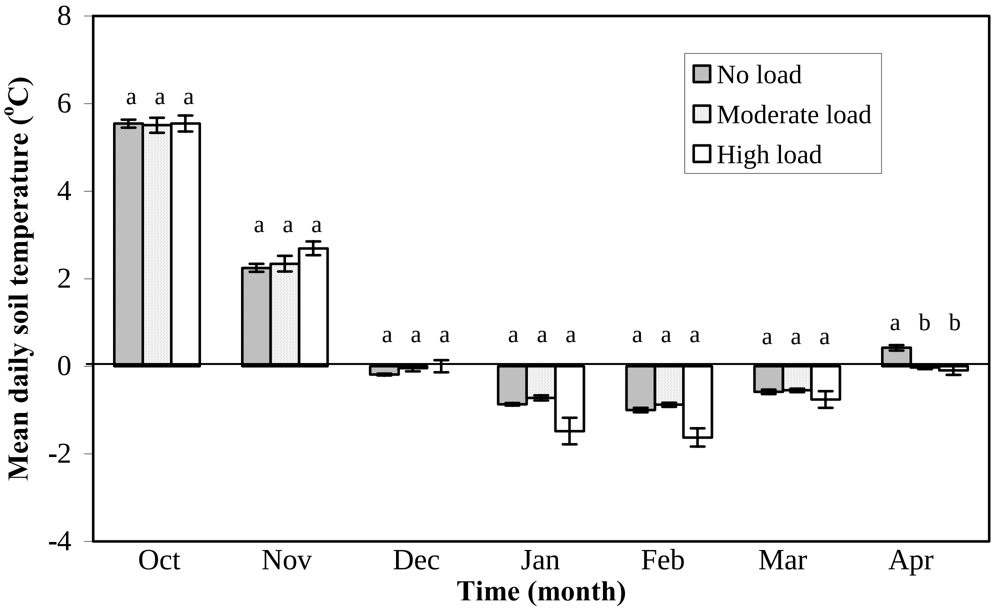

Figure 4.15 Mean daily soil temperature (10 cm below the LFH-mineral soil interface) under varying slash loads in winter cutblocks during the first winter season (1999-2000). Bars with the same letter within the same month are not significantly different from each other at *p* = 0.05. Error bars indicate standard deviation.

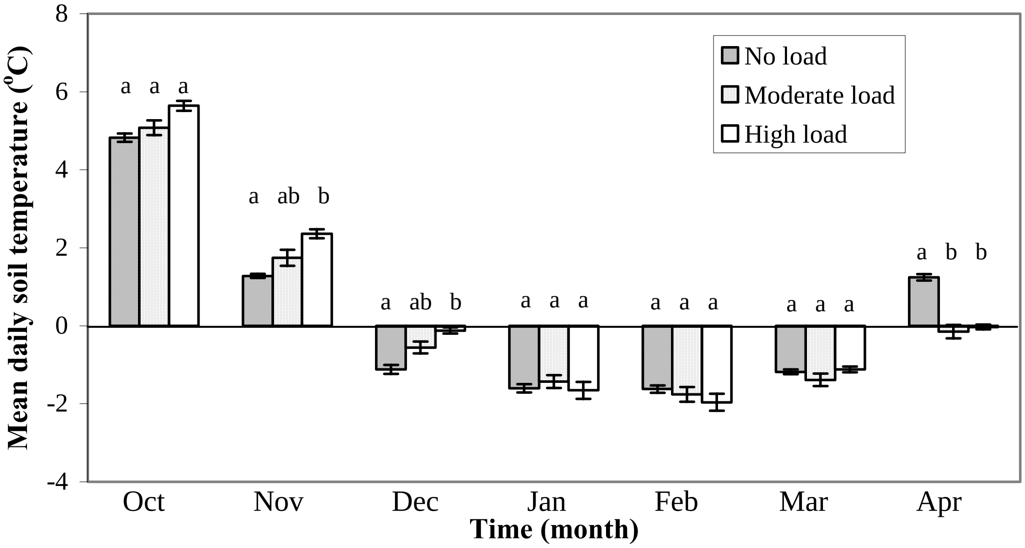

Figure 4.16 Mean daily soil temperature (10 cm below the LFH-mineral soil interface) under varying slash loads in winter cutblocks during the first winter season (1999-2000). Bars with the same letter within the same month are not significantly different from each other at *p* = 0.05. Error bars indicate standard deviation.

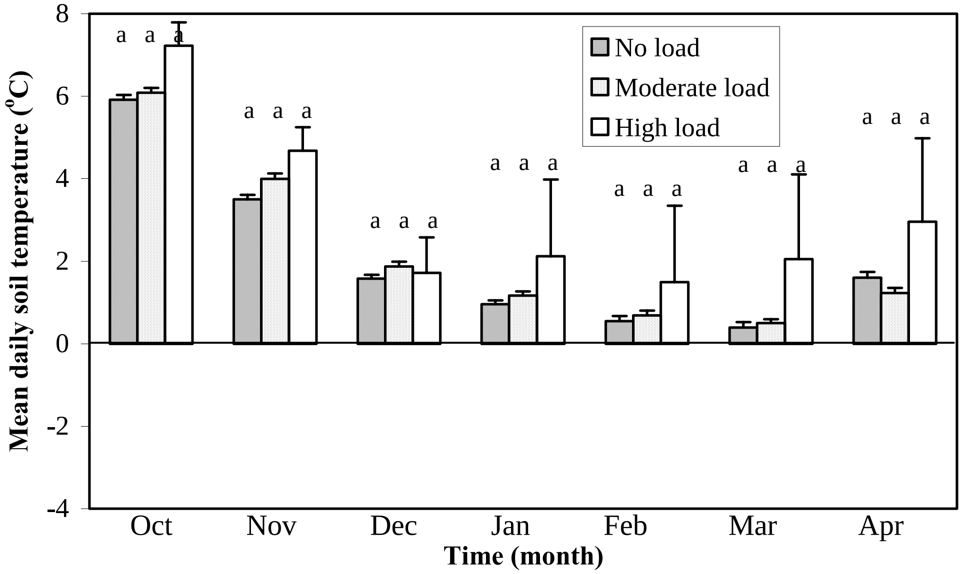

Figure 4.17 Mean daily soil temperature (10 cm below the LFH-mineral soil interface) under varying slash loads in winter cutblocks during the second winter season (2000-2001). Bars with the same letter within the same month are not significantly different from each other at p = 0.05. Error bars indicate standard deviation.

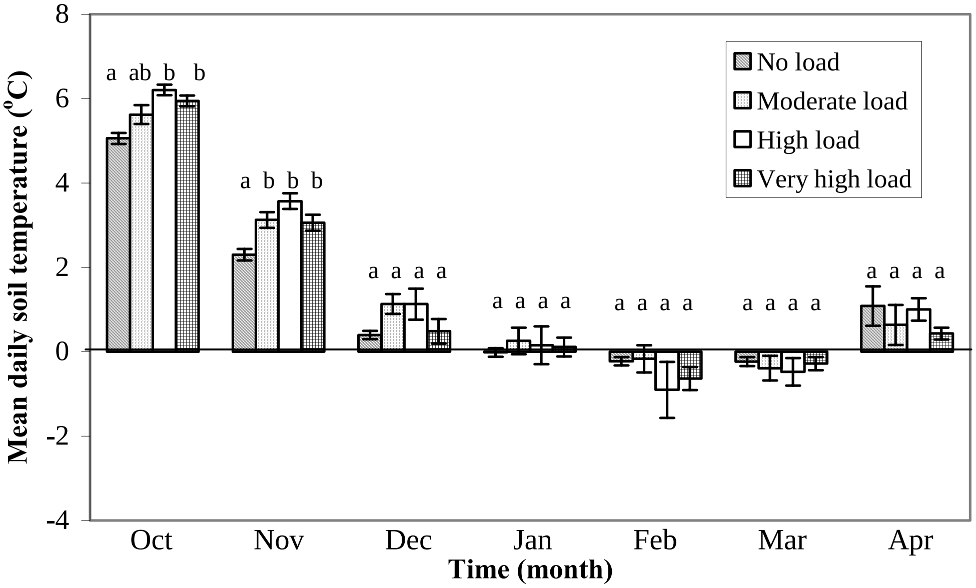

Figure 4.18 Mean daily soil temperature (10 cm below the LFH-mineral soil interface) under varying slash loads in summer cutblocks during the second winter season (2000-2001). Bars with the same letter within the same month are not significantly different from each other at p = 0.05. Error bars indicate standard deviation.

As the majority of suckering aspen roots in the research area were found to initiate growth at the LFH mineral soil interface (described in chapter 5), and since the daily mean soil temperatures at 10 cm below the LFH-mineral soil interface were not strongly altered by slash loads, the rest of the soil temperature examination focused on soil conditions at the LFH-mineral soil interface.

4.3.1.3 Diurnal temperature fluctuations

Because slash loading likely acts as an insulative layer for the soil surface, soil temperatures under heavy slash loading were expected to result in a dampening effect on the diurnal temperature cycle. Examination of field data indicated that, as expected, daily soil temperatures at the LFH-mineral soil interface during the growing season may be affected by slash loading (Figure 4.19). Those areas under no slash load have likely encountered higher mean daily maximum values. In Figure 4.19, no values are noted for soil temperatures under very high slash load during the month of April as these soil temperature probes were installed at the end of April shortly after spring thaw.

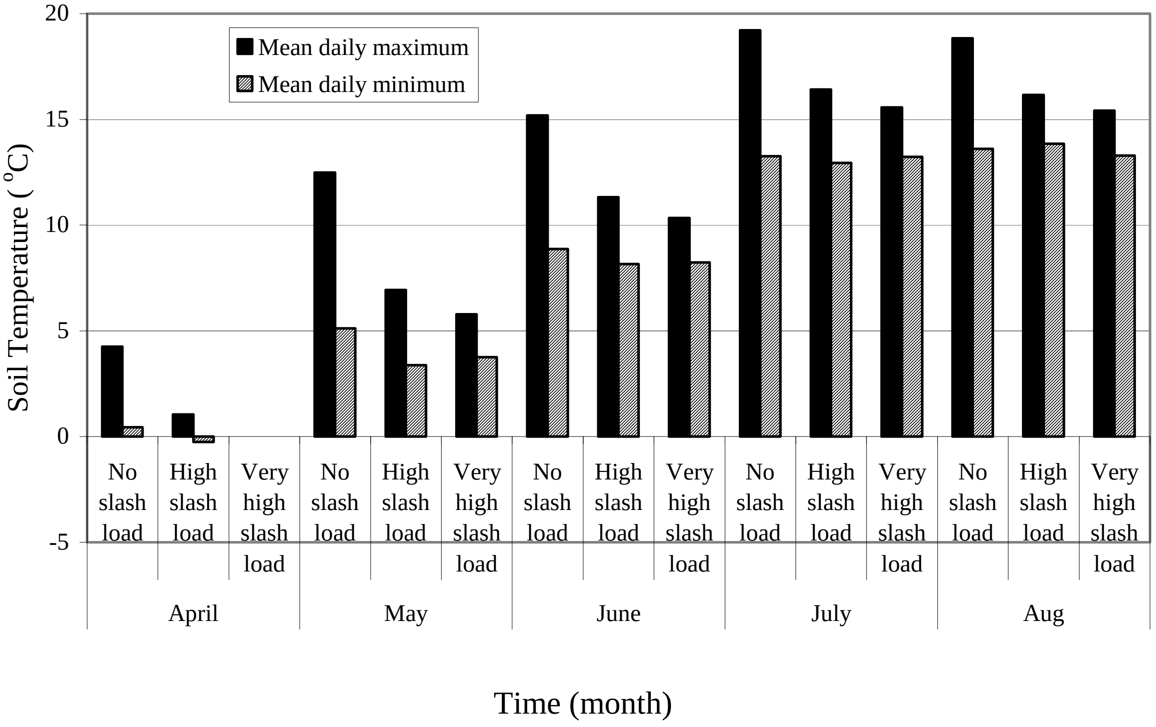

Figure 4.19 Daily soil temperature maximum and minimum values during the second growing season for all cutblocks.

4.3.1.4 Date of first frost and spring thaw

In the winter cutblocks during the first growing season, those areas under lower slash loads reached freezing soil temperatures before those areas under high slash loads (Table 4.1). High slash loads also resulted in the spring thaw occurring significantly later in the year than those areas under moderate slash load or no slash load. Those areas under high slash loads thawed approximately one month later than those areas under no slash load. In total, those areas under lower slash loads had fewer total days where the soil temperature was below freezing. During the second winter and spring seasons, similar trends were noted but differences in seasonal lengths were not significant.

Table 4.1 Effect of slash load on first frost, first thaw, and number of days less than zero in winter harvested cutblocks (soil temperatures at the LFH-mineral soil interface). Date of the first frost and date of spring thaw were compared using Julian dates.

Slash Load	**Days less than 0 ^{o}C**	**First frost**	**Spring thaw**
		First winter season	
None	136 a†	November 17 a	March 18 a
Moderate	146 ab	November 18 a	April 8 b
High	149 b	November 21 b	April 13 c
		Second winter season	
None	139 a	November 17 a	March 22 ab
Moderate	131 a	November 23 b	March 16 a
High	145 a	November 23 b	April 11 b

† Values in a column during the same season with the same letter are not significantly different at $p = 0.05$.

In the summer cutblocks during the first growing season, those areas under lower slash loads froze later in the year, thawed earlier in the year and appeared to have fewer total days where the soil reached freezing temperatures (Table 4.2). During the second winter season, four of the six probes under no slash load had a battery failure at a critical point for this calculation thus these values were omitted from this statistical examination. During the second growing season, again, similar freeze and thaw trends were observed; however, differences were not significant.

Table 4.2 Effect of slash load on first frost, first thaw, and number of days less than zero in summer harvested cutblocks (soil temperatures at the LFH-mineral soil interface). Date of the first frost and date of spring thaw were compared using Julian dates.

Slash Load	Days less than 0 °C	First frost	Spring thaw
	First winter season		
None	76 a†	January 12 a	April 7 a
Moderate	89 a	December 2 a	April 20 a
High	165 a	November 18 a	April 24 a
	Second winter season		
None	--- ‡	---	---
Moderate	68.75 a	January 26 b	April 5 a
High	81.00 a	January 10 a	April 7 a
Very High	113.83 a	December 2 a	April 24 a

† Values in a column within the same season with the same letter are not significantly different at $p = 0.05$.

‡ No data recorded.

4.3.1.5 Growing degree days

In the winter cutblocks, during the first growing season, the growing degree days (calculated with a base value of 15 °C) were significantly lower under high and moderate slash loads compared to those with no slash (Table 4.3). As was seen in the daily average temperature trends, by the time the second growing season was reached, there was no significant effect on growing degree days. In the summer cutblocks, there was a significant decrease on growing degree days associated with moderate, high and very high slash loads during both the first and second growing seasons compared to the no slash load (Table 4.3). In the summer cutblocks, there was no difference in growing degree days between the moderate and the high slash load treatment.

Table 4.3 Growing degree days (15 °C) at the LFH-mineral soil interface for winter and summer cutblocks during the first and second growing season.

	Growing Degree Days	
Slash Load	**First Growing Season**	**Second Growing Season**
	Winter harvest	
None	54.6 a†	38.1 a
Moderate	31.2 b	35.7 a
High	11.6 b	18.8 a
	Summer Harvest	
None	94.4 a	131.3 a
Moderate	50.4 b	68.8 b
High	34.4 b	63.0 b
Very High	‡	26.1 c

† Values in a column within the same harvest season with the same letter are not significantly different at $p = 0.05$.

‡ No data recorded.

4.3.1.6 Number of hours each day where soil temperature is above 15 °C

Increased levels of slash loading resulted in a significant decrease in the number of hours each day where the soil temperature reached 15 °C in both the winter cutblocks (Table 4.4) and summer cutblocks (Table 4.5). These differences were accentuated during June, July and August. As well, June, July, and August were the three months during the growing season that consistently had a substantial number of hours where soil temperature was above 15 °C. The month of July may be the most influential time for aspen sucker growth as it had the most hours each day where soil temperatures in the rooting zone reached 15 °C.

Table 4.4 Mean number of hours each day where the soil temperature at the LFH-mineral soil interface in winter cutblocks was at least 15 ^{o}C during both the first and second growing seasons.

	Mean hours each day where soil temperature $\geq$ 15 ^{o}C				
Load	**May**	**June**	**July**	**August**	**September**
		First Growing Season			
None	0.9 a†	6.4 a	12.6 a	10.0 a	0.2 a
Moderate	0.1 b	3.3 b	10.0 b	9.2 a	0.1 a
High	0.0 b	0.8 c	6.0 c	5.5 b	0.0 a
		Second Growing Season			
None	0.8 a	1.9 a	11.3 a	9.7 a	1.0 a
Moderate	0.0 b	1.2 ab	11.0 a	9.6 a	0.4 ab
High	0.0 b	0.1 b	8.3 b	6.6 b	0.0 b

† Values in a column within the same season with the same letter are not significantly different at *p* = 0.05.

Table 4.5 Mean number of hours each day where the soil temperature at the LFH-mineral soil interface in summer cutblocks was at least 15 ^{o}C during both the first and second growing seasons.

	Mean hours each day where soil temperature $\geq$ 15 ^{o}C				
Load	**May**	**June**	**July**	**August**	**September**
		First Growing Season			
None	---†	---	19.6 a‡	15.8 a	0.6 a
Moderate	---	---	16.9 b	13.6 ab	0.4 a
High	---	---	15.8 b	12.5 b	0.1 a
		Second Growing Season			
None	0.8 a	5.1 a	17.7a	14.9 a	0.9 a
Moderate	0.3 ab	2.2 b	15.6 b	13.3 a	0.8 a
High	0.0 b	0.7 c	13.7 b	13.2 a	0.1 bc
Very High	0.0 b	0.1 c	9.3 c	9.4 b	0.0 c

† No data recorded.

‡ Values in a column within the same season with the same letter are not significantly different at *p* = 0.05.

4.3.2 Aspen regeneration

Compared to those areas in cutblocks under no slash loads, those areas under slash loads were less productive in terms of aspen sucker regeneration. Increased slash loads had a significantly negative effect on the number of suckers produced, the leaf area index (LAI) and the total sucker volume in both the winter (Table 4.6) and the summer (Table 4.7) cutblocks. In winter cutblocks, the average number of suckers decreased from 15 suckers m^{-2} (150 000 suckers ha^{-1}) under no slash load, to 1.4 suckers m^{-2} (14 000 suckers ha^{-1}) under high slash loads. Both the moderate and high slash loads resulted in a decrease in the average number of suckers produced. In the winter cutblocks the LAI and sucker volume also significantly decreased under high slash loads compared to the no and moderate slash loads. The moderate slash load however, did not have a significantly different effect on LAI and sucker volume compared to those under the no slash load treatment. In the summer cutblocks, there was a significant decrease in aspen sucker production under the moderate slash load, the high slash load, and the very high slash load compared to the no slash load (Table 4.7). The average number of suckers decreased from 15 suckers m^{-2} (150 000 suckers ha^{-1}) under no slash load to 1.8 suckers m^{-2} (18 000 suckers ha^{-1}) under very high slash loads. LAI and sucker volume also significantly decreased under very high slash loads.

Table 4.6 Mean (n=6) number of suckers (NUM), mean leaf area index (LAI), mean sucker height (HT), mean sucker root collar diameter (RCD), and mean total sucker volume (TVOL) in 1 m^2 plots at the end of the second growing season in winter cutblocks.

Slash Load	NUM (m^{-2})	LAI	HT (cm)	RCD (cm)	TVOL (cm^3 m^{-2})
None	15.0 a†	1.02 a	81.8 a	0.9 a	292.6 a
Moderate	9.5 b	0.77 a	67.2 ab	0.8 a	214.6 a
High	1.4 c	0.12 b	49.3 b	0.6 a	37.2 b

† Values in a column with the same letter are not significantly different at p = 0.1.

Table 4.7 Mean (n=6) number of suckers (NUM), mean leaf area index (LAI), mean sucker height (HT), mean sucker root collar diameter (RCD), and mean total sucker volume (TVOL) in 1 m^2 plots at the end of the second growing season in summer cutblocks.

Slash Load	NUM (m^{-2})	LAI	HT (cm)	RCD (cm)	TVOL (cm^3 m^{-2})
None	15.0 a†	0.60 a	45.4 a	0.6 a	52.2 a
Moderate	7.7 b	0.37 ab	39.1 a	0.4 a	19.9 b
High	4.3 b	0.30 ab	39.7 a	0.4 a	12.7 b
Very High	1.8 b	0.11 b	31.9 a	0.4 a	10.4 b

† Values in a column with the same letter are not significantly different at p = 0.1.

4.4 Discussion

Inspection of slash loading and distribution within the cutblocks in the Duck Mountain area indicated that due to present harvesting techniques there was an ample amount of slash present within cutblocks. As our categories were initially chosen based on visual estimations, visually the “moderate” amount of slash in summer cutblocks was chosen to correspond with the average levels of slash across the entire cutblock. In Chapter 3 an estimate of the mean amount of slash found in winter cutblocks was determined, using the modified Newman line intercept method, to be 10.42 kg m^{-2} while in summer cutblocks the mean value was 6.96 kg m^{-2}. The average level of slash did in fact fall into the visually determined “moderate” category established in both the winter and summer cutblocks. The effects of moderate slash loads on soil temperatures, initiation, and successful aspen growth, may be experienced on a cutblock scale.

Slash at moderate levels across cutblocks certainly affects soil temperatures during both the growing season and the spring thaw. During the first and second growing seasons, soil temperatures at the LFH-mineral soil interface were significantly decreased under both moderate and heavy loads of slash in both summer and winter cutblocks. While the highest soil temperatures occurred during the late summer months (July and August), the difference in soil temperature was most pronounced during the months of May, June and July. Although more ideal growing conditions occur during the warmer months late in the summer, cambial cell division, a measure of plant activity and growth, occurs as early as March and April in aspen trees (Jones and Schier, 1985). Maximum cambial activity has been noted to occur during late May and June and to drop sharply early in the month of July (Jones and Schier, 1985). Since early competitive interactions in cutblocks can greatly affect plant establishment, significant decreases in soil temperatures during both the early and late growing season are likely to result in decreased aspen regeneration.

Although both the winter and summer cutblocks experienced an insulative effect on soil temperatures related to slash during the growing seasons, there were slightly different patterns of this effect for the areas harvested during different seasons. In summer cutblocks, during July and August, the moderate slash load responded in a similar manner as the high slash load by significantly decreasing soil temperatures. In contrast to this, in the winter cutblocks, during July and August, the moderate slash load did not result in any measurable difference in soil temperature from those areas under no slash load. Since the moderate (5 kg m^{-2} to 15 kg m^{-2}) and high slash loads (15 kg m^{-2} to 30 kg m^{-2}) in the summer cutblocks were lower or equal to the moderate slash loads (5 kg m^{-2} to 30 kg m^{-2}) in the winter cutblocks, this may indicate that summer cutblock soil temperatures were altered more easily by the effects of slash loading.

Soil temperatures at the LFH-mineral soil interface responded more quickly to seasonal changes in air temperature than those at 10 cm below the LFH-mineral soil interface likely because of their proximity to the surface. Differences in soil temperature at the LFH-mineral soil interface associated with increasing slash loads were more distinct than at 10 cm below the LFH-mineral soil interface and are likely to have a more substantial effect on initiation and early growth of aspen roots growing within this zone. Since an examination of the pattern of sucker initiation in the Duck Mountain area indicates that the majority of aspen suckering occurred within the LFH layer, the temperature data from the LFH-mineral soil interface is likely to be of the most value when considering ecological implications for aspen forest regeneration.

Although winter season soil temperatures generally have little effect on aspen growth, unless they reach extremely low temperatures harmful to plant material (Kaspar and Bland, 1992), these values were summarized in order to create a broader picture of the magnitude of change in soil temperature induced by increasing slash loads and to consider whether the slash acted in an insulative manner during the winter freeze and spring thaw of soil. During the cold periods at both the LFH-mineral soil interface and at 10 cm below the LFH-mineral soil interface, daily mean soil temperatures did not reach extremely cold temperatures. Examination of winter soil temperature patterns under different levels of slash demonstrated the insulative effect of slash early during the season, the complexity of soil temperatures during snow-covered periods of the winter season, spring thaw patterns, and the existence of relatively similar and moderate soil temperatures throughout the winter season under all treatments.

Early in the first growing season in the summer and winter cutblocks, both moderate and high slash loads had lower soil temperatures than those areas under no slash. Since both vegetation cover and litter have been shown to effectively delay spring thaw and decrease summer soil temperatures (Hogg and Lieffers, 1991), distinct differences in soil temperatures during the early part of the growing season were likely related to the lack of vegetation cover. The effect of vegetation cover was accentuated by the end of the growing season when differences between treatments were not as divergent in both winter and summer cutblocks. Since the growth and establishment of plants alters the soil thermal regime by shading the soil surface and additionally by changing the soil moisture regime (Hillel, 1998), the effects of vegetation cover are significant and make soil temperature trends under different surface treatments increasingly difficult to analyze and understand.

Differences in soil temperature response between the summer and winter cutblocks are probably related to the differences in vegetation and slash distribution as a direct result of season of harvest. Further evidence of this effect is seen as significant differences in soil temperature extended throughout the second growing season in summer cutblocks but not in winter cutblocks. Even though summer cutblock slash load categories actually had a lower mean amount of slash than those in the winter cutblocks, since the first growing season was shorter in the summer cutblocks, it is very likely that differences in temperature are related to the surrounding vegetation not having a chance to become as firmly established as in the winter cutblocks.

Although the examination of daily mean soil temperatures under different conditions does reflect the growing conditions for aspen growth, it is also important to consider the effect of the differences within the context of growing season length. In the winter cutblocks those areas under no slash froze several days before those under high slash but thawed almost one month earlier. Such a significant difference in both the length of the first growing season and the mean daily soil temperatures must cumulatively have had an effect on aspen regeneration. Those areas under heavy slash thawed later and had significantly more days above 0 ^{o}C. In conjunction with the figures from the aspen regeneration measurements under the different slash loads, this data suggests that an alteration in both the length of the growing season and the mean daily soil temperatures together may have a meaningful impact on aspen initiation and growth.

To better examine the length of the growing season and in order to provide a comparison between the growing season of those areas under no slash, moderate slash and heavy slash, growing degree days were calculated. Since aspen suckering appears to be inhibited at temperatures less than 15 °C (Maini and Horton, 1966; Navratil, 1991), this number was used as the base value in the calculation of growing degree days. By choosing 15 °C as the base value, this growing degree day calculation was effectively a measure of the amount of time during the growing season where soil temperatures were warm enough to allow for aspen sucker initiation and growth. Examination of the growing degree days highlights the difference in soil temperature under different loads of slash. This difference draws attention to the measurable effect of slash on season length and daily mean soil temperatures more effectively than the examination of freeze and thaw measurements or daily means alone.

However, both the examination of growing degree days and of freeze thaw cycles simply examines a measure of the number of growing days in the season. When considering the biological significance of the alteration of soil temperature profiles it is important to realize that it is not only that there are more days in the year that reach soil temperatures which are favourable for aspen sucker initiation and growth, but that there are more hours in each day. Examination of the number of hours each day when soil temperatures are greater than 15 °C emphasizes that there is a significant difference in soil temperature profiles under no slash, moderate slash loads, heavy slash loads and very heavy slash loads in both winter and summer cutblocks during both the first and second growing seasons. Fraser et al. (2002) and Frey et al. (2003) speculate that a few degrees difference in soil temperature is not enough to effectively alter the initiation and early growth of aspen; however, because the areas under high levels of slash have both lower daily means and a shorter growing season, cumulatively these differences add up.

These differences are visible in the early growth of aspen suckers in field conditions under different levels of slash loads. In addition to its effect on sucker growth in field conditions, this cumulative effect must not be neglected when preparing experimental designs of growth chamber studies.

Not only do slash loads effectively intercept a large part of the radiation normally captured by the soil, they also decrease the flow of radiative heat into and out of the soil. This results in reduced soil temperatures during the summer and a decrease in the length of the growing season by delaying spring thaw. Soil temperature changes can significantly alter growth, development and productivity of aspen suckers by altering nutrient uptake, nutrient utilization, photosynthesis and carbon partitioning (McMichael and Burke, 1996; Landhausser et al., 2001). Slash residues may delay spring thaw similarly to the vegetation cover and litter studied by Hogg and Lieffers (1991). A significant delay in spring thaw or an early fall frost results in a shorter growing season and fewer hours each day when conditions are favourable for growth of newly established suckers in cutblocks. Slash distribution alone is a factor that has the ability to greatly affect both soil temperatures and aspen regeneration. The distribution of slash pieces may not only create an insulative layer, but also, act as a physical barrier to sucker initiation. These less favourable conditions under different levels of slash in cutblocks in the Duck Mountain area were tangibly demonstrated to alter the growth of aspen suckers by a decrease in the number of suckers produced, a decrease in the LAI and a decrease in the total volume of sucker biomass produced in both winter and summer cutblocks.

In winter cutblocks the moderate slash load was not different than no slash load on all aspen regeneration parameters except the number of suckers produced. In summer cutblocks the number of suckers produced and the sucker volume were both significantly decreased at only moderate levels of slash loading. The LAI was also significantly decreased but only under very high levels of slash loading. Similar to our results, Corns and Maynard (1998) found that aspen regeneration was significantly higher under no residue (8.5 stems m^{-2}) than under >10 cm of chipped branches and bark residue (3.9 stems m^{-2}) after 1 year of aspen regeneration. The average LAI in aspen cutblocks in the Rocky Mountains was found to be 0.58 m^2 m^{-3} after 1 year and 0.75 m^2 m^{-3} after 3 years (Shepperd, 1993) which corresponds to those LAI values under no slash and moderate slash in this study. In growth chamber studies, the total leaf area of aspen seedlings was 81% higher when grown at 20 ^oC as compared to 6 ^oC (Landhausser and Lieffers, 1998).

The trend for aspen sucker production in summer cutblocks was similar to the trend observed in daily soil temperatures in summer cutblocks. While any amount of slash had a negative effect, there was no significant decrease in aspen regeneration between moderate slash loads and high slash loads. Since the moderate and high slash loads in the summer cutblocks were lower than those in the winter cutblocks, this suggests that the summer cutblocks were more sensitive to the effects of slash loading on soil temperatures. Differences in sucker growth and response to different levels of slash loading between the winter and summer cutblocks may in part be due to the fact that summer cutblocks were harvested in mid-July, and thus had a shorter first growing season than the winter cutblocks or to the differences in harvesting technique employed and the difference in the average amount of slash material left on the cutblock. This may also be connected by the decreased ability of parental root systems to produce suckers when harvested late in the growing season as a result of a lack of carbohydrate reserves in parental root systems (Bates et al., 1991; Genoway, 1999).

Hogg and Lieffers (1991) indicate that increased levels of slash residues, combined with established vegetation cover, result in a delayed spring thaw. Because winter cutblocks were estimated to have a higher mean slash load than summer cutblocks, the effects of slash on aspen regeneration have the potential to be more severe. However, this is complicated by the amount of auxin produced and carbohydrate reserves available for sucker initiation which are significantly different according to season of harvest (Eliasson, 1971; Schier and Zasada, 1973; Bates et al., 1993). Summer cutblocks most often exhibit a decreased amount of available root carbohydrates (Schier and Zasada, 1973) as some have been consumed for bud break and leaf expansion and increased levels of auxin production (Eliasson, 1971). Because of the decreased amount of available nutrients in summer cutblocks, the summer cutblocks may be more sensitive to changes in environmental conditions such as soil temperature or increased slash loads.

Murray and Kenkel (2001) report poor regeneration only occurs in areas with very heavy slash loading in the Duck Mountain region and that these areas are generally restricted to loading areas and road obstructions both thought to be a minor component of cutblocks. The data from our study shows a significant decrease in aspen regeneration under even moderate slash loads across the cutblocks. The examination of slash loading at a cutblock level shows that the average amount of slash in both winter and summer cutblocks falls into the moderate slash load category. Additionally, using the Modified Newman Line Intercept method, it was found that the incidence of moderate to very heavy loads of slash in cutblocks is near 68% in winter cutblocks and 49% in summer cutblocks. Clearly, moderate to very heavy slash loads are in fact common in both winter and summer cutblocks and the effect of decreased aspen regeneration associated with these levels of slash loads may occur throughout cutblocks and not confined just to roads and landings.

Although the effects of this decrease in regeneration will likely be experienced throughout cutblocks, some maintain that because aspen roots tend to produce vast numbers of suckers, decreases in early initiation are not substantial enough to be detrimental to aspen regeneration levels. Typical stocking densities after harvest operations can be higher than 80 000 suckers per ha but vary substantially (Steneker, 1976; Huffman et al., 1999). Manitoba’s current Forest Renewal Standard for hardwood regeneration requires that after 5 years of growth, acceptable minimum hardwood densities range from 2 500 to 6 000 stems ha^{-1} (Delaney, 1995). However these values cannot be directly compared with those densities measured in the first year after harvest since aspen stands are known to reach their peak sucker production usually within two years following harvest operations and self thinning rapidly begins to occur thereafter (Johnston, 1969; Peterson and Peterson, 1992; Shepperd, 1993). According to Bates et al. (1991) and Huffman et al. (1999), 25 000 suckers per ha is an accepted minimal amount of initial sucker production for successful stand regeneration. Under the heavy slash load in winter cutblocks, sucker production was decreased to levels of 14 000 suckers ha^{-1}, and to 18 000 ha^{-1} under the very heavy slash load in summer cutblocks. Although these values are significantly greater than those required by Manitoba's current Forest Renewal Standards, they are still below the estimation of densities necessary for successful restocking according to Bates et al. (1991) and Huffman et al. (1999) and it is likely that if slash loads of these levels occur on a widespread basis throughout cutblocks there will be a significant effect to the long term production of aspen regeneration in these areas.

The supposition that a decrease in early aspen regeneration to low levels is detrimental is guarded as additional criticisms lie in the question of long-term effects of this decrease in early aspen regeneration. Johnston (1969) and Bella (1986) show that treatment effects on aspen regeneration, although initially significantly different during the first two years after treatments, often disappear rapidly afterwards. In an examination of the logging practices and their effect on stand development in east-central Saskatchewan, Bella (1986) found that differences in stand density decreased to less than 30 % after five years for both amount of slash and time of harvest.

However, evidence supporting the importance of maintenance of parental root systems in order to ensure long-term sustainable harvest operations cannot be disregarded. Shepperd (1993) in his examination of growth, development and clonal dynamics of regenerated aspen reinforces the importance of producing early aspen stands with an abundance of suckers. Suckers growing in low-density stands were not only smaller but also had shorter leaders than suckers growing in well stocked stands (Shepperd, 1993). Suckers injected with herbicide killed connected stems of all sizes emphasizing that aspen suckers function as integrated units and that development of the suckers as a whole is connected (Shepperd, 1993). In addition to this dependance of suckers on parental root systems for nutrients and other resources, according to Desrochers and Lieffers (2001) a significant decrease in early sucker production may be a measure of the ability of a clone to maintain its parental root system. As newly initiated suckers as well as well developed aspen stands depend on the maintenance of parental root systems in order to uptake both water and nutrients from the soil and carbohydrates from reserves, a decrease in the density of early initiation may be related to a loss of root vitality (Navratil, 1996). Damage which results in a decrease in both root and tree growth is very significant as it also increases vulnerability to disease, insects and other pressures (Spittlehouse and Stathers, 1990).

Very heavy slash loads have a negative effect on sucker regeneration which is likely related both to the delay in soil warm up and to the cumulative effect of cooler soil temperatures throughout the entire growing season. Changes in temperature affect the density of suckers produced, and this may significantly alter competitive interactions within the entire surrounding plant community (Thompson and Naeem, 1996). Cooler soils temperatures under slash loads have a detrimental effect on aspen regeneration parameters and, as moderate to very high levels of slash do commonly occur within cutblocks, they will certainly have both long term and short term effects on aspen forests within the Duck Mountain area.

4.4.1 Summary

Differences in soil temperature at the LFH-mineral soil interface under different slash loads indicate that there is a significant effect of slash load on soil temperature. These temperature differences were most pronounced in the early part of the growing season and by the second growing season, these differences were smaller or nonexistent likely due to surrounding vegetative growth. The high slash loads had a significant effect on soil temperatures in both summer and winter cutblocks; however, as the amount of slash in the high slash load in summer cutblocks was lower than that in the winter cutblocks, this indicates that the aspen regeneration in summer cutblocks may in fact be more sensitive to slash loading. The increased slash loads also had an effect on season length and number of hours each day above 15 ^{o}C; this decreases the cumulative amount of time suckers experience soil temperatures warm enough to reach the soil surface and warm enough to thrive after surfacing.

The most important question related to increased slash loads is: does increased slash loading affect stocking levels of regenerated aspen? It is clear that after the first two years of growth, stocking level is not impeded to levels below provincial standards; however, increased slash loads clearly affect the number of suckers that surface, the total surface area of leaves that they produce (effectively a measure of their photosynthetic capacity, ability to support early growth and to maintain parental root systems), and the total wood volume. According to the studies by Desrochers and Lieffers (2001) and Spittlehouse and Stathers (1990) a significant decrease in early sucker production may alter the ability of a clone to maintain its parental root system and to resist disease and insect infestation.

Moderate to high slash loads had a negative effect on sucker regeneration after two seasons of growth, suggesting that this reduced growth may have implications for long term forest sustainability; 68% and 49% of winter and summer cutblocks, respectively, may be under moderate to high levels of slash. Understanding the effects of slash loading and decreased soil temperatures is complex as the examination of slash loading is limited to estimation of mass and as the examination of early growth of aspen may be altered by many factors. This is an area that unquestionably needs to be studied in further detail, especially in order to better ascertain long term implications for forest management. Effective communication of the serious implications of creating heavy loads of slash in cutblocks to forest harvest operators and creating easy visual identification methods of heavy slash loads in order to avoid their creation may aid in averting the incidence of unsustainable forest harvest management techniques in the future for aspen stands.

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5 SUCKER INITIATION AND DEPTH TO SUCKER INITIATION

5.1 Introduction

Although recent authors have reservations about the strength of influence of soil temperature on aspen sucker initiation and early growth (Fraser et al., 2002; Frey et al., 2003), past studies have shown strong responses of sucker initiation and early growth to changes in soil temperature (Maini and Horton, 1966; Gifford, 1967; Zasada and Schier, 1973; Landhausser and Lieffers, 1998). Soil temperature fluxes within soil profiles depend on depth from the soil surface, surface conditions, time of day, time of year, and numerous soil physical properties (Glinski and Lipiec, 1990). Factors such as slash loading, which alter soil temperature conditions, may influence the ability of aspen to reproduce under cooler soil temperature conditions. These induced changes may negatively affect both aspen sucker initiation and early development if soil temperatures decrease significantly (Maini and Horton, 1966; Hogg and Lieffers, 1991; McInnis and Roberts, 1995; McMichael and Burke, 1996; Navratil, 1996).

If soil temperature does exert a strong effect on aspen regeneration, the response of aspen roots to naturally existing and induced changes to soil temperatures should result in the proliferation of aspen suckers in warmer areas within the soil profile. Soil temperature profiles in the Duck Mountain area demonstrate a decrease both as depth from the surface increases (described in Chapter 4 sections 4.3.1.1 and 4.3.1.2) and as the amount of slash above the soil increases (described in Chapter 4 sections 4.3.1.1 and

4.3.1.2). Examination of the location of sucker initiation and the depth of sucker initiation from within the soil profile, in conjunction with the amount of slash overlying the soil surface, is of interest to better understand the response of aspen regeneration to soil temperature fluxes, in particular those induced by increased levels of slash loading.

It is clear that aspen suckers thrive in warm soil temperature conditions and that slash loading has a significant effect on soil temperature. The hypothesis of this study was that increased levels of slash would result in sucker initiation occurring closer to the soil surface. The objective of this study was to determine whether slash loading altered the depth of sucker initiation or had an effect on the location of sucker initiation from the parent root and the depth of sucker initiation.

5.2 Methods

5.2.1 Study area

The study sites were located within twelve cutblocks (six winter cutblocks and six summer cutblocks) throughout the Duck Mountain area of west-central Manitoba (described in Chapter 3 section 3.2.1). A summary of soil characteristics is presented in Appendix A.

5.2.2 Sampling

In each cutblock, two randomly assigned 100 m transects were established and suckers excavated every 10 m along each transect. In each 1 m^2 excavation plot, the depth of forest floor, depth to sucker initiation from the top of the forest floor, location of initiation on the parental root (top, bottom, or side), and estimation of slash above all suckers within the plot (using the modified Newman line intercept method as described in Chapter 3 section 3.2.2.2) were measured and recorded.

5.2.3 Statistical analysis

For the depth of the LFH layer and the depth to sucker initiation, all measurements were summarized by determining means for summer cutblocks and winter cutblocks and by determining a standard deviation for these means. Additionally, these were categorized according to the amount of slash overlying each quadrat examined. A regression analysis was performed to examine the relationship between slash load and depth to sucker initiation (SAS)(Version 8.0, SAS Institute Inc. Cary, NC, USA). Location of sucker initiation on the parental root was examined by summarizing winter and summer cutblocks together.

5.3 Results

In the winter cutblocks, the mean depth of the LFH layer was 10.4 ± 4.2 cm and the mean depth of the parent root from which suckers initiated was 4.6 ± 2.4 cm. In the summer cutblocks, the mean depth of the LFH layer was 5.9 ± 2.6 cm and the mean depth to sucker initiation from the parent root was 3.4 ± 2.1 cm. In all the suckers that were excavated across both the winter and summer cutblocks, only 7% of the suckers had initiated from parental roots below the LFH layer within the soil profile. Across these 12 cutblocks, aspen sucker initiation occurred on those parental roots which were located very near the soil surface. Additionally, of all the suckers that were excavated in both the winter and summer cutblocks, 68% had initiated from the top, 28% from the sides, and only 4% from the bottom of the parental root.

When the depth to sucker initiation was examined with respect to the amount of slash above the excavated sucker, a weak positive correlation was found (Figure 5.1). Figure 5.2 and Figure 5.3 demonstrate no noticeable effect of slash load on depth to sucker initiation.

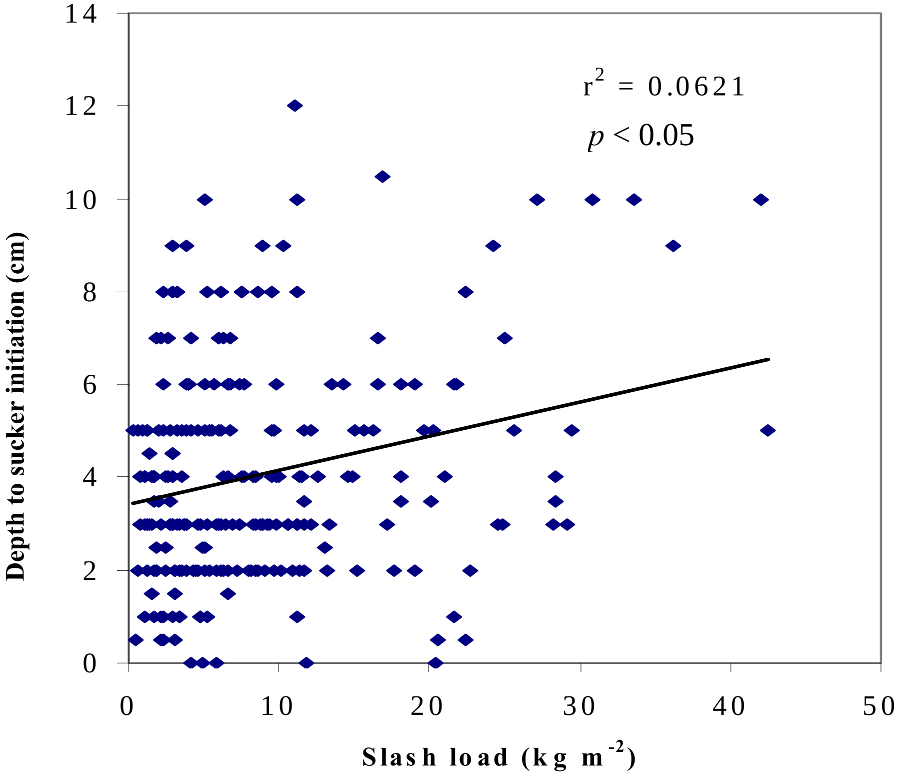

Figure 5.1 Relationship between depth in soil profile to sucker initiation and slash loading in 240 sample 1 m^2 plots in 12 cutblocks in the Duck Mountain ecoregion.

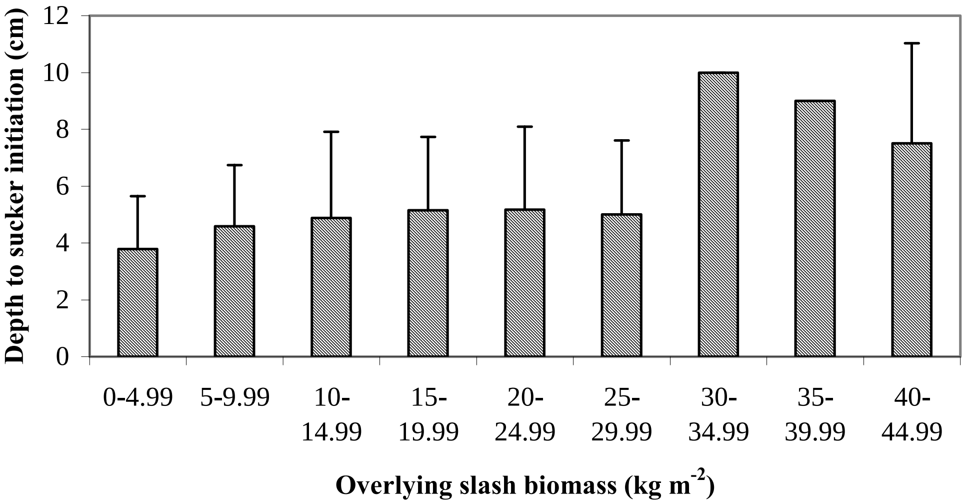

Figure 5.2 Mean depth of sucker initiation from the parental root to the soil surface of aspen suckers excavated from under varying loads of slash in winter cutblocks (n = 120). Error bars indicate standard deviation.

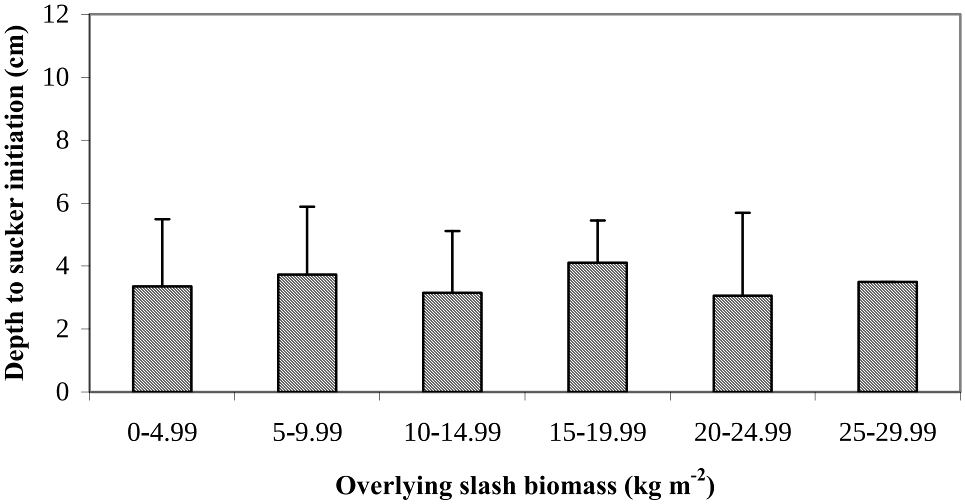

Figure 5.3 Mean depth of sucker initiation from the parental root to the soil surface of aspen suckers excavated from under varying loads of slash in summer cutblocks (n = 120). Error bars indicate standard deviation.

5.4 Discussion

Maini and Horton (1966) showed that decreasing soil temperatures resulted in significantly less aspen sucker growth. Because of this response to decreasing soil temperatures in conjunction with the decrease in soil temperatures related to increased levels of slash loads discussed in chapter 4 (section 4.3.1), we expected that higher amounts of slash would be associated with lower soil temperatures and thus the depth to suckering would decrease. However, suckering depth was not greatly affected by the amount of slash in either the winter or the summer cutblocks. Figure 5.2 indicates that the depth to suckering increased in those categories with > 30 kg m^{-2} slash; however, this is likely because of the very small sample size in these categories ($n < 3$). The lack of response of depth to sucker initiation to increasing slash loads may be due either to the inherent distribution of aspen parental root systems in the soil profile or the inability of suckers initiating from deeper within the profile to successfully reach the soil surface and compete with surrounding vegetation.

While it is possible that suckering could have occurred from roots that were located lower within the soil profile, the random excavation method used in this study did not encounter any of these. All of the suckers excavated had initiated from roots within the top 15 cm of the soil profile, even though aspen roots have been found to extend to depths of 1.2 m within soil profiles (Stone and Kalisz, 1991; Van Rees, 1997). It may be that in the sample areas covered with a heavier load of slash, where we expected sucker initiation to occur from shallow locations within the soil profile, there simply were not any parental roots nearer the surface to sprout from. The lack of relationship may also be related to the fact that the majority of the suckers did sprout very near to the soil surface. Because of comparatively cool soil temperatures in Manitoba, most root system growth would be expected to initiate where the warmest soil temperature occurs which is likely within the LFH layer within the soil profile. Frey et al. (2003) suggest that suckers initiated from deeper within the profile may not survive because growth is slower at cooler temperatures, that there may be insufficient carbohydrate resources for the initiated sucker to emerge at the soil surface, that apical dominance effects from the suckers which reach the surface more quickly inhibit further growth, or suckers initiating at a shallow depth have a competitive advantage and proliferate.

Examination of the pattern of sucker initiation in the Duck Mountain area, similar to numerous studies, indicated that suckering consistently occurred at a very shallow depth within the soil profile (<5 cm) and almost exclusively from within the LFH layer. Perala (1991) and Peterson and Peterson (1992) indicated that the majority of suckering occurs from aspen roots located in the upper 12 cm of the soil profile, while Farmer (1962) and Kemperman (1978) indicated that in field conditions most suckers occur at 1 to 3 cm root depth. Kemperman's (1978) studies in northern Minnesota showed that most sucker initiation occurs from roots within the litter and humus layers of the soil profile and that only 2 to 8 % had developed from roots found within mineral soil layers. In the Duck Mountain area, surveyed suckers also most consistently initiated from the top side of the parental root, the area most susceptible to heavy impact. Sucker initiation nearer the soil surface and from the top side of the parent roots suggests that the potential for root injury caused by heavy machinery and routine forest harvesting traffic may be substantial.

Any alteration in natural suckering patterns related to forest harvest operations may ultimately limit successful reforestation. Forest harvest operations in theory should be conducted in such a manner that they mimic natural disturbance events such as forest fire as closely as possible in order to ensure successful forest regeneration with as little intervention as possible. The effect of harvest operations on rooting patterns, especially depth, may create a situation that does not follow this natural disturbance paradigm. When fires burn forests they generally consume the forest floor likely killing roots existing within the forest floor layer. This may result in fire origin stand suckers initiating from deeper within the soil profile than those seen under harvested conditions. Schier and Campbell (1978) found that in burned clearcuts in the Rocky Mountains of Utah and Wyoming the mean depth of parent roots was 7.8 cm and 7.2 cm, but that parent roots at depths up to 28 cm had successfully produced aspen suckers. Although these root depths are deeper than those observed in this study (mean depth was 4.6 cm in winter cutblocks and 3.4 cm in summer cutblocks) and those in other studies which also occurred in cutblocks (Kemperman, 1978; Perala, 1991; Peterson and Peterson, 1992), because of the variability among aspen clones and aspen suckering responses to site conditions these values are reasonable. This makes a comparison of the difference in depth to suckering under forest harvest conditions and those suckering patterns following forest fires difficult. The possibility of the failure to stay within the bounds of the natural disturbance paradigm should, however, not be overlooked since it is possible that by altering the depth to suckering we may be setting up these harvested forest ecosystems to fail in the long term.

5.4.1 Summary

Careful examination of aspen sucker depth to initiation and pattern of suckering is essential to evaluate whether aspen suckers which initiate following mechanical harvest are detrimentally different from those which initiate under natural disturbance conditions. Although sucker initiation depth may not be directly affected by slash loading, examination of suckers in the Duck Mountain area demonstrates that suckers are initiating mainly from within the LFH layer, at a very shallow depth within the soil profile, and frequently from the top side of the parental root. Because aspen suckers are initiating near the soil surface heavy machine traffic must be monitored closely or kept to a minimum during summer harvest.

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6 DIURNAL TEMPERATURE FLUCTUATION

6.1 Introduction

Diurnal soil temperatures most often fluctuate sinusoidally in a regular pattern. These fluctuations are often overlooked in scientific examinations of the effects of temperature on plant growth, and mean daily soil temperatures. The use of daily means and similar measures of soil temperature neglect to consider the additive effect of increased or decreased night or day temperatures. Altered diurnal temperature variations, especially increased night temperatures, have the potential to increase plant and forest respiration, the effective length of the growing season, soil respiration, litter decomposition, mineralization of N from soil organic matter, and nutrient uptake (Luxmoore et al., 1998). Depending on which of these responses is dominant, global warming or similar alterations to soil temperature profiles may result in an increase or decrease in plant growth, changes in species geographic distribution, and negative or positive feedbacks to global warming (Matyas, 1994; Luxmoore et al., 1998). Luxmoore et al. (1998) suggest that under increased night temperature conditions related to global warming or altered diurnal fluctuations, the effect of increased respiration may outweigh the benefits of increased temperatures on forest growth; however, this is definitely an area which needs further study to clarify these relationships.

In order to simplify and to attempt to determine significant temperature factors affecting aspen growth and regeneration, numerous field and controlled environment studies have been conducted. Although several studies indicate that an increase in soil temperature will significantly increase aspen sucker initiation and initial growth (Farmer, 1963; Maini and Horton, 1966; Gifford, 1967; Zasada and Schier, 1973; Landhausser and Lieffers, 1998), no conclusive evidence has been found which can determine the extent of the effect of soil temperature on aspen regeneration and other researchers question the ability of small temperature changes to result in significant changes to aspen initiation and early growth (Fraser et al., 2002; Frey et al., 2003). Contrary to these ideas, several field studies have associated alteration to the forest floor, likely related to temperature changes, with an increase in regeneration (Steneker, 1976; Hungerford, 1988; McInnis and Roberts, 1995; Navratil, 1996; Amacher et al., 2001). The difficulty with field studies, however, is that there are many unknown variables creating complex conditions which are often difficult to analyse.

Numerous controlled environment studies have been conducted which attempt to isolate and examine the effect of soil temperature on aspen regeneration with most determining that soil temperature affects on both sucker initiation and growth (Maini and Horton, 1966; Gifford, 1967; Zasada and Schier, 1973). However, one recent study indicated that increasing daytime soil temperatures above 12 ^{o}C had no effect on sucker initiation when root pieces were exposed to the same number of growing degree days (Fraser et al., 2002). Both Fraser et al. (2002) and Frey et al. (2003) suggest that soil temperature is not the most significant factor influencing early aspen sucker initiation after harvest. Fraser (2002) and Frey et al. (2003) cite the short duration of initiation used in earlier studies and the use of short root segments as biasing sucker initiation towards higher temperature treatments; however, as field studies indicate similar findings to earlier growth chamber studies, (soil temperature increases related to increases in sucker initiation and growth) it is probable that there was at least some merit to earlier studies which concluded that increased temperatures do affect sucker initiation and growth. The effects of temperature on cellular processes alone demands that there be further study to clarify the presence or absence of increased initiation and early growth related to soil temperature fluxes.

The failure to isolate the extent of the soil temperature effect on the initiation and early growth of aspen suckers may be related to the fact that the designs of previous growth chamber experiments have not been ideal. Early studies used constant soil temperatures throughout both the day and night (Maini and Horton, 1966; Gifford, 1967). The significance of using variable temperature conditions to simulate day and night conditions was reinforced by Zasada and Schier (1973), who showed that temperatures greater than 23 ^{o}C were inhibitory to aspen regeneration but not when night temperatures were lower than 23 ^{o}C. Later studies have since implemented a two temperature daily cycle in an attempt to create separate day and night time growth conditions (Bate and Canvin, 1971; Zasada and Schier, 1973; Fraser et al., 2002). In addition to these artificial temperature conditions, growth chamber studies have often been conducted using temperature conditions that were warmer than field soil temperature values. While one would expect the higher temperatures often used in growth chamber studies to reveal the effects of fluxes more definitely, it does significantly decrease the practicality of these findings.

Soil temperatures ascertained in the earlier study in Chapter 4 of this thesis demonstrate several key findings. Chapter 4 indicated that soil temperature daily means during the growing season varied from 5 ^{o}C to 16 ^{o}C. In addition, the daily cycle of soil temperatures follow a sinusoidal fluctuation with daily minimum and daily maximum values being consistently dampened by increasing levels of slash loading. Because slash loading resulted in a layer that insulates the soil surface, the soil temperatures under heavy slash loading indeed resulted in a dampening effect on the diurnal temperature cycle. Data collected for the study conducted in Chapter 4 demonstrated that not only were increased levels of slash loads associated with significantly lower soil temperatures and shorter growing season lengths but also with significantly lower aspen sucker density and initial growth.

To further clarify the changes in soil temperature with aspen regeneration, a controlled environment study was conducted which implemented similar diurnal fluctuations to those found in field conditions. Field temperature measurements from slash loading plots were examined to establish day and night time temperature extremes and the time of their occurrence during the daily cycle. The hypothesis of this study was that decreased diurnal temperature variation would have a detrimental effect on aspen regeneration. The objective of this study was to use field temperature data from different levels of slash loads, in a growth chamber study, in order to determine if different diurnal temperature fluctuations influenced aspen suckering.

6.2 Methods

6.2.1 Temperature profiles

Soil temperatures measured from field experiments described in Chapter 4 (section 4.2.2.3) were examined in terms of daily maximums and minimums over the growing season as well as the pattern of daily fluctuation (Table 6.1). These soil temperatures were used as a foundation to create temperature regimes for the growth chamber experiment (Figure 6.1).

Table 6.1 Monthly soil temperature (at the LFH-mineral soil interface) maximum and minimum values (^{o}C) during the second growing season (April 2000 - August 2000) for 12 cutblocks in the Duck Mountain area.

Slash Load	Date	Mean	Minimum	Maximum
None	April	1.91	0.44	4.26
	May	8.28	5.12	12.48
	June	11.73	8.87	15.19
	July	15.94	13.25	19.22
	August	16.00	13.60	18.84
High	April	0.29	-0.25	1.05
	May	5.03	3.38	6.94
	June	9.79	8.15	11.33
	July	14.66	12.94	16.41
	August	15.44	13.84	16.16
Very High	April	---†	---	---
	May	4.71	3.76	5.78
	June	9.26	8.23	10.34
	July	14.36	13.23	15.57
	August	14.38	13.29	15.41

† No data recorded.

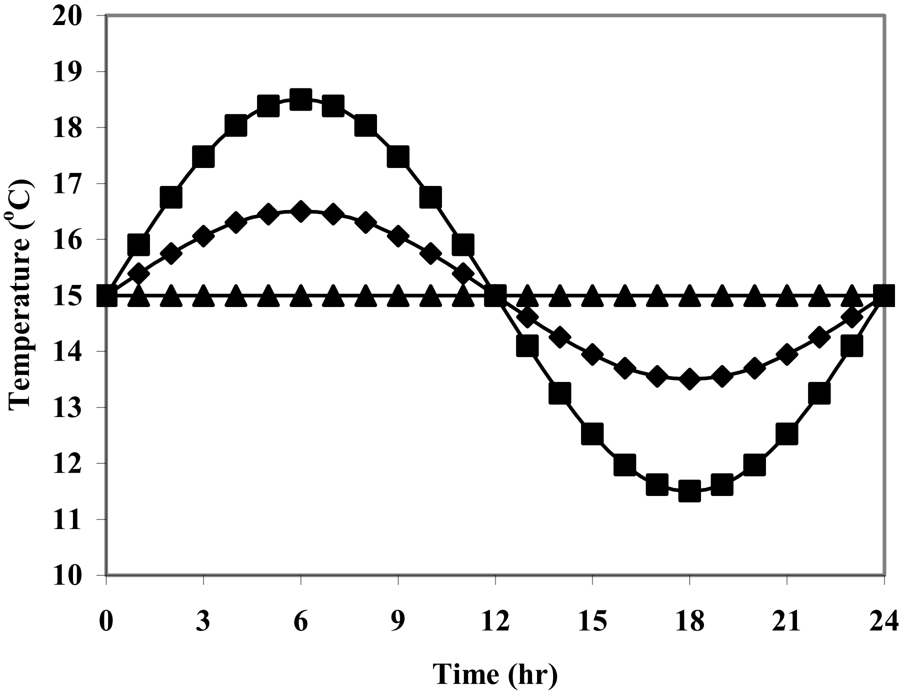

Figure 6.1 Fluctuating temperature regimes used in the growth chamber experiments.

Three temperature regimes were established in three separate growth chambers (Figure 6.1). One growth chamber had a constant temperature of 15 ^oC with no diurnal fluctuation. The second chamber had a daily mean temperature of 15 ^oC but a diurnal fluctuation of 3 ^oC (daily maximum of 16.5 ^oC and daily minimum of 13.5 ^oC) which was representative of soil temperature conditions at the LFH-mineral soil interface under a "heavy slash" load across the twelve cutblocks. The third growth chamber also had a daily mean temperature of 15 ^oC but a diurnal fluctuation of 7 ^oC (daily maximum of 18.5 ^oC and daily minimum of 12.5 ^oC) which was similar to soil temperature conditions found under "no slash" load across the twelve field sites. In theory, soil temperature oscillates as a sinusoidal function of time around an average value (Hillel, 1998);

examination of field soil temperature fluctuation in the Duck Mountain area demonstrated a similar fluctuation. Each of the three temperature conditions was replicated in two separate growth chambers (a total of six growth chambers).

6.2.2 Experimental design and root collection

For the growth chamber study, 10 cm long aspen root cuttings (1.0 ± 0.5 cm diameter) were obtained from six mature stands on Luvisolic soils within the Duck Mountain area. Root cuttings were excavated May 30, 2001, transplanted, and grown in a growth chamber for eight weeks. Eighteen pots were used in each chamber; each of the six clones (one from each of the six stands) had three replications. Three root cuttings from the same clone were planted in each pot at 4 cm depth since the optimal depth for maximum suckering response ranges from 4 to 6 cm (Farmer, 1963; Johansson and Lundh, 1988). Cuttings were planted in Luvisolic soil collected from the Duck Mountain area. Soil moisture was maintained at 15% water content by weighing pots each alternate day and replacing any losses. Pots were randomly distributed and redistributed each alternate day throughout each growth chamber for the entire eight week growth period. One Hobo temperature probe (Hobo H8 Pro Series; 2 channel) was placed within each chamber to monitor both chamber and soil temperatures. Soil temperatures consistently mirrored growth chamber temperatures. No light was used for the duration of the growth period.

The number of suckers per 10 cm cutting, number of suckers sprouted which did not reach the soil surface (sprouts), dry weight of suckers, diameter of sucker stem at root collar (RCD), and height of suckers were measured. Because there were three cuttings per pot, the average number of suckers per 10 cm cutting, average number of suckers sprouted below the soil surface per 10 cm cutting, average dry weight of suckers per 10 cm cutting, average RCD per 10 cm cutting, and average height per 10 cm cutting was determined for each pot. The temperature experiment was statistically analyzed using a general linear model to perform an analysis of variance for a two factor factorial completely randomized design (SAS)(Version 8.0, SAS Institute Inc. Cary, NC, USA). Factors were temperature (three temperature conditions) and clones (six clones) and were replicated three times (three pots). The experiment was replicated twice in time (two growth chambers per temperature treatment).

6.3 Results

The number of suckers in each pot at the end of the eight week growth period ranged from one to nine under no diurnal temperature variation, one to six under 3 ^{o}C diurnal temperature variation, and from one to 11 under 7 ^{o}C diurnal temperature variation. The number of sprouts in each pot at the end of the growth period was slightly higher and ranged from one to 28 under no diurnal temperature variation, one to 35 under 3 ^{o}C diurnal temperature variation, and from one to 33 under 7 ^{o}C diurnal temperature variation. Comparison of mean values indicated that diurnal temperature fluctuations did not have any effect on the number of aspen suckers or the number of aspen suckers which had not yet reached the soil surface (Table 6.2).

Table 6.2 Effect of diurnal temperature variation on mean number of trembling aspen (*Populus tremuloides* Michx.) suckers (NUM), mean number of suckers which did not sprout through the soil surface (SPR), mean number of both suckers and suckers which did not sprout through the soil surface (TOT), mean height (HT), mean root collar diameter (RCD), and mean dry mass (DMASS) at 15 °C. Mean values and total values indicate the mean and total found in a single pot.

Diurnal Temperature Variation (°C)	**NUM**	**SPR**	**TOT**	**HT (cm)**	**RCD (cm)**	**DMASS (g)**
0	1.5 a†	8.6 a	10.1 a	9.2 a	0.34 a	0.041 a
3	0.9 a	9.6 a	10.5 a	9.4 a	0.35 a	0.021 a
7	1.5 a	12.7 a	14.2 a	9.2 a	0.47 a	0.044 a

† Values in a column with the same letter are not significantly different at $p = 0.05$.

Mean sucker height ranged from 1.4 cm to 25.9 cm under no diurnal temperature fluctuation, from 1.6 cm to 21.9 cm under 3 °C diurnal temperature fluctuation, and from 1.2 cm to 34.1 cm under 7 °C diurnal temperature fluctuation. Mean sucker RCD ranged from 0.2 cm to 1.9 cm under no diurnal temperature fluctuation, from 0.3 cm to 2.8 cm under 3 °C diurnal temperature fluctuation, and from 0.3 cm to 2.1 cm under 7 °C diurnal temperature fluctuation. Table 6.2 indicates that with a daily mean of 15 °C, diurnal temperature fluctuations of 3 °C and 7 °C did not significantly affect early sucker growth (height, RCD and biomass).

Examination of the number of suckers, sucker height, sucker RCD and sucker dry mass did not reveal any strong trends. There was no diurnal temperature effect detectable on aspen suckers that had initiated and reached the soil surface as well as no effect on sprouts that had not yet reached the surface.

6.4 Discussion

Past studies have led to the belief that diurnal temperature fluctuations may play a favourable role in both sucker initiation and early sucker growth; however, new theories have suggested that alterations to diurnal fluctuation patterns may, under field conditions, lead to a decrease in plant growth related to increases in plant respiration during night periods. Maini and Horton (1966) showed that aspen had poor suckering potential during hot days and increased suckering potential associated with cool nights. While Maini and Horton (1966) found that temperatures above 23 ^{o}C were inhibitory to aspen suckering if they were held constant, Zasada and Schier (1973) showed that if a diurnal fluctuation occurs (25 ^{o}C / 15 ^{o}C), these temperatures were no longer restrictive to aspen sucker growth. Bate and Canvin (1971) established that altering day or night temperatures can have an adverse effect on the rate of carbon gain during photosynthesis. Since increased amounts of slash dampen the diurnal fluctuation in soil temperatures, this may be responsible in part for decreased sucker production associated with increased slash loading in field conditions.

Contrary to the majority of previous field and growth chamber research, results from this growth chamber study indicated that there was no effect of increased diurnal fluctuation on the initiation and early growth of aspen suckers. Only one recent study showed similar results of no effect of soil temperature on aspen initiation, and this study focused on temperatures above 12 ^{o}C (Fraser et al., 2002). Data from our field studies emphasized that differences in soil temperatures under different slash treatments were most pronounced during the earlier part of the growing season when mean soil temperature conditions were often less than 15 ^{o}C (Chapter 4). In order to solidify the absence of any effects of diurnal soil temperature fluctuations on aspen sucker initiation in field-like conditions, further study of sucker initiation should focus on slightly lower soil temperatures closer to those found during the early growing season when differences in temperature are distinct and sucker initiation is likely to commence.

Although there was no significant difference in sucker initiation found in this short term study, the use of growing degree days in the study conducted by Fraser et al. (2002) highlights an important factor in aspen sucker initiation and early growth: the biological significance of increased or decreased length of growing season in conjunction with alterations to soil temperatures. While those suckers grown under higher temperatures produced the same number of suckers as those grown under low temperatures during a significantly longer growth period (Fraser et al., 2002), in field conditions it is most likely that the opposite takes place: areas with lower soil temperatures are often exposed to shorter growing seasons (Chapter 4). Although Fraser et al. (2002) indicated that there was no effect of temperature on sucker initiation, they did note that those pieces of aspen roots exposed to warmer soil conditions initiated earlier in the incubation period. Areas with warmer soil temperatures may produce suckers earlier in the growing season and will likely not only have a longer growing season with which to produce more suckers but a competitive advantage as well. Although the total number of aspen suckers may not be affected when exposed to similar growing degree days, the competitive interaction of aspen with surrounding vegetation will definitely be affected, as temperature differences of less than 5 ^{o}C alter the dormancy status of seeds and grasses (Thompson and Naeem, 1996). Further study in this area should not only implement the use of soil temperatures closer to those encountered during the earlier part of the growing season, it should also consider appropriate length of growing seasons for different temperature treatments.

The lack of response of early aspen sucker growth was more unexpected than the lack of response of sucker initiation to differing diurnal temperature fluxes. However, this was likely related to the absence of light in the chamber. The absence of light in the chamber may have resulted in a cumulatively equal level of respiration for each of the treatments as there was no photosynthetic period. The importance of the effect of increased temperatures during a non-photosynthetic period on respiration rates is emphasized by the work of Zeiher et al. (1994) who showed that for a cotton crop, when night time temperatures were increased, the warming treatment caused significant reductions in stem weight, plant height, and seed yield. According to Luxmoore et al. (1998), uneven increases to either photosynthetic capabilities or respiration rates due to alterations in diurnal temperature fluctuations may have serious consequences for forest growth and may result in positive or negative feedback effects on global warming.

The measure of early sucker growth in dark conditions is also complicated by the fact that aspen is a shade intolerant species (Farmer, 1963). Other studies examining the effects of temperature, which implemented the use of light, have shown that changes in temperature do significantly affect the amount of carbohydrates an aspen tree can produce (Bate and Canvin, 1971). Farmer (1963) showed shading of aspen suckers resulted in a reduced height growth rate under warmer temperature regimes (24.4 ^{o}C day and 21.7 ^{o}C night) than under cooler temperatures (21.1 ^{o}C day and 18.9 ^{o}C night). Farmer (1963) suggests that under the cool conditions net photosynthesis was high enough that height growth was not limited by substrate and temperature became the limiting factor. However, under the warm conditions shading did have an effect on height growth, as temperature was clearly not a limiting factor. As our chamber temperature conditions were lower than those used by Farmer (1963), we did not anticipate or find any shading effect apart from the problems associated with a lack of light and thus a lack of photosynthetic capability of aspen suckers. However, in order to both avoid the complexity of day length, light intensity, and soil and air temperature differences and focus on soil temperature effects alone, it was necessary to exclude light from the experimental design. It is difficult to create conditions in growth chambers that successfully mimic both temperature and light conditions while still maintaining the ability to isolate one of these variables for study.

Although the lack of difference in early aspen sucker growth between temperature treatments is likely associated with the lack of light in the chambers, there were also related complexities. Examination of shoots after an eight week growth period in the absence of light was unsuccessful as the amount of sucker growth produced during this period was effectively too small to notice any differences between treatments. In addition, some suckers had already started to die as they had been growing without light for seven weeks. Tew (1970) experienced similar early rapid sucker growth and then a sudden stop in growth and contributed this effect to a depletion of carbohydrate reserves. Likely, the early growth of aspen suckers, under such growth conditions, is strongly linked to the amount of carbohydrates stored in the root pieces.

6.4.1 Summary

Results from this study, in contrast to indications from field studies, indicate that there is no effect of diurnal soil temperature variations on aspen regeneration at soil temperatures near 15 ^{o}C. A combination of additively higher daytime soil temperatures and increased season length is likely responsible for producing more aspen suckers in field conditions rather than alterations to diurnal temperature fluctuations alone. Although this study indicated that there is no effect of diurnal soil temperatures on aspen regeneration, in the context of field conditions, those areas with higher diurnal temperature fluctuations may still encounter increased aspen regeneration as they may also experience longer growing seasons related to higher daily soil temperatures and early thaw and effectively a competitive advantage. Further study is needed to clarify the relationship between soil temperature, aspen sucker initiation, photosynthetic rates, respiration rates, and early sucker growth in both field and controlled environment conditions. The determination of controlled environment chamber conditions must be considered carefully to critically evaluate their biological significance and use in growth chamber studies.

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7 GENERAL DISCUSSION AND CONCLUSIONS

Examination of the pattern of sucker initiation indicated that suckering was consistently occurring at a very shallow depth within the soil profile (<5 cm) and almost exclusively from within the LFH layer. In addition, suckers more consistently initiated from the top side of the parental root, the area most susceptible to heavy impact. Sucker initiation nearer the soil surface means that the potential for exposure to root injury could increase with harvesting equipment. Because aspen suckers are initiating from parental roots located very near the soil surface simply due to the nature of aspen growth habit in this area, heavy machine traffic should be minimized in the cutblock during summer operations if aspen regeneration is a management goal.

Daily mean soil temperature profiles strongly indicated that increased levels of slash loading resulted in decreased soil temperatures especially right after harvest and during the early part of the growing season. Analysis of the first date of the spring thaw, fall frost, length of the winter season and the growing degree days also indicated that not only does an increased slash load result in lower daily mean soil temperatures, it also results in a shorter growing season for those suckers under the heavier slash loads. As decreased soil temperatures and decreased growing season lengths have significant implications for aspen growth, harvest operations should try to avoid leaving large areas with high amounts of slash loads in order to ensure optimal soil temperature conditions for aspen regeneration.

Although the greatest differences in soil temperatures between treatments were observed in May, the majority of aspen growth is likely to occur in July when soil temperatures reach consistently warm temperatures. In both the winter and summer cutblocks during the month of July, increased levels of slash loading resulted in a significant decrease in the amount of hours each day that soil temperature was above 15 ^{o}C. During the month of July, soil temperatures were consistently warm enough to encourage abundant sucker growth.

The analysis of the effects of slash loads on sucker regeneration produced extremely interesting results. Previous studies which examined the effects of slash loading on regeneration did not implement quantitative descriptions of the amounts of slash cover, and the specific effects of slash loading on soil temperatures were not considered. In this study, in summer cutblocks, moderate levels of slash do indeed limit aspen sucker initiation and growth while in winter cutblocks high levels of slash loading were capable of limiting both aspen sucker initiation and production. Increased slash loads resulted in decreases in soil temperature and growing season length and decreases in the number of aspen suckers and their growth.

The effects of slash loading on aspen regeneration also mirrored those effects noted for soil temperature. The trend for aspen sucker production in summer cutblocks was similar to the trend observed in daily soil temperatures in summer cutblocks. While any amount of slash does have a negative effect, there was no significant decrease in aspen regeneration between moderate slash loads and high slash loads. Since the moderate and high slash loads in the summer cutblocks were lower than those in the winter cutblocks, this suggests that either the aspen suckers in the summer cutblocks are more sensitive to the effects of slash loading on soil temperatures or that the summer cut methods differed from the winter cut methods in some way which correlated with the slash left on the cutblock. It is necessary to be especially cautious with the amount and distribution of slash left in summer cutblocks by harvest operations. In conjunction with slash loading resulting in decreased aspen regeneration in summer cutblocks, summer cutblocks may also be susceptible to root injury due to the season of harvest and the fact that parental roots grow at a shallow depth within the soil profile. In order to ensure successful aspen regeneration, it may be necessary to make an improved effort to distribute slash evenly within summer cutblocks.

When examined under environmentally controlled conditions to isolate the effect of diurnal temperature fluctuations associated with varying degrees of slash loads it was apparent that this dampening in the amplitude of the daily temperature may not be the sole reason for the decrease in sucker production associated with increased levels of slash loading. Although increased diurnal fluctuations had no effect on early aspen sucker initiation or growth in the growth chamber, increased temperatures have been found to affect the date of initiation. As the date of initiation holds great significance ecologically in terms of competition and ability for suckers to thrive, it is probable that those areas in cutblocks which endure lower daily and nightly soil temperatures and shorter growing season lengths will not succeed. Although the results from this study indicate that diurnal temperature fluctuations have no effect on sucker initiation and growth, when considering that the temperature fluctuations will in the long term likely result in those areas in aspen cutblocks with increased growing degree days having earlier initiation, this may additively affect aspen growth and successful regeneration. Further study in controlled environment chambers should implement the use of soil temperatures closer to those found during the early growing season, should take into account the biological significance of the induced growing periods in conjunction with examining accumulated heat units, and should measure and count initiating suckers on a daily basis instead of at the termination of the experiment and when possible include the use of light.

The effects of slash loading on both soil temperature and aspen regeneration must be considered in terms of its relative importance at a field scale. The potential negative effects of high levels of slash loading are only of importance if there is an incidence of high levels of slash normally found in cutblocks. Using the two slash estimation methods allowed for the estimation of the mean amount of slash in both winter and summer cutblocks. In both the winter and the summer cutblocks, the mean amount of slash most often fell within the “moderate slash” loading category. In winter cutblocks, the mean amount of slash would likely have a small impact on aspen regeneration. However, 14% of the area measured had slash which fell into the heavy category. Aspen growing under these conditions are likely to encounter a decrease in productivity. In the summer cutblocks, the mean amount of slash fit into the moderate slash load category. Moderate slash loads do significantly decrease soil temperatures and aspen regeneration in summer cutblocks. These moderate amounts of slash will likely result in a significant decrease in aspen suckering capability on a larger scale in the summer cutblocks. Additionally, 11% of the sampled area in the summer cutblocks fell into the heavy category and would most likely result in a measurable decrease in aspen suckering success.

It may be argued that the number of suckers produced under high slash loads was still greater than the minimal amount of suckers necessary for successful regeneration according to provincial restocking standards. This negative effect on aspen is extremely important in terms of maintaining sustainable forest harvest practices since early sucker growth is believed to be necessary to maintain the parental root system in the long term. Until suckers have developed their own root systems, they depend on the parental root system for moisture and nutrients, thus it is important and necessary to maintain a healthy parental root system in order to have successful long-term aspen suckering. These parental root systems initially provide the essentials for sucker growth but suckers must in turn provide carbohydrates necessary to maintain the healthy rooting system. Because sucker density standards are quite low, it may in fact be necessary to establish a higher density of aspen suckers in the first few years of forest regeneration in order to ensure that the parental root system is maintained. Distributing slash more evenly in cutblocks may decrease this negative effect on aspen suckers and aspen root systems. Harvest operations should avoid producing areas of very dense slash to ensure that healthy aspen root systems are able to sustain mature, fully stocked stands.

Extensive aspen sucker production within the first years of regeneration is essential in order to ensure that a healthy stand is produced. Ensuring that slash is distributed evenly in cutblocks may decrease the negative effect on aspen suckers and on aspen root systems. Perhaps further investigation of slash loading in cutblocks will elucidate optimal or maximal levels of slash distribution for successful aspen regeneration. To reinforce the importance of slash distribution on a cutblock level, two visual slash loading guides were created; a detailed guide was created for informational purposes for forest harvest company employees and a shorter guide was created for quick visual reference for harvest operators to use in the field (Appendix D). Ideally, this was meant to be a visual estimation system developed for machine operators to use to avoid creating very heavy levels of slash and by doing so to ensure successful stand regeneration and to further enhance communication between researchers and field operators. Louisiana-Pacific is currently using these guides in their forest harvest operations in the Duck Mountain area.

Soil temperature is a factor that has a strong influence on root growth, root development, and ultimately aspen sucker productivity. Soil temperature likely works together with many factors to determine the initiation and early growth of aspen after forest harvest operations. Soil temperature in conjunction with length of growing season, which directly relates to slash load, have a strong influence on early initiation and successful growth. Knowledge about this subject, is critical to implement management applications which will ensure long-term forest sustainability. Although many areas related to the early growth and initiation of aspen suckers demand further study, hopefully by using the information gained in this study, analysis, and the visual slash loading guide, the ecology of trembling aspen and factors affecting stand re-establishment will be better understood.

Appendix A: Soil characteristics in the Duck Mountain study area

Table A.1 Summary of soil characteristics for six winter cutblocks in the Duck Mountain area.

Site	Depth (cm)	Organic Carbon (%)	Nitrogen (%)	pH	Total Carbon (%)
Minnitonas Cr. 1	lfh (7.0)†	32.473	2.263		31.567
	0-15	1.056	0.083	6.74	1.269
	15-30	0.526	0.040		1.590
	30-45	0.243	0.021		2.660
Minnitonas Cr. 2	lfh (7.5)	40.507	2.333		38.333
	0-15	0.751	0.054	6.40	0.944
	15-30	0.644	0.052		0.721
	30-45	0.719	0.046		1.992
West Favel	lfh (6.0)	24.347	1.863		24.367
	0-15	1.328	0.094	5.68	1.447
	15-30	0.698	0.069		0.946
	30-45	0.557	0.042		2.480
Route H	lfh (8.0)	29.417	1.673		32.733
	0-15	1.576	0.104	6.94	1.740
	15-30	0.894	0.066		1.551
	30-45	0.431	0.040		3.717
Arm Lake	lfh (7.5)	31.153	1.690		32.400
	0-15	0.613	0.039	6.95	0.772
	15-30	0.706	0.054		2.157
	30-45	0.440	0.033		2.863
Madge Lake	lfh (8.0)	39.843	2.043		37.200
	0-15	0.891	0.065	6.55	1.036
	15-30	0.674	0.054		0.687
	30-45	0.529	0.051		0.663

† The value in brackets indicates the depth of leaf litter layer.

Table A.2 Summary of soil characteristics for six summer cutblocks in the Duck Mountain area.

Site	Depth (cm)	Organic Carbon (%)	Nitrogen (%)	pH	Total Carbon (%)
Wine Lake	lfh (6.5) †	41.877	2.188		37.750
	0-15	1.626	0.142	6.16	1.958
	15-30	0.420	0.052		0.628
	30-45	0.417	0.049		0.967
Watjask Lake	lfh (6.5)	37.260	1.888		34.075
	0-15	1.109	0.077	6.16	1.139
	15-30	0.684	0.063		0.748
	30-45	0.550	0.067		0.855
Cryderman's Pit	lfh (9.0)	35.837	2.093		36.367
	0-15	0.800	0.064	5.90	1.039
	15-30	0.628	0.054		0.762
	30-45	0.293	0.035		0.493
Route W	lfh (4.5)	27.807	1.442		28.500
	0-15	3.197	0.216	6.68	3.223
	15-30	1.228	0.088		1.267
	30-45	0.663	0.050		3.558
Upper Dam	lfh (4.0)	32.503	2.098		34.375
	0-15	1.070	0.073	7.03	1.220
	15-30	0.659	0.056		0.979
	30-45	0.980	0.054		2.547
Ethelbert Trail	lfh (5.0)	32.623	1.868		33.425
	0-15	1.056	0.068	6.86	1.145
	15-30	0.849	0.060		2.238
	30-45	0.421	0.036		2.935

† The value in brackets indicates the depth of leaf litter layer.

Table A.3 Selected soil characteristics at the Wine Lake permanent sample plot, in the Duck Mountain eco-region, Manitoba.

Rep	**Slash Load**	**Effective Soil Texture**	**Bulk Density (g m^{-3})**	**pH**	**Field Capacity (KPa)**	**Permanent Wilting Point (KPa)**
1	None	Clay loam	1.64	5.19	28.2	27.4
	Half	Clay loam	1.52	5.98	33.8	30.2
	Full	Clay loam	1.60	5.67	31.2	31.0
	Double	Clay loam	1.29	5.49	35.4	32.0
2	No	Clay loam	1.35	6.97	35.6	34.3
	Half	Clay loam	1.51	5.22	29.4	25.7
	Full	Clay loam	1.40	6.36	35.1	32.5
	Double	Clay loam	1.67	5.76	28.6	26.3
3	No	Clay loam	1.54	6.25	24.0	19.5
	Half	Clay loam	1.54	5.51	30.7	29.1
	Full	Clay loam	1.65	6.32	30.3	27.8
	Double	Clay loam	1.68	6.06	26.9	22.3
4	No	Clay loam	1.42	5.30	33.6	32.3
	Half	Clay loam	1.58	5.81	30.0	28.8
	Full	Clay loam	1.57	5.69	28.2	25.0
	Double	Clay loam	1.58	5.84	26.2	24.2

Table A.4 Summary of soil characteristics for the Wine Lake permanent sample plot in the Duck Mountain area, Manitoba.

Rep	Slash	Depth (cm)	Organic Carbon (%)	Nitrogen (%)	Carbon (%)
1	None	Lfh	13.41	0.786	14
		0-10	1.8	0.135	1.84
		10-20	0.397	0.0538	0.604
		20-30	0.164	0.0414	0.346
	Half	Lfh	38.77	1.64	35.95
		0-10	1.255	0.1425	1.555
		10-20	0.483	0.0796	0.751
		20-30	0.23	0.0499	0.459
	Full	Lfh	40.19	1.86	37
		0-10	1.718	0.167	1.77
		10-20	1.181	0.103	1.15
		20-30	0.748	0.0995	0.955
	Double	Lfh	20.86	0.96	20
		0-10	1.812	0.193	2.08
		10-20	0.616	0.0968	0.917
		20-30	0.315	0.05145	0.596
2	None	Lfh	32.44	1.61	30.4
		0-10	2.887	0.253	3.04
		10-20	0.811	0.0784	0.892
		20-30	0.744	0.12	1.35
	Half	Lfh	33.06	1.54	31.6
		0-10	2.769	0.246	3.03
		10-20	0.721	0.0789	0.861
		20-30	0.545	0.0635	0.708
	Full	Lfh	25.7	1.23	23.5
		0-10	2.553	0.207	2.64
		10-20	1.1	0.106	1.22
		20-30	0.557	0.0654	0.714
	Double	Lfh	38.48	1.56	34.1
		0-10	2.64	0.217	2.97
		10-20	0.651	0.0809	0.888
		20-30	0.514	0.07	0.702†

† Table continued on following page.

Table A.4 continued. Summary of soil characteristics for the Wine Lake permanent sample plot in the Duck Mountain area, MB.

Rep	**Slash**	**Depth** **(cm)**	**Organic Carbon** **(%)**	**Nitrogen** **(%)**	**Carbon** **(%)**
3	None	Lfh	32.51	1.57	31.3
		0-10	1.025	0.0977	1.21
		10-20	0.374	0.059	0.641
		20-30	0.256	0.0423	0.453
	Half	Lfh	24.88	1.335	25.2
		0-10	1.261	0.124	1.26
		10-20	0.711	0.0696	0.717
		20-30	0.289	0.044	1.28
	Full	Lfh	18.22	0.966	18.7
		0-10	1.308	0.13	1.42
		10-20	0.622	0.0695	0.708
		20-30	0.267	0.0477	0.516
	Double	Lfh	37.49	1.7	35.3
		0-10	2.42	0.206	2.38
		10-20	0.835	0.0865	1.02
		20-30	0.473	0.0531	0.67
4	Full	Lfh	27.76	1.41	26.5
		0-10	1.618	0.16	1.77
		10-20	0.65	0.0699	0.81
		20-30	0.245	0.0549	0.542
	None	Lfh	29.48	1.49	29.1
		0-10	2.201	0.19	2.17
		10-20	0.638	0.0702	0.759
		20-30	0.428	0.0659	0.67
	Half	Lfh	20.7	0.944	18.1
		0-10	1.097	0.09235	1.305
		10-20	0.691	0.0673	0.758
		20-30	0.399	0.047	1.43
	Double	Lfh	9.486	0.575	9.98
		0-10	0.895	0.0834	0.976
		10-20	0.412	0.0629	1.05
		20-30	0.201	0.0399	1.07

Appendix B: Estimation of slash loading

Table B.1 Unit biomass (kg m^{-2}) according to diameter size of slash used to calculate slash loads for the modified Newman line intersect calculations.

Diameter size (cm)	Unit biomass (kg m^{-2})
< 1	0.015956
1 to 5	0.31374892
5 to 10	2.63948893
10 to 20	7.71979111
> 20	21.2986755

Once quantified, it was apparent that the visual method used to establish plots was, in most cases, reasonably accurate at delineating distinct slash load categories under each of the soil temperature probes (Table 9.2). Table 9.2 demonstrates that while the slash load category overlap was moderate in winter cutblocks, there was no overlap in summer cutblocks. Although in most cases the categories were reasonably distinct, in the winter cutblocks, the high slash load plot established at Minnetonas Creek 2 (Min 2) seemed to be too light of a slash load to be categorized in the high slash load category (Table 9.2). When this plot was removed, there was clear separation between categories and the mean in the high category increased from 57.55 kg/m^2 to 66.29 kg/m^2. To keep the slash categories discrete, the temperature data and aspen regeneration data collected from this plot were not used in statistical evaluation of the effects of slash loading on both soil temperatures and aspen regeneration. The no slash load category is absent from this table as these plots were chosen with no slash on them and were not quantified.

Table B2 Estimated slash load (kg m^{-2}) at all 12 cutblocks separated by visual slash load categories.

Winter Cutblocks			**Summer Cutblocks**			
Site	**Moderate**	**High**	**Site**	**Moderate**	**High**	**Very High**
Min 1	16.39	28.30	Wine Lake	7.01	13.42	61.93
Min 2	4.66	**13.87**	Watjask	6.77	17.37	40.88
West Favel	4.99	61.56	Cryderman	7.05	25.29	78.61
Route H	12.71	110.27	Route W	13.36	22.52	42.70
Arm Lake	16.89	86.08	Upper Dam	4.35	29.24	35.00
Madge Lake	13.75	45.24	Ethelbert	4.96	20.94	50.81
Mean	11.57	57.55	**Mean**	7.25	21.46	51.65

Visual subsample plots were established for the aspen regeneration measurements, and when these slash measurements were brought back to the lab and the amount of slash in the subsample plots was calculated, a problem was noted in the plots chosen in the summer cutblocks (Table 9.3). In most cases, the subsample plots in the summer cutblocks, which were visually chosen, did not seem to fit into the appropriate slash load category. As these plots were visually selected at the same time that the very high plots were chosen for the summer cutblocks, it is likely that the categories were overestimated in the search for areas within the cutblock with “very heavy slash” loads. Subsamples in the summer cutblocks were recategorized according to their slash load in order to reduce the category overlap and obtain similar slash load means to the first samples which were already well established (Table 9.4).

In the winter cutblocks the estimated mean slash load in the moderate and heavy categories (11.94 kg m^{-2} and 62.94 kg m^{-2}) were fairly similar to the means before the subsamples were included (11.57 kg m^{-2} and 57.55 kg m^{-2}). The plot at Minnetonas Creek 2 (Min 2) was the only plot that seemed to differ from the first plots that were established. This plot seemed to be slightly on the high side for a “moderate” slash load, however, it did not overlap with the heavy category. The lack of overlap in the categories in the winter cutblocks indicated that our visual estimation was acceptable and no subsamples were omitted or recategorized (Table 9.3, Table 9.4).

Table B.3 Estimated slash load (kg m^{-2}) at all 12 cutblocks under varying slash loads.

Winter Cutblocks			**Summer Cutblocks**			
Site	**Moderate**	**High**	**Site**	**Moderate**	**High**	**Very High**
Min 1	16.39	28.30	Wine Lake	7.01	13.42	61.93
Min 1	14.52	43.05	Wine Lake	20.70	42.01	
Min 2	4.66	---†	Watjask	6.77	17.37	40.88
Min 2	19.07	32.93	Watjask	15.24	48.21	
West Favel	4.99	61.56	Cryderman	7.05	25.29	78.61
West Favel	10.76	94.09	Cryderman	25.87	52.40	
Route H	12.71	110.27	Route W	13.36	22.52	42.70
Route H	9.54	89.06	Route W	10.92	42.75	
Arm Lake	16.89	86.08	Upper Dam	4.35	29.24	35.00
Arm Lake	5.02	38.05	Upper Dam	10.93	37.99	
Madge Lake	13.75	45.24	Ethelbert	4.96	20.94	50.81
Madge Lake	15.02	63.73	Ethelbert	20.73	52.60	
Mean	**11.94**	**62.94**	**Mean**	**12.32**	**33.73**	**51.65**

† This plot was excluded as the slash load did not fall within the boundaries of the high slash load category.

Table B.4 Estimated slash load (kg m^{-2}) at all 12 cutblocks with subsamples in the summer cutblocks recategorized.

Winter Cutblocks			**Summer Cutblocks**			
Site	**Moderate**	**High**	**Site**	**Moderate**	**High**	**Very High**
Min 1	16.39	28.30	Wine Lake	7.01	13.42	61.93
Min 1	14.52	43.05	Wine Lake		20.70	42.01
Min 2	4.66	Excluded	Watjask	6.77	17.37	40.88
Min 2	19.07	32.93	Watjask		15.24	48.21
West Favel	4.99	61.56	Cryderman	7.05	25.29	78.61
West Favel	10.76	94.09	Cryderman		25.87	52.40
Route H	12.71	110.27	Route W	13.36	22.52	42.70
Route H	9.54	89.06	Route W	10.92		42.75
Arm Lake	16.89	86.08	Upper Dam	4.35	29.24	35.00
Arm Lake	5.02	38.05	Upper Dam	10.93		37.99
Madge Lake	13.75	45.24	Ethelbert	4.96	20.94	50.81
Madge Lake	15.02	63.73	Ethelbert		20.73	52.60
Mean	**11.94**	**62.94**	**Mean**	**8.17**	**21.13**	**48.82**

Appendix C: Location of field sites

Table C.1 Global Positioning Co-ordinates of cutblocks.

Site	Global Positioning Co-ordinate
	Winter Cutblocks
Madge Lake	14 U E 0323312 N 5721002
Arm Lake	14 U E 0353060 N 5697543
Route H	14 U E 0353046 N 5697551
West Favel	14 U E 0360075 N 5755538
Minnitonas Creek 1	14 U E 0353139 N 5758412
Minnitonas Creek 2	14 U E 0353697 N 5758529
	Summer Cutblocks
Watjask	14 U E 0328283 N 5721856
Cryderman’s Pit	14 U E 0368444 N 5768650
Route W	14 U E 0349845 N 5754500
Wine Lake	14 U E 0343967 N 5703731
Ethelbert Trail	14 U E 0390835 N 5711661
Upper Dam	14 U E 0365919 N 5702021

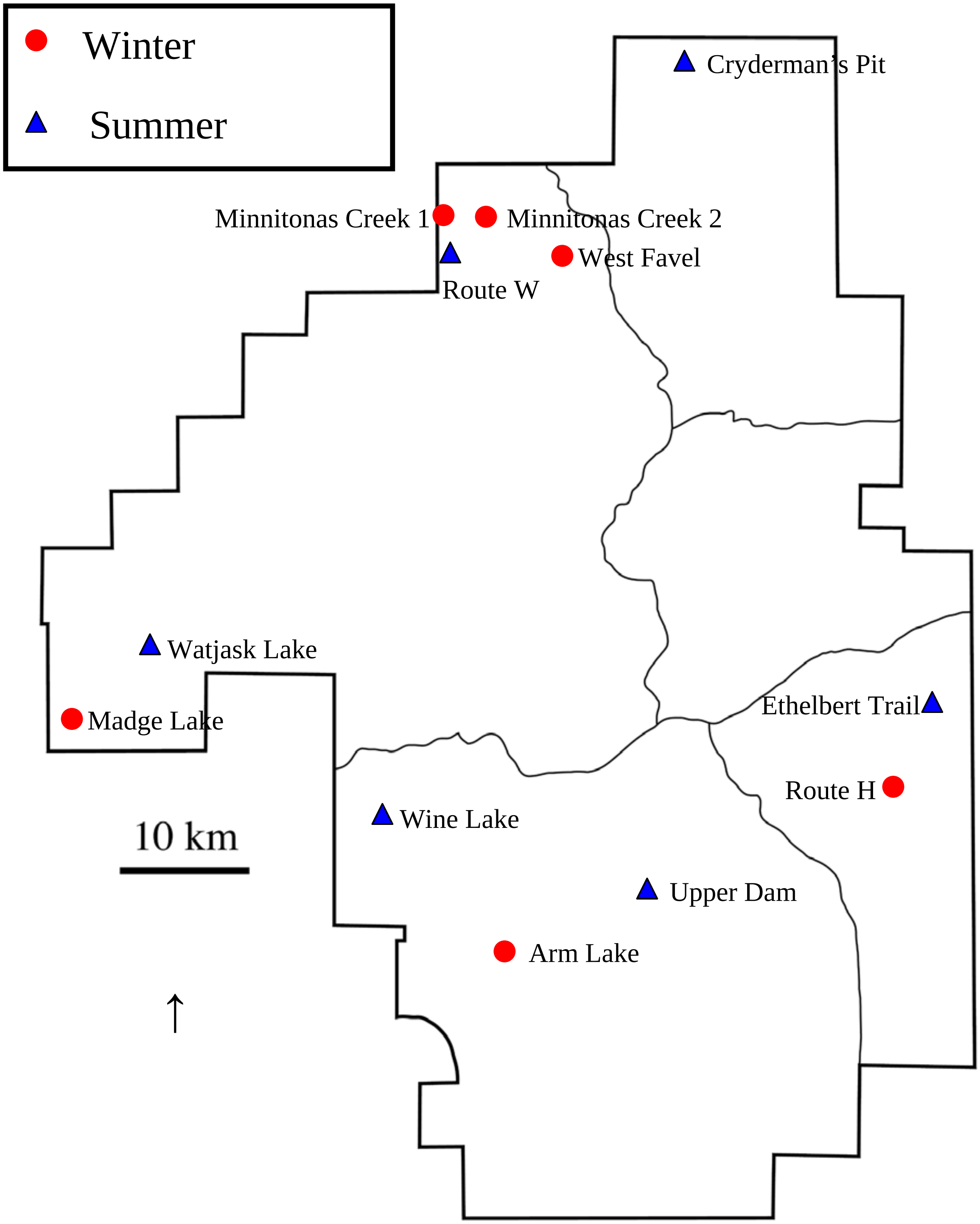

Figure C.1 Spatial Distribution of twelve cutblocks within the Duck Mountain area.

Appendix D: Visual slash loading guides

Using pictures of various levels of slash, two visual guides were created. A shorter guide was created in order to establish a quick, easy to use, reference for field operators, while a longer, more in depth guide was created for management staff. Both guides visually identified three levels of slash loads: loads greater than 200 t ha^{-1}, loads between 200 t ha^{-1} to 400 t ha^{-1}, and loads less than 400 t ha^{-1}. These guides use indicator levels slightly different than those in the study; because of the different levels of slash in winter and summer cutblocks, these levels were chosen to represent a combination of moderate, high and very high slash loads in both winter and summer cutblocks. These guides emphasized that levels above 400 t ha^{-1} will likely have a visible effect on aspen regeneration in both winter and summer cutblocks and operators should attempt to redistribute the slash in such areas throughout the cutblock. These guides are not published, however, they have been made available to L-P staff and harvest operators.

Visual Slash Loading Guide

Forest companies are concerned about the effects of heavy slash loads on aspen regeneration. Increased slash loads result in decreased soil temperature and this affects the number of aspen suckers and growth. This negative effect on aspen is important since early sucker growth is necessary to maintain the parental root system.

Distributing slash more evenly in cutblocks may decrease this negative effect on aspen suckers and aspen root systems. Harvest operations should avoid producing areas of very dense slash to ensure healthy aspen root systems able to sustain mature, fully stocked stands.

To visually determine levels of slash where aspen suckering will be affected, the following categories should be considered:

	Light	**Moderate**	**Heavy**
Slash load (t/ha)	<200	200 - 400	> 400
Exposed forest floor (%)	>60	40-80	<20
Effects on aspen regeneration	none	minimal	moderate to severe

Machine operators should distribute slash at levels less than 400 t/ha. Areas with heavy slash loading should be minimized to ensure successful aspen regeneration throughout the cutblock.

Light

Moderate

Heavy

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306-966-6853, November 2000

Slash Loading

A VISUAL GUIDE

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November 2000

Slash Loading

Trembling aspen (*Populus tremuloides* Michx.) is the dominant hardwood tree species harvested in the Canadian Prairie Provinces. Because of the strong pioneering capability of aspen and its ability to produce suckers, natural regeneration is the primary method used to restock these hardwood forests. Successful regeneration of these hardwood forests depends on warm soils after clearcutting in order to stimulate sucker growth. Slash left on the cutblock after harvest greatly affects soil temperatures by intercepting solar energy and acting as an insulator. Because soil temperature depends on the movement of heat energy to and from the soil surface, the type and density of slash left on the cutblock can have significant effects on aspen regeneration. Increased levels of slash loading result in reduced aspen regeneration and reduced aspen growth.

In terms of its effects on aspen regeneration, slash loading in the cutblock can be broken down to three simple categories: light, moderate, and heavy. Areas with a heavy covering of bark and wood chips have a negative effect on aspen growth similar to those under heavy slash loads. The following slash loading guide is a visual display of these different levels of slash.

Light	- less than 200 t/ha of slash - greater than 60% of forest floor visible - no noticeable effect on aspen regeneration
Moderate	- 200 t/ha to 400 t/ha of slash - 40% to 80% of forest floor visible - minimal effect on aspen regeneration
Heavy	- more than 400 t/ha of slash - slash may be several layers high - less than 20% of forest floor visible - visible effect on aspen regeneration

Light (0-200 t/ha)

Moderate (200-400 t/ha)

Heavy (>400 t/ha)

Tree bark

Recommendations

In order for operators to visually determine levels of slash where aspen suckering is likely to be affected, they must be able to distinguish between Light, Moderate, and Heavy slash loads. Optimally, residual slash should be distributed within the cutblock so that areas with more than 400 t/ha are minimized. Long term management and proper distribution of slash within cutblocks will ensure that healthy aspen root systems will be maintained which will in turn ensure aspen forest sustainability.