Using a Geographic Information System and Remotely Sensed Thermal Imagery to Investigate Frost-prone Areas within the Cariboo Forest Region

by

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B.Sc., University of Victoria, 1993

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in the Department of Geography

We accept this thesis as conforming
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Abstract

Frost can be a significant limitation to forest re-growth in the interior areas of British Columbia. Knowledge of frost sensitive areas can facilitate the selection of replanting strategies after harvesting. Technology associated with geographic information systems (GIS) and remote sensing provides new methods to investigate climatic phenomena such as frost. This research uses a GIS to combine selected topographic, forest and soil data variables with remotely sensed nocturnal surface temperatures for five areas within the Cariboo Forest Region (British Columbia, Canada). Nocturnal surface temperatures were measured via airborne thermal imagery taken during a calm, clear night (September 2, 1988). The GIS worked well to combine the spatial information and produce the multivariate spatial databases. Due to the limited statistical capabilities of the GIS, the analysis of the variables was completed using statistical software. Cross-tabulation, ordinary least squares regression, and interval regression were performed on the multivariate data to investigate the influence of the selected variables on surface temperature. Conducting analysis using multivariate databases was an important advantage since they provided additional explanation for specific relationships (*e.g.* anomalies) between certain variables. Local relative elevation and slope were the only two variables found to have consistent positive relationships with surface temperature for all five selected study areas. In addition, it was found that relative elevation was most influential in one of the study areas which had a substantially higher average slope. Upon further investigation, it was also found that slope was most influential for study areas which had a large difference in relative elevation. Despite certain limitations, this research has demonstrated that greater knowledge with respect to frost research can be gained by using remotely sensed thermal imagery and GIS.

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Acknowledgments

Funding for this research was provided by a research grant from Forest Renewal British Columbia. I would also like to thank the B.C. Ministry of Environment, Lands and Parks and the B.C. Ministry of Forests for supplying necessary spatial data and translation programs for this research project.

I sincerely appreciate the support of Ordell Steen and Ray Coupé of the B.C. Ministry of Forests (Cariboo Forest Region) for providing data, information and assistance for this research. I would also like to thank Richard Reich and Ralph Adams of the B.C. Ministry of Forests for their advice and support, Dr. Arthur Sweetman (Dept. of Economics, University of Victoria) for his generous help and guidance with the statistical analyses, and Ze'ev Gedalof for his assistance with the GIS work.

Dedication

I would like to dedicate this to my wife, Jacqueline, and to my parents, for being my sources of inspiration, strength and determination.

Chapter 1

Introduction

Frost is a well known, naturally occurring phenomenon which can significantly affect our lifestyles. The effects of frost can reverberate from the cost of orange juice, to road conditions when we drive, to the cost of lumber to build houses, to list but a few examples. Frost can have severe consequences in areas where it is common. However, in areas which experience very few frost events, the severity can be even greater due to the unexpectedness and lack of preparedness.

Frost is defined by the temperature of a surface (*i.e.,* ground, plant, object) being at, or below, 0^{o}C (Geiger 1965). There are two general types of frosts: advection frosts and radiation frosts. Advection frosts occur over large areas by the advection of cold air. Radiation frosts are caused by *in situ* radiational cooling under calm conditions (*i.e.,* low winds) and clear skies. Common frost prevention measures are most effective against radiation frosts since local site characteristics are easier to control (Oke 1987).

Methods have been developed to reduce frost danger by taking direct and active intermediary actions when frost occurs. These methods range from simple frost warnings to more complex methods of frost intervention. Intervening methods to protect against frost range from sprinkler irrigation (provides latent heat of fusion as water turns to ice), to heat generators (produces internal heat and creates turbulence within the crop environment), to wind machines (mixes cold air near the ground with warmer air aloft), to artificial fog production and protective covers (reduces net longwave radiation loss by creating an absorbing and re-emitting barrier between the ground and the open sky) (Kalma *et al.* 1992, Geiger 1965).

The above methods are costly and time consuming and were developed primarily for agriculture rather than larger scale applications such as forestry. As reforestation efforts come to the forefront of forest management, frost occurrence within regenerated areas can represent a severe danger and cost to re-establishing forests after harvesting.

Therefore, a balance is required between ensuring adequate survival of plantations in frost-prone areas and the cost involved in doing so.

Passive methods can also be used to reduce the chance of damage caused by frost. These techniques often involve a greater commitment of time for research and planning, but in the long term can be more effective, less costly and less labour intensive. Passive methods are varied and range from methods of soil management (*e.g.,* keeping soils bare, firm and moist), plant management (*e.g.,* growing taller plants, timely pruning and application of fertilizer), to the use of growth regulators to delay or induce flowering (which is generally the most susceptible stage in plant development with respect to frost damage) (Blanc *et al.* 1963 as cited by Kalma *et al.* 1992).

Careful site selection is another effective passive method to reduce the negative impacts associated with frost (Oke 1987). "The most effective weapon that men possess against frost damage is preventative action" (Geiger 1965, 510). This idea is supported further by W.J. Humphreys in a quote from 1914 referring to frost risk in orchards (cited by Geiger 1965, 510): "The best time to protect an orchard against frost is when the orchard is being established.". Careful consideration and assessment of microclimate influences which inhibit or enhance the occurrence of frost should therefore be completed before investing time and money into an area where frost could be a detriment to the investment. If an area is highly susceptible to frost, certain decisions can be made about harvesting design (*i.e.,* partial cutting, refraining from harvesting, shelterbelts) and regeneration (*i.e.,* replanting frost resistant species) before disturbing the area. Even though careful frost assessment and planning is one of the most effective methods to reduce the detrimental effects of frost, it often is overlooked or ignored in agriculture and forestry planning, leading to failures of many agricultural crops and forest plantations (Geiger 1965, Steen *et al.* 1990).

In order to initiate this method of passive frost risk management, it is necessary to be familiar with the theoretical relationships of variables which can influence the occurrence of frost. With respect to specific variables related to frost occurrence, much knowledge has already been gathered through previous research. Therefore, a strong theoretical foundation exists on which to base further investigation.

1.1 Objectives of Research

Information regarding many of the variables investigated in previous frost research are presently available in several separate digital spatial databases. Variables such as slope, aspect, elevation, terrain convexity/concavity, forest species, crown closure, stand height, stand age, and soil classifications are contained in spatial databases which can be directly compared and customized to investigate unique relationships related to frost. In addition, remote sensing devices, such as thermal scanners, can be used to collect continuous spatial surface temperature measurements of landscapes subject to frost. Therefore, it now is possible to collect data related to frost (*i.e.,* surface temperatures) and combine these with data on other factors identified to influence frost occurrence.

In order to understand how the variables influence frost, a structure is required to combine the separate spatial data sets to investigate the relationship between the influential variables and surface temperatures. A geographic information system (GIS) provides a computational structure which enables the combination of spatially related information. Subsequently, statistical analyses can be used to investigate relationships which may exist between the independent variables and the resultant variable (*i.e.,* frost).

The primary objective of this research is to investigate the relative influence of selected variables on remotely sensed surface temperatures using a GIS to combine relevant spatial data. The possible implication of this research is that sites which are susceptible to frost could be more readily identified, allowing forest managers to avoid conducting frost sensitive forestry activities on frost sensitive sites.

1.2 Organization of Thesis

The following chapter begins by briefly reviewing early frost research and then focusing on specific variables which influence frost formation. The theoretical relationships of these variables with surface temperature and frost is discussed and focuses on recent research relevant to these variables. The chapter then introduces some problems with traditional techniques of frost research and concludes by discussing how current technology (used in this research) can help to alleviate some of these problems.

Chapter Three reviews the sources of data used for this research. The first section of this chapter introduces the research study areas and gives the rationale for their selection. A short description of each area is presented, including an introduction to the associated portion of thermal imagery and recent aerial photographs. The chapter concludes by reviewing the sources of the digital spatial data for many of the frost control variables.

The methods used for this research are outlined in the fourth chapter. This chapter reviews the processes used to create the spatial databases for each of the study areas (guided by the site specific variables discussed in Chapter Two). More specifically, the chapter reviews the methods used to produce, translate, input, manipulate and model the relevant data in order to produce the final multivariate spatial databases for each study area. The last section of this chapter reviews the selection of statistical techniques evaluated for this research.

The results from the statistical analyses are presented in Chapters Five and Six. The fifth chapter provides a summary of the cross-tabulated relationships which exist between the dependent/independent variable pairings in each study area. The results from the regression analyses are presented in Chapter Six. The first section reviews the results from each study area. The second section compares the influence of each variable between study areas. The final section of this chapter summarizes the results from the interval regression analysis.

The last chapter concludes this thesis by discussing the main findings. In addition, the limitations of the research are presented with recommendations for future research. The chapter concludes by discussing possible implications of this research.

Chapter 2

Theoretical Context and Research Review

Early frost risk research, particularly as it pertains to agriculture and forestry, has been well documented in Geiger's (1965) "*The Climate Near the Ground*". Geiger (1965) cites many examples of frost related research pertaining to such things as topographic influence (*e.g.*, Geiger and Fritzsche 1940; Geiger 1926; Winter 1958), frost prevention measures (*e.g.*, van Eimern 1955; Small 1949; Dinkelacker and Aichele 1958; Kessler and Kaempfert 1940; von Pogrell 1958; Niemann 1957) and early frost mapping research (*e.g.*, Godske 1944; Aichele 1953; Kaps 1952; van Eimern 1951; Kern 1951; Schüepp 1948; Mason 1958; Franken 1959; Krühne 1954; Reichelt 1954; Winter 1958).

For large scale frost risk assessments, Geiger (1965) recognizes the importance of being able to assess the distribution of nocturnal minimum temperatures over larger areas. Geiger (1965, 402) categorizes the previous research relating to large scale frost assessment into three methods:

> "The first method, which is independent of all hypotheses, is to plot all minimum temperatures observed on a particular night on a height contour map of the area....The second method, which is used much more frequently, is to plot the average frost danger based on temperature measurements and observational frost damage. The maps are then constructed to show three to five frost-danger zones, depending on the purposes for which they are designed....The effects of any single damaging frost, of course will depend on the weather situation, wind and cloud cover on that particular occasion....These only summarize the average situation, and do not describe a particular one....The third method is to map the actual damage caused by frost"

Kalma *et al.* (1992) also provide a comprehensive overview of frost and review more recent literature and research. Of particular interest is 1) the detailed discussion of variables which influence frost, 2) modern research techniques to map, investigate and evaluate frost risk, and 3) the expansion of traditional frost research method.

The following section of this chapter will review prominent factors which influence frost (*i.e.*, variables). Since this research focuses on specific variables, the particular variables will be identified followed by a rationale for their selection. The third section of this chapter reviews theoretical parameters of the selected variables as they relate to frost and reviews recent frost research pertaining to these variables. The section concludes with a review of certain problems associated with traditional data collection for frost research. This provides a logical progression to the next section of the chapter which explores how the technology associated with remote sensing and geographic information systems can be used to alleviate some of the problems identified and help to progress frost research.

2.1 Prominent Variables which Influence Frost

The reasons why frost, particularly radiation frost, occurs at a specific site has much to do with the site characteristics and how these characteristics influence climatic processes which, in turn, influence frost. Site specific factors refer to variables such as soil composition, slope, aspect, elevation, ground curvature and vegetation cover (*i.e.,* species composition, height, crown closure) which remain relatively constant with respect to time. Atmospheric variables also influence frost (*i.e.,* wind, humidity, air temperature, cloud cover). Atmospheric variables, however, are much more dynamic through time and space, and generally are measured by standard climate stations spaced at large intervals. Kalma *et al.* (1986) express the risk of using climate station data since the spatial density of the climate stations is generally not adequate to investigate frost on a meso-scale. Climate stations also are commonly located in valley bottoms which limits the topography sampled.

It is generally simpler to examine site specific variables (*i.e.,* slope, aspect, elevation, ground cover) on a meso-scale since most of these variables are relatively stable (temporally and spatially). These variables also are better represented on paper maps or digital spatial databases. Therefore, this research will focus its attention on site specific variables. This, however, is not meant to imply that atmospheric variables have any less importance than the selected site variables with respect to frost formation.

2.1.1 Topographic Variables

It has been proposed in earlier research that frost classification can be based on certain site specific variables in those areas which lack intensive climate station networks (or climate stations at all). Hocevar and Martsolf (1971) examined the temperature distribution during a radiation frost event and how the temperatures were related to the local topography. They suggested that cold air drainage is governed by the features of relief and that the relative height of the site above the valley bottom has a large influence on frost potential. Therefore, it was concluded that topography should be used as a first approximation for testing frost (Hocevar and Martsolf 1971). Another important observation of their research was that frosts occur in similar places on representative radiation frost nights (*i.e.,* calm and clear nights).

Mahrt and Heald (1983) similarly examined the role of elevation in determining nocturnal surface temperatures. They also concluded that terrain curvature was the dominant process which influenced how surface temperatures were distributed on the landscape.

Steen *et al.* (1990) investigated a number of site characteristics within the Cariboo Forest Region in British Columbia to determine frost risk and derive a frost risk classification. In their research, they suggested that frost risk assessment based on biogeoclimatic variants (*i.e.,* a landscape classification based on vegetation, physiography and climate) could be further refined by using meso-slope position and slope gradient. They suggested that, on a meso-scale, areas near the base of slopes with slope gradients less than 15 per cent are conducive to accumulating cold air. These areas, therefore, present a greater frost risk. Conversely, areas near tops of slopes and at mid-slope with slope gradients greater than 15 per cent tend to shed cold air and are, therefore, relatively warmer. Steen *et al.* (1990) recognized that further refinements may be necessary due to the interaction of variables and suggest that upslope source area, impediments to cold air drainage, cold air channeling, microtopography, aspect, vegetation cover and mineral soil exposure are among other factors to consider when assessing an area for frost risk.

Kalma *et al.* (1983) used land cover information for frost mapping (in Southern Victoria, Australia), and found that elevation, terrain, and land cover were the most important meso-scale determinants of frost. Kalma *et al.* (1986) further investigated trends which deviated from the dependence of apparent surface temperatures on elevation and found that the convexity/concavity of the landscape, vegetative cover and water surfaces accounted for a large portion of the deviation on representative frost nights. Kalma *et al.* (1992) subsequently developed a simple elevation model to explore this relationship. The intervening influence of land cover (*i.e.*, vegetation) was recognized to affect surface temperatures. Kalma *et al.* (1992) therefore suggested that frost maps should only be used to interpret land covers that are similar to those for which the data were obtained, and on which the algorithms are based.

The following sub-sections will review the theory of how topographical variables (slope, aspect, elevation and terrain curvature) influence frost.

2.1.1.1 Slope and Aspect

Slope and aspect are inextricably linked since every sloped surface, by definition, has an aspect. In addition, some theoretical parameters relating to frost which are affected by slope also are affected by aspect. This theoretical review will first consider the slope variable, and then discuss the influence of the aspect variable with respect to frost.

The occurrence of frost on a site can be significantly influenced by the slope of the landscape. Generally, areas which have steep slopes are likely to have relatively higher surface temperatures compared to areas with little or no slope. Greater slopes produce greater katabatic drainage rates (Oke 1987). This effect has much to do with how cold air behaves under the influence of gravity. Cold air is denser and is negatively buoyant compared to warmer air. Therefore, it will flow down a slope (like water) until it reaches neutral buoyancy (by warming), or until it is impeded (*e.g.*, at the bottom of an enclosed basin, a wall of trees at the lower end of a clearing). The analogy between cold air drainage and water drainage has been used to derive models which examine the role of slope by linking the convergence and divergence of streamlines to cold air dispersal and accumulation at a site (*e.g.*, Laughlin and Kalma 1987).

The flow of cold air which occurs within a few metres of the ground surface is referred to as skinflow. It is the most responsive component of the katabatic flow with respect to the spatial differences of cooling rates (Laughlin and Kalma 1987). "In the case of skinflow, the resulting driving force for a given density gradient in the downslope direction, should be proportional to slope. In other words, as the slope becomes steeper it is less likely cold air will accumulate there" (Laughlin and Kalma 1987, 11).

An interesting feature found to occur on steep slopes is the gusting of cold air flow (Geiger 1965, Oke 1987). Reasons for the gusting cold air drainage on steep slopes are not well understood. However, some explanations have been put forth. Nitze (1936 as cited by Geiger 1965) suggested that as long as the slope gradient is small, the air will flow very slowly since the amount of friction is great when the air is in contact with the ground. However, when the slope is steeper and the cold air collects in sufficient quantity, the air begins to slide, overcoming frictional forces and entraining the air behind it. A strong cold air current develops which persists until there is no longer cold air behind the flow to support it. The term "air avalanche" has been used to refer to this gusting of cold air drainage on steeper slopes (Geiger 1965).

Slope angle also affects the radiational cooling/warming of the ground surface and, thus, the temperature of the lower air. In clear and windless nocturnal conditions, slopes can effectively reduce the amount of longwave radiation lost at a site by reducing the proportion of the cold open sky. For example, if a site is located on a flat area, it will be exposed to the entire 180° hemisphere of the cold, open sky. However, if a site is located on a slope, a certain amount of the open sky is replaced by the earth's surface. During the night, the open sky is much colder than the earth's surface, therefore, more longwave energy will be lost from an area situated on a flat site compared to a sloped site. This is due to the difference in emissivity and temperature between the earth and the open sky. The effect is the same as for other vertical obstructions to the open sky (*i.e.*, trees) (discussed below in Section 2.1.3). During the day, solar energy warms the surface and this energy can also be transferred and stored in the subsurface. This provides a source of energy to keep the surface (and the air layer close to the surface) warm at night.

Slope also affects the amount of solar irradiance received at a site. Solar irradiance is composed of both direct and diffuse beam. Direct beam solar irradiance is that energy received directly from the sun. Diffuse beam is that energy from the sun which has been reflected and scattered by clouds, dust particles, atmospheric gases, *etc.*. Slope affects direct beam solar irradiance much more than diffuse beam solar irradiance. This is because the concentration of energy per unit area is much greater for direct beam solar irradiance. In addition, direct beam solar irradiance is highly directional, whereas diffuse beam solar irradiance is more uniform since it comes from the entire sky dome.

The irradiance received by a surface from direct beam solar irradiance (S) depends upon the angle of S to the surface. Since S is approximated as a parallel beam, the irradiance received by a horizontal surface is a function of the angle of the beam to that surface (Oke 1987). Following the cosine law of illumination, the relationship between the illumination and the angle of S is illustrated by the following equation for direct beam solar irradiance on a horizontal surface:

(Equation 2.1)

$$S = S_i \cos\Theta$$

where S = flux density of the direct solar beam at the horizontal surface
S_i = flux density normal to the beam
Θ = angle between the beam and the normal to the horizontal surface.

Sloping surfaces will affect the flux density of direct beam solar radiation received at the ground surface, therefore yielding the relationship illustrated by the following equation (Sellers 1965, 35):

(Equation 2.2)

$$S^I = S_i \cos\Theta' = S_i[\cos\Theta \cos\iota + \sin\Theta \sin\iota \cos(a - a')]$$

where S^I = instantaneous flux of direct beam solar radiation on a sloping surface
Θ' = angle between the incident solar rays and the normal to the sloping surface
ι = angle between the sloping surface and a horizontal surface
a = azimuth angle of the sun from the south
a' = azimuth angle of the normal to the surface from south.

These equations show that maximum direct beam solar radiation occurs when the receiving surface is perpendicular to the beam of the sun's rays. Thus, deviations from the perpendicular reduce the instantaneous flux of the direct beam solar radiation. As shown in Equation 2.2, an additional consideration is the role of aspect (accounted for by a and a'). Since the aspect will affect the angle of the direct solar irradiance beam to the surface, it is considered in combination with slope angle.

Aspect primarily influences frost occurrence at a site by the effect it can have on the receipt of energy during the daytime. All other variables being equal, it would be expected that areas subjected to direct beam solar irradiance for longer periods of time would receive more energy which could be transferred and stored in the sub-surface. The energy stored in the subsurface could then be liberated at night to warm the ground surface in the absence of energy input from the sun. If more energy is stored in the sub-surface, the ground surface can be kept warm longer as the energy is released throughout the night.

In the northern hemisphere, it would be expected that southern aspects and, to a lesser extent, eastern and western aspects would receive more direct beam solar irradiance than northern aspects. Therefore, a higher degree of energy could be stored in the sub-surface to later warm the surface throughout the night. Since a northern aspect receives the least amount of direct solar radiation, there is relatively less energy to be absorbed and stored in the sub-surface during the day. Therefore, less energy is available to be liberated at night to warm the surface (described below in Section 2.1.2).

2.1.1.2 Local Relative Elevation

With respect to localized, meso-scale frost formation, lower elevation sites are generally colder than higher elevation sites. This is primarily due to cold air being denser than warmer air and, therefore, subsiding to lower elevation under the influence of gravity (as discussed above in Section 2.1.1.1).

Kalma *et al.* (1986) conducted research to assess the role of local elevation as a determinant of minimum temperature variation in gently undulating grazing country in the Southern Tablelands of N.S.W., Australia. Linear regressions were performed with minimum air temperature on local elevation and it was found that high R^2 values and large, positive $\partial T/\partial Z$ values (*i.e.*, change in temperature (T) with elevation (Z)) represented strong stratification and significant terrain effects. They also found there was an increase in temperature with local elevation during calm, clear conditions. However, in conditions of increased wind and cloud cover, there was a diminished effect and, in some instances, there was a decrease in temperature with elevation (Kalma *et al.* 1986).

Even when an area has ideal radiational frost conditions (*i.e.*, clear skies with an absence of wind), the influence of local elevation is not so simple due to the presence of other variables. For example, high and mid-elevation sites can be colder if air stagnates due to 1) an impedance of cold air drainage (*e.g.*, cold air damming at the lower edge of a clearing), 2) an insufficient slope to shed the cold air, or 3) neutral buoyancy occurring before the air parcel sinks to the lowest elevation.

2.1.1.3 Terrain Curvature

It is quite well established within the literature that certain topographic features shed cold air or have a tendency to collect cold air (Geiger 1965). This principle is easily understood with respect to the buoyancy of cold air and the gravitational effects on negatively buoyant air over variable terrain. Generally, sites with predominantly convex terrain (*e.g.*, hilltops) will direct cold air away and sites with predominantly concave terrain (*e.g.*, valley bottoms) will accumulate cold air displaced from convex areas. This process can be observed with respect to mountain/valley situations where cold air drains from the mountain slopes (convex situation) and accumulates within the valley (concave situation). If the valley bottom has sufficient slope and if there is a sufficient pressure gradient, the cold air accumulated in the valley bottom will flow down the valley in what is typically referred to as a mountain wind (Figure 2.1) (Stathers 1989, Geiger 1965). However, katabatic slope drainage is required to initiate the mountain wind at

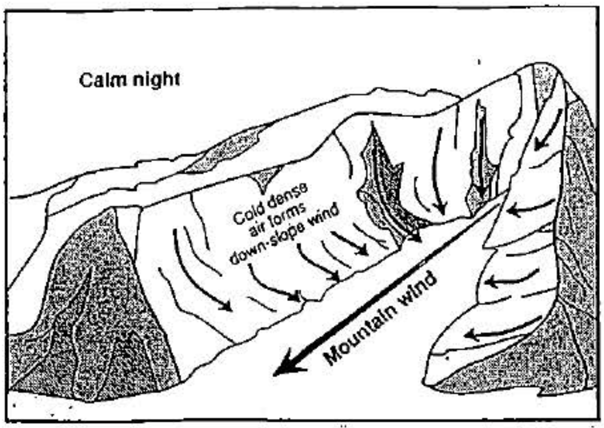


Figure 2.1 A typical nighttime wind flow pattern in mountainous terrain under clear, calm weather conditions. (from Stathers 1989, 8)

night (Geiger 1965). The mountain/valley situation is a meso-scale example. The displacement or accumulation of cold air by convex or concave sites also can occur in a variety of other scales. Geiger (1965) presents four factors (besides katabatic drainage) which influence the nocturnal cooling of concave sites: 1) the increase in counter-radiation which results in a screening of the horizon in the hollow, leading to a change in radiation balance that <u>reduces</u> the frost hazard, 2) the reduction in turbulent exchange produced by the dish shape, which keeps the temperature low at night, 3) the heat supply from the soils of the slopes when the hollows are deep and narrow, and 4) shortening of the daylight as the sun rises later and sets earlier. The relationships of the above factors vary with size and form of the depression (Geiger 1965). For shallow depressions (Figure 2.2 (a)), low nocturnal temperatures are generally a result of the accumulation of cold air. For deeper hollows (Figure 2.2 (b)), the low nocturnal temperatures are mainly

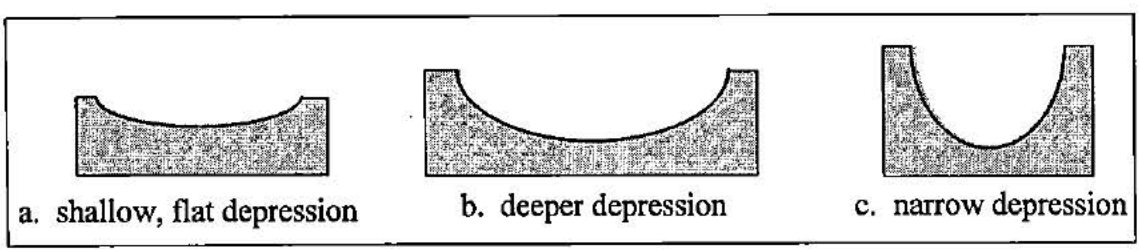


Figure 2.2 Three types of small depressions

due to a reduction in turbulence. Deep and narrow hollows (Figure 2.2 (c)) are comparatively warmer due to the heat supplied by the walls and also the screening of the horizon despite the absence of turbulence (Geiger 1965).

2.1.2 Soils

Frost research conducted by Nixon and Hales (1975) focused more exclusively on soils. In particular, they examined nocturnal surface temperatures during a radiation frost over agricultural landscapes. They concluded the surface temperature distribution in the agricultural landscape was related to soil moisture conditions. Since their research focused on soils, there is little information regarding the other site specific variables. It is assumed the area was relatively flat and absent of substantial land cover (*i.e.*, trees), owing to a greater emphasis on soil moisture influencing the surface temperatures.

Chen *et al.* (1982) also investigated the effects of soils and water to delineate cold-prone areas in Florida. In northern and central Florida, they found higher nocturnal surface temperature values (obtained from a satellite platform) were associated with water or wetland surfaces, while low nocturnal surface temperature values corresponded to well-drained and excessively well-drained sandy soils with little or no surface water.

Soils generally affect frost occurrence by how they store heat in the daytime and liberate heat during the night. Since the flow of heat through soils is almost entirely by molecular conduction, the conditions of the soil can have substantial influence on the ability of the soil to store and transfer heat (Wilson 1968).

The actual energy transfer from the surface to the sub-surface is commonly known as the Ground Heat Flux Density (G) and, following convention, G is negative during the day since it represents energy moving away from the ground surface. During the night G is positive and is an important source of heat energy to the cooling surface, potentially inhibiting frost formation.

Ground heat flux density (G) may be expressed as:

(Equation 2.3)

$$G = -k\,(\partial T/\partial z)$$

where k = thermal conductivity of the soil (the rate at which heat energy passes through the soil for a given temperature gradient) assuming no temperature change in the ∂z layer of the soil

$\partial T/\partial z$ = temperature gradient measured downward from the soil surface.

From this equation it is evident that the primary factors influencing G are thermal conductivity (k) of the sub-surface soil and the vertical temperature gradient in the sub-surface. The value of k will vary depending upon the composition of the soil. Soils with high concentrations of mineral matter and low concentrations of air and organic matter will have a higher k value than soils with more organic matter and air (Sellers 1965). The soil moisture content will also affect the k of the soil such that soils with high moisture content will have higher values of k than dry soils.

During the day, a proportion of the energy from the sun is absorbed by the surface of the earth. The surface is warmed and heat energy is transferred through the soil and stored in the sub-surface. The amount of energy available for storage is highly dependent on the amount of energy available at the ground surface during the day (including incident solar and longwave radiation, reflected solar radiation and evaporative heat flux density). This will vary in accordance with a number of variables particular to each surface condition, (*i.e.*, surface albedo, evaporation, exposure to the open sky and vertical obstructions, proportion of direct and diffuse solar irradiance, cloud cover, slope, aspect) .

The rate of temperature change in the soil is influenced by k and by the volumetric heat capacity ($\rho_b c_s$) where ρ_b is the bulk density of the soil and c_s is the specific heat of the soil (Sellers 1965) . The temperature change through time ($\partial T/\partial t$) can be expressed as:

(Equation 2.4)

$$\partial T/\partial t = \kappa\,(\partial T^2/\partial z^2)$$

where κ = thermal diffusivity ($k/\rho_b c_s$).

The value of κ is the ratio of the rate at which heat passes through the soil at a given temperature gradient to the amount of energy needed to warm the soil a given amount (Kalma *et al.* 1992). The value of κ will vary spatially and temporally with changes in moisture content and porosity, therefore Equation 2.4 is invalid when heat transport in the soil is by means other than conduction (*e.g.*, movement of soil water) (Van Wijk and Derksen 1963).

Since the longwave radiation emitted by the ground surface is a function of the surface temperature, the amount of energy transferred to the surface by G will influence the ground surface temperature and contribute to the longwave radiation emitted by the ground surface.

From this discussion of ground heat flux density, it is evident that areas which have a reduced ability to transfer and store energy in the sub-surface ($-G$) will contribute less energy to the cooling surface during the night ($+G$). From the equation for G (Equation 2.3), areas with poor soil thermal conductivity (*i.e.*, organic rich soils, moisture deficient soils, soils with a high amount of air spaces) will contribute to a decreased G and foster frost formation during frost susceptible nights. We also can infer from the relationship (Equation 2.3) that there must be a sufficient temperature gradient (decreasing temperature with depth) existing in the daytime to allow the transfer of energy to the sub-surface. Greater subsurface energy transfer and storage will be possible if a strong temperature gradient exists. Conversely, if a low temperature gradient exists, energy transfer by G to the sub-surface will be inhibited, which will result in less energy available to be liberated to the surface at night by G. Areas with low temperature gradients in the subsurface during the day, therefore, will be more susceptible to frost at night compared to those areas with higher temperature gradients in the subsurface.

However, it is the amount of available energy to be absorbed by the surface which is the most dominant factor influencing *G*.

2.1.3 Ground Cover

Ground cover, in the form of vegetation, can have many influences on frost occurrence with respect to factors such as 1) radiative exchange between the ground/ground cover zone and also the ground cover/atmosphere zone, 2) windspeed, 3) cold air drainage, 4) turbulent exchange of cold air and overlying warmer air, and 5) the ability of the underlying soil to store heat (Stathers 1989). The height, structure and density of vegetation can influence the above factors and either enhance or inhibit the occurrence of frost at a particular site

With respect to radiation exchanges, any obstructions to the atmosphere in the 180° hemisphere above the ground surface will emit longwave radiation ($L^{\uparrow}$) in accordance with the Stefan-Boltzmann equation:

(Equation 2.5)

$$L^{\uparrow} = \varepsilon\sigma T^4$$

where $L^{\uparrow}$ = emitted longwave radiation (W/m^2)
σ = Stefan-Boltzmann constant (5.67×10^{-08} $W/m^2\,K^4$)
T = absolute temperature of the emitting material (K)
ε = emissivity of the object.

The size, height and proximity to the ground surface of an obstruction (view factor) will determine to what degree it contributes to incident longwave radiation absorbed by the ground surface. An obstruction can prevent frost by reducing the rate at which net radiation is lost from the ground surface. This is because obstructions generally have higher emissivities and higher radiant temperatures than the open sky. As a consequence, obstructions will re-emit some of the energy ($L\downarrow$), which would normally be lost to the atmosphere, back to the ground surface, thereby reducing the net radiation lost by the surface.

Obstructions to the open sky can be of various forms (*e.g.*, tree or vegetation canopies, tree walls at the edges of clearings, cliffs). Obstruction to the open sky can also be defined by the position of the surface relative to the surrounding topography. If the ground surface of interest is in a valley or on a slope (as described above in Sections 2.1.1.1 and 2.1.1.3), a certain portion of the surrounding topography will cut off part of the open sky dome compared to that of a flat surface. Equations have been developed to take account of these factors for longwave radiation loss over varying terrain surfaces (see Sellers (1965, 63)).

Zones of stagnant air below the canopy are created if the vegetation canopy is of sufficient height and density. A tall, dense canopy decreases the windspeed between the canopy and the ground compared to less dense canopies. Decreased circulation is conducive to low air temperatures since warmer air is not able to readily mix from above. If the canopy is sparse, wind can penetrate deeper into the canopy to allow for greater turbulent exchange. This enables the ground to cool at a slower rate since the air cools more slowly. Chen *et al.* (1982, 1528) state

> "...vegetative cover modifies microclimate depending upon height and density. Because of low mass and rapid aerodynamic exchange of most vegetative cover compared with the surface layer of soil, vegetative cover microclimate effects are mediated primarily through changes in height-distributed solar radiation absorption, and turbulent exchanges of sensible heat and latent heat (water vapour), rather than through thermal inertia."

It is apparent that these effects only occur if there is a significant wind.

In addition to radiative influences, the surface cover of a slope can have a strong influence on the development and persistence of cold air drainage. Much research neglects the influence of surface cover when modeling cold air drainage. However, Bergen (1969) includes the effect of surface cover for cold air drainage within a forest canopy situation by taking into account the foliage distribution on a slope. Devito and Miller (1983) also demonstrate the effect of differing surface cover on the vertical air drainage profile. Cold air drainage over a bare surface was generally the simplest situation, where the cold air drainage was associated with a temperature inversion in the cold air drainage zone. It was suggested that the development of cold air drainage within a leafed forest canopy is dependent upon the height and completeness of the crown (Devito and Miller 1983).

As discussed above (Section 2.1.2), heat from the soil which is liberated at night can be an important factor in reducing the frost occurrence of an area. However, the amount of energy which can be stored in the soil during the day is greatly affected by the vegetative cover. A dense vegetative canopy will reduce the amount of solar energy able to reach the ground surface. However, a canopy of lesser density will foster more potential for heat to be absorbed into the soil profile.

2.1.4 Summary

Throughout the discussion in the previous sections it has become apparent that there is a high degree of interaction among the site specific variables. While some research and theories relate only to one specific variable, others recognize and discuss the interactions between the variables. The current research is designed to investigate the characteristics of frost prone areas and also the relative influence of the independent variables on surface temperatures. Some of the following sections of this chapter will describe how current technology can be used to combine data to investigate these variables and how the same technology can be used to alleviate problems associated with traditional methods used to investigate frost.

2.2 Problems Associated with Traditional Methods to Investigate Frost

There are certain problems associated with using traditional climate station data to interpret frost. The purpose of this section is to review some of these problems. The last section of this chapter discusses how new tools and technology can help to alleviate some of these problems.

The most traditional method to evaluate frost risk on a regional scale has been to obtain relevant data from climate station networks. While this method is still commonly used to assess regional frost risk, it is limited due to the insufficient densities of stations within the network and, thus, requires interpolation between point source data (Kalma *et* *al.* 1992). The problem is further compounded in areas with variable terrain. As previously discussed, there is often poor topographic representation in areas of complex terrain (*i.e.*, steep slopes, high elevations, inaccessible areas, *etc.*). In order to somewhat alleviate these problems, the observations from climate station networks are sometimes supplemented with mobile surveys (*e.g.*, Hocevar and Martsolf 1971; Lomas *et al.* 1969, 1972 as cited by Kalma *et al.* 1992).

An additional problem associated with using climate station networks to examine frost is that formation of frost is defined by the surface temperature of an object (*i.e.*, the ground surface, leaf surface, *etc.*) being below 0°C (Geiger 1965; Oke 1987). Typical climate stations record air temperature at a height of 1.5 metres with temperature sensors mounted in a Stevenson screen. Minimum air temperatures at 1.5 meters rarely equate to minimum surface temperatures. It is common for researchers to use air temperature measurements to derive ground surface temperatures. However, the methods used vary greatly. Certain models assume that minimum nocturnal air temperatures at screen height (1.5 metres) and nocturnal surface temperature are equal (*e.g.*, Brunt 1952 and Gardner *et al.* 1990 as cited by Kalma *et al.* 1992). The criticism against this method is that, during calm and clear nights, air cools (in the vertical air profile) from the ground up (Kalma *et al.* 1992). Therefore, there may be a significant difference in temperature between the ground surface and the sensor located 1.5 metres above the ground surface. At night, the earth surface cools at a faster rate than the air. The air near the ground surface, therefore, will be most sensitive to the drop in surface temperature and cool faster than air further from the ground surface. Throughout the night, the surface temperature will have an increasing influence on the vertical profile of the air lying above the ground surface.

An inversion layer (temperature increasing with height) is indicative of the extent to which the air above the ground is affected by the cooling of the ground surface. Inversions are generally strongest just before sunrise when maximum cooling of the ground surface has occurred. Above this inversion layer turbulent mixing may take place and the amount of turbulence will influence the height of the inversion layer. If moderate turbulence exists, development of the inversion layer is hindered. However, under minimal turbulence, the inversion layer will build due to the influence of radiational cooling by the earth's surface. During nights of low turbulence, the ground surface and the adjacent air layers are particularly susceptible to a rapid cooling. This occurs since the rate at which heat is lost (by radiation) is far greater than the rate at which stored heat can be transferred by the subsurface soil to the ground surface (by conduction) (Kalma *et al.* 1992).

The above criticisms are certainly valid and, therefore, justify the use of equipment which measure surface temperature by radiational properties (*i.e.*, thermal scanners) to investigate radiation frosts during calm, clear nights.

2.3 Context of using Thermal Imagery and GIS to Investigate Frost

Much of the previous frost mapping and modeling research has relied heavily on air temperature observations from climate station networks and the previous section outlined some of the potential problems of using climate station data. While there has been a vast amount of knowledge gained from research using these types of data, advancing technology offers new methods of obtaining frost related data.

Remote sensing technology has given climatologists a new set of tools to examine climatic phenomena. Since the surface temperature of a material can be related to the electromagnetic energy (longwave radiation) emitted (see Equation 2.5), electromagnetic radiation sensors are able to acquire surface temperature data of ground based materials. With respect to frost research, it is possible to collect spatially continuous surface temperature data using electromagnetic energy sensors mounted on airborne or satellite platforms.

The primary advantage of remotely sensed thermal image data is that they provide a spatially continuous overview of surface temperature patterns of relatively large areas; conventional ground measurements (*i.e.*, climate stations) only represent a few discrete observation points (Sutherland *et al.* 1981). Thermal imagery also improves upon traditional methods since interpolation between discrete observation points doesn't apply for spatially continuous data. An additional benefit of using airborne electromagnetic sensors is that surface temperatures are derived from the radiation emitted by the surface and are not interpreted from air temperature data.

The main disadvantage of remotely sensed thermal imagery is that it is not always apparent what is being recorded. Remote sensing devices are very good for detecting the surface temperatures of homogeneous objects (*e.g.*, lakes, roads, exposed rock and soils). However, if the composition of the area being recorded is heterogeneous, it may be difficult to ascertain what the sensor is detecting. If, for example, the sensor records the surface temperature of a forest which has a crown closure of 90%, it is most likely detecting the surface temperature of the tree crown. However, if the crown closure were only 20% the sensor will detect more of the forest floor. If information is available regarding the composition of the surface, it can offer some aid to determine what the sensor may be detecting, thus reducing this limitation.

Research has been conducted using thermal image data collected from both satellite platforms (*e.g.*, Chen *et al.* 1979, 1982, Caselles *et al.* 1983) and airborne platforms (*e.g.*, Nixon and Hales 1975, Kalma *et al.* 1986). Airborne thermal scanners are recognized to have certain advantages for studying frost events when compared to satellite platforms. The primary advantage of aircraft devices is the higher possible spatial resolution (between 1 and 20 m^2), compared to satellite devices (*e.g.*, 0.36 km^2 for the Heat Capacity Mapping Mission Satellite) (Kalma *et al.* 1986). Another advantage of airborne devices is the reduction of atmospheric attenuation, since attenuation is directly related to atmospheric path length through which the radiation is sensed (Mahrt and Heald 1983, Lillesand and Kiefer 1994). The main disadvantage of airborne thermal scanners is the inconsistent data gathering schedules. As airborne data collecting missions tend to be project specific, a continual schedule of data collection is rare. Another disadvantage associated with the inconsistent collection of airborne data is the difficulty of combining data sets, since varying data standards may be used to collect data for different projects. Overall, the advantages of remote sensing techniques generally outweigh the disadvantages.

Kalma *et al.* (1983, 18) suggest "...in the absence of a (standard) network of climate stations or mobile topo-climatological surveys, local frost mapping will continue to depend on data obtained during representative nights with thermal scanners carried in aircraft and/or detailed assessment of terrain and land cover.". Kalma *et al.* (1986, 413) discuss the role of airborne remotely sensed thermal imagery data as "...an important aid in understanding spatial distribution patterns of night-time air temperatures and, hence, in regional frost risk assessment.". In addition, Avissar and Mahrer (1988) recognize the importance of remotely sensed surface temperature data for testing established frost models.

Remotely sensed thermal imagery is well recognized as a tool that can promote advances in understanding frost (Sutherland *et al.* 1981). It also is well recognized that other data (*e.g.*, terrain and land cover data) must be used to supplement thermal imagery when interpreting frost (Kalma *et al.* 1983, Avissar and Mahrer 1988).

The use of thermal imagery data has been discussed as an aid in interpreting frost patterns and testing certain models. However, little mention has been made of actually using thermal imagery data to investigate variables which influence frost (*e.g.*, assessing the relative importance of variables). It would seem appropriate to incorporate thermal image surface temperature data into methods of frost analysis since frost is defined by the surface temperature of an object falling below $0^{o}C$ (Oke 1987, Geiger 1965).

A logical way to integrate spatial data to qualitatively and quantitatively evaluate frost is to use a Geographic Information System (GIS). A GIS is a computational system which enables the management of spatially related data. As the name implies, information contained within the system are geographical in nature and are spatially linked by a common spatial coordinate system. Within a GIS, spatial data can be input, manipulated, transformed, visualized, combined, queried, analyzed, modeled and output (Bonham-Carter 1994). The primary purpose of a GIS is to output useful information from raw spatial data sets. The information derived from a GIS can be in the form of interactive queries, maps, databases and statistical reports (Bonham-Carter 1994). Therefore, information obtained from a GIS can be used as an aid to enhance knowledge or to gain a better understanding of the subject under investigation.

Much of the information related to frost (as discussed above) can be obtained or derived from readily available spatial data sets. The GIS provides the computational structure and functionality to combine data from different sources through input, translation, modeling and manipulation of different data sets. Once the data are spatially comparable, the GIS provides the means to combine the data to produce a multivariate spatial database. Once the database is produced, relationships between the variables can be explored using statistical methods.

There has been little research investigating the use of thermal imagery with other relevant information inside a GIS to investigate frost. Laughlin and Kalma (1990) and Kalma *et al.* (1992) have used basic GIS functionality to generate an elevation model (DEM) to interpret the effects of terrain on minimum nocturnal air temperatures, but there has been little research beyond this.

The merits of the previous research efforts are well recognized and certain methods and techniques provide a strong basis on which to establish future research. The technology associated with remote sensing and GIS provides a new and intriguing way in which to amalgamate spatial data associated with frost. Therefore, the present research will be focused in this direction.

The next two chapters explore the reality of assembling the variables described in this chapter within a GIS. Chapter Three will introduce the thermal image data, indicate where it was collected, and describe the areas selected for this research. In addition, the data sets which contain the site specific variables will be described. Chapter Four discusses the methodology used to produce multivariate spatial data sets for each study area. Chapter Four concludes by reviewing the statistical methods which were evaluated to investigate the multivariate data sets.

Chapter 3
Data Sources

This chapter describes the source of thermal image data and reviews the selection of study areas. Subsequently, each study area is introduced by providing a basic description of its topographic features and the climatic characteristics. The last part of this chapter reviews the sources of the explanatory spatial data.

3.1 Source of Thermal Imagery and Selection of Study Areas

The Cariboo Forest Region, in the province of British Columbia, Canada, exhibits ideal conditions for radiation frost during the active growing season. It is located in the central interior of the province in the lee of the Coast Mountains. Therefore, the moderating effects from the moist Pacific air are greatly diminished (Annas and Coupé 1979). A very large portion of the region is situated on the Fraser Plateau (approximately 1000 metres A.S.L.). The high elevation contributes to a cool climate. As a result of these combined factors, the Cariboo Forest Region is subject to very light precipitation and a high frequency of clear skies, which results in large diurnal temperature differences; conditions which are very conducive to frost (Annas and Coupé 1979, Chilton 1981). In particular, growing season frosts are common and particularly dangerous for reforestation applications (*i.e.,* forest plantations) (Steen *et al.* 1990).

Remotely sensed thermal image data collected in the Cariboo Forest Region will be used in this research to investigate frost. Thermal image data were collected September 2, 1988 (03:00 - 05:00 LST) in order to record spatial distributions of nocturnal surface temperatures under radiation frost conditions (Stathers 1989, Steen *et al.* 1990). Since frosts occur in similar places on representative radiation frost nights (Hocevar and Martsolf 1971), the one night of thermal imagery data should be indicative of areas prone to radiation frosts.

Intera Technologies (Ottawa, Canada) was contracted by the British Columbia Ministry of Forests to collect and deliver the thermal image data. Information regarding the scanner and details of the scanning mission were obtained through personal communications with Intera Technologies (Ottawa, Ontario) (Tracey 1989, Kirby 1994, MacKay 1995 personal communications).

The thermal image data were collected using an analogue multispectral thermal line scanner (model AADS1230, Daedalus Enterprises Inc., Ann Arbor, Michigan) mounted in a twin-engine Piper Navajo aircraft (MacKay 1995 personal communication). The operating altitude of the scanner was 15,000 feet (4,673 metres) above mean ground level (Tracey 1989 personal communication). The specifications for the AADS1230 are summarized in Table 3.1.

Table 3.1 Specifications of the AADS1230 analogue multispectral thermal line scanner (Kramer 1994, 347-348; MacKay 1995 personal communication).

Operating wavelengths:	3-5.5 and 8-14μm	IFOV: (instantaneous field of view)	2.5 mrad
Aperture:	12.7 cm.	Gated IFOV:	77° 20'
Focal length (f):	15.2 cm.	Temperature resolution:	0.2 °C
Aperture curvature (effective):	f/2	Velocity/Height ratio:	0.2 radians/sec.
Scan rate:	80 cycles/sec.	Roll correction:	total ± 10°, unvignetted ± 5°
TFOV: (total field of view)	87° 20'	Swath width:	70% of flying altitude above ground level

The AADS1230 scanner had two infrared detectors; one operating at 3.0 - 5.5 μm and the other operating at 8.0 - 14.0 μm. Thermal scanners detect radiation from the surface of ground objects (*i.e.*, within the first 50μm) (Lillesand and Kiefer 1994). Since radiation frost preferentially occurs on the surface of objects exposed to the open sky, surface temperatures collected by the thermal scanner should be sufficient to interpret frost. In order to collect thermal data focused within the specific surface temperature range of +6° Celsius to -6° Celsius, the 8-14 μm photoconductive detector was used. To calibrate the sensor, the system utilized black body temperature reference sources (assuming an emissivity of 1.0) which allowed the sensor operator to define reference point temperatures which the scanner used to calibrate observed ground scene temperatures (MacKay 1995 personal communication). Since the surface emissivity was assumed to be 1.0, the sensor recorded the radiant surface temperature rather than the actual surface temperature. The collected image data, subsequently, were classified (level sliced) into 2°C intervals and printed onto photographic paper (Kirby 1994 personal communication).

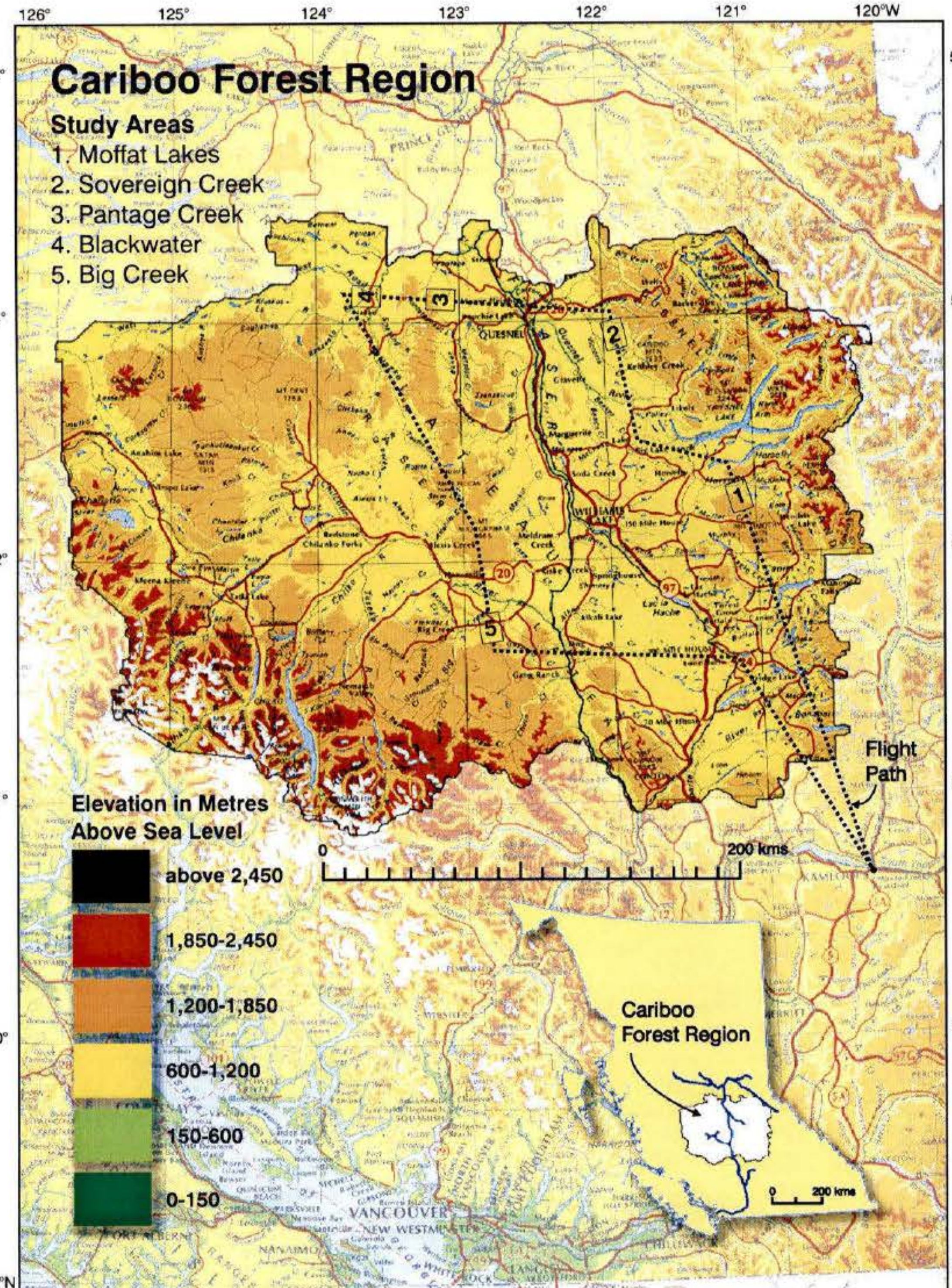
Five areas dispersed throughout the Cariboo Forest Region were selected from the thermal imagery (Figure 3.1) on the basis of the data quality (*i.e.,* distinguishable surface temperature patterns, relatively clean images) as well as additional considerations (*i.e.,* the diversity of topography and land use). This was done in consultation with the British Columbia Ministry of Forests (Adams 1995 personal communication).

The following sections will provide a brief description of each of the study areas selected for this research. The description will contain: 1) the location of the area by longitude and latitude, 2) proximity to urban centers, 3) a description of the general topography, 4) general characteristics of the land cover, 5) synoptic weather information from the closest regularly maintained climate stations and, where available, 6) specific meteorological conditions during the night on which the thermal imagery was recorded.

3.1.1 Blackwater/Pantage Creek Study Area

The Blackwater/Pantage Creek area was selected as the pilot study area. This area was subjected to methodological investigations to produce a set of procedures which would be applied to the other selected study areas.

The Blackwater/Pantage Creek area is located along the northern extent of the Cariboo Forest Region. The selected portion of thermal imagery runs east to west from



Portion of B.C. Government Map 1Jr (B.C. Relief) reproduced with permission from Geographic Data BC Ministry of Environment, Lands and Parks.

Figure 3.1 Location of study areas

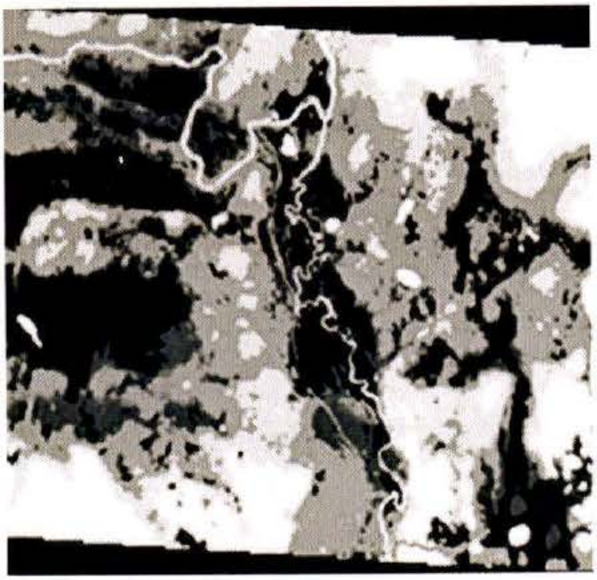
about 123°00' W to 123°40' W between latitudes 53°02' N and 53°07' N. The area is about 90 km southwest of Prince George and 75 km west of Quesnel. The elevation of the selected area varies from 800 to 1500 metres above mean sea level.

Originally, the Blackwater and Pantage Creek study areas were selected as one spatially continuous study area. Between the two areas the terrain is very topographically complex. The slopes are very steep with a high number of irregularly orientated valleys. Due to the logistical constraints of the data, it was necessary to divide this area into two separate areas. More specifically, the 3-dimensional relief of the central portion of the image was too complex to correct the 2-dimensional image. As a result, the central portion of the image was excluded and the two ends of the image section were retained. Therefore, from this point, the Pantage Creek area and the Blackwater area are identified as separate areas (see Figure 3.1).

The Blackwater study area (Figure 3.2a) includes the confluence of the Blackwater and Nazko Rivers. There also is a meandering portion of the Nazko River which indicates a river flood plain (Figure 3.2b, 3.3c). Near the confluence there are a number of small lakes and one larger lake. In addition, creek valleys are associated with some of these lakes.

The Pantage Creek study area is located to the east of the Blackwater study area (Figure 3.3a). This area is characterized by a high number of geometrically-shaped forest clearings with distinct edges and associated roads (Figure 3.3c). The terrain in this study area is varied. In the west of this study area, the rolling terrain is incised by the Pantage Creek system (alongside many of the clearings). In the eastern part of the image the presence of small lakes and swamps along the main portion of Pantage Creek indicates that the terrain is relatively flat. At the extreme eastern edge of the image the rolling terrain resumes, incised by a few creeks which drain into Pantage Creek (Figure 3.3b).

The Blackwater and Pantage Creek study areas are located on the Fraser Plateau. The characteristic dry climate regime of the Cariboo Forest Region combined with the effect of the high elevation of the Fraser Plateau result in a relatively short frost-free period (Table 3.3) for these two areas (Annas and Coupé 1979; Lord and Walmsley



N

Approximate Scale
1:110,000

lighter shades are warmer
darker shades are cooler

a.thermal imagery of the Blackwater study area

b. looking from north to south down Nazko River

c. looking west across the Nazko River floodplain

Figure 3.2 Thermal imagery and aerial photographs of the Blackwater study area

a. Thermal imagery of the Pantage Creek study area

b. Looking east from the central part of the study area

c. Looking west from the central part of the study area
(looking towards the Blackwater study area)

Figure 3.3 Thermal imagery and aerial photographs of the Pantage Creek study area

1988). Since the area is relatively close to Prince George and Quesnel, detailed climate data are available from regularly maintained weather stations in these cities (Table 3.2).

The long-term climatic averages are fairly similar between the two cities which may suggest similar trends might occur in the selected area of interest. However, it must be noted that both Quesnel and Prince George are located in the Fraser Basin which is at a lower elevation than the Fraser Plateau (see Figure 3.1).

Less comprehensive and shorter term climate stations near the Blackwater and Pantage Creek study areas are located at Gillies Crossing (53°16' N, 123°31' W, elevation: about 848 metres A.S.L) and Nazko (52°55' N, 123°37' W, elevation: 899 metres) (Table 3.3).

Windspeed and net radiation were recorded in the Pantage Creek area during the night of the thermal data collection. The average windspeed between 04:00 and 08:00 (LST) was 2.6 m/s. Net radiation recorded at 0:00, 04:00 and 08:00 (LST) were -57.3 W/m^2, -52.9 W/m^2 and -26.2 W/m^2 respectively (Coupé 1996, personal communication).

Table 3.2 General climate information from Quesnel (53° 02' N, 122°31'W, 545m A.S.L.) and Prince George (53° 53' N, 122° 41'W, 676m A.S.L.) at 01:00 and 07:00 LST. Monthly averages for June, July, Aug. and Sept. (1951-1980) (Environment Canada 1984).

Quesnel	June		July		August		September	
time (LST)	01:00	07:00	01:00	07:00	01:00	07:00	01:00	07:00
Station Pressure (kPa)	94.98	95.1	95.15	95.3	95.13	95.24	95.15	95.24
Vapour Pressure (kPa)	1.01	1.03	1.18	1.21	1.18	1.18	0.93	0.91
Dewpoint (°C)	6.8	7.2	9.3	9.5	9.1	9.2	5.6	5.2
Temperature (°C)	9.4	10.8	11.3	12.5	10.7	10.7	6.9	6.2
Prince George	June		July		August		September	
time (LST)	01:00	07:00	01:00	07:00	01:00	07:00	01:00	07:00
Station Pressure (kPa)	93.45	93.55	93.66	93.76	93.61	93.69	93.59	93.66
Vapour Pressure (kPa)	0.94	0.96	1.10	1.14	1.09	1.12	0.87	0.86
Dewpoint (°C)	5.7	6.1	8.1	8.7	8.0	8.4	4.6	4.3
Temperature (°C)	9.1	10.8	11.1	12.5	10.3	10.7	6.5	5.8

Table 3.3 Climate data near the Blackwater and Pantage Creek study areas (modified from Lord and Walmsley 1988, 13).

Station	Mean Temperature (°C) Annual	July	Mean Precipitation (mm) Annual	May-Sept.	Freeze-free period (days)	annual climatic moisture balance (mm)
Gillies Cross	2.2	13.7	502	268	40(est.)	-172
Nazko	2.3	13.9	442	248	40(est.)	-189

3.1.2 Big Creek Study Area

The Big Creek Study area is located in the central part of the Cariboo Forest Region approximately 60 km southwest of Williams Lake between latitudes 51° 40'N and 51° 46'N and between 122° 45' W and 122° 55' W. The study area is oriented NW/SE due to the path in which the thermal imagery was flown. The elevation of the selected area varies from 975 metres to 1750 metres above mean sea level.

The study area is bounded to the north by Big Creek, and the southern portion of the imagery extends to Gaspard Creek. The northern portion of this study area is characterized by flat terrain with scattered lakes and swamps. The flatness of the terrain encourages agricultural activity as indicated by some of the characteristic patterns on the thermal image and photos (Figure 3.4a, 3.4b). In addition, the meandering creeks are indicative of flat terrain. The landscape increases in elevation in the southern portion of this study area. The increasing abundance of vegetation appears to coincide with the elevation change. In addition, forest clearings are present at the higher elevations (Figure 3.4c).

The Big Creek Study area is located on the west side of the Fraser Plateau (Annas and Coupé 1979, Valentine *et al.* 1987). This area is subject to a rainshadow effect due to its proximity to the Coast mountains, resulting in low precipitation and clear skies (Valentine *et al.* 1987). Additionally, the higher elevations of this study area favor a short frost-free period by encouraging the formation and retention of cooler air (Annas and Coupé 1979, Valentine *et al.* 1987).

The closest regularly maintained weather station which records comprehensive measurements is located at Williams Lake Airport (52° 11' N, 122°03'W, elevation: 940 metres A.S.L.) (Table 3.4). In addition, basic weather station data were collected from the Big Creek Atmospheric Environment Service (A.E.S.) weather station (51°43'N, 123°02'W elevation: 1128 metres A.S.L.) located within the Big Creek Study area (Table 3.5).

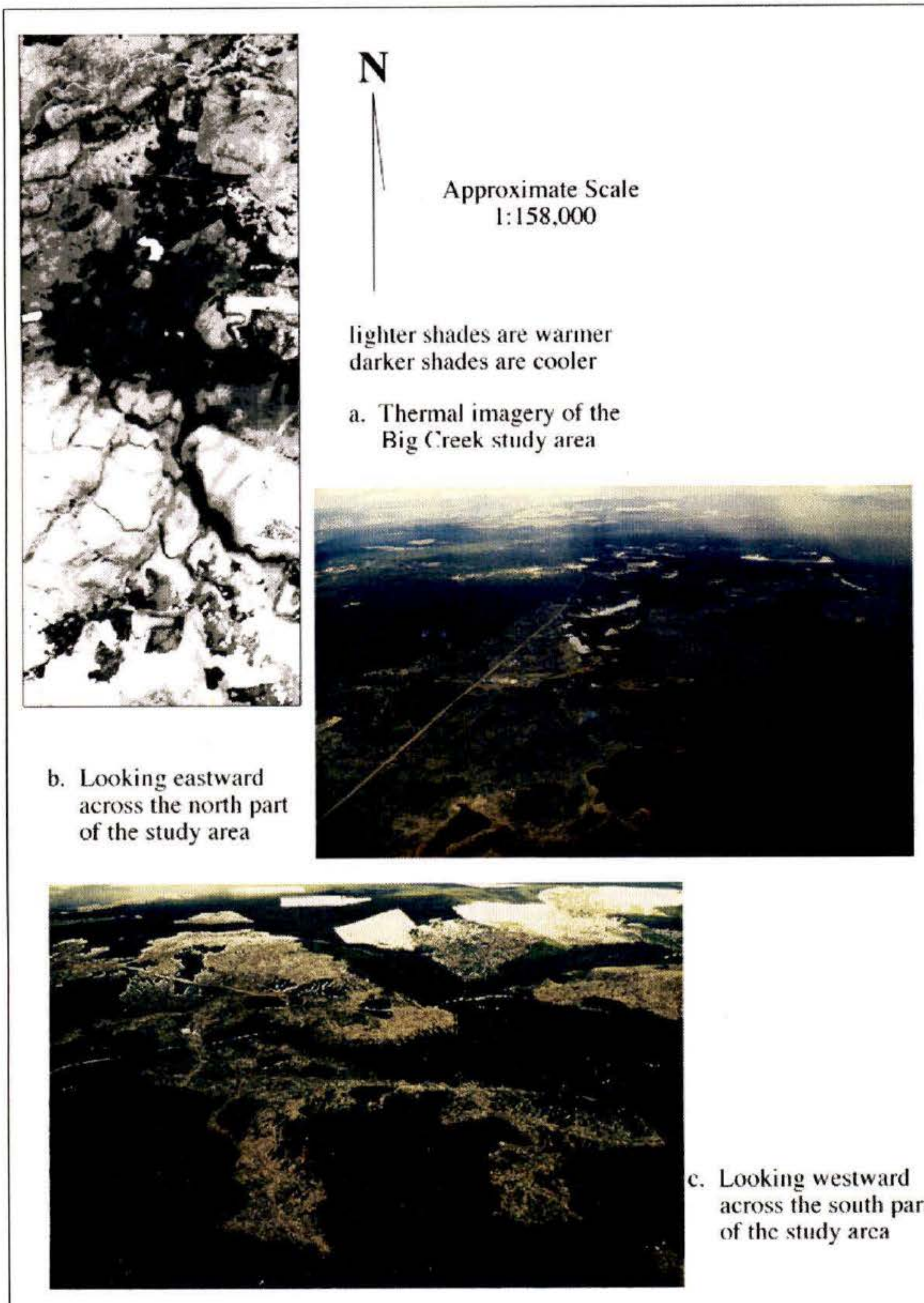


Figure 3.4 Thermal imagery and aerial photographs of the Big Creek study area

Table 3.4 General climate information from Williams Lake Airport at 01:00 and 07:00 LST. Monthly averages for June, July, Aug. and Sept. (1951-1980) (Environment Canada 1984).

Williams Lake	June		July		August		September	
time of record (LST)	01:00	07:00	01:00	07:00	01:00	07:00	01:00	07:00
Station Pressure (kPa)	90.61	90.68	90.81	90.89	90.75	90.82	90.72	90.78
Vapour Pressure (kPa)	0.84	0.86	0.99	1.02	1.0	1.04	0.82	0.82
Dewpoint (°C)	4.1	4.5	6.5	7.0	6.7	7.2	3.6	3.8
Temperature (°C)	9.5	10.7	11.7	12.7	11.5	11.7	7.2	6.6

Table 3.5 Climate data from within the Big Creek study area (modified from Valentine *et al.* 1987, 8).

Station	Mean Temperature (°C) Annual	July	Mean Precipitation (mm) Annual	May-Sept.	Freeze-free period (days)	annual climatic moisture balance (mm)
Big Creek	2.0	n/a	340	180	20-24	n/a

3.1.3 Sovereign Creek Study Area

The Sovereign Creek study area is located approximately 40 km east of Quesnel and approximately 90 km northeast of Williams Lake (Figure 3.1). It is situated between 52° 47'N and 53° 00'N latitude and between 121° 45'W and 121° 55'W longitude. The elevation in this study area varies between 970 meters to 1300 metres above mean sea level.

The central portion of the study area is dissected by a number of creeks, some of which flow into small lakes. In addition, some of the lakes and creeks have wetland areas flanking their sides (Figure 3.5b and 3.5c). The shape and consistent orientation of the temperature patterns to the south of this study area appears to indicate the presence of glacier-formed drumlins. Some of these features extend into the southern portion of this study area although not to the same degree (Figure 3.5a).

Since the Sovereign Creek study area is located near the transition zone between the Fraser Plateau and the Quesnel Highland (Figure 3.1), its climate is influenced by the

N

Approximate Scale
1:135,000

lighter shades are warmer
darker shades are cooler

a. Thermal Imagery of the Sovereign Creek study area

b. Looking east from the central part of the study area

c. Looking southeast from central part study area

Figure 3.5 Thermal imagery and aerial photographs of the Sovereign Creek study area

Quesnel Highland (*i.e.,* sharp increase of colder and wetter conditions). The Quesnel Highland is a physiographic region within the Cariboo Forest Region which represents a significant spatial transition in topography from the Fraser Plateau. Whereas the Fraser Plateau is predominantly gently rolling terrain, the Quesnel Highland is characterized by moderate relief consisting of folded and faulted volcanic and sedimentary rocks and increased elevation. This variation in topography has considerable effects on the climate (Annas and Coupé 1979).

Since the Sovereign Creek area is relatively close to Quesnel, detailed climate data are available from a regularly maintained weather station at the Quesnel Airport (Table 3.2). A less comprehensive climate station is located approximately 30 kilometres southeast of the Sovereign Creek study area at Likely (52°36'N, 121°32'W elevation: 724 metres A.S.L.) (Table 3.6).

Table 3.6 Climate data near the Sovereign Creek study area (modified from Lord 1984, 12).

Station	Mean Temperature (°C)		Mean Precipitation (mm)		Freeze-free period (days)	annual climatic moisture balance (mm)
	Annual	July	Annual	May-Sept.		
Likely	4.0	15.4	709	260	63	-216

3.1.4 Moffat Lakes Study Area

The Moffat Lakes study area is located in the eastern part of the Cariboo Forest Region approximately 75 km east of Williams Lake. The study area is located between 52°03' N and 52°10' N latitude and 121°00'W and 121° 07'W longitude. The elevation in this study area varies between 1000 metres and 1900 metres above mean sea level.

The Moffat Lakes are located in the central part of the study area and are flanked by hills to the north and south. On the hills south of the lakes, forest clearings are distinctive on the imagery and the photos (Figure 3.5a and 3.5b). Two small lakes exist in the hills to the north of the lakes with associated creeks draining into the western end of Moffat Lakes (Figure 3.6c). The southwest portion of this study area is marked by hilly terrain and a number of forest clearings. It is evident there is inter-clearing surface temperature variability in some of the clearings which may indicate that surface temperatures are being influenced by topographic variables (*i.e.,* slope, aspect, elevation and/or curvature).

Since the Moffat Lakes study area is located in the Quesnel Highlands (Figure 3.1), it is susceptible to the influences imposed by the physiographic factors present in this area (*i.e.,* higher elevations near the foot of the Cariboo Mountains). The high amount of precipitation and low temperatures which exist in the Quesnel Highlands are generally a result of higher elevations encountered near the Cariboo Mountains (Annas and Coupé 1979).

The closest regularly maintained weather station is Williams Lake Airport (Table 3.4). In addition, less comprehensive weather stations are located near this study area. The Black Creek station (52° 17'N, 121° 07'W elevation: 867 metres A.S.L.) (Table 3.7) is located approximately 20 kilometres northwest of the Moffat Lakes study area and the Boss Mountain station (52° 06'N, 120° 53'W elevation: 1532 metres A.S.L.) (Table 3.7) is located about 10 kilometres east of the Moffat Lakes study area.

Table 3.7 Climate data near the Moffat Lakes study area (modified from Lord 1984, 12).

Station	Mean Temperature (°C)		Mean Precipitation (mm)		Freeze-free period (days)	annual climatic moisture balance (mm)
	Annual	July	Annual	May-Sept.		
Black Creek	4.4	15.8	566(est.)	252	60	-261
Boss Mtn.	1.3	12.3	1321	414	94	+231

N

Approximate Scale
1:120,000

lighter shades are warmer
darker shades are cooler

a. Thermal imagery of the Moffat Lakes study area

b. Looking southeast from central part of study area (across Moffat Lakes)

c. Looking northeast from central part of study area (across Moffat Lakes)

Figure 3.6 Thermal imagery and aerial photographs of the Moffat Lakes study area

3.2 Sources of Explanatory Spatial Data

Many explanatory (independent) variables required for this research (as reviewed in the previous chapter) are contained in several different spatial data sets. This section reviews each of the data sets and the information they contain relevant for investigating frost. In addition, a summary of the accuracy report is given for each data set (where available).

3.2.1 Terrain Resource Information Mapping Data

Terrain Resource Information Mapping (TRIM) data were provided by the British Columbia Ministry of Environment, Lands and Parks. TRIM is a digital topographic spatial database at the 1:20,000 BCGS (British Columbia Geographic System) mapsheet grid level (B.C. Environment, Lands and Parks 1992). The DEM (digital elevation model) point data were the primary TRIM data used for this research project. The planimetric data (*i.e.,* roads and hydrology features) were of secondary importance, used for geocorrecting the images. The TRIM data were supplied in MOEP binary format, in a UTM projection derived from a NAD83 datum (GRS80 spheroid) (B.C. Environment, Lands and Parks 1992).

As stated in the *British Columbia Specification and Guidelines for Geomatics, Vol. 3 (Digital baseline mapping at 1:20,000)* (B.C. Environment, Lands and Parks 1992), the accuracy specifications for the TRIM data used in this research are as follows:

1. 90% of all-well defined planimetric features shall be coordinated to within 10 metres of their true position.
2. 90% of all discrete spot elevations and DEM points shall be accurate to within 5 metres of their true position.
3. 90% of all points interpolated from DEM shall be accurate to within 10 metres of their true elevation.

3.2.2 Forest Cover Data

Forest cover data from the British Columbia Ministry of Forests consist of two components; 1) a graphics file (FC1), and 2) an attribute file (Forest Inventory Planning

(FIP) file). FC1 and FIP are linked by common database fields (B.C. Ministry of Forests 1994). The forest cover information are represented by polygon data with associated data tags linked to the associated FIP records. FC1 data are also based on 1:20,000 BCGS mapsheet grids (B.C. Ministry of Forests 1994). The FC1 data were supplied in an interactive graphic design system (IGDS) format, in a UTM projection derived from the NAD27 datum (Clarke 1866 spheroid) (B.C. Ministry of Forest 1994). The FIP database files were supplied in a MOF FIP format.

Forest cover data required for this research were provided by the British Columbia Ministry of Forests. FC1/FIP data were primarily obtained for forest cover information (*i.e.,* stand height, crown closure, stand age, species composition, non-productive areas, and forest activity). Even though the graphics files contain other spatial attributes, only forest cover levels were extracted.

The following information regarding data accuracy standards was obtained from the *Forest Inventory Manual: Preparation and Creation of F.R.G.I.S. Datafiles (vol. 5)* (B.C. Ministry of Forests 1994). Forest cover typelines are typically interpreted from aerial photographs at 1:15,000 or 1:20,000 scale and are either transferred to a manuscript and digitized into a map file, or are digitized directly from the aerial photography using an encoded stereoplotter. The accuracy of the typeline vectors is a function of the experience of the photo interpreter, the quality of the aerial photograph, the extent of ground truthing, and the characteristics of the forest cover and terrain. A true representation of the accuracy of these vectors, therefore, is difficult to specify. However, error statistics are available for transfer of forest cover from aerial photography to a digital map file. These accuracy standards are valid when TRIM mapping is available. Photogrammetric transfer accuracy (error introduced by the operator/stereoplotter instrument during the compilation of the manuscript) shall be accurate to 20 metres (1.0 mm at map scale) of their true position for 90 per cent of all forest cover typeline. Digitizing accuracy shall be accurate to 20 metres (1.0 mm at map scale) of their true position for 90 per cent of all forest cover typeline. Forest cover positional files shall be accurate to 30 metres (1.5 mm at map scale) of their true position for 90% of all captured forest cover typelines. When forest cover typelines are coincident with natural boundaries (*e.g.*, rivers, lakes) present within TRIM map positional files, the accuracy of these typelines shall be as per the *British Columbia Specifications and Guidelines for Geomatics, Vol. 3 (Digital Baseline Mapping at 1:20,000)* (B.C. Ministry of Environment Lands and Parks 1992) for TRIM data (as described above).

3.2.3 Soils Data

Soils data were purchased from the Canadian Soils Inventory Survey (CanSIS) in polygon format. For each polygon, the data contain soil classification attributes such as primary, secondary and tertiary soils and extents.

The soils data are based on 1:100,000 NTS (National Topographic System) mapsheet grids. The data were supplied by CanSIS in an ArcInfo export format, in a UTM projection derived from a NAD27 datum (Clarke 1866 spheroid).

Soils data in the Cariboo Forest Region are based on very general surveys, where large areas were mapped quickly with few ground checks and much reliance was placed on information that could be gained from aerial photographs (Valentine *et al.* 1987). With respect to the accuracy of the soil survey mapping (and subsequent accuracy of the digital spatial data), a post-survey test was conducted in the Lac la Hache - Clinton area. For areas classified with one principal soil type, 85% of the test sites matched the principal soil type (Valentine *et al.* 1987). For areas classified as principally containing two soil types, 55-75% of the test sites matched the soil types (Valentine *et al.* 1987). There is no information regarding classification accuracy of areas containing three soil types.

Literature regarding the accuracy of soils data was requested, however, this information was not made available by the time of writing. Since aerial photographs were extensively used to create the polygon data it is assumed that methods used to create the digital soils data were similar to those employed in the creation of the forest cover information. Therefore, it is assumed that similar types of errors (*i.e.*, photo interpretation errors, digitizing errors) were encountered.

Chapter 4
Methods

This chapter describes the methods used to investigate frost (by means of surface temperature data) using the explanatory variables discussed in the preceding chapters. The first section reviews the selection of the GIS and image analysis software used for this research. The second section reviews methods used to obtain, translate, create and assemble the various spatial data into a multivariate data set to investigate frost. The chapter concludes with a review of the statistical methods evaluated and selected to investigate and analyze the multivariate data sets.

4.1 GIS/Image Analysis Software

The rationale for choosing the GIS and image analysis software for this research was a balance between user familiarity/friendliness, functionality, data compatibility and data transfer capabilities. As a result, ArcInfo (version 7.0.2; Unix based) (Environmental Systems Research Institute, Inc. Redlands, California) was chosen as the GIS software and PCI (version 5.3; Unix based) (PCI, Inc. Richmond Hill, Ontario) was chosen as the image analysis software. In the absence of any true GIS/image analysis integration software, these choices represented the best compromise and proved to be suitable for most aspects of this research.

ArcInfo is a vector-based GIS, which also has raster functionality in its GRID module. PCI is an image analysis software package designed for remote sensing, image processing and data visualization. In addition, PCI has good data transfer functionality to ArcInfo GIS.

4.2 Data Translation Procedures

Data translation procedures were required to convert TRIM and FC1/FIP data from their original data formats to ArcInfo GIS format. Data translation procedures do not affect the spatial integrity of the data; rather, they modify the file structure to be compatible with the GIS.

TRIM DEM point data and selected TRIM planimetric vector data were translated to ArcInfo GIS using a translation program developed by the Pacific Forestry Center (Victoria, British Columbia). The DEM point data were translated in order to produce secondary data (*e.g.,* slope, aspect, elevation range, curvature). Planimetric data (*i.e.,* hydrology, roads, clearings) were translated to geocorrect the thermal imagery and to provide a digital map base to geocorrect other spatial data. As described in the previous chapter, TRIM data were provided in a UTM projection defined by a NAD83 datum. The projection and datum for TRIM were not modified since all other spatial data were corrected and transformed to the same projection and datum as TRIM.

The FC1/FIP data were translated into ArcInfo GIS using a few different procedures. The FIP attribute files were translated from MOF FIP format to DBF format using the FIPDBASE translation program created by the British Columbia Ministry of Forests. Translation of the spatial attributes was accomplished using a translation program initiated by the British Columbia Ministry of Forests and made operable by this researcher. The translation procedure was written as an ArcInfo Macro Language (AML) and is included in Appendix A. The AML translates the FC1 graphics data from IGDS format and combines the database attributes translated from the FIP files. The AML also includes checks to ensure the translated spatial data are free of topological errors (*e.g.,* open polygons, multiple tags). The translated data were checked for errors (*e.g.,* labeling errors, missing attributes) using hard copy (*i.e.,* paper print) maps. In addition, forest cover data were transformed from the NAD27 datum to the NAD83 datum in order to be consistent with TRIM. Subsequent to the translation procedure, minor linear shifts were required for each study area. These shifts were based on matching recognizable features on the forest cover and TRIM data (*e.g.,* roads, lakes, clearings).

Soils data were provided in ArcInfo export format and, therefore, did not require translation. However, soils data were provided in a UTM projection defined by the NAD27 datum and therefore were transformed to the NAD83 datum.

4.3 Thermal Image Input and Image Manipulation

Continual inquiries were made to Intera Technologies (Ottawa, Ontario) requesting the original digital thermal imagery data. After many months of communication it was eventually revealed that, due to their age, the original image data, and the equipment required to process the data, had been discarded (MacKay 1995 personal communication). In consideration of the time which had been invested into the project, it was decided to continue the research using the thermal image information contained on the photographic strips.

The thermal images from the original photographic strips were converted into digital data by scanning the selected areas using a flatbed scanner. The images were scanned at a resolution of 300 dots per inch (dpi) using an eight bit grayscale (256 grayshades). The original thermal scanner resolution, based on the instantaneous field of view (IFOV) and the average elevation above ground level, is 11.43 m in diameter (102.61m^2). At a scanning resolution of 300 dpi and a scale of 1:60,000 (based on a flying altitude of 15,000 feet above mean ground level (Tracey 1989 personal communication)), the ground resolution of the scanned photographs is approximately 5 m x 5 m (25 m^2). The scanned image should, therefore, have sufficient resolution to capture the detail of the original images.

Since the original images (8 gray levels) were scanned using the minimum 8-bit data gray scale (256 possible gray level values), additional gray level values were introduced into the digital image data. In order to convert the images shades back to 8 gray levels, the PCI isodata clustering procedure was used. Isodata clustering is an image histogram manipulation used to arrange image histogram values into a specified number of clusters. Since the original images were level sliced into eight gray levels (Tracey 1989 personal communication), the digital image histogram values were grouped into eight clusters. The resultant images were cleaned of noise (*e.g.,* missing scan lines, scratches) using a subjective, user-specified median filter in Adobe Photoshop (Adobe Systems, Inc.).

Georectification (correcting the images to map co-ordinates) was performed on the digital image data in PCI. Planimetric data from TRIM were imported into PCI to correct the images. The images were successively geocorrected to roads, clearings, then hydrologic features, in consideration of the spatial and temporal stability of these features in geographic space (Lillesand and Kiefer 1994). In all cases, a sufficient number of ground control points (*i.e.,* > 40) were collected to subject the images to fourth order polynomial corrections.

After all image corrections were complete, the modified images were transferred to ArcInfo as a single variable file (SVF) in order to retain the geographic linkages. The images were then imported as raster data (ArcInfo GRID format). Additional geocorrection was completed within ArcInfo using the transformed forest cover vectors as a reference. In general, only minor adjustments were required. However, in the Blackwater/Pantage Creek study area, the middle section had to be excluded since the required adjustments were too large. The problem was associated with correcting a 2-dimensional image to a complex 3-dimensional surface. The errors introduced were too large to be acceptable, and could not be overcome with the current software. As already noted on page 29, it was decided to exclude this problem area and retain the two ends of the image which could be successfully geocorrected.

Once all the images were geocorrected, they were converted to polygon data to compare them with the other polygonal data. In doing so, the resolution of the original thermal scanner was considered and the images were filtered to ensure polygons less than the minimum thermal scanner resolution (as described above) were eliminated.

4.4 Secondary Data Creation

Certain data required for this research were produced from TRIM DEM point data. Data created from other data are referred to as secondary data. Slope, aspect, relative local elevation, and terrain curvature data were the secondary data produced from TRIM DEM data. In order to produce secondary terrain data, the DEM points were input into the ArcInfo GIS. A Digital Terrain Model (DTM) was created using the triangular irregular network (TIN) function in ArcInfo. The TIN function was used since it could incorporate features (*e.g.*, lakes, rivers, roads) which help define the terrain. Once the TIN was created, it was converted to a lattice (regular grid) to extract secondary data using classification ranges (functionality not available using TIN). The lattice was formed on a 25m x 25m grid following guidelines for supplementary DEM data resolution in *British Columbia Specifications and Guidelines for Geomatics, Vol. 3 (Digital Baseline Mapping at 1:20,000)* (B.C. Ministry of Environment, Lands and Parks 1992).

4.4.1 Slope

Slope data for each study area were obtained from the interpolated lattice. In consideration of previous research (*e.g.*, Steen *et al.* 1990), slope classes were categorized in 5% slope increments from 0% to 25% which were specified in a user-defined look-up table (LUT). Slope values greater than 25% were classified as one value. The resultant categorized slope lattices were converted to polygonal data coverages.

4.4.2 Aspect

Aspect data for each study area were derived in a similar manner as slope data. Classification of aspect values was accomplished using an ArcInfo default aspect classification LUT which categorized aspect into eight equivalent sections with an additional classification value for flat areas (no aspect) (Figure 4.1). The resultant classified aspect lattices were also converted to polygonal data coverages.

0. Flat (no aspect)
1. North
2. Northeast
3. East
4. Southeast
5. South
6. Southwest
7. West
8. Northwest

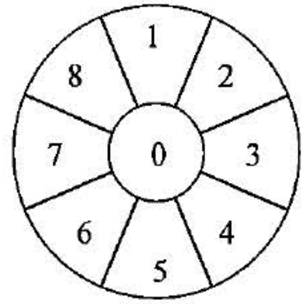


Figure 4.1 Aspect class representation

4.4.3 Terrain Curvature

Curvature data for each study area were produced using the functionality for deriving curvature in the GRID module of ArcInfo. In order to produce curvature data independent of slope, the 'planform curvature' option was used. The resultant data were a grid of continuous values representing the values of planform curvature. Negative values represented concave features and positive values represented convex areas, whereas values approaching zero were representative of flat areas. Curvature data were categorized on the basis of convexity, concavity or flatness. Flat areas were determined by finding the range of values in areas known to be flat (*e.g.*, lake surfaces). It was determined that areas with -0.5 to 0.5 planform curvature values were flat. The curvature data were classified into three classes (concave, flat and convex), and the resultant grids were converted to polygonal coverages.

4.4.4 Local Relative Elevation

Relative elevation range data for each study area were categorized from continuous elevation values interpolated by the lattice. Elevation values were classified into 10 metre intervals from the minimum elevation value to the maximum elevation value for each study area. The resultant categorized elevation range data were converted to polygonal coverages.

4.5 Merging of Spatial Data

The spatial data described above composes the relevant data under investigation in this research. To this point, the data exist in the GIS as separate coverages (spatial databases) with a common georeferenced co-ordinate system (UTM projection and NAD83 datum). In order to analyze these data, they must be merged together in the GIS. The overlay function is used to merge spatial data within a GIS. Since the data are in vector format, areas are represented by polygons and each polygon is defined by its unique attributes. In the process of overlaying spatial data coverages, polygons from one data coverage are merged with polygons of another data coverage. The resultant is a multivariate coverage with polygons which contain information from each input coverage.

Overlay functionality was used in order to create a spatial database which contained all the variables described in the preceding chapter. The 'intersect' overlay command was used since the areal extents of the input coverages differed slightly. The intersect overlay function only outputs an area spatially common to both input coverages (Figure 4.2). Therefore, it ensures that data is present for each input coverage over the entire extent of the output coverage. Producing an overlay coverage which contains all the relevant variables enables occurrences of these variables to be spatially compared and analyzed.

Since ArcInfo doesn't allow for more than two coverages to be input for overlaying at one time, data coverages were pair-wise combined until the final resultant overlay coverage was produced which contained all the variables (Figure 4.3). Table 4.1 represents the data contained in this multivariate coverage, the level of measurement, and examples of the categories into which the variables were defined.

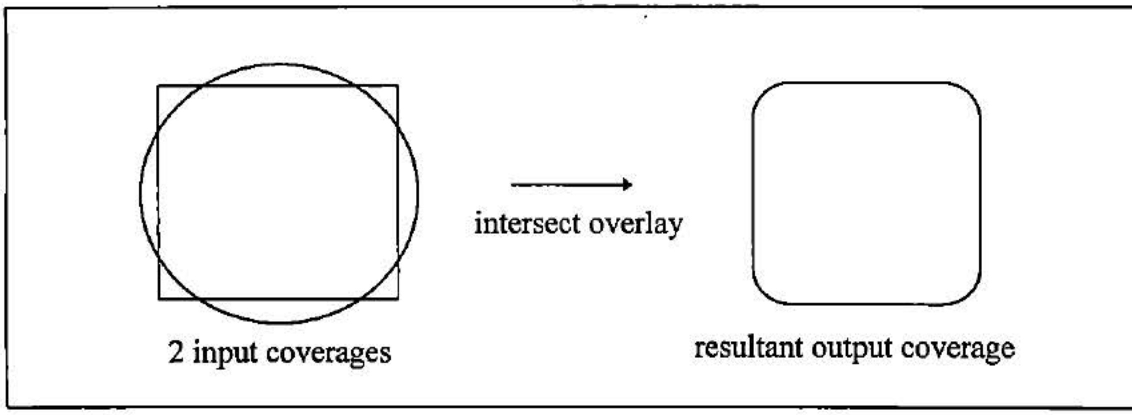


Figure 4.2 Intersect overlay process.

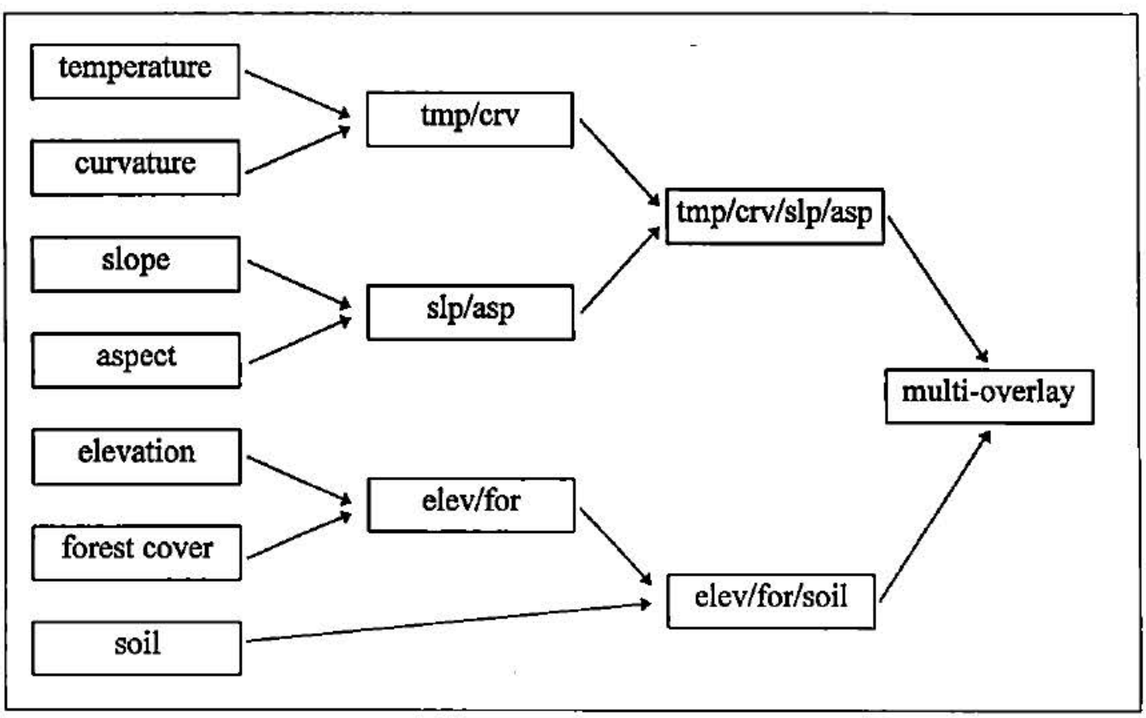


Figure 4.3 Overlay sequence of coverages to generate the multivariate spatial databases

Table 4.1 Variables used in this research

Coverage	Level of Measurement	examples of categories
Dependent variable		
Surface temperature	Ordinal (categorical)	1 (< -6°C), 2 (-6 to -4°C), 3 (-4 to -2°C), 4 (-2 to 0°C), 5 (0 to 2°C), 6 (2 to 4°C), 7 (4 to 6°C), 8(> 6°C)
Independent variables		
Aspect	Nominal (categorical)	1 (N), 2 (NE), 3 (E), 4 (SE), 5 (S), 6 (SW), 7 (W),8 (NW)
Slope	Ordinal (categorical)	1 (0-5%), 2 (5-10%), 3 (10-15%), 4 (15-20%), 5 (20-25%), 6 (25% +)
Elevation range	Interval (categorical)	*e.g.*, 1 (810-820 m), 2 (820-830 m), 3 (830-840 m) ......
Soil	Nominal (categorical)	1 (soil composition type 1) 2 (soil composition type 2)
Curvature	Ordinal (categorical)	1 (concave- negative curvature) 2 (flat - zero curvature) 3 (convex - positive curvature)
Forests -non forest areas	Nominal (categorical)	R (river), L (lake), S (swamp)
-species composition	Nominal (categorical)	1 (species composition 1) 2 (species composition 2)....
-age class	Ordinal (categorical)	0 (0 years), 1 (0 - 20), 2 (21-40), 3 (41-60), 4 (61-80), 5 (81-100), 6 (101-120), 7 (121-140), 8 (141-250), 9(251+)
-height class	Ordinal (categorical)	0 (0 m), 1 (0.1-10.4 m), 2 (10.4-19.4 m), 3 (19.5-28.4 m), 4 (28.5-37.4 m), 5 (37.5 -46.4 m), 6 (46.5-55.4 m), 7 (55.5-64.4 m), 8 (64.5+ m)
-crown closure class	Ordinal (categorical)	0 (0-5%), 1 (6-15%), 2 (16-25%), 3 (26-35%), 4 (36-45%), 5 (46-55%), 6 (56-65%), 7 (66-75%), 8 (76-85%), 9 (86-95%), 10 (96-100%)
-activity	Nominal (categorical)	*e.g.*, L (logging), B (fire), W (weeding)
-activity year	Interval (categorical)	*e.g.*, 78, 79, 80

Another consideration in the overlay process was the quantity and size of the resultant polygons in the multivariate database for each study area. The number of polygons generated in the multivariate coverage was a function of many factors (*e.g.*, size of the study area, number of polygons in each of the input coverages, size and shape of polygons in the input coverages, the tolerance selected to exclude polygons under a minimum area). The resultant multivariate spatial databases had substantial quantities of polygons (approximately 125,000 to 350,000), many of which were very small (*i.e.*, < 1

m^2). The meaning of small resultant polygons generated from overlays is questionable. However, an acceptable rationale to exclude small polygons for this research was not forthcoming due to the accuracy uncertainty for the input data. As it was computationally feasible to work with the quantity of polygons generated for each multivariate spatial database, it was decided to proceed with analysis using all the polygons.

4.6 Review of Analytical Methods to Investigate Surface Temperature by Site Variables

Since the statistical functionality of the GIS was limited with respect to vector polygon data, it was necessary to export the multivariate spatial database outside the GIS. The resultant multivariate databases were exported to SPSS for Windows (version 5.01) (SPSS Inc. Chicago, Illinois) for statistical analyses. Exporting the multivariate databases to the statistical software resulted in much greater analytical capability, however, some spatial information was sacrificed. The exported multivariate databases, however, do retain the spatial association between variables which is of greatest importance for this research.

After the multivariate databases were exported to SPSS, statistical methods were used to: 1) test for multicollinearity among independent variables, 2) conduct cross-tabulation analysis of the dependent/independent variable pairs, and 3) investigate the relative influence of independent variables on surface temperatures. In addition, it was possible to investigate certain relationships (*i.e.,* anomalies) among the spatially associated variables by filtering the multivariate datasets. This was accomplished by filtering the data set to include only the anomalous situation and investigating the characteristics of each of the independent variables. Anomalies could also have been investigated using the GIS to give a visual representation. In this research, due to the extremely high number of polygons in each study area, the high number of independent variables, and the extremely small size of many of the polygons, a visual representation would have little meaning compared to the information obtained by the method of filtering the statistical data set.

4.6.1 Preparation of Data for Statistical Analyses

Since the multivariate spatial data were obtained from a GIS vector polygon overlay, each observation (representing one polygon) within the database had to be corrected for areal dissimilarity. This was accomplished by weighting each observation (polygon) by its area using the weighting functionality of SPSS.

Forest composition and soil composition data also required special attention since each polygon could have multiple species or soil type classification of different proportions. Forest and soil compositions were re-coded so that each unique composition was represented by a specific numerical value. This was accomplished using SPSS programming functionality.

In addition, the multivariate database required filtering of events which took place after 1988 (the year in which the thermal imagery data were collected) in the forest cover information. The primary concern was that areas subjected to activity (*i.e.*, logging, wildfire) after 1988 be excluded from the analyses by filtering so as not to erroneously affect the analyses.

4.6.2 Bivariate Analyses of Dependent/Independent Variable Pairings

Bivariate analyses will be used for initial exploratory purposes to investigate relationships between the dependent (surface temperature) and the independent variables. Due to the categorical nature of many of the variables, the most straightforward bivariate technique to employ is a simple cross-tabulation procedure. The purpose of this analysis is to investigate the percentage composition of each independent variable class in each temperature class, particularly within the extreme temperature classes (*i.e.*, $< -6^{o}C$ and $> 6^{o}C$).

4.6.3 Evaluation of Statistical Methods to Investigate the Relative Influence of the Independent Variables

There are a number of variables contained in the multivariate data sets which, in theory, can influence frost at a particular site (Table 4.1). Whereas the cross-tabulation analysis is used to investigate the characteristics of each surface temperature class, further analytic techniques are required to investigate the relative influence of the independent variables with respect to surface temperatures.

In the following sections multivariate statistical techniques are evaluated with respect to how well they fit the problem and why they are accepted or rejected for this research.

4.6.3.1 Logit Analysis

Logit analysis is an extension of logistic regression. Both of these methods are meant to handle multivariate analysis of categorical data although they differ in the requirements of the dependent variable. Whereas logistic regression requires a dichotomous dependent variable, logit analysis can have a dichotomous or polychotomous dependent variable. In the logit model, the dependent variable is not the actual value of the variable but rather the log-odds (the ratio of frequency of occurrence to frequency of non-occurrence of the variable) (Norusis 1990). The first component of logit analysis constructs a multidimensional cross-tabulation which includes one cell for each possible combination of dependent and independent categories. The multidimensional cross-tabulation for the logit model gives a similar output to the cross-tabulation procedure mentioned in the previous section. Each cell contains the observed count and percentage, the expected count and percentage, the residual, the standardized residual, and the adjusted residual. The percentages are not based on the total table count but on the counts of each category of the independent variable (Norusis 1990). Thus, the percentages sum to 100 for each category of the independent variable.

The parameter estimates are the next component of the logit analysis. The parameter estimates are the actual lambdas (Norusis 1990). In the logit model, the parameter estimates are used to predict the log odds of cell frequencies (Norusis 1990). The measures of dispersion of the dependent variable can be used to calculate what proportion of the total dispersion in the dependent variable is attributed to the model (similar to the R^2 in regression). However, it is cautioned that measures of dispersion must be interpreted carefully since the coefficient may be small even when the variables are strongly related (Norusis 1990).

It is practically impossible to conduct a logit analysis on the multivariate data sets produced for this research. Since the number of variables and the number of categories within each variable produces a multidimensional cross tabulation with several million cells, interpretation of the output would be extremely difficult. In addition, the computational procedure in SPSS will not accept the number of variables required to be entered.

4.6.3.2 Multiple Discriminant Analysis

Due to the shortcomings of the logit analysis, multiple discriminant analysis was reviewed and evaluated with the multivariate data set. The primary objective of multiple discriminant analysis is to identify to which group a case belongs. Thus, each case falls into a group which can, theoretically, be explained by a set of independent variables chosen by the analyst (Hair *et al.* 1992).

With respect to the constraints of multiple discriminant analysis, the dependent variable must be categorical and the independent variables must be directional. Certain assumptions regarding the data must be met for the discriminant function to operate optimally. First, each group must be a sample from a multivariate normal population and second, the population covariances must all be equal (Norusis 1990).

The multiple discriminant analysis would be appropriate for those variables which are directional. Since a majority of the variables are non-directional and categorical, multiple discriminant analysis is not appropriate for this research.

4.6.3.3 Ordinary Least Squares (OLS) Regression

Since much of the data in the multivariate data sets are categorical, they are not immediately conducive to OLS regression. However, OLS regression can be used if dummy variables are created for the true categorical variables and the other categorized directional variables are modified to approximate continuous data (*i.e.*, selecting mid-values of the category). OLS regression is desirable since it offers a quick and efficient model with respect to computer processing. Therefore, it can be used as a quick approximation to test certain scenarios of data modification (*e.g.*, reduce complexity of categorical data by combining classes within a variable, test the contribution of polynomial transformations).

Through the use of OLS regression it was found that many of the classification units of the forest species variable (as described above) could be significantly reduced with very little explanatory loss of the model. Initially, the forest species classification variable was reduced to a forested/non-forested classification level. Independent OLS regressions were performed which separated forested and non-forested areas, and the performance of the model, as indicated by the R^2 value, was affected very little. However, in consideration of previous research (Stathers 1989, Steen *et al.* 1990), the forest species classification variable was classified into coniferous, deciduous and conifer/deciduous mix. This takes into account the different influences broad-leafed, deciduous species might have on surface temperatures compared to needle-leafed, coniferous species (Steen *et al.* 1990). Polygons which contained greater than 30% of a secondary species of opposite class were considered a coniferous/deciduous mix.

A similar reclassification of soil classification variables was performed with minimal loss of explanation by the model. The soils were originally classified by unique names. The soils were then re-classified in order to retain the major soil classification (*e.g.*, brunisol, podzol, mesisol, regosol). The same criteria which were used to identify the mixed class for forest species variables were used with the soils (*i.e.*, 30% or greater).

OLS regression also allows for the use of polynomial transformations for directional variables. Directional independent variables were subjected to polynomial transformation to investigate non-linearity of these variables with the dependent variable. For all variables, a fifth-order polynomial transformation was evaluated and then reduced to a third order due to the non-significance of the fourth-order and fifth order polynomials.

4.6.3.4 Interval Regression

When the dependent variable is reported in categories, a special type of regression model can be used. The interval regression (or grouped data regression) model is used when the dependent variable is categorical and the limits of the categories are known. The advantage of this analysis is that it retains a level of information in the dependent variable (the limits of the categories for the categorical data) which is absent in similar regression procedures (*e.g.*, logit).

The variables for interval regression are set up almost identical to OLS regression. The primary difference is that, for interval regression, the category threshold values are specified for the dependent categorical variable. The interpretation of the model coefficients is exactly the same as OLS regression. Other model outputs are also similar to OLS regression. In particular, interval regression outputs a log-likelihood value rather than an R^2 value. The log-likelihood value describes the the model fit (similar to the R^2 value in OLS regression). However, a perfect fit is indicated by a log-likelihood value of zero, whereas a perfect fit for an R^2 is 1.0 (Hair *et al.* 1992). The level of significance is also interpreted similarly between the two methods. The OLS regression method uses degrees of freedom to calculate the significance (*t*-distribution), whereas the interval regression uses a value of infinity to calculate significance (*z*-distribution). As the number of observations approaches infinity (*i.e.*, greater than a few hundred observations), the two distributions are essentially identical.

The standard OLS regression, as described in the preceding section, provides a good method of evaluating variable modifications and transformations. However, since SPSS does not perform interval regression, the data need to be exported to another statistical package. Stata (Stata Corporation, College Station, Texas), in addition to being more computationally efficient than SPSS, has the interval regression functionality and can weight the data using analytical weights.

Analytical weighting is preferable for regression since frequency weighting inflates the number of observations in proportion to the weighting variable (*i.e.*, the 'area' variable). In essence, this erroneously implies each post-weighted observation has been measured and recorded in the same way as the original observation. Since this method of weighting artificially increases the number of observations in proportion to the polygon area, significance tests are no longer valid. Analytical weighting considers data in the polygon as the average condition over the entire area of the polygon. Therefore, the weighting variable contains a representation of some number over which the average was calculated (or a number proportional to that amount). Thus, the average of the weighting variable sums to one, making significance tests valid. It must be noted that the frequency weights are not a concern with the cross-tabulation analysis. Since the sizes of the polygons were relative to one another, the frequency weight provided a simple method to compare categorical variables through cross-tabulation.

A major problem which exists with interval regression, as with most regression procedures, is autocorrelation. This is not a problem with the modeling procedure, but rather due to the nature of the data. The following describes the problem of spatial autocorrelation as it applies to this research.

With regression analyses, it is assumed that errors are independent from one observation to the next. This means error in one observation will not help predict error in the adjacent observation. However, if observations near one another are correlated, this assumption is violated.

Spatial information, by definition, is autocorrelated due the nature of geographical data. The principle behind autocorrelation is that things which are closer together are generally more similar than things further apart. In classical statistical testing, one degree of freedom exists for each independent observation. The difficulty with autocorrelated data is their lack of independence, such that new observations do not introduce one full degree of freedom (Legendre 1993). Therefore, autocorrelation results in some degree of multiple-counting which can bias statistical estimates, such as overestimating the R^2 value (Johnston 1980).

The problem of autocorrelation can be remedied (*i.e.*, using lagged variables) if the phenomena are autocorrelated in one direction, such as with time series data or unidirectional spatial data (*e.g.*, dispersion of effluent in a river) (Johnston 1980). However, most spatial phenomena are multi-directional which greatly increases the complexity of the autocorrelation problem.

The question arises whether statistical analyses are valid if spatial autocorrelation exists. This primarily depends on the particular objectives of the analysis (*i.e.*, whether it is for explanatory, descriptive or predictive purposes) (Johnston 1980). If the information used for an analysis is spatially autocorrelated, a certain degree of bias may occur within the analysis. If the information is being used for exploratory purposes, it may be acceptable to proceed with the recognition of a certain degree of bias.

4.6.4 Interpreting Data using Regression Analysis

The purpose of regression analysis is to analyze the relationship between a dependent variable and hypothesized independent variables in order to generate an equation which best predicts the dependent variable. In some cases, it is desirable to use the equation to predict actual values of the dependent variable for actual observations of the independent variable. Due to the problems associated with spatial autocorrelation in this research, surface temperature predicted from actual observation of the independent variables would be biased. In addition, the equation is very specific to the variables in the study area and the equation is too precise with respect to the uncertainty associated with much of the data. As a result, it is more appropriate to extract general relationships from the model rather than the specific measurement of model fit as indicated by the model outputs (*i.e.*, R^2 and log-likelihood values). Therefore, the regression analysis will be used for its other analytical functions and properties. In particular, it is possible to examine the relative influence of the independent variables by using the regression models.

The regression coefficients give some indication of the influence of the variables within the equation. However, regression coefficients are affected by measurement units. Therefore, variables measured in different units cannot be directly compared using the regression coefficients. One method to assess the relative influence of variables within a regression model is to standardize the coefficients (*i.e.,* beta coefficients). Standardizing the coefficients is accomplished by transforming the raw data into new measurement variables with a mean of zero and a standard deviation of 1.0 (Hair *et al.* 1992). When transformed, the intercept assumes a value of zero and the standardized regression coefficients are output as beta coefficients. In addition, beta coefficients can be used to estimate the relative influence of the variable within the equation since they reflect the relative impact of a change of one standard deviation in the independent variables on the dependent variable (Hair *et al.* 1992).

Upon closer examination, the use of beta coefficients in this research is not straightforward. Dummy variables are problematic with respect to beta coefficients. Since beta coefficients are meant to standardize continuous directional variables, they have little or no meaning with respect to dummy variables (Nichols 1996 personal communication). An additional problem associated with beta coefficients is their inability to evaluate polynomial transformations. This is because a separate beta coefficient is output for each term in the polynomial. Therefore, the combined effect of the polynomial cannot be evaluated using beta coefficients (Sweetman 1996 personal communication).

An alternative way of investigating the relative influence of independent variables within the prediction equation is to observe the change in the predicted dependent variable (surface temperature) by adjusting each of the independent variables individually from a hypothetical observation. This method may not be as statistically grounded as the use of beta coefficients. However, it is a straightforward and meaningful method to investigate the relative influence of variables in real units rather than statistical constructs (*i.e.,* beta coefficients).

Two methods were evaluated to investigate the relative influence of independent variables. In the first method, a hypothetical observation was generated which was derived from the mean of each variable (including the mean of each dummy variables). This observation was replicated numerous times to allow for evaluation of adjusting each independent variable. For each replicated observation, one independent variable was adjusted while the rest remained at their mean (except for polynomials where each polynomial term is adjusted accordingly).

It was found that this method was not adequate since it could not be used to correctly investigate the effects of the dummy variables. In order to correctly compare the dummy variables to an omitted category, it was necessary to set the dummy variables to zero rather than their mean. Therefore, the second method is identical to the first, however, it sets the dummy variables to zero rather than their mean.

Chapter 5
Cross-tabulation Analysis and Results

The multivariate data sets from each study area will be analyzed using cross-tabulation and regression analyses. This chapter will review the results of the cross-tabulation analysis, whereas the following chapter will review the results of the interval regression analysis. The intent of these analytic procedures is to investigate the relationship and relative influence of each independent variable with respect to frost related surface temperatures. If the independent variables can aid in the identification of frost-prone areas, it would greatly enhance the worth of these datasets by providing an important source of information to resource planners concerned with frost occurrence.

5.1 Summary of Study Areas by Surface Temperature Class

This section provides a brief summary of the distribution of surface temperatures in each study area (Table 5.1). Warmer surface temperatures predominate in the Pantage Creek study area; only 32.5 % of the study area is below 0°C and only 0.6 % is in the lowest temperature class. Most of the areas in the Blackwater study area are subject to surface temperatures in the middle of the range (near 0°C), although, trending towards lower temperatures. In the Sovereign Creek study area there is a greater proportion of areas with lower surface temperatures since 77% of the area is below 0°C. For the Big Creek study area there is more of a balance between the percentage of areas over and

Table 5.1 Summary of surface temperature class as a relative percentage of study area

Study Area	Temperature Class (°C)							
	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
Pantage Creek	0.6%	6.1%	8.5%	17.3%	10.7%	5.1%	13.2%	38.5%
Blackwater	3.9%	18.6%	16.2%	34.9%	14.7%	5.2%	3.7%	2.8%
Sovereign Creek	33.7%	23.3%	12.0%	8.0%	5.8%	3.3%	6.9%	7.0%
Big Creek	11.2%	14.6%	7.8%	15.8%	7.9%	9.7%	9.4%	23.5%
Moffat Lakes	5.2%	11.3%	13.8%	9.2%	7.9%	5.8%	10.3%	36.6%

under 0°C. There is a greater proportion of areas above 0°C in the Moffat Lakes study area, and the highest temperature class has a greater percentage of area than any other class.

5.2 Multicollinearity in the Independent Variables

All combinations of independent pairs were cross-tabulated and tested for multicollinearity (*i.e.*, two independent variables linearly related). Age class and stand height class were the only combination of independent variables which showed evidence of multicollinearity. In all study areas, the correlation between these two variables had a Pearson's r above 0.90 and well within the accepted level of significance (0.05). This indicates that age and height are essentially providing the same information. In consideration of the multicollinearity, the age class variable was excluded from the analyses.

5.3 Cross-tabulation Results of the Dependent/Independent Variable Pairs

After testing for multicollinearity among the independent variables, the independent/dependent bivariate pairs were cross-tabulated to investigate the characteristics of the surface temperature classes, particularly the extreme surface temperature classes (< -6°C and > 6°C). The following sections summarize the results of the cross-tabulations for the dependent/independent pairs for each study area

5.3.1 Surface Temperature and Aspect

Aspect, by itself, does not perform well as an indicator of frost-prone areas as indicated by surface temperature. Table 5.2 shows the aspect class composition in each surface temperature class for all five study areas. The shaded cells in Table 5.2 indicate higher percentages (*i.e.*, > 15%) of the aspect class within a surface temperature class for the extreme surface temperature classes. There is no consistent aspect-surface temperature trend between the five study areas (Table 5.2).

Table 5.2 Aspect class composition (%) of each surface temperature class (columns for each study area add to 100%)

Study Area	aspect	Surface Temperature Class (°C) < -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
Pantage Creek	flat	4.2	1.7	0.5	0.7	0.5	0.1	0.3	0.1
	N	4.7	7.8	17.0	12.9	13.3	13.0	12.8	17.2
	NE	33.4	18.7	21.8	18.7	16.1	14.0	12.9	14.4
	E	28.5	28.4	21.1	20.8	19.8	15.7	13.7	11.1
	SE	5.9	15.1	16.5	15.8	19.6	19.8	17.8	13.2
	S	2.0	5.5	5.4	6.1	9.4	12.1	12.9	11.1
	SW	2.4	3.6	4.5	6.5	6.9	7.6	6.7	9.8
	W	15.3	13.4	7.2	12.0	8.9	9.7	12.9	10.7
	NW	3.6	5.9	6.0	6.5	5.4	7.8	9.9	12.3
Blackwater	flat	12.7	5.1	3.5	1.8	1.3	1.4	0.9	14.1
	N	15.6	10.3	12.2	10.4	8.8	5.6	4.8	5.3
	NE	11.7	10.8	11.7	11.1	10.9	9.3	3.3	3.4
	E	15.1	14.2	15.7	13.9	10.7	12.0	7.0	11.1
	SE	6.0	8.9	8.3	8.7	6.2	6.4	2.1	2.9
	S	5.9	10.4	8.3	7.9	5.4	4.9	4.4	4.0
	SW	7.9	12.8	11.1	10.5	11.8	13.6	10.7	8.5
	W	14.8	17.8	17.6	23.0	28.9	37.9	47.0	33.9
	NW	10.2	9.7	11.6	12.6	16.1	8.9	19.7	16.9
Sovereign Creek	flat	1.8	1.4	.8	.3	.3	1.2	3.1	.9
	N	9.3	7.7	5.8	6.3	6.2	6.6	6.4	5.3
	NE	17.9	14.1	13.8	18.8	16.9	21.9	17.2	10.3
	E	16.4	14.0	18.2	17.9	15.1	21.2	17.5	12.9
	SE	7.8	9.5	13.2	12.6	8.3	7.7	6.7	7.6
	S	9.2	12.8	11.5	17.1	16.5	9.3	13.3	16.0
	SW	15.0	19.8	19.0	14.6	19.1	14.2	16.4	25.5
	W	14.4	13.2	10.7	6.6	10.5	11.3	13.9	15.5
	NW	8.0	7.5	7.0	5.7	7.2	6.6	5.3	6.0
Big Creek	flat	5.8	3.3	3.2	2.8	1.9	2.0	0.9	0.6
	N	16.7	21.4	20.7	21.9	23.0	25.7	23.2	27.4
	NE	12.6	18.1	21.1	20.0	23.5	22.1	29.1	30.2
	E	10.2	10.9	11.7	13.0	14.0	12.6	13.9	10.5
	SE	9.9	8.3	8.7	9.3	8.4	6.8	7.3	6.4
	S	11.9	8.9	7.8	6.9	6.1	5.8	4.5	5.5
	SW	10.0	7.2	5.9	5.5	4.0	4.7	3.8	3.7
	W	10.2	8.6	7.8	7.1	5.3	5.6	4.0	4.7
	NW	12.7	13.5	13.0	13.5	13.7	14.7	13.3	11.1
Moffat Lakes	flat	2.9	1.6	.9	.6	.6	.7	.6	1.4
	N	11.3	15.1	15.2	18.0	16.9	12.4	10.1	11.1
	NE	9.3	7.0	5.5	5.0	4.3	4.6	3.0	4.4
	E	9.1	7.3	4.6	4.2	3.6	4.3	2.5	4.7
	SE	17.5	12.4	9.9	9.4	8.0	8.5	7.5	7.7
	S	18.3	17.6	18.9	18.9	17.7	19.8	19.3	18.2
	SW	13.6	19.4	24.5	25.5	27.6	28.6	33.5	27.6
	W	8.9	10.9	11.7	10.5	11.7	12.3	15.7	14.2
	NW	9.1	8.7	8.8	7.8	9.5	8.8	7.8	10.7

5.3.2 Surface Temperature and Slope

Slope appears to be a relatively good indicator of surface temperature. In all the study areas, low surface temperatures almost exclusively occur in areas with slopes less than 10%. For example, in the lowest surface temperature class (< -6°C), the proportion of areas with slopes of less than 10% ranges from 73.8% (Sovereign Creek study area) to 97.0% (Big Creek study area) (shaded cells in Table 5.3). In addition, areas which have

Table 5.3 Slope class composition (%) of each surface temperature class (columns for each study area add to 100%)

		Surface Temperature Class (°C)							
Study Area	slope	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
Pantage Creek	< 5%	47.0	32.6	15.6	14.3	14.1	10.4	10.9	4.0
	5 - 10%	33.4	29.5	23.9	18.8	25.6	24.4	26.2	13.0
	10 - 15%	12.7	19.7	26.8	21.1	21.8	23.8	25.9	23.8
	15 - 20%	4.8	10.2	19.4	21.5	15.5	18.5	17.4	26.1
	20 - 25%	1.6	4.4	8.9	14.3	11.2	11.9	10.3	17.7
	> 25%	.5	3.6	5.4	9.9	11.7	11.1	9.3	15.5
Blackwater	< 5%	67.7	62.0	49.6	37.2	25.8	22.9	17.3	47.1
	5 - 10%	24.2	25.0	30.0	33.3	36.7	28.9	28.9	7.8
	10 - 15%	5.1	8.1	11.4	14.8	20.2	24.4	28.9	16.2
	15 - 20%	1.4	2.9	4.7	6.7	8.5	11.6	12.4	16.2
	20 - 25%	.3	1.0	2.2	3.7	3.3	5.8	8.5	10.1
	> 25%	1.2	1.0	2.1	4.3	5.4	6.4	4.0	2.5
Sovereign Creek	< 5%	38.3	39.9	28.0	18.7	14.4	15.6	19.7	16.5
	5 - 10%	35.5	32.7	36.8	33.8	27.2	25.4	25.6	22.8
	10 - 15%	16.9	15.9	20.5	28.8	32.5	29.3	27.7	24.2
	15 - 20%	6.8	7.3	9.4	12.5	18.4	17.6	16.1	20.0
	20 - 25%	1.9	2.8	3.8	4.0	5.8	8.6	6.4	8.9
	> 25%	.7	1.4	1.5	2.2	1.7	3.6	4.5	7.5
Big Creek	< 5%	76.2	65.3	52.3	50.9	40.3	43.6	27.9	16.9
	5 - 10%	20.8	26.0	29.7	30.4	34.4	33.0	34.4	28.3
	10 - 15%	2.5	6.9	12.4	12.4	16.0	14.4	22.3	23.2
	15 - 20%	.3	1.4	4.0	4.4	6.0	5.5	9.5	15.8
	20 - 25%	.1	.2	1.0	1.1	2.0	1.9	3.8	8.0
	> 25%	.1	.2	.6	.8	1.3	1.6	2.2	7.8
Moffat Lakes	< 5%	58.4	49.7	32.7	24.4	21.0	24.3	23.4	21.4
	5 - 10%	32.2	39.9	43.9	37.3	35.0	33.9	35.4	25.8
	10 - 15%	7.0	8.5	16.3	21.0	23.4	24.0	25.1	20.6
	15 - 20%	2.1	1.7	5.0	10.3	11.6	11.1	9.9	14.3
	20 - 25%	.3	.2	1.8	5.3	6.7	4.7	4.2	9.2
	> 25%	.0	.0	.4	1.7	2.4	2.0	2.0	8.7

slopes greater than 20% tend to have higher surface temperatures. An exception occurs in the Blackwater study area where 47% of the area in temperature class 8 (> 6°C) occurs in slope class 1 (<5%) (cross-hatched cell in Table 5.3). By filtering the data set to investigate this anomaly, it was found that 73% of this area is classified as water. Since water bodies exhibit very little thermal response, surface temperatures differ very little from day to night (Oke 1987). This can be attributed to four characteristics: 1) water allows short-wave radiation to penetrate to considerable depth and is diffused through a large volume, 2) convection and mass transport by fluid motion permits heat gains/losses to be spread throughout large volumes, 3) unlimited water provides an efficient heat sink and evaporation tends to destabilize the surface and enhance mixing, and 4) the thermal capacity of water is exceptionally large therefore requiring approximately three times a much heat to raise a unit volume of water through the same temperature interval as most soils (Oke 1987). Most importantly, during the night it takes three times as much heat loss to lower the temperature of a unit amount of water compared to the same unit amount of soil. This is the primary reason for higher surface temperatures of water bodies compared to other surfaces (*i.e.,* soils and vegetation).

5.3.3 Surface Temperature and Local Relative Elevation

Relative elevation classes used in this research are based on 10 metre intervals between the minimum and maximum elevation values for each study area. Local relative elevation, theoretically, can have two opposing effects on surface temperature depending on time. Initially, high elevation sites tend to cool quicker than lower elevation sites but, as the night progresses, cold air will be shed from high elevation sites and collect at lower elevations if the area is sloped. At the time the thermal imagery data were collected (03:00-05:00 LST), there should have been sufficient time for cold air to flow and accumulate in low elevation areas.

The cross-tabulation results from each study area are presented in charts rather than tables. This presentation method is chosen since each study area has a high number of elevation classes (*i.e.,* 30 - 75) (see Appendix B for complete cross-tabulation results).

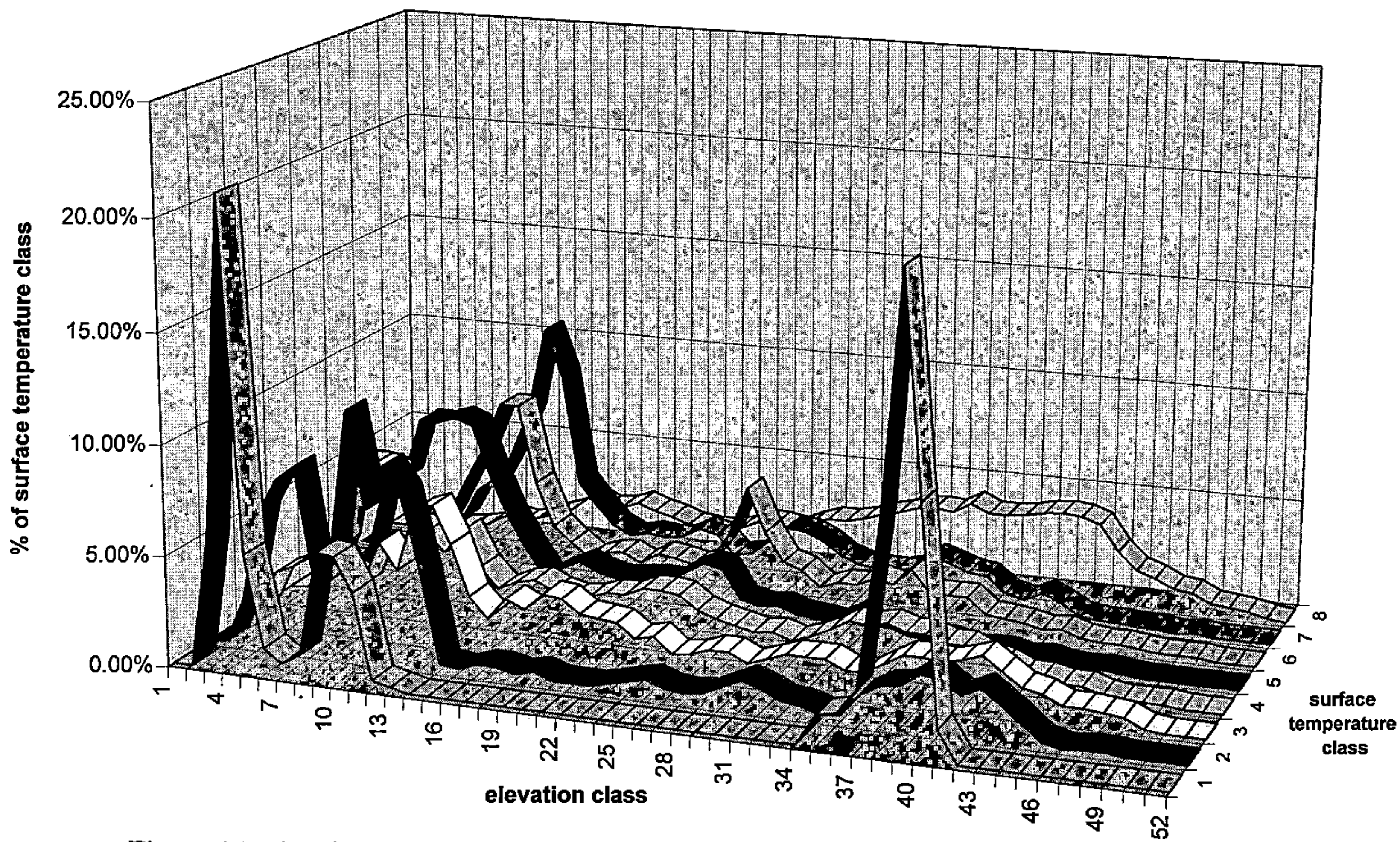


Figure 5.1 Elevation class composition of each surface temperature class in the Pantage Creek study area

In the Pantage Creek study area low surface temperatures predominantly occur at lower elevation (Figure 5.1 and Appendix B Table B1). Out of 52 elevation classes (representing an elevation difference of 520 metres), 21% of the area in temperature class 1 (< -6°C) occurred in elevation class 4 (30 - 40 m) and 5.3% of the area in temperature class 1 occurred in elevation class 5 (40 - 50 m). In addition, 33% of the area in temperature class 2 (-6°C to -4 °C) occurred between elevation classes 9 and 12 (80 - 120 m). It was found that 21% of the area in temperature class 1 occurred in elevation class 39 (380 - 390 m) which may suggest an area from which cold air couldn't drain (*i.e.*, cold air stagnating on a high elevation plateau). By filtering the multivariate database to investigate this anomaly, this area was found to be 100% logged and 98.2% of the logged area had a slope of less than 10%. These characteristics would likely produce low surface temperatures since cold air would be trapped and stagnate in the clearing.

In the Blackwater study area there are 30 elevation classes representing a difference of 300 metres from the lowest elevation to the highest elevation (Figure 5.2 and Appendix B Table B2). Approximately 10% of the area in temperature class 1 (< -6°C) occurs in elevation class 2 (10 - 20 m). Approximately 55% of the area in temperature class 2 (-6°C to -4 °C) occurs between elevation classes 1 and 6 (0 - 60 m) and approximately 40% of the area in temperature class 3 (-4°C to -2 °C) occurs between elevation classes 2 and 6 (10 - 60 m). The higher elevation areas show a greater tendency for warmer surface temperatures. Approximately 29% of the area in temperature class 8 (> 6°C) is between elevation classes 25 and 28 (240 - 280 m). In addition, approximately 46% of the area in temperature class 7 (4°C to 6 °C) is between elevation classes 21 and 26 (200 - 260 m).

An interesting anomaly that could suggest stagnation of cold air (*i.e.*, cold air ponding) is that approximately 20% of the area in temperature class 1 (< -6°C) occurred in elevation class 16 (150 - 160 m). By filtering the multivariate database, it was found that 60% of this area was swamp, and 40% of this area was forested, of which 83% of the forested area had slopes less than 5%. The low surface temperatures are likely due to cold air stagnation on the flat swamp and the flat forested land. In addition, the swamp is also likely to cause low surface temperatures since bog soils can't store much heat

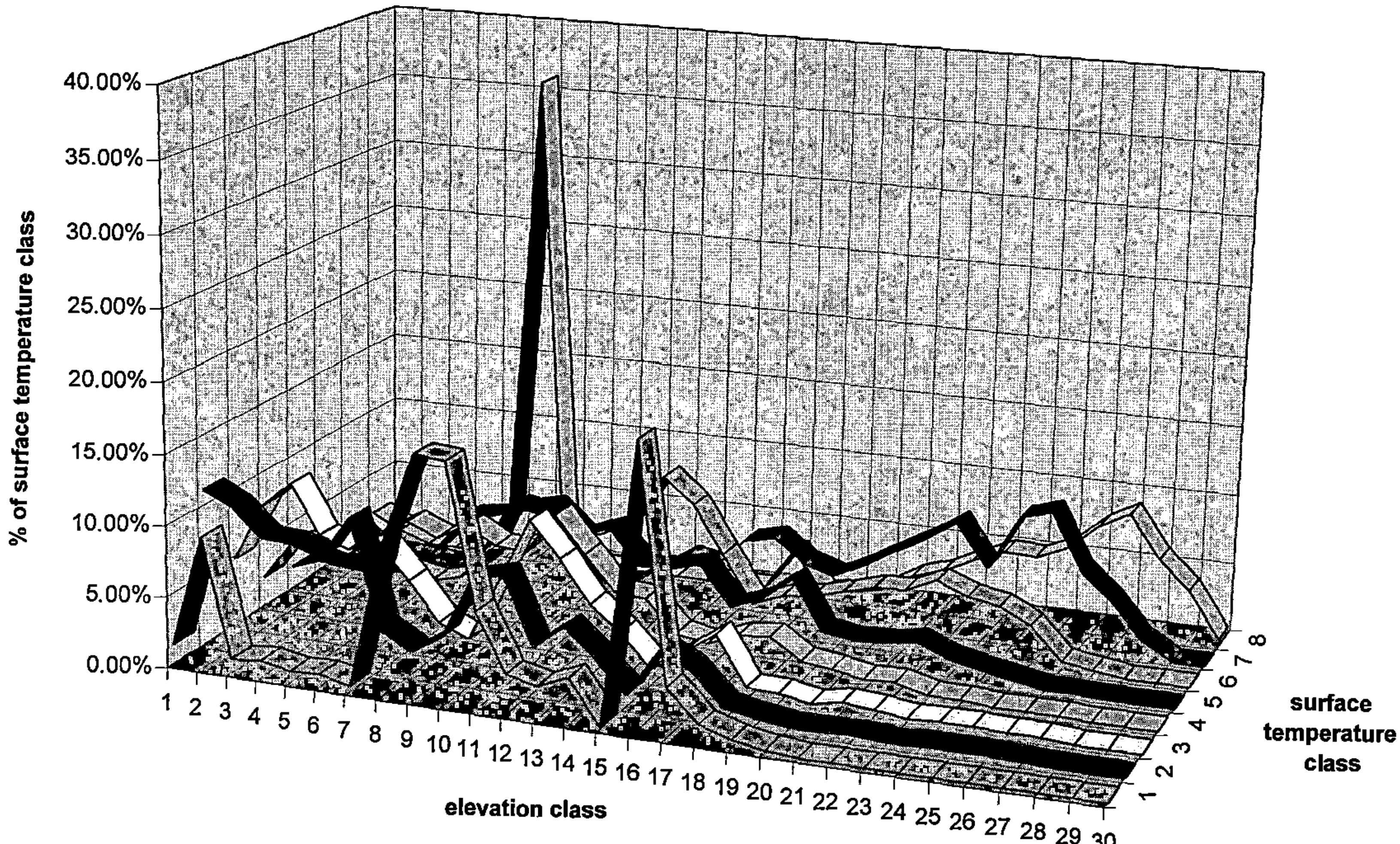


Figure 5.2 Elevation class composition of each surface temperature class in the Blackwater study area

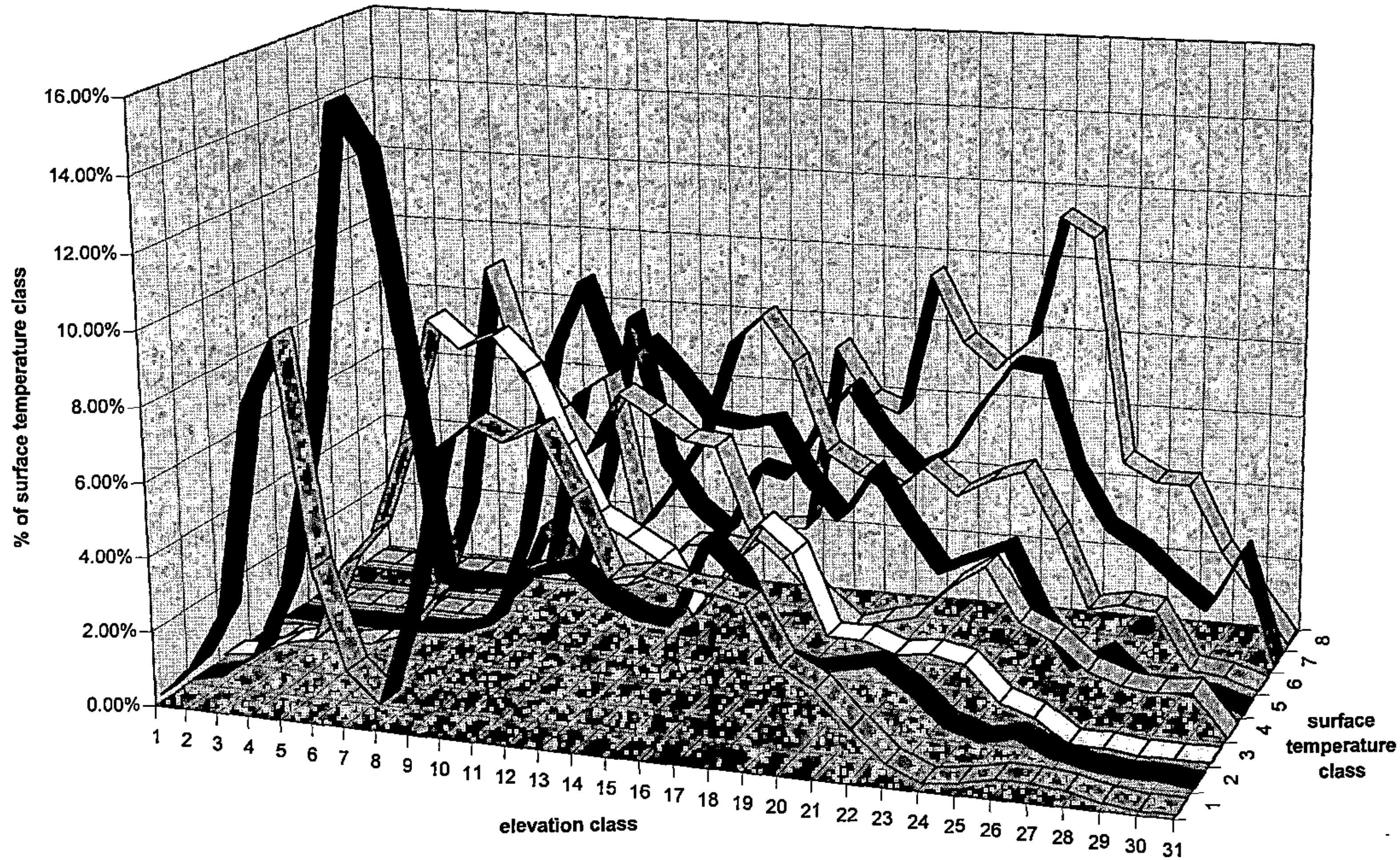


Figure 5.3 Elevation class composition of each surface temperature class in the Sovereign Creek study area

in the daytime due to evaporation at the surface (see Section 5.3.5 for further explanation).

Another anomaly in the Blackwater study area is that 36% of the area in surface temperature class 8 (< 6 °C) occurs in elevation class 7. Upon further investigation, it was found that 80% of this area is a lake (see Section 5.3.2 for further explanation).

There are 31 elevation classes which represent a elevation difference of 310 metres between minimum and maximum elevation in the Sovereign Creek study area (Figure 5.3 and Appendix B Table B3). The data reveal similar trends as the previous two areas. For example, in temperature class 1 (< -6 °C), 18% of the area occurs in elevation classes 4 and 5 (30 - 50 m). In temperature class 2 (-6°C to -4 °C), 48% of the area occurs between elevation classes 5 and 8 (40 - 80 m). In temperature class 3 (-4°C to -2 °C), 38% of the area occurs between elevation classes 8 and 11 (70 - 110 m). In contrast, low elevation classes (1 to 9) have no values for the highest temperature class (8), but for temperature class 8 (>6°C), 65% of the area occurs between elevation classes 20 and 25 (190 - 250 m).

The Big Creek study area has 73 elevation classes which represent an elevation difference of 730 metres between the minimum and maximum elevation (Figure 5.4). Lower surface temperatures coincide with low elevation classes. For example, 78% of the area in temperature class 1 (< -6°C) and 58% of the area in temperature class 2 (-6°C to -4 °C) occurs between elevation classes 13 and 16 (120 - 160 m). In contrast, there is a trend for higher surface temperatures to be coincident with higher elevations, while the coincidence of low surface temperatures with higher elevations is extremely rare.

In the Moffat Lakes study area, there are also 73 elevation classes (Figure 5.5). 65% of the area in temperature class 1 (< -6°C) occurs within elevation classes 24 to 27 (230 - 270 m). In addition, 82% of the area in temperature class 2 (-6°C to -4 °C) occurs within elevation classes 23 to 29 (220 - 290 m) and 60 % of the area in temperature class 3 (-4°C to -2 °C) occurs in elevation classes 23 to 28 (220 - 280 m). Conversely, 30% of the area in temperature class 8 (> 6°C), occurs within elevation classes 30 to 37 (290 - 370 m). The coincidence of low temperatures at high elevation is extremely low. An anomaly occurs at the secondary peak of surface temperature class 1 (< -6° C) at elevation

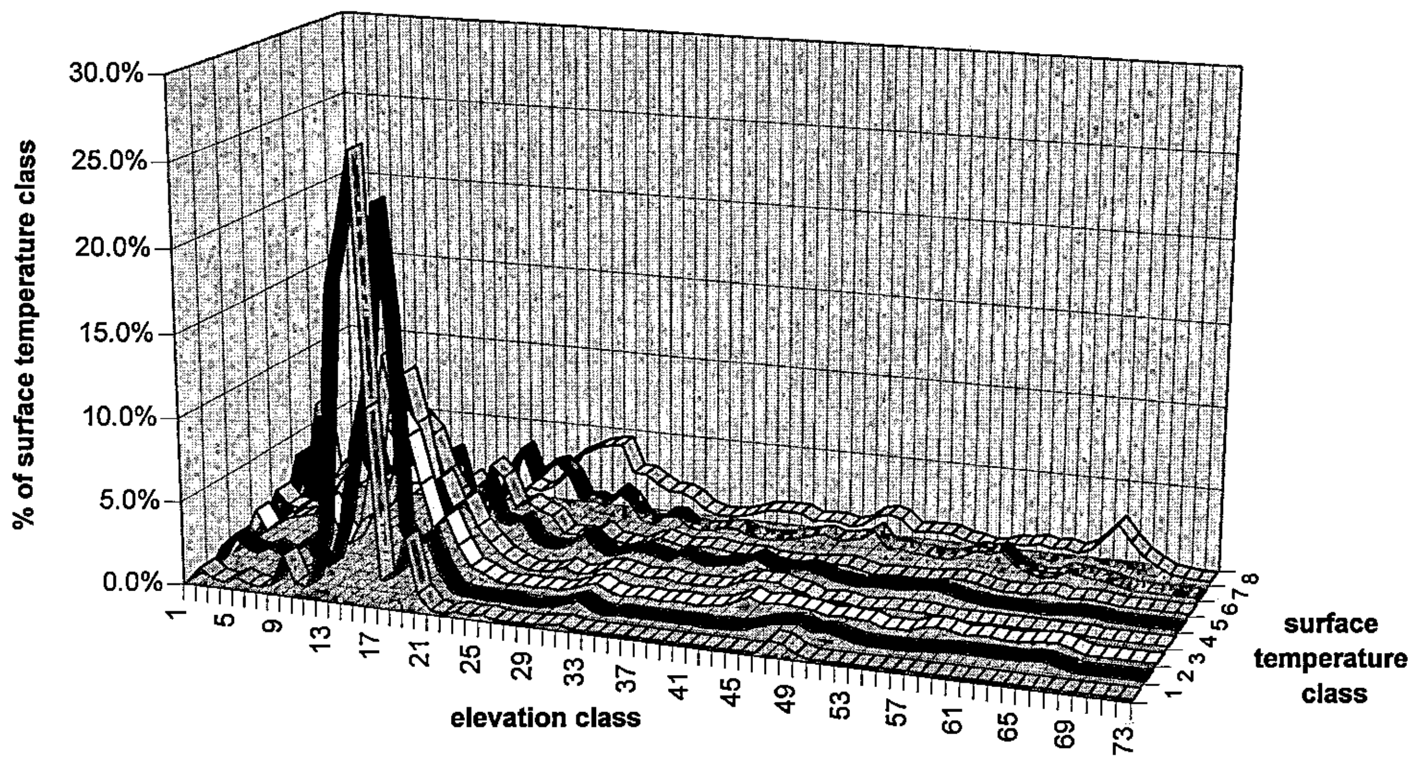


Figure 5.4 Elevation class composition of each surface temperature class in the Big Creek study area

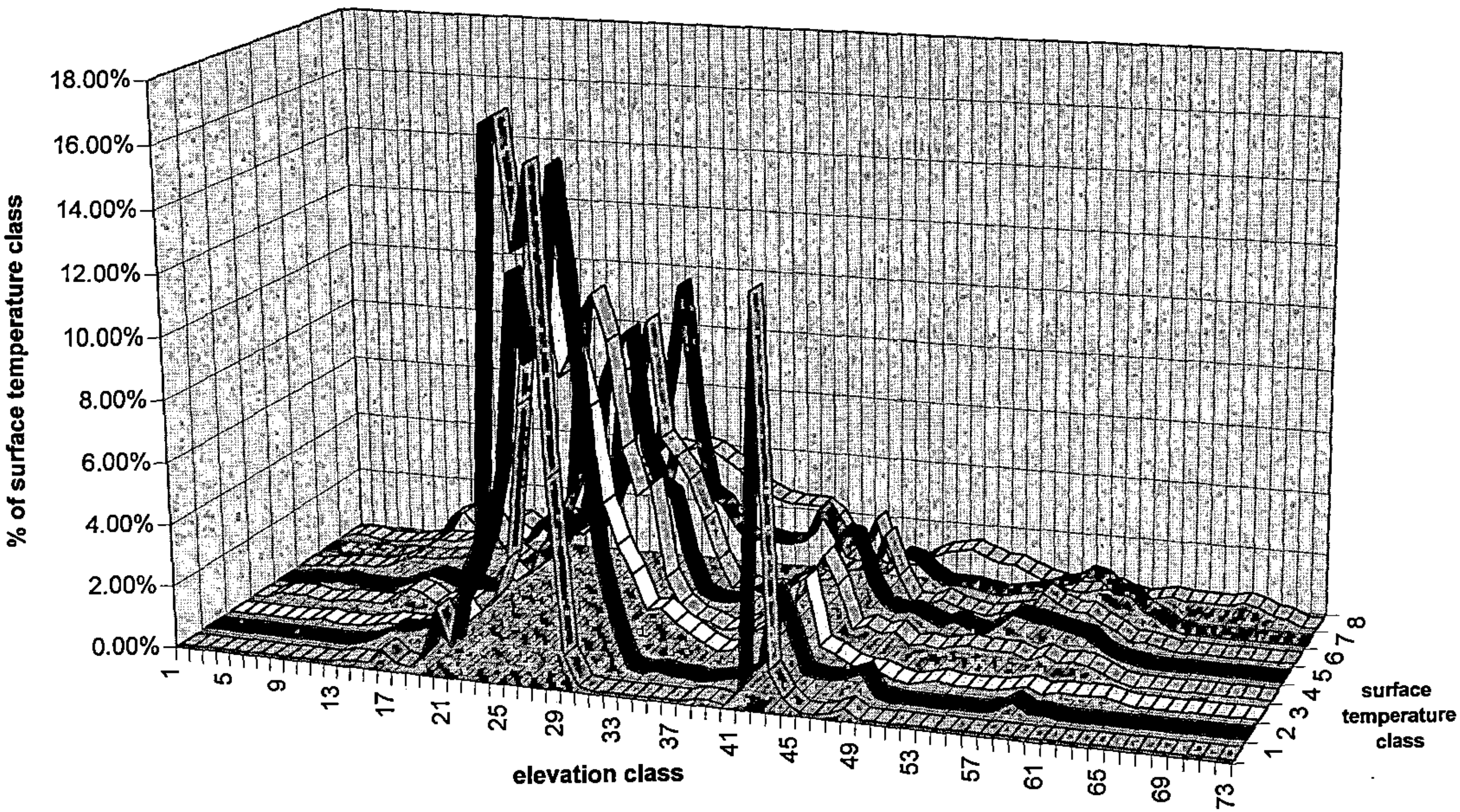


Figure 5.5 Elevation class composition of each surface temperature class in the Moffat Lakes study area

class 42. It was found that this anomaly was due to 58% of the area being swamp and 42% of the area being conifer forest with slopes of less than 10%. These characteristics suggest cold air stagnation due to low slopes of the landscape. In addition, the swamp can contribute to cold surface temperatures if the bog soils are wet due to reduced diurnal heat storage (see Section 5.3.5 for further explanation).

In summary, it is evident that the overall trend is for lower surface temperatures to occur at lower elevation. It is assumed that high elevations are associated with slopes and, therefore, will shed cold air. Lower elevation are assumed to be much more likely to be located at valley bottoms and flat areas. The cross-tabulation reports show that there is generally a direct relation between surface temperature and local relative elevation. Anomalies were found to exist, where the above assumptions do not hold. The anomalies were due to specific features of the landscape (*i.e.,* logged areas, swamps, flat forested areas, or lakes). If caution is used with respect to the presence of other variables which affect the drainage of cold air to lower elevations (*e.g.*, plateaus, logged areas), local relative elevation is a good indicator of surface temperatures. Another benefit of this relationship is that elevation data are usually easy to obtain and/or generate from digital elevation models.

5.3.4 Surface Temperature and Terrain Curvature

Theory suggests that concave areas should be more susceptible to lower surface temperatures due to cold air ponding and stagnation, whereas, convex areas should be relatively warmer since they tend to shed cold air. Cross-tabulation data generated from the combination of surface temperature and curvature variables for the study areas shows only a slight indication that this may be occurring (Table 5.4).

Cells are highlighted in Table 5.4 if the difference between the convex and concave classes for the extreme surface temperature classes (< -6 °C and > 6 °C) is greater than 5%. All the study areas have highlighted cells in the highest surface temperature class (> 6 °C). Only the Pantage Creek and Blackwater study areas have highlighted cells in the lowest surface temperature class (< -6 °C).

Table 5.4 Terrain curvature class composition (%) of each surface temperature class (columns for each study area add to 100%)

		Surface Temperature Class (°C)							
Study Area	curvature	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
Pantage Creek	concave	27.7	29.8	33.5	32.0	29.1	28.7	28.1	27.0
	flat	53.0	44.9	38.9	38.4	40.0	39.8	41.6	36.3
	convex	19.3	25.3	27.7	29.6	30.9	31.5	30.2	36.7
Blackwater	concave	21.3	25.0	24.6	24.5	23.4	21.1	19.1	14.3
	flat	61.5	54.6	49.9	48.6	47.8	50.8	55.5	65.9
	convex	17.2	20.4	25.5	26.9	28.8	28.1	25.4	19.8
Sovereign Creek	concave	22.4	21.3	22.4	21.2	21.4	20.7	20.2	20.2
	flat	56.5	55.6	53.3	52.8	51.1	51.0	51.3	48.5
	convex	21.1	23.1	24.3	26.0	27.4	28.3	28.4	31.3
Big Creek	concave	20.6	20.5	22.1	22.1	24.0	22.8	25.2	21.9
	flat	61.0	59.9	55.5	55.1	51.1	51.6	48.4	48.7
	convex	18.3	19.6	22.4	22.8	25.0	25.6	26.4	29.4
Moffat Lakes	concave	26.2	25.2	25.6	26.7	28.1	27.6	27.7	25.7
	flat	50.4	50.3	47.2	46.2	43.9	44.0	44.7	43.9
	convex	23.4	24.5	27.1	27.1	28.0	28.4	27.6	30.4

In summary, the differences between surface temperatures in convex and concave sites are considerably less than would be expected by theory. Therefore, the differences aren't large enough to suggest that terrain curvature (as defined here) can be used as an indicator of surface temperatures.

5.3.5 Surface Temperature and Soil

As mentioned in the preceding chapter, soils information was reclassified so that one number represented each unique soil composition. In the discussion of the results, the soil composition will be referred to as follows: the first 3 letters are the primary soil classification (Table 5.5), followed by the modifier in brackets (if applicable), followed by the percentage composition of the primary soil. If applicable, this also extends to the secondary and tertiary soils. Primary, secondary and tertiary soils are separated by a slash(/). For example, soil composition type ORM(5)40/BRT30/ORM(9)30 is 40% shallow lithic Ormond soil, 30% Barret soil, and 30% very shallow lithic Ormond soil.

Since the soil classification polygons are much larger than the surface temperature polygon with which they are being compared, the discussion of results will include only

Table 5.5 Soil classification codes, names, types and modifiers which occur in the five study area.

AIX - Alix soil - orthic dystric brunisol	KNK Keno Lake soil - orthic humo-ferric podzol
ALZ - Aleza soil - orthic luvic gleysol	LDN - Lynn soil - lithic orthic humo-ferric podzol
ARH - Archie soil - podzolic gray luvisols	MOF - Moffat Lakes soil - ortho humo-ferric podzol
ART - Art soil - brunisolic gray luvisol	ORM - Ormond soil - orthic dystric brunisol
BGC - Big Creek soil - orthic eutric brunisol	PTZ - Piltz soil - orthic gray luvisol
BGR - Big Bar soil - chernozem (orthic dark brown)	RAM - Ramsey soil - orthic humo-ferric podzol
BRT - Barret soil - orthic gray luvisol	RKL - exposed bedrock
CHM - Chasm soil - eluviated eutric luvisol	ROA - Roaring soil - orthic dystric brunisol
CIF - Chief soil - typic mesisol	SEW - Shemwell soil - orthic gray luvisol
CMY - Chimney soil - chernozem (orthic dark brown)	SLL - Salt Lake soil - orthic gray luvisol
DAG - Dragon soil - orthic humo-ferric podzol	SOU - Spout soil - podzolic gray luvisol
DES - Deserters soil - gleyed brunisolic gray luvisol	STK - Stellako soil - gleyed regosol
DMI - Dominion soil - luvisolic humo-ferric podzol	TEE - Tyee soil - orthic gray luvisol
DZK - Dezaiko soil - orthic humo-ferric podzol	TGP - Telegraph soil - eluviated dystric brunisol
ELT - Elliot soil - carbonated rego-humic gleysol	VWM - Vedan Meadow soil - orthic gray luvisol
GUI - Guilford soil - gleyed cumulic regosol	WLA - Williams Lake soil - orthic gray luvisol
HWK - Hawk soil - eluviated eutric brunisol	WSD - West Road soil - eluviated dystric brunisol
KEI - Keithly soil - typic mesisol	ZZZ - Zezaiko soil - chernozem (orthic dark brown)
Modifiers:	
1 - gleyed subgroups	9 - very shallow lithic soils; bedrock within 50 cm
5 - lithic soils - shallow to bedrock within 100 cm	11 - terric (shallow) organics
7 - saline phase	14 - eroded phase
8 - carbonated phase	17 - bouldery phase; stony class = 5 or 3

those soil composition classes which have a significantly high percentage of area overlay within the extreme temperature classes (see Appendix C for complete cross-tabulation).

In the Blackwater study area (Appendix C Table C2), lower surface temperatures occured in AIX85/CIF15, CIF70/CIF(11)15/ALZ15, STX70/AIX15/CIF(11)15 and WSD50/AIX35/ CIF15 soils. Since the common soil type in each of the soil classes is CIF, this could suggest that CIF may have a negative influence on surface temperature. In contrast, there was a prevalence for warm temperatures in WSD65/BRT35 and ORM(5)40/BRT30/ ORM(9)30 soils. The BRT soil was present in both soils, suggesting a possible influence for higher surface temperatures.

There was a tendency for low surface temperatures to occur in CIF70/CIF(11)15/ ALZ15 In the Pantage Creek Area (Appendix C Table C3). In contrast, higher surface temperatures occurred in ORM(5)40/BRT30/ORM(9)30, TGP85/SLL15 and

TGP60/ORM(5)25/ORM(9)15. This suggests that there may be similarities with the Blackwater area (which is expected since the two areas are relatively close together). Again, the CIF is associated with low surface temperatures. It also appears that the BRT soils are associated with warm areas, along with ORM and TGP soils. The modifiers (5) and (9) indicate shallow lithic soils where bedrock is less than 100 cm or 50 cm from the surface, respectively.

In the Sovereign Creek study area (Appendix C Table C4), low surface temperatures were prevalent within DMI60/ALZ25/CIF15 and CIF70/ALZ30. In contrast, there was a tendency for higher temperatures to occur with DMI60/DAG(5)25/DAG(9)15 soils. Again, it can be observed that the CIF soil classification appears in the low surface temperature classes.

Low surface temperatures occurred within the SEW100, TEE80/BGR20 and VWM60/TEE25/BGR15 in the Big Creek study area (Appendix C Table C5). Conversely, there was a tendency for higher surface temperatures to occur within the TEE100 and the PTZ85/ PTZ(5)15 soils. This possibly suggests that the BGR soil class may have a tendency to be associated with colder areas (since it occurs with TEE which, by itself, is predominantly in the higher surface temperature classes).

KNK and KEI soil types are included in the soils associated with low surface temperatures in the Moffat Lakes study area (KEI100, KNK60/KEI40 and the MOF50/KNK50) (Appendix C Table C6). Conversely, the ARH soil type is common to the soils that had high temperatures (ARH60/ARH(5)40 and the LDN(5)60/ARH40).

In summary, the CIF (Chief) soil type is common to areas with lower surface temperatures in three of the five areas described above. Chief soils are typic mesisol which are highly organic, very poorly drained, and usually have 5 to 20 cm of peat moss at the surface with very little vegetation and characteristically occur in bogged area (Lord and Walmsley 1988). The thermal conductivity (and frost-proneness) of organic soils can fluctuate with soil moisture. Dry organic soils are typically more frost-prone than other soils due to their reduced thermal conductivity and heat storage ability. However, when organic soils are extremely wet (*e.g.*, bog soils), very little heat can be transferred to the sub-surface since much daytime heat is lost to evaporation at the surface (Geiger 1965).

This increases the risk of frost in bog and swamp areas. Chief soils also occupy depressional or very gently sloping areas generally below 1200 metres (A.S.L.), which further enhances the possibility of frost due to cold air drainage from higher areas and stagnation of cold air in these areas (Lord and Walmsley 1988).

KEI (Keithley) soils in the Moffat Lakes study area are also typic mesisols which are highly organic and are very poorly drained (Lord 1984). These soils generally accumulate on gentle slopes and in depressions at high elevation sites in the Quesnel Highland well above 1100 metres (Lord 1984). Since these soils are typic mesisols, they are likely to have similar thermal properties as the Chief soils discussed above.

BGR (Big Bar) soils in the Big Creek study area are classified as orthic dark brown chernozems, semiarid, very well drained and have considerable organic matter in the surface horizon (Valentine *et al.* 1987). As a result of the dryness of the soil and the organic surface layer, the thermal conductivity of the soil would be low, resulting in lower surface temperatures during the night. In addition, these soils are commonly covered with grass and have very few trees (Valentine *et al.* 1987).

The soils which coincide with higher surface temperature are primarily gray luvisols (BRT, SLL, TEE, PTZ, and ARH) and/or brunisols (WSD, ORM and TGP). With respect to gray luvisols, there is very little or no organic matter incorporated into the top of this mineral soil. These fine to medium textured soils contain clay which contributes to a high thermal diffusivity resulting in high subsurface heat storage compared to organic soils. Brunisols are also fine to medium textured mineral soils (loamy); features which contributes to high heat storage to the subsurface (Geiger 1965). As both these soils types are conducive to diurnal heat storage, they could provide a source of heat at night to reduce the cooling of the ground surface. Since both of these soil types commonly occur under forest canopies it is difficult to determine whether the soil properties are contributing to the higher surface temperatures or if it is due to other variables (*e.g.*, forest cover, crown closure).

5.3.6 Surface Temperature and Forest Species Composition

Each forest cover polygon can be composed of a primary, secondary, tertiary and quaternary forest species with associated percentage values (see Table 5.6 for forest species codes). In the discussion of the results, the forest composition will be referred to as follows: the first letters are the primary forest species, followed by the percentage composition of the primary species. If applicable, this also extends to the secondary, tertiary and quaternary species. The primary, secondary, tertiary and quaternary species are separated by a slash(/). For example, forest species composition type PL50/S30/AT20 is 50% Lodgepole pine, 30% Spruce, and 20% Aspen.

Table 5.6 Forest species composition codes used in this research

Forest Species codes	
AC - Balsam/Poplar/ Cottonwood	PL - Lodgepole pine
AT - Aspen	S - Spruce
B - True fir	SB - Black spruce
BL - Alpine fir	SE - Engelmann spruce
EP - Common paper birch	SW - White spruce
FD - Douglas fir	

As with the soils, discussion of results for the forest species composition will include only those forest species composition classes which have a significantly high percentage of area overlay within the extreme temperature classes (see Appendix D for complete cross-tabulation).

There was no consistent relationship between the study areas with respect to a particular forest species and a low or high surface temperature class. Spruce (S, SW and SB) was, by far, the most dominant forest species and it was usually found in areas of both high and low surface temperatures. The same was true for Lodgepole pine which was the second most dominant species. Therefore, these species offered very little with respect to distinguishing between high and low surface temperatures. Within two study areas, there were some consistencies for certain species to be coincident with high or low temperatures. In the Big Creek study area (Appendix D Table D5), cold surface temperatures were found to occur where aspen (AT) was present in the forest composition (AT60/PL40, AT50/PL50, PL100, PL80/FD10/AT10, PL73/AT27, PL60/AT40 and

PL48/AT45/FD7). Conversely, higher surface temperatures were found to coincide with the presence of Douglas fir (FD) in the forest composition (FD100, FD80/PL20, PL90/FD10 and PL80/FD20). In the Sovereign Creek study area (Appendix D Table D4), the presence of Alpine Fir (BL) in the forest species composition seemed to coincide with higher surface temperatures (PL70/SW30, PL60/SW30/BL10, SW80/BL20, SW70/PL30, SW60/BL35/AT5, SW60/FD20/BL20, SW60/FD20/PL20, SW60/PL20/BL20, SW60/PL30/BL10). In summary, cross-tabulation analysis using forest species composition and surface temperature class doesn't reveal much conclusive information regarding frost occurrence.

5.3.7 Surface Temperature and Crown Closure

Forested areas with sparse crown closure had a greater frequency of low surface temperatures than areas with more complete crown (Table 5.7). Measured surface temperature was generally found to have a positive relationship with crown closure in all the study areas, therefore, as the crown closure increased, the surface temperatures increased. This relationship can become obscured as the crown closure increases. As the crown coverage approaches 100%, the sensing device records the surface temperature of the tree crown surface rather than the ground surface. With a complete (or near complete) crown closure, the tree crown layer cools directly via net longwave radiation loss. It is possible that this might be occurring in the Blackwater study area (*e.g.,* 27% of the area in the coldest temperature class (< -6^{o}C) was in crown closure class 7 (56 - 65%)). Upon further investigation, it was found that 94% of this area had slopes of less than 10%. This could indicate that cold air may be stagnating on the tree crown surface.

Another anomaly is found in the Blackwater study area where 45% of the area in the warmest temperature class (> 6^{o}C) was in the lowest crown closure class (< 5%). Upon further investigation (filtering the database for only those data which were crown closure class 1 (< 5%) and temperature class 8 (> 6 ^{o}C)), it was found that 100% of this anomaly was due to water features (*i.e.,* lake) (see Section 5.3.2 for further explanation).

Table 5.7 Crown closure class composition (%) of each surface temperature class (columns for each study area add to 100%)

Study Area	crown closure	Surface Temperature Class (°C)							
		< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
Pantage Creek	< 5%	23.7	15.3	5.7	2.7	1.1	1.2	1.0	.5
	6 - 15	53.1	23.7	32.9	28.2	10.3	8.4	1.9	.7
	16 - 25	.0	10.7	24.9	18.6	10.3	7.0	1.6	.8
	26 - 35	5.2	15.6	6.0	5.0	5.6	3.0	.4	.0
	36 - 45	16.5	21.2	15.7	9.3	5.7	4.5	3.1	1.5
	46 - 55	.1	3.7	3.2	7.3	18.2	12.8	14.2	4.1
	56 - 65	.7	3.6	4.0	8.4	8.4	10.2	11.8	7.5
	66 - 75	.0	3.3	4.8	13.8	27.6	31.3	38.1	41.2
	76 - 85	.7	2.8	2.9	6.5	12.8	21.6	27.9	43.7
Blackwater	< 5%	55.2	51.1	26.1	12.2	8.6	7.6	4.9	44.5
	6 - 15	5.2	4.0	2.6	.9	.7	1.3	1.4	.5
	16 - 25	.8	4.0	4.2	4.7	1.1	.1	.0	.0
	26 - 35	.6	1.4	1.2	.8	.3	.3	.0	.0
	36 - 45	.1	4.7	3.4	4.1	2.0	.0	.0	1.1
	46 - 55	6.7	14.6	34.1	42.5	25.7	7.0	2.7	.9
	56 - 65	26.8	10.8	14.8	20.4	26.9	17.3	40.5	19.0
	66 - 75	4.7	9.5	13.5	14.4	33.6	64.0	46.6	33.6
	76 - 85	.0	.0	.0	.1	1.2	2.3	3.8	.4
Sovereign Creek	< 5%	19.0	14.7	8.9	9.3	7.1	6.8	6.7	8.4
	6 - 15	18.6	11.9	7.8	14.6	3.6	2.9	1.7	.7
	16 - 25	6.1	3.8	4.7	9.4	5.7	7.4	2.7	3.0
	26 - 35	7.5	4.9	6.8	6.4	10.0	14.1	13.3	7.9
	36 - 45	30.2	24.6	27.9	24.8	30.2	39.5	27.0	35.8
	46 - 55	14.8	24.3	27.4	24.5	29.4	19.7	35.2	21.2
	56 - 65	3.7	15.8	16.5	10.9	13.8	9.7	13.4	23.0
	66 - 75	.1	.0	.0	.1	.0	.0	.0	.0
Big Creek	< 5%	38.0	31.2	30.3	19.3	17.4	11.5	12.2	16.5
	6 - 15	15.4	4.6	3.6	3.3	4.3	3.2	4.0	1.7
	16 - 25	12.5	13.4	13.1	10.7	13.0	16.7	12.0	6.7
	26 - 35	8.2	9.2	12.6	15.1	13.3	13.4	17.5	24.9
	36 - 45	11.6	24.8	23.9	26.6	27.9	27.5	27.4	16.2
	46 - 55	2.4	4.4	8.5	17.4	17.5	20.7	16.3	22.0
	56 - 65	7.1	6.2	3.5	4.2	3.5	4.0	5.2	7.5
	66 - 75	4.6	6.2	4.3	3.2	2.7	2.9	4.6	3.7
	76 - 85	.3	.1	.1	.1	.4	.1	.7	.6
	86 - 95	.0	.0	.0	.0	.0	.0	.0	.3
Moffat Lakes	< 5%	50.6	48.0	24.8	29.3	25.9	23.1	10.7	10.8
	6 - 15	32.2	24.8	17.3	13.9	7.3	2.9	2.2	2.1
	16 - 25	2.5	3.8	4.4	4.1	2.6	1.5	1.1	.5
	26 - 35	.1	1.1	3.9	7.7	12.6	13.7	19.6	11.9
	36 - 45	4.7	4.1	3.3	7.5	13.1	21.6	24.4	19.8
	46 - 55	.8	2.6	4.1	5.7	10.1	11.0	15.8	16.6
	56 - 65	3.8	3.6	5.2	5.5	6.8	5.9	7.5	10.6
	66 - 75	4.0	6.4	15.2	8.7	5.7	3.7	3.4	4.9
	76 - 85	.9	4.4	16.8	11.2	8.1	6.1	7.0	14.4
	86 - 95	.3	1.1	4.9	6.3	7.8	10.4	8.3	8.4

In summary, an increase in crown closure is often associated with an increase in surface temperature. Crown closure appears to be an important indicator of surface temperature, although caution must be used when dealing with complete, or near complete crown coverages.

5.3.8 Surface Temperature and Stand Height

Surface temperatures, theoretically, should increase as stand height increases under a partial forest cover. The surface temperature/height class cross-tabulation data show some relation to this theory (Table 5.8). However, if the forest crown cover is

Table 5.8 Stand height class composition (%) of each surface temperature class (columns for each study area add to 100%)

Study Area	stand height	Surface Temperature Class (°C)							
		<-6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	>6
Pantage Creek	0 metres	23.7	15.3	5.7	2.7	1.1	1.2	1.0	.5
	0.1 - 10.4	71.2	71.5	79.7	61.1	31.9	23.9	9.7	4.9
	10.5 -19.4	4.3	3.5	2.7	3.7	7.6	10.6	14.4	22.3
	19.5 - 28.4	.8	9.7	11.8	31.7	57.0	61.3	70.5	67.3
	28.5 - 37.4	.0	.0	.1	.8	2.2	3.0	4.3	4.9
Blackwater	0 metres	41.3	27.0	11.1	4.8	4.8	7.2	4.9	44.5
	0.1 - 10.4	40.9	20.6	18.8	14.7	5.1	2.6	1.4	.5
	10.5 -19.4	9.1	17.8	30.3	34.0	46.6	56.0	49.1	34.0
	19.5 - 28.4	8.7	34.6	39.8	46.4	43.5	34.2	44.4	20.5
	28.5 - 37.4	.0	.0	.0	.0	.0	.0	.2	.5
Sovereign Creek	0 metres	19.1	14.7	8.9	9.4	7.1	6.8	6.7	8.4
	0.1 - 10.4	34.1	18.3	10.6	16.0	4.5	3.9	2.1	.5
	10.5 -19.4	5.6	3.9	3.9	2.1	3.3	5.1	5.5	2.2
	19.5 - 28.4	23.3	36.0	34.0	25.3	33.4	20.4	34.0	41.3
	28.5 - 37.4	17.7	27.0	42.3	47.0	50.5	62.6	51.3	47.7
	37.5 - 46.4	.1	.1	.3	.2	1.1	1.2	.3	.0
Big Creek	0 metres	24.9	23.8	25.3	17.0	15.2	9.7	11.4	16.2
	0.1 - 10.4	46.3	29.3	23.1	15.9	12.3	11.4	12.6	17.2
	10.5 -19.4	26.8	40.9	44.5	56.6	57.5	58.1	57.3	53.9
	19.5 - 28.4	1.9	4.0	5.9	10.2	14.8	20.7	18.5	12.5
	28.5 - 37.4	.1	2.0	1.3	.3	.2	.1	.1	.2
Moffat Lakes	0 metres	34.2	27.0	13.5	12.0	10.6	7.3	6.7	10.0
	0.1 - 10.4	53.9	52.2	34.4	35.5	24.5	19.2	6.0	2.3
	10.5 -19.4	1.7	1.6	3.0	4.7	6.5	8.1	10.5	10.3
	19.5 - 28.4	10.2	18.6	46.1	45.8	55.0	63.1	72.1	70.3
	28.5 - 37.4	.1	.5	3.0	2.0	3.3	2.3	4.6	6.9
	37.5 - 46.4	.0	.0	.0	.0	.0	.0	.1	.1

complete, or near complete, the above relationship doesn't necessarily apply, particularly if the sensor is measuring the surface temperature of the crowns of the trees rather than the ground surface (see Section 5.3.7 for further explanation). An anomaly to the theoretical relationship occurs in the Blackwater study area data where 45% of the area in temperature class 8 are in height class 0 (0 metres) (cross-hatched cell in Table 5.8). Upon further investigation, it was found that 100% of this anomaly was due to water features (*i.e.*, lake) which contribute to the higher surface temperature (see Section 5.3.2 for further explanation).

In summary, stand height appears to be a fairly good indicator of surface temperatures, such that increased stand height class often is associated with an increase in temperature class.

5.4 Summary of Cross-tabulation Results

It is evident, from the results described above, that some variables are more closely associated with surface temperatures than others. In particular, the variables which appear to be good indicators of surface temperatures and which are consistent with theory are: 1) stand height, 2) crown closure, 3) relative elevation, and 4) slope. To a lesser extent certain soils (*i.e.*, organics) seem to coincide with colder surface temperatures; a relationship which has theoretical foundations.

Unexpectedly, curvature data which theoretically should have a strong relationship with surface temperature, had a consistently weak relationship. Forest species composition data and aspect data had inconsistent relationships with surface temperatures. It is possible that these variables may have greater importance in the interval regression analysis. The following chapter will discuss the results from the interval regression analysis which investigates the relative influence of the independent variables with respect to surface temperature.

Chapter 6

Interval Regression Analysis and Results

Ordinary least squares (OLS) regression was used as a first approximation of the relationships between independent variables and the dependent variable (surface temperature). OLS regression also was used to evaluate data consolidation (*e.g.,* forest species composition and soils composition variables) and polynomial transformation of continuous directional data (*i.e.,* stand height, crown closure, relative elevation, and slope).

Subsequent to OLS regression, interval regression was used. Interval regression further refines OLS regression by incorporating interval class threshold values. The output generated from each type of regression is very similar since both OLS and interval regression models are designed for prediction. For this research, the prediction functionality of these models will only be used for exploratory purposes to investigate the relative influence of the independent variables on surface temperature. This will be accomplished by using the interval regression model coefficients. The relative influence of each independent variable will be investigated by changing the values of the each independent variable (individually) from a hypothetical observation and observe the change in predicted surface temperature.

6.1 Presentation of Results by Study area

In the following sections, results from the regression analyses are presented for each study area. The outputs from each type of regression and the predicted surface temperature data for each study area are contained in Appendix E. The predicted surface temperatures from the interval regression, which represent each modified condition, are summarized and presented in graphical form. It must be noted that the graphs include forest activity variables (*i.e.,* logging, weeding, fire, scarifying) and non-productive forest variables (*i.e.,* water, rocks, clearings, swamp). The interpretation of the graphs will be limited primarily to those variables which are being explicitly investigated in this research. However, the influence of logged areas on surface temperatures will be discussed since it also is of importance to this research . The final section of this chapter compares the results from each of the study areas and offers a summary of the most consistent and influential variables with respect to surface temperature

6.1.1 Pantage Creek Study Area

The results from the regressions for the Pantage Creek study area are contained in Appendix E (Tables E2, E3 and E4). The R^2 value reported from the OLS regression is 0.71 and the log-likelihood reported from the interval regression is -138901. Predicted surface temperatures from the Pantage Creek study area (Table E4) are summarized in Figure 6.1. The predicted surface temperature of the hypothetical observation from the interval regression is 3.9 °C.

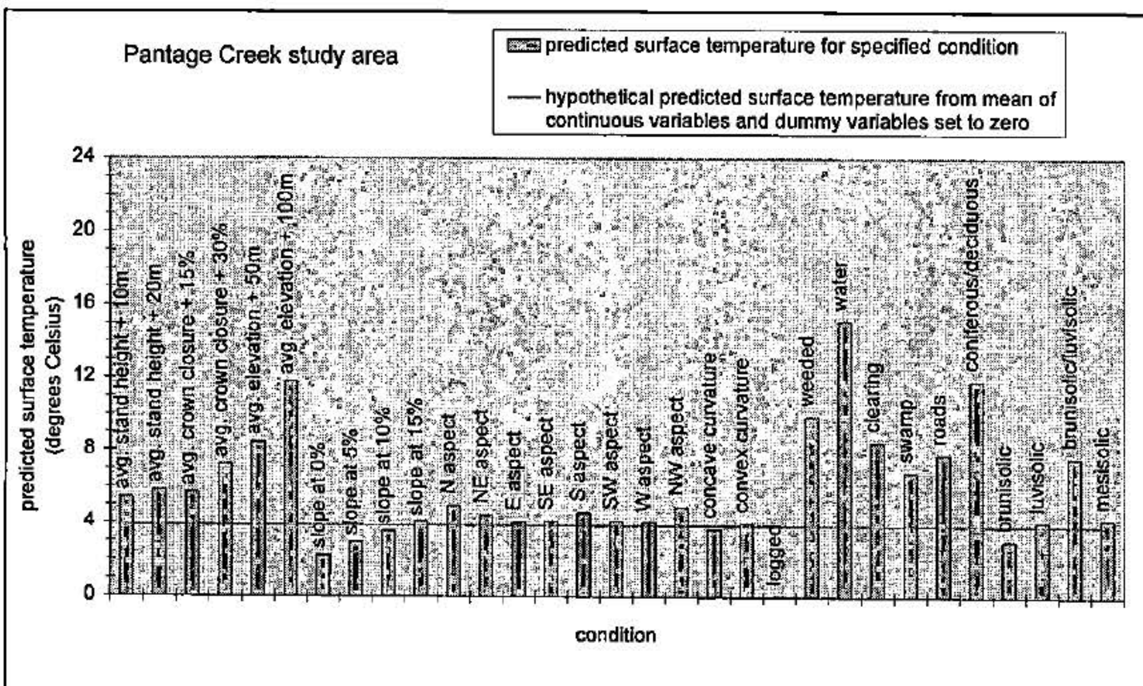


Figure 6.1 Resultant predicted surface temperatures of the Pantage Creek study area

Relative elevation appears to have the strongest influence on predicted surface temperatures in this study area. Crown closure and slope also have a strong positive influence on predicted surface temperatures. Stand height also has a positive influence but the effect diminishes as stand height increases. Substantial increases in the predicted surface temperature occur in the presence of coniferous/deciduous mixed forest stands and also in the presence of brunisolic/luvisolic mixed soil type. The presence of logged areas substantially reduces the predicted surface temperature.

6.1.2 Blackwater Study Area

The results from the regressions for the Blackwater study area are contained in Appendix E (Tables E5, E6 and E7). The R^2 value from the OLS regression is 0.55 and the log-likelihood from the interval regression is -177195. Predicted surface temperatures from the Blackwater study area (Table E7) are summarized in Figure 6.2.

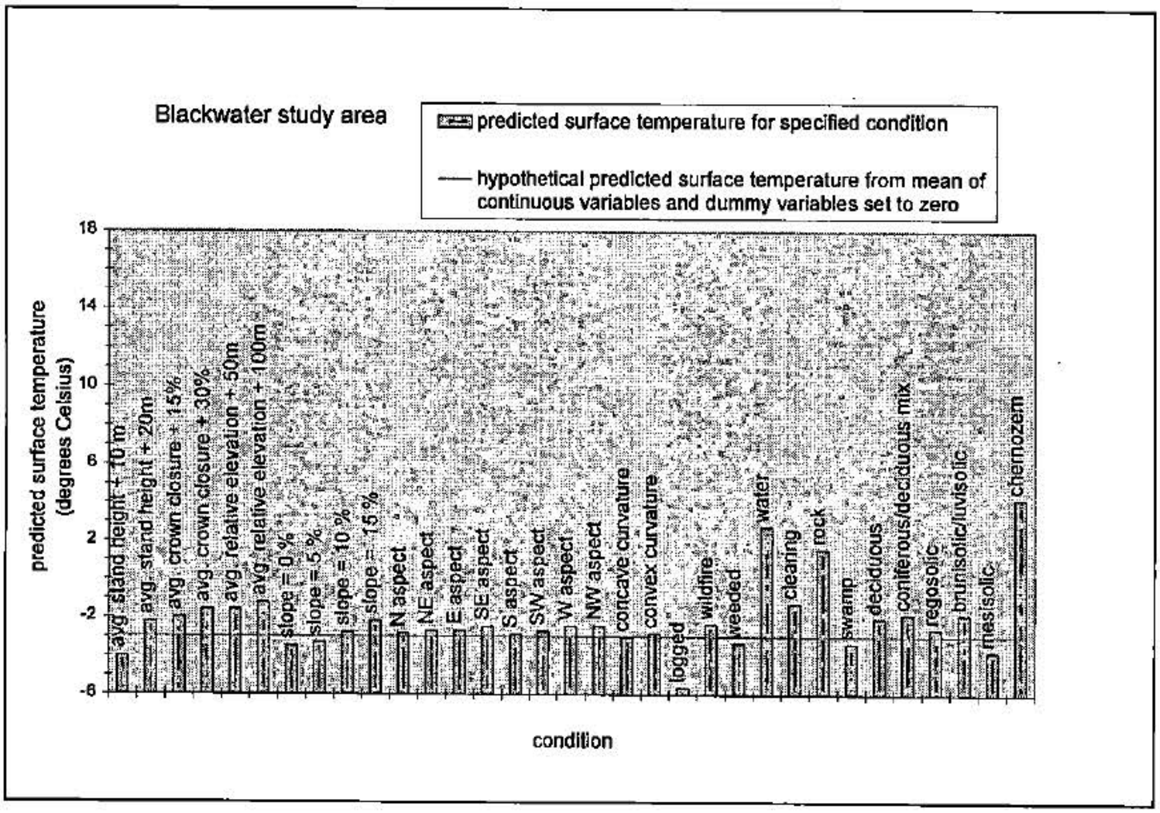


Figure 6.2 Resultant predicted surface temperatures of the Blackwater study area

The predicted surface temperature of the hypothetical observation from the interval regression is -3.0 °C.

All the continuous variables have a moderate positive influence on surface temperature. Stand height and slope have the largest influence when their values are high. In contrast, the influence of crown closure and relative elevation appear to diminish for larger values. With respect to the categorical variables, the presence of the orthic dark brown soil (chernozem) is the only single categorical variable which substantially increases surface temperature. By filtering the multivariate data set for chernozem soils, it was found that 96% of the area was classified as water. Therefore, the resultant increase in surface temperatures were due to water rather than the soil type (see Section 5.3.2 for explanation). The presence of logged areas is the only categorical variable which results in a substantial decrease in predicted surface temperature.

6.1.3 Big Creek Study Area

The results from the regressions for the Big Creek study area are contained in Appendix E (Tables E8, E9 and E10). The R^2 value from the OLS regression is 0.43 and the log-likelihood from the interval regression is -527626. Predicted surface temperatures from the Big Creek study area (Table E10) are summarized in Figure 6.3. The predicted surface temperature of the hypothetical observation from the interval regression is -1.0 °C.

Slope, stand-height, crown closure, and relative elevation have strong positive influences on predicted surface temperatures. The positive influence of stand height and crown closure on predicted surface temperature slightly diminishes as the value of each variable increases, whereas, the positive influence of relative elevation slightly increases as relative elevation increases.

A surprising feature of the graph is the slight increase of predicted surface temperatures in the presence of logged areas. By filtering the multivariate database, it was possible to investigate why the presence of logged areas resulted in an increase in

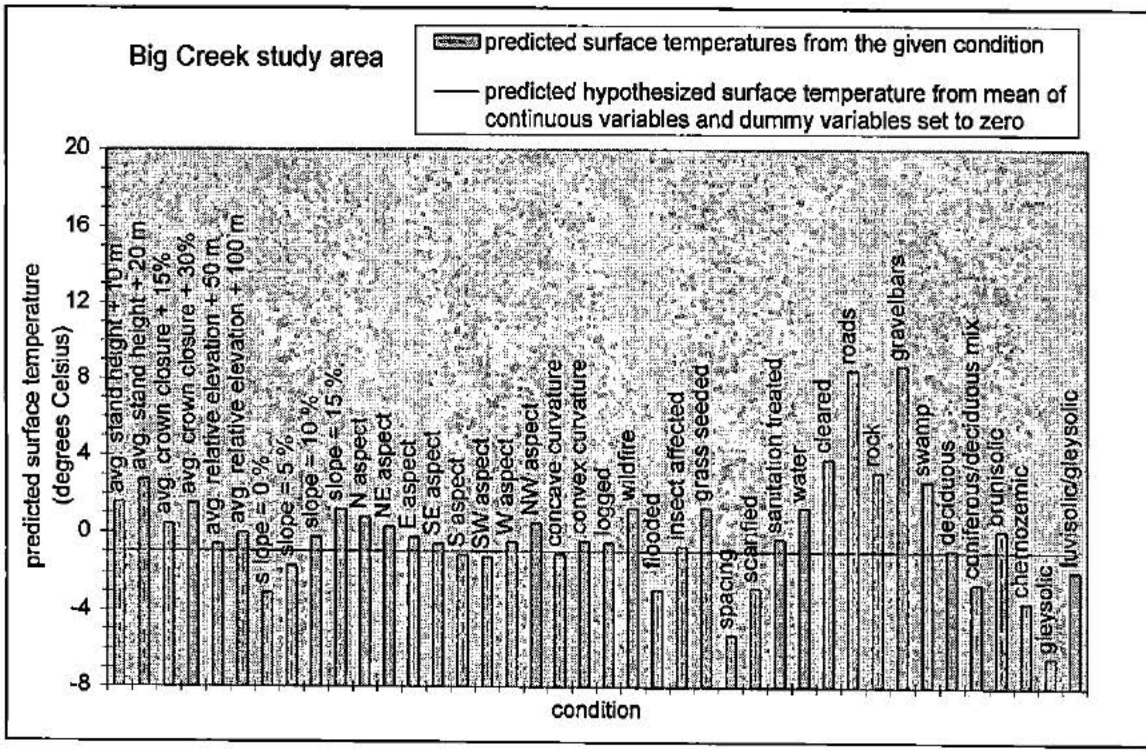


Figure 6.3 Resultant predicted surface temperatures of the Big Creek study area

predicted surface temperature. It was found that 78% of the logged areas were categorized as forested (*i.e.,* forest re-growth). Therefore, the substantial re-growth in logged areas likely contributes to the higher surface temperatures.

Aspects with a northern component (*i.e.,* N, NW and NE) also had unexpected increases in predicted surface temperature. By filtering the multivariate database, it was found that approximately 26% of the combined area of these aspect classes are classified as having insect damage. Additional filtering of the database was performed to investigate the characteristics of the 3 aspect classes affected by insect damage. It was found that a large majority (95%) of the selected area had crown closures between 20% and 50%. Due to the low crown coverage (a possible result of insect damage) it may be possible that the sensing device is recording a larger component of the ground surface under the canopy, which may result in higher surface temperatures, due to decreased radiation loss by the ground surface under partially forested canopies

With respect to soils, predicted surface temperatures substantially drop when gleysolic soil types are present. Gleysols, characteristically, are wet soils composed largely of fine sediments (*i.e.*, clay) and often occur in depressions or valley bottoms. It is likely that their occurrence in depressions and valley bottoms contributes to the low surface temperatures.

6.1.4 Sovereign Creek Study Area.

The results from the regressions for the Sovereign Creek study area are contained in Appendix E (Tables E11, E12 and E13). The R^2 value from the OLS regression is 0.63 and the log-likelihood from the interval regression is -226056. Predicted surface temperatures from the Sovereign Creek study area (Table E13) are summarized in Figure 6.4. The predicted surface temperature of the hypothetical observation is 0.8 °C.

Of all the continuous variables, relative elevation has the strongest positive influence on predicted surface temperature. This influence increases as relative elevation values increase. Slope and stand height have a moderate positive relationship with predicted surface temperature. Crown closure, however, has an unexpectedly strong

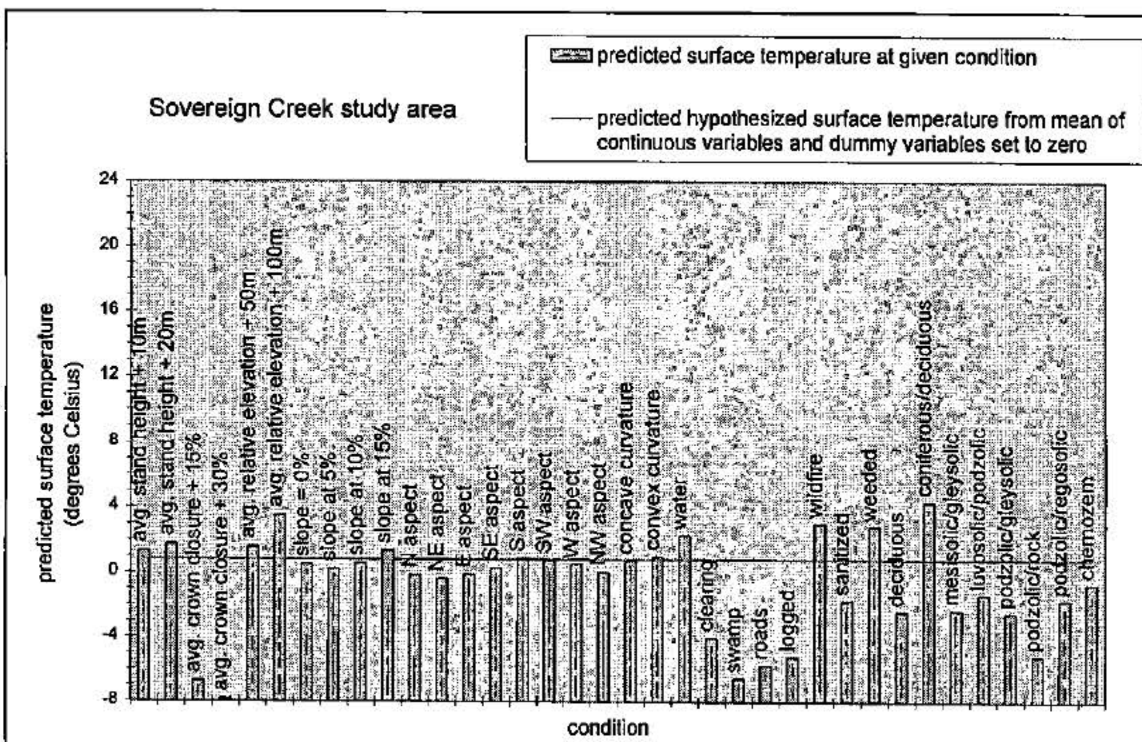


Figure 6.4 Resultant predicted surface temperatures of the Sovereign Creek study area

negative relationship with predicted surface temperature. By filtering the multivariate database (for crown closures less than 50% and surface temperatures less than -6 °C), it was found that 86% of the area had slopes less than 10%. In addition, approximately 75% of the area was located 40 - 60 metres above the minimum elevation. The cold surface temperatures, therefore, are probably the result of cold air collecting and stagnating on this gently sloping, low elevation area. The presence of logged areas, podzolic/rock mixed soils types and deciduous tree types all resulted in substantially lower predicted surface temperature.

6.1.5 Moffat Lakes Study Area

The results from the regressions for the Moffat Lakes study area are contained in Appendix E (Tables E14, E15 and E16). The R^2 value from the OLS regression is 0.60 and the log-likelihood from the interval regression is -403851. Predicted surface

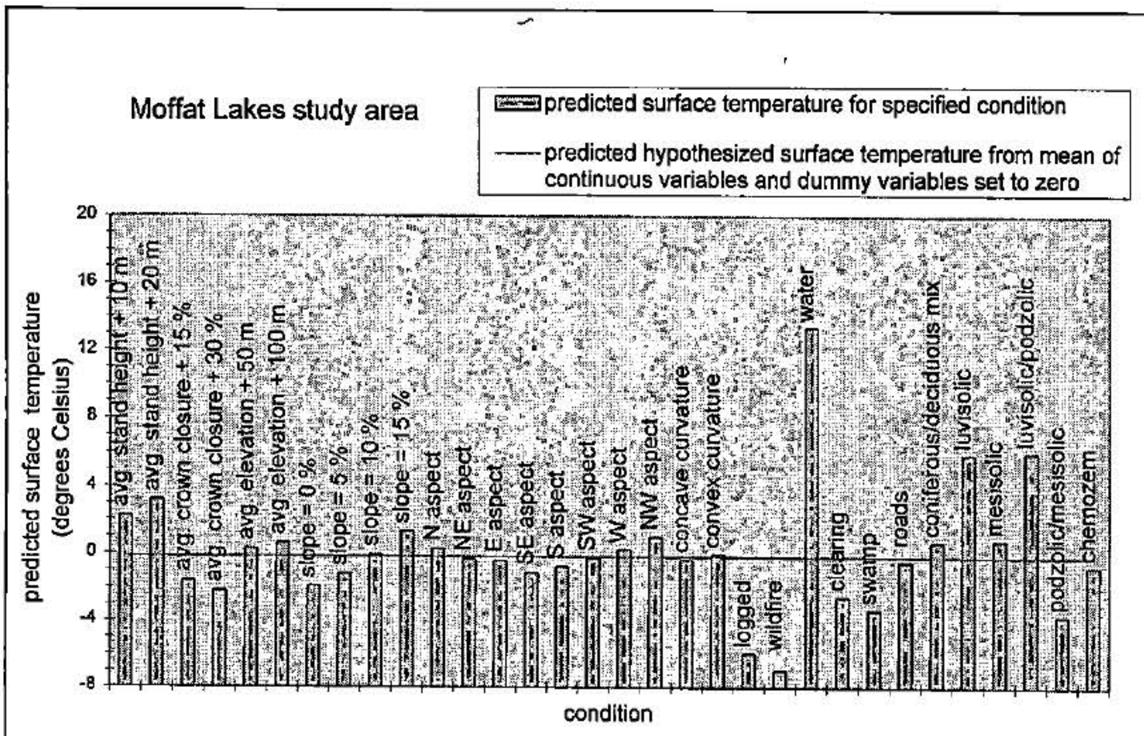


Figure 6.5 Resultant predicted surface temperatures of the Moffat Lakes study area

temperatures from the Moffat Lakes study area (Table E16) are summarized in Figure 6.5. The predicted surface temperature of the hypothetical observation is -0.2 °C.

Slope appears to be the most influential continuous variable which exhibits a positive relationship with predicted surface temperature. Stand height also has a strong positive influence on predicted surface temperatures; however, the influence diminishes with increasing stand height. The effect of relative elevation also has a positive, but less influential relationship with predicted surface temperature. Crown closure has a moderate influence on predicted surface temperature. However, the effect is opposite of what would be expected by theory. The result is similar to the Sovereign Creek study area, such that an increase in crown closure results in a decrease of predicted surface temperature. By filtering the data set (for areas with crown closures greater than 50% and surface temperature less than -6 °C), it was found that this was caused by two areas with very low slopes located at 240 metres and 420 metres above the minimum elevation. It is likely that cold air is stagnating on these two areas resulting in the lower surface temperatures. It is likely that these two specific areas greatly influence the predicted surface temperatures since their crown closure values are concentrated on those values which were used to test the increase of crown closure (*i.e.*, 60% and 75% crown closure).

The presence of luvisolic soil types and the presence of the mixed luvisolic/ podzolic soil types result in a substantial increase in predicted surface temperatures. In contrast, the presence of logged areas and mixed podzolic/mesisolic soil types result in substantially lower predicted surface temperatures.

6.2 Consistency of Independent Variable Influence between Study Areas

In this research, surface temperatures were investigated in relation to a selected number of variables. From the results presented above, it is apparent that surface temperatures are the result of complex interactions of these variables as well as other variables which haven't been investigated in this research. The objectives of this research is to investigate the influence of the selected variables on surface temperature. This section will summarize the similarities between the study areas to see if any variables consistently result in an increase or decrease of computed surface temperatures in all the study areas. Figure 6.6 summarizes the mean change in surface temperature for each variable for all five study areas.

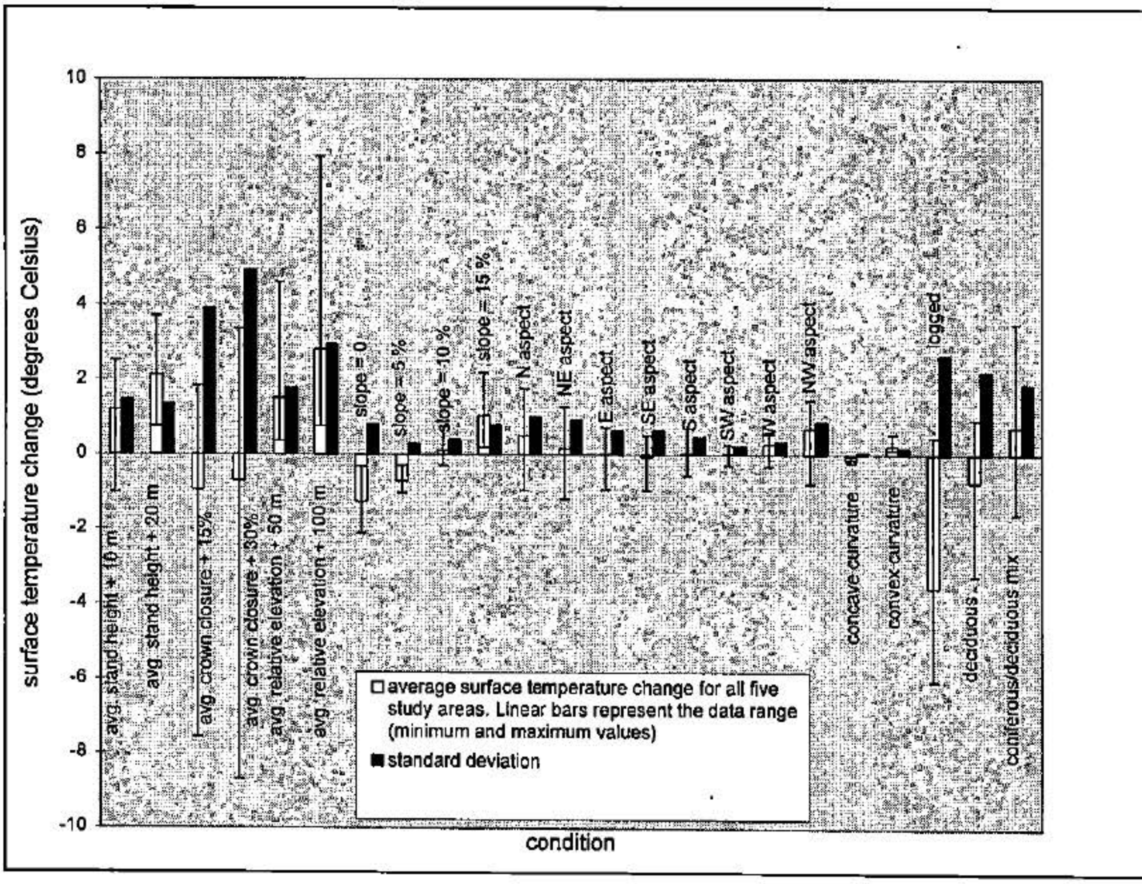


Figure 6.6 Summary of mean surface temperature change for each independent variable common to all five study areas

6.2.1 Stand Height

On average, increasing stand height results in an increase of surface temperature (Figure 6.6). All the study areas, except the Blackwater study area, show an increase in predicted surface temperature with a 10 m and 20 m increase in stand height. In the Big Creek, Moffat and Pantage Creek study areas, the increase in surface temperature from the mean was considerable for a 10 m to 20 m increase in stand height (approximately 1.5°C to 2.0 °C). In the Blackwater study area (Figure 6.2), there was an initial decrease in predicted surface temperature with a 10 metre increase in stand height, however, when the stand height was increased to 20 metres, there was a substantial increase in predicted surface temperature.

6.2.2 Crown Closure

In the Big Creek, Blackwater and Pantage Creek study areas, an increase in crown closure resulted in a significant increase of predicted surface temperature. However, in the Moffat Lakes and Sovereign Creek Study areas the increase in crown closure produced a substantial decrease in predicted surface temperatures. The decrease in these two areas was large enough to offset the increase in the other three areas, resulting in an average decrease for the five areas (Figure 6.6). By filtering the multivariate databases, it was found that the low surface temperatures in these areas with higher crown closures are probably due to cold air stagnation due to insufficient slopes to shed the cold air.

Theoretically, an increase in crown closure would be expected to produce increased surface temperatures, particularly at the ground level, since the tree crowns (relatively warm) reduce the amount of open sky (relatively cool) exposed to the ground surface. If the crown closure is complete (or near complete) this relationship can be obscured. The sensing device will collect surface temperatures of the tree crowns rather than the underlying ground surface. In these instances, lower surface temperatures may be recorded since vegetative objects have a low thermal storage ability thus, the vegetative surface cools rapidly by net longwave radiation loss and/or by cold air accumulating on the tree crown surface.

6.2.3 Local Relative Elevation

Local relative elevation has a consistently strong positive relationship with predicted surface temperature (Figure 6.6). In all the study areas there is an increase in predicted surface temperature with an increase in relative elevation. The predicted surface temperatures increase the most in the Pantage Creek study area and increase the least in the Moffat Lakes study area. The characteristics of the topography could be a possible explanation for the high increase in surface temperature with elevation in the Pantage Creek study area. For example, the average slope for the Pantage Creek study area is 14%, whereas the average slopes for the other areas range between 7.5% to 9%. Steeper slopes could, theoretically, produce greater differences between surface temperatures with elevation due to air stratification by gravitational influences (*i.e.*, cold, dense air sinking to low elevations).

6.2.4 Slope

Slope is another variable which has a consistent and relatively substantial influence on predicted surface temperature. In all the areas, predicted surface temperature increases as slope increases. In addition, it appears that there could be another possible relationship between slope and elevation. From the graphs (Figures 6.1 to 6.5) it appears that study areas with high relative elevation differences (between minimum and maximum elevations) have the greatest predicted surface temperature differences between the slope conditions which were tested. For example, the Big Creek and Moffat Lakes study areas have the largest difference in relative elevation (720 metres). The difference in predicted surface temperature from flat areas to areas with a 15% slope is 4.3°C for the Big Creek study area (Figure 6.3) and 3.3 °C for the Moffat Lakes area (Figure 6.5). The Pantage Creek study area has the next highest elevation difference (510 metres) and the difference in predicted surface temperatures between the flat area and areas with a 15% slope is 1.8 °C (Figure 6.1). In contrast, the elevation differences for the Blackwater study area and the Sovereign Creek study area are approximately 300 metres. The difference in predicted surface temperature from flat areas to areas with 15% slopes is 1.3°C for the Blackwater study area (Figure 6.2) and 0.8 °C for the Sovereign Creek study area (Figure 6.4).

In summary, slope appears to have the greatest influence on surface temperature in those areas with the greatest differences between minimum and maximum relative elevation. This could possibly be a result of the upslope cold air drainage area (*e.g.*, Steen *et al.* 1990). In study areas with large relative elevation differences, the upslope drainage areas should be relatively larger than those study areas with smaller elevation differences. Therefore, a greater amount of cold air can collect which can potentially drain onto flat surfaces at lower elevations.

6.2.5 Aspect

There appears to be no consistent relationship with aspect and predicted surface temperature between study areas. In most of the study areas, the influence aspect class is generally less than 1°C. Southern aspects are expected to be relatively warmer than northern aspects. Since the surface temperature data were collected during the time of year when the duration of night and day are almost equal, the effect of aspect is likely to be quite weak. As vegetative surfaces (*i.e.,* tree crowns) store very little energy, there is not likely to be an observable aspect effect unless the composition of the surface being recorded is mineral matter (*i.e.,* exposed rock or mineral soil).

In the Big Creek and Moffat Study areas (Figure 6.3 and 6.5, respectively), the differences between aspect classes can be as much as 2°C. It is interesting to note, again, that these two areas have the greatest difference in relative elevation (720 metres). Another interesting characteristic of these two areas is that the greatest increase in predicted surface temperatures occurs for the northern facing aspects (*i.e.,* N and NW), while the south aspect has the greatest decrease. In the Big Creek study area, there was found to be insect damage on a substantial area (26%) in these aspect classes and in 95% of the insect damaged area the crown closure is 20 - 50%. It may be possible that, in these areas, the temperature sensing device is recording surface temperature below the tree canopy. The surface temperatures below the forest canopy could be higher since less surface is exposed to the cold open sky (less longwave radiation loss).

Further investigations were also conducted on the Moffat Lake study area, however, there was no apparent reason for the surface temperature increase in the N and NW aspect classes.

In summary, the role of aspect as an influencing variable is very minor. In most of the study areas, it appears that other variables are likely suppressing the effect of aspect on surface temperatures.

6.2.6 Terrain Curvature

The terrain curvature has a consistently insignificant influence on predicted surface temperature for all the study areas. Concave areas are colder and convex areas are warmer compared to the omitted class (flat areas). This is in accordance with previous research, however, the difference between the two curvature classes is generally less than 1°C.

It was anticipated that terrain curvature would have a much greater influence on surface temperatures. A possible explanation for the failure of this variable to influence the predicted surface temperature could be a result of how the variable was defined. Since planform curvature was used the curvature values were derived independent of slope. Previous research which found an association between terrain curvature and frost may have used a definition of curvature which includes the effects of slope, thus, producing different results.

Another possible explanation for the results of the curvature variables may be due to the scale at which the GIS calculated curvature. A GIS can calculate curvature at the micro-scale due to its fine precision (*i.e.*, detecting curvature change for each raster grid cell (25 m x 25 m)). With respect to the data used for this research, a meso-scale (*i.e.*, hill tops and larger depressions), or even macro-scale measurement of curvature (*i.e.*, ridges and valleys) would have been sufficient. The data were generalized into concave, flat and convex areas in an attempt to reduce data from a micro-scale to a meso-scale. It is possible the data generalization did not adequately reduce the precision since curvature data in each of the study areas were quite fragmented by small polygons.

6.2.7 Logged areas

In all the study areas, except the Big Creek study area, the presence of logged areas substantially reduced the surface temperature (Figure 6.6). In the Big Creek study area, it was found that a large proportion (78%) of the logged area was classified as forested (*i.e.,* forest re-growth) which likely contributes to the increase in surface temperatures.

The decrease in surface temperatures ranged from approximately 3°C in the in the Blackwater study area (Figure 6.2), to approximately 6°C in the Moffat Lakes and Sovereign Creek study areas (Figures 6.5 and 6.4, respectively).

In the daytime, forest clearings have a greater potential to absorb more solar radiation (compared to forested areas) since more mineral matter (*i.e.,* soil) is likely to be exposed. At night, forest clearings have a less favourable conditions for retaining energy through longwave radiation exchange. Forested areas have a tree layer to absorb and re-radiate longwave energy to the ground surface during the night, whereas much of the longwave energy emitted from a forest clearing is lost to the atmosphere. As the night progresses, much of the energy that is stored during the day in the clearing is lost at night, thereby increasing the chance of frost in clearings.

With respect to the remote sensing device, surface temperatures will be higher in forested areas if the device is sensing a component of the ground surface under partial crown closure. If the crown closure is complete the sensing device detects the surface temperature of the tree crown surface in forested areas rather than the ground surface which could result in lower surface temperatures (see Section 6.2.2).

6.2.8 Forest Type

In all study areas, coniferous trees substantially dominated the forest type. In general, the coniferous trees composed over 95% of the forest areas in each study area. Therefore, the coniferous forest type was the omitted group in the regressions to which the deciduous and the mixed coniferous/deciduous forest types were compared. All study areas had a coniferous/deciduous mixed forest class. However, the Pantage Creek and Moffat Lakes Study areas did not have a deciduous forest type. With the exception of the Big Creek study area, the presence of coniferous/deciduous mixed forest types increased the predicted surface temperatures. The largest increase for coniferous/deciduous mixed forest types (8°C) was in the Pantage Creek study area (Figure 6.1) and the smallest increase (1 °C) was in the Moffat Lakes study area (Figure 6.5). In the Big Creek study area, the presence of the coniferous/deciduous mixed forest type resulted in a decrease of 1.5 °C (Figure 6.3).

Predicted surface temperatures were inconsistent (*i.e.*, some increased and some decreased) in the presence of the deciduous forest type. On average, the presence of deciduous trees decreased the predicted surface temperature (Figure 6.6). In the Blackwater study area the presence of the deciduous forest type increased the predicted surface temperature by 1 °C (Figure 6.2). In contrast, the presence of the deciduous forest type in the Sovereign Creek study area decreased the predicted surface temperature by 3 °C (Figure 6.4). In the Big Creek study area, the presence of the deciduous forest type only resulted in a very small increase in the predicted surface temperature (<0.1 °C) (Figure 6.3).

Due to the inconsistent results between the study areas, the differing forest type variables do not appear to have a consistent influence on surface temperature. The differences in predicted surface temperature are likely a result of factors which contribute to the growth of the tree types in specific area (*e.g.*, cottonwood trees may preferentially grow on river floodplains which are conducive to frost). Therefore, it appears the influence of forest types on surface temperatures is not clearly defined.

6.2.9 Soil Type

It is difficult to compare the influence of soils types on predicted surface temperatures between study areas since each study area has different soil types. Organic soils generally have properties which are conducive to low surface temperatures. This is largely due to the moisture content of the organic soils. When organic soils are very dry, there is commonly lots of air content. Therefore, not much heat is stored in the sub-surface of organic soils since the thermal conductivity of organic matter and air is much lower than mineral matter. Water in the soil fills the air spaces and generally improves the thermal conductivity. However, if there is excessive water in the soil (*e.g.*, bog soils), energy which could normally be transferred to the sub-soil is lost to evaporation at the surface. This reduces the amount of energy stored in the sub-surface and makes these areas more prone to frost (particularly since bog areas or swamps occur on flat terrain and have little or no tree coverage). Poorly drained organic soils (mesisols) are present in all study areas except the Big Creek study area.

The presence of the mesisols has inconsistent influences on predicted surface temperature. In the Pantage Creek and Moffat Lakes study areas (Figures 6.1 and 6.5, respectively) , the presence of mesisolic soils slightly increases the predicted surface temperature (0.4°C and 1°C, respectively). In the Blackwater study area, the presence of mesisolic soils decreases the predicted surface temperature by 0.8 °C (Figures 6.2). In the Sovereign Creek study area, the mesisolic soil is combined with the gleysolic soil. The presence of this soil combination reduces the predicted surface temperature by 3 °C (Figure 6.4).

All the mesisols in the study areas are described as being generally poorly drained, however, the soil moisture is likely to fluctuate throughout the year and between study areas. Therefore, the influence of the organic mesisol on the predicted surface temperature is most likely a result of the moisture content of the soil.

6.3 Summary

The consistent positive relationship of the relative elevation and slope variables between the study areas reinforce the theoretical relationship of these variables with surface temperature. Since the relationship of these variables with surface temperature is consistent across the five study areas, they appear to be the most important variables with respect to their influence on surface temperature.

The comparison of the relative elevation and slope variables between study areas also led to other findings. In particular, it was observed that the relative elevation variable seemed to be more influential if the average slope of the area was greater. It also was found that if the difference between minimum and maximum elevation was large, the slope variable was more influential.

Stand height also appears to be a variable which, in general, has a positive relationship with surface temperature (*i.e.,* increase in stand height causes an increase in surface temperature). The Blackwater study area does show an initial decrease in surface temperature with an increase in stand height, however, a further increase in stand height results in a substantial increase in predicted surface temperature. Therefore, stand height appears to be a moderately influential variable with respect to surface temperature.

Crown closure was the only continuous variable which had an inconsistent relationship with surface temperature for the five study areas. As a result of this inconsistency, crown closure appears to be an unreliable indicator of frost risk. As mentioned in this chapter (see Sections 6.1.4 and 6.1.5) this is likely a result of cold air collecting and stagnating on these areas due to an insufficient slope to shed the cold air. In addition, the remote sensing device could be recording the surface temperature of the tree crown surface rather than the ground surface if the crown closure is dense.

Even though the effect of logged areas on surface temperatures is not explicitly being investigated in this research, it is presented in the results since the main focus of this research is directed towards forestry applications. It was found that in four of the study areas, the presence of logged areas substantially decreased the predicted surface temperature (a decrease between 3 - 6^{o}C). In the other study area (Big Creek), the increase in surface temperature is likely attributed to substantial forest re-growth in logged areas. These results suggest that logging activity has a strong influence with respect to reducing surface temperature which is likely a result of increased longwave radiation loss throughout the night compared to forested areas.

An additional finding of the regression analysis was that there was no consistent relationship for any one aspect class, forest type, or soil type for the five study areas. The terrain curvature variable (as defined in this research) was consistent between all the study areas, however, the influence of each curvature class (convex and concave) on predicted surface temperatures was very small. Therefore, these variables are also unreliable with respect to their influence on surface temperature.

Chapter 7
Discussion and Conclusion

7.1 Main Findings

The primary purpose of this research was to determine if a GIS, in combination with statistical analysis, could be used to investigate frost-prone areas on a landscape using remotely sensed thermal imagery and topographic data. With respect to the methods which were used in this research, it was found that the GIS worked very well for assembling and combining spatial information and producing multivariate spatial databases. Once the multivariate spatial databases were assembled by the GIS, it was found that statistical packages were more suited to investigating relationships between the variables. This was due to 1) the lack of desired statistical capabilities of the GIS, 2) the spatial database was much larger compared to the statistical database, and 3) the computational efficiency of the statistical software packages when working with large databases. The primary disadvantage of using the statistical software was the loss of some spatial information. However, it was possible to extract much information regarding the relationships among variables without the additional spatial information.

The cross-tabulation and regression analyses each served a specific purpose. The cross-tabulation analysis was used to investigate the characteristics of the surface temperature classes, particularly the extreme surface temperature classes. The regression analysis was used to investigate the relative influence of each independent variable on surface temperature.

For both the cross-tabulation and interval regression analyses, it was possible to examine specific relationships (*e.g.*, anomalies) by filtering the multivariate databases. Conducting analyses with multivariate databases is an important advantage since it enables the researcher to seek additional explanation for specific relationships between certain variables (*e.g.*, anomalies).

From the cross-tabulation analysis, it was found that low surface temperatures were found in areas with 1) low local relative elevation (*e.g.*, valley bottoms), 2) slopes of less than 10%, 3) low forest stand height, 4) low forest crown closure, and 5) poorly drained organic soils (*i.e.*, mesisols). In contrast, areas located on high elevation sites and sites with steep slopes (*i.e.*, greater than 10%) were found to have very little association with low surface temperature classes but coincided more with high surface temperature classes. Anomalies in the cross-tabulations, generally, were caused by specific features in the landscape (*e.g.*, lakes, swamps, logged areas)

The interval regression analysis provided a method to observe and compare the influence of the independent variables on surface temperature. In addition, it also provided a method to assess the consistency of these influences between study areas. Relative elevation and slope had the most consistent influence on predicted surface temperature across the five study areas. For both variables, the relationship with predicted surface temperatures was positive, thus, an increase of the variable resulted in an increase in surface temperature. Stand height also had a consistent positive relationship with predicted surface temperature in all but one of the study areas. It also was found that the presence of logged areas substantially reduced the predicted surface temperature. Even though forest activity variables were not being explicitly investigated, this finding broadens the implications of the research.

In addition, the interval regression analysis revealed variables which were either inconsistent with theory or had inconsistent relationships with predicted surface temperatures between study area (*e.g.*, aspect, terrain curvature, forest type). There were some apparent relationships for crown closure and soil types with surface temperatures but not consistent across the whole range of crown closure values or soil types. In most cases, it is likely that the more dominant variables (*i.e.*, relative elevation and slope) masked the influence of the other variables.

There were additional findings which developed from the interval regression results. In particular, it was observed that relative elevation had the largest influence on predicted surface temperature in the study area that had a substantially larger value for average slope (*i.e.*, Pantage Creek study area). As discussed in Chapter Six, steeper slopes could result in a greater movement of cold, dense air to lower elevations by gravitational influence. As a result, the air temperature could be more vertically stratified, producing a greater increase of surface temperature with elevation.

Upon further investigation, it was also observed that the slope variable was most influential on predicted surface temperatures in those areas which had the largest relative elevation difference (Big Creek and Moffat Lakes study areas). A possible explanation for this finding could be that study areas with larger relative elevation differences could have greater upslope drainage areas. This could result in a greater amount of cold air subsiding to flat areas which causes those flat areas to be substantially cooler that the upslope areas. While these findings were primarily serendipitous, they could prove to be significant for researchers trying to evaluate frost risk solely on the basis of terrain data.

7.2 Limitations and Recommendations for Future Research

It is often said that the whole is greater than the sum of its parts. This is certainly true with respect to research projects. While it is rewarding to present all the significant results, it is extremely important, though not as rewarding, to present the limitations and constraints of the research. Therefore, the whole research project recognizes not only its successes but also its limitations or failures. It was said by Lin Yutang "Sometimes it is more important to discover what one cannot do, than what one can do" (cited in Fitzhenry 1981). By presenting the limitations and constraints of the research, it enables the researcher to put in context the implications for the research as well as offer recommendations for other researchers who may be able to overcome these limitations. This section discusses the limitations and problems encountered in this research and offers recommendations for further research. The chapter concludes with the discussion of the implications of this research.

7.2.1 Limitations of the Thermal Data

Since the thermal data used for this research were originally collected for a different project, there were certain constraints associated with the thermal image data. Many of the limitations resulted from having access only to secondary data rather than the original collected data. This meant that thermal information existed as level-sliced data in 2°C intervals on photographic paper. If the original data were available, the temperature intervals could have been customized to suit the purposes of this research. In addition, using the original data would have avoided the error associated with scanning the data from the photographic strips. Since the thermal images were scanned from photographic prints, it was inevitable that some errors were introduced. The scanning process introduced extraneous gray shades which were reverted back to eight gray shades using the functionality of the image analysis software. Even though the process grouped the data in the eight most natural gray level value classes, some pixels could have been misclassified. It is impossible to know the extent of this error since the original data were not available.

7.2.2 Geometric Image Correction Limitations

One of the problems associated with geometric correction of images to digital map files is the assumption that the digital map files are correct. Most of the map files used for this research were interpreted from aerial photography, therefore, errors can arise from misinterpretation of features, digitizing errors, or a change in the features over time (*e.g.*, rivers, creeks, road construction). The severity of these types of error is virtually unknown to the users of such data, however, it is recognized that some error exists within the data.

There were also constraints to geometrically correcting the thermal data to the map files. It was assumed that certain features such as lakes, rivers, roads and forest clearings could be sufficiently distinguished (*i.e.*, provided sharp boundaries) on the thermal image to allow for geometric correction to the map files. In most cases, the images were corrected very close to the digital files (*i.e.*, within 10 metres). However, small discrepancies between the digital lines and the images were inevitable. Therefore, a small degree of uncertainty existed between the imagery and the digital map files.

7.2.3 Emissivity Correction

The thermal data were collected assuming a surface emissivity of 1.0 (MacKay 1995 personal communication). Since the emissivity of the surface can have a significant effect on the absolute surface temperature it would have been appropriate to adjust the thermal image for emissivity before the data were classified into 2°C intervals. This could be accomplished relatively easily using the GIS, since information exists regarding the surface cover.

Since the thermal data were provided in 2°C intervals, it would be impossible to determine whether the new surface temperatures corrected for emissivity would remain in the original temperature class. Therefore, the emissivity correction was not applied to this data. If possible, future research should consider accounting for emissivity.

7.2.4 Limitations of the Spatial Data

The inherent weakness associated with geographic data is the uncertainty and imprecision associated with input data. Uncertainty is defined as our degree of knowledge (or ignorance) regarding data, whereas imprecision is a feature of the data itself and is a range of how data can be described (*e.g.*, exactly, approximately or ambiguously) (Altman 1994). The problem associated with much of the digital geographic data input into GIS is that the data are implied to be exact due to particular data representation (*i.e.*, vector and raster). In many cases geographic features defy the hard boundaries imposed by vector and raster data formats. The real boundaries may often be blurred or be a mixture of attribute classes. As discussed in Chapter Three, all data in this research are represented by discrete vector polygons. Due to the nature of resource related data, discrete polygon representation doesn't address the occurrence of transitional or 'fuzzy' boundaries (*e.g.*, transition between forest types and soil types). The issue of adequate data representation for transitional boundary attributes is currently being studied in GIS and spatial data research. Since the common method of producing and obtaining resource data is in sharp-edged vector or raster data representation, research to cope with these problems is also being investigated (*e.g.*, epsilon bands (Perkal 1966 as cited by Blakemore 1984), and fuzzy set methods (Burrough 1989)).

It was beyond the scope of this research to investigate data adaptations to account for fuzzy boundaries or to account for uncertainty of boundaries through epsilon bands. However, future research may consider these problems and offer an interesting comparison of results.

7.2.5 Limitations of the Map Overlay Procedure

Additional limitations exist in the overlay procedure which are partially a result of the limitations of the source data (see section 7.2.4) and partially a result of the overlay process itself. MacDougall (1975) identified many instances where inaccuracies can occur in the map overlay process. MacDougall (1975) identifies propagation of errors through the overlay process from source data as a real concern for inaccuracies in overlay maps. However, Chrisman (1987 in Peuquet and Marble 1990) challenges that the propagation of error in overlays is not a straightforward matter as presented by MacDougall (1975). Chrisman (1987 in Peuquet and Marble 1990) explains that, depending on the covariance between data sets, the combination of diverse data sources can actually strengthen the value of the information, rather than degrade it.

Due to the differing sources of information and the uncertainty of the accuracy of the original data, it is beyond the scope of this research to investigate the degradation (or lack of degradation) caused by the overlay procedure. If the proper information were to exist, this would be a useful and interesting area to consider in future research.

7.2.6 Limitations of the Statistical Analysis

The interval regression was able to accommodate many of the characteristics of the data. As described in Chapter Four, interval regression allowed the model to retain information in the dependent variable which would have been lost by the other methods which were reviewed. In addition, interval regression was able to accommodate categorical variables through the use of dummy variables.

The presence of spatial autocorrelation within the data was a limitation for this research. Since the regressions were used only for exploring the relative importance of variables in the model, some of the problems associated with spatial autocorrelation were avoided (*i.e.,* overestimated R^2 values).

Where regression-type analyses are confounded by the presence of spatial autocorrelation, other types of analysis have been shown to take advantage of the spatial association of observations. For example, kriging (univariate) and co-kriging (bivariate/multivariate) have shown promising results for estimating variables based on the spatial association with neighbouring observations (*e.g.,* Ishida and Kawashima 1993). A recommendation for future research would be to explore the use of kriging and co-kriging operations on these data to evaluate the performance against regression analysis.

7.3 Implications of Research

In light of the limitations described in the previous sections, this research has demonstrated how current technology can be used to investigate frost by combining relevant spatial variables with remotely sensed surface temperatures within a GIS and, subsequently, investigating their relationships using statistical analysis.

The main findings of this research could be valuable to researchers or planners trying to assess frost risk using topographic variables. The slope and relative local elevation variables had consistent positive relationships with surface temperature for both the cross-tabulation and interval regression analyses in all five study areas. Since the relative elevation and slope variables are not constrained by any particular location, these findings are important since they can be applied to different sites to investigate frost risk for a wide range of applications. For example, this information could be used to help determine frost risk for forest plantations, crop locations, and areas on highways. In addition, it was found that logged areas resulted in a substantial reduction of surface temperature. From this information, it may be possible for forest planners to identify sites which, if harvested, would have a high frost risk. This type of information would be of particular importance for reforestation success after harvesting (*i.e.*, survival of regenerated trees).

7.4 Conclusion

This research has attempted to investigate a fair number of the influential variables which are theoretically related to frost. The GIS was fundamental to creating multivariate databases which, in turn, were used to statistically analyze the surface temperature patterns of the thermal images. Since GIS and remote sensing were not available when most of the theories related to frost were derived, it is interesting to apply the 'new' tools to the 'old' theories.

In this research, some results were consistent with the theoretical relationships, whereas others seemed to be overshadowed by more dominant variables or the limitations. It is apparent there is still progress to be made with respect to the limitations (*i.e.*, data collection, data quality, statistical methods) With further research, many of these limitations are likely to be resolved and greater inferences regarding the controls of frost may be possible.

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Appendix A: Arc Macro Language Translation Procedure (FC1/FIP to Arc)

```
&args file zone_number
&set igdsfile [entryname %file%]
&set bcgsname [before %igdsfile% .]
&set pathdbf [dir %file%]
&messages &on

dbaseinfo %pathdbf%/%bcgsname%.dbf %bcgsname%.dat

igdsarc %file% fc-%bcgsname% 2D # # # # OVERLAP 16
forest 9 * * * 4
labels 10 * 0 0 7
end
y

&do
  build fc-%bcgsname% line
  additem fc-%bcgsname%.aat fc-%bcgsname%.aat utm_len 4 12 f 3
  build fc-%bcgsname% point
  additem fc-%bcgsname%.pat fc-%bcgsname%.pat utm_area 4 12 f 3
  additem fc-%bcgsname%.pat fc-%bcgsname%.pat utm_per 4 12 f 3
&end

tables
select fc-%bcgsname%.acode
reselect igds-type NE 7
purge
y

/* to remove graphic group number which produce multiple labels*****

reselect igds-ggno NE 0
purge
y

/*

alter igds-text
igds-text
16
I
igds-text
quit
dropitem  fc-%bcgsname%.acode  fc-%bcgsname%.acode
igds-layer
igds-type
igds-level
igds-ggno
igds-class
igds-props
igds-color
igds-style
```

```
igds-weight
igds-font
igds-cpxid
igds-cpxtype
igds-offset
end
/*
/*
/*
tables
select %bcgsname%.dat
reselect rank_cd NE '1'
purge
y
quit
/*

/*
&if [exists fc-%bcgsname% -cover] &then &do
   tables
   select fc-%bcgsname%.acode
   alter igds-text
   polygon_id
   16
   I
   igds-text
   quit
   joinitem fc-%bcgsname%.pat fc-%bcgsname%.acode fc-%bcgsname%.pat  fc-%bcgsname%-id ~
   fc-%bcgsname%-id
   joinitem fc-%bcgsname%.pat %bcgsname%.dat fc-%bcgsname%.pat polygon_id polygon_id

   /*correct for label errors *****
   arcedit
   edit fc-%bcgsname%
   editfeature label
   select polygon_id = 0
   delete
   save
   quit
   /*
&end

/*
/* adjusts global origin *****
/*
&do
   create xxfc-%bcgsname% fc-%bcgsname%
   tables
   select xxfc-%bcgsname%.tic
   calc xtic = xtic + -4
   calc ytic = ytic + 5296
   calc xtic = xtic * 1000
   calc ytic = ytic * 1000
   quit
```

```
  transform fc-%bcgsname% xxfc-%bcgsname%
  kill fc-%bcgsname% all
  rename xxfc-%bcgsname% fc-%bcgsname%
  projectdefine cover fc-%bcgsname%
projection utm
units meters
datum NAD27
zone %zone_number%
parameters
end
/*
/*check for dangling nodes*****
/*
nodeerrors fc-%bcgsname% dangle
&sv cont = [query 'Do you wish to continue <Y>' .TRUE.]
&if %cont% = .FALSE. &then &do
&type Fix the problems in fc-%bcgsname% then run fc7.aml to continue.
&return
&end

&else

/*
 clean fc-%bcgsname% # 5 # poly
/*
tables
&if [exists fc-%bcgsname% -arc] &then &do
select fc-%bcgsname%.aat
&end
&if [exists fc-%bcgsname% -poly] &then &do
select fc-%bcgsname%.pat
calc utm_area = area
calc utm_per = perimeter
quit
&end

/*eliminate slivers*****

labelerrors fc-%bcgsname%
&sv cont = [query 'Do you want to fix slivers <Y>' .TRUE.]
&if %cont% &then &do

 eliminate fc-%bcgsname% temp-%bcgsname%
 reselect area < 50
 ~
 n
 n

 kill fc-%bcgsname% all
 rename temp-%bcgsname% fc-%bcgsname%

 &end
/*
&return
```

Appendix B - Cross-tabulation of Elevation Class with Surface Temperature

Table B1 Pantage Creek study area

elevation class	surface temperature (°C)							
	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
1	0.0%	0.0%	0.5%	0.1%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.1%	0.6%	0.7%	0.2%	0.0%	0.0%	0.0%
3	5.8%	2.1%	2.4%	0.8%	0.6%	0.3%	0.0%	0.0%
4	21.2%	6.2%	2.8%	1.0%	0.4%	0.9%	0.3%	0.0%
5	5.3%	7.8%	3.3%	2.9%	2.1%	0.7%	0.6%	0.2%
6	1.2%	8.5%	4.1%	7.0%	5.6%	0.9%	1.1%	0.3%
7	0.6%	3.5%	2.8%	7.0%	5.4%	1.5%	1.6%	0.5%
8	1.1%	4.6%	2.3%	6.8%	8.3%	3.0%	3.2%	1.0%
9	5.8%	11.3%	4.4%	4.3%	8.3%	4.7%	3.5%	0.8%
10	5.7%	6.9%	3.2%	4.1%	8.6%	6.3%	5.1%	1.1%
11	4.2%	9.0%	6.1%	3.2%	8.3%	8.5%	7.2%	1.4%
12	0.4%	7.8%	6.4%	4.3%	6.0%	8.5%	11.4%	1.7%
13	0.2%	4.3%	4.7%	2.7%	4.1%	4.9%	9.2%	2.4%
14	0.0%	0.3%	2.4%	1.8%	2.7%	2.9%	4.1%	2.0%
15	0.0%	0.2%	1.5%	2.2%	1.5%	2.2%	3.1%	2.1%
16	0.0%	0.5%	2.5%	2.4%	2.0%	1.6%	2.2%	2.4%
17	0.0%	0.5%	2.1%	2.0%	2.4%	1.9%	1.8%	2.1%
18	0.0%	0.3%	2.9%	1.8%	2.0%	2.0%	2.0%	1.9%
19	0.0%	0.5%	2.8%	1.9%	1.8%	1.6%	1.9%	1.6%
20	0.0%	0.2%	2.2%	2.2%	1.9%	2.1%	2.0%	1.5%
21	0.0%	0.2%	2.1%	2.2%	2.0%	2.0%	2.5%	1.5%
22	0.0%	0.2%	2.0%	2.6%	2.0%	1.8%	2.3%	1.7%
23	0.0%	0.4%	1.4%	2.6%	2.5%	2.1%	1.4%	2.1%
24	0.0%	0.6%	1.6%	2.5%	3.0%	3.4%	1.6%	2.1%
25	0.0%	0.8%	0.9%	1.9%	2.8%	5.7%	2.3%	1.9%
26	0.0%	0.5%	1.0%	1.6%	1.5%	3.7%	3.0%	2.3%
27	0.0%	0.4%	1.3%	1.4%	1.3%	2.4%	2.9%	2.6%
28	0.0%	0.5%	1.3%	1.2%	1.4%	2.1%	2.5%	2.6%
29	0.0%	0.9%	0.9%	1.3%	1.1%	1.4%	1.9%	2.8%
30	0.0%	1.3%	1.2%	1.0%	1.0%	1.7%	1.6%	3.1%
31	0.0%	1.0%	1.5%	1.3%	0.9%	1.7%	1.5%	3.3%
32	0.0%	0.6%	1.5%	1.7%	1.4%	2.1%	1.5%	3.6%
33	0.0%	0.5%	1.5%	2.2%	1.0%	1.9%	1.7%	3.7%
34	0.0%	0.2%	1.1%	2.1%	1.0%	2.7%	2.4%	3.6%
35	1.4%	0.3%	1.1%	2.3%	0.7%	1.7%	2.1%	4.1%
36	1.6%	1.3%	1.6%	2.0%	0.7%	1.7%	1.8%	3.7%
37	2.7%	1.8%	2.1%	2.0%	0.7%	1.7%	1.7%	3.7%
38	9.8%	1.9%	2.1%	1.7%	0.4%	1.0%	1.0%	3.8%
39	20.6%	2.5%	2.0%	1.7%	0.5%	0.9%	0.8%	4.0%
40	10.9%	2.4%	2.2%	1.3%	0.5%	0.8%	1.2%	4.1%

Table B1 (cont'd) Pantage Creek study area

elevation class	surface temperature (°C)							
	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
41	1.4%	1.8%	2.5%	1.1%	0.3%	0.6%	0.8%	4.0%
42	0.0%	2.2%	1.9%	0.7%	0.4%	0.7%	0.3%	3.7%
43	0.0%	1.6%	1.3%	0.7%	0.2%	0.4%	0.2%	2.5%
44	0.0%	0.9%	1.1%	0.5%	0.1%	0.3%	0.2%	1.7%
45	0.0%	0.2%	0.7%	0.5%	0.2%	0.3%	0.1%	1.4%
46	0.0%	0.0%	0.7%	0.2%	0.1%	0.2%	0.1%	1.0%
47	0.0%	0.1%	0.6%	0.1%	0.0%	0.1%	0.0%	0.9%
48	0.0%	0.1%	0.5%	0.1%	0.0%	0.1%	0.1%	0.5%
49	0.0%	0.0%	0.1%	0.1%	0.0%	0.1%	0.0%	0.4%
50	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
51	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
52	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table B2 Blackwater study area

elevation class	surface temperature (°C)							
	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
1	1.4%	11.1%	4.8%	2.1%	1.6%	2.5%	2.1%	1.9%
2	9.3%	10.1%	9.0%	5.0%	2.3%	2.8%	0.5%	0.8%
3	1.0%	8.2%	10.9%	5.3%	2.1%	2.0%	0.4%	0.0%
4	1.2%	8.1%	7.4%	4.7%	2.0%	0.8%	0.3%	0.0%
5	0.8%	7.4%	6.7%	6.4%	2.4%	0.4%	0.0%	0.0%
6	0.9%	10.5%	7.4%	7.7%	4.2%	0.9%	0.5%	3.8%
7	0.4%	2.9%	5.0%	6.8%	7.1%	3.2%	5.4%	36.0%
8	10.5%	1.6%	2.3%	8.0%	7.4%	3.8%	4.9%	0.6%
9	17.0%	3.0%	1.4%	6.8%	8.1%	4.7%	1.1%	0.0%
10	16.8%	7.4%	5.9%	6.6%	8.6%	5.1%	0.4%	0.0%
11	6.8%	7.9%	10.5%	9.6%	6.7%	5.6%	0.3%	0.0%
12	2.8%	3.2%	8.0%	7.0%	7.6%	6.8%	1.7%	0.0%
13	2.3%	4.9%	5.1%	4.6%	5.1%	10.4%	3.1%	0.0%
14	3.2%	3.0%	3.4%	4.4%	5.2%	8.6%	2.7%	0.0%
15	0.1%	0.8%	1.1%	2.2%	5.8%	5.2%	4.9%	0.0%
16	19.8%	4.2%	2.6%	1.8%	3.0%	1.9%	5.4%	3.1%
17	3.5%	3.1%	4.2%	2.7%	3.9%	2.7%	3.8%	0.2%
18	1.3%	0.9%	0.8%	2.9%	5.6%	3.0%	3.1%	0.6%
19	0.6%	0.5%	0.7%	1.5%	2.1%	3.6%	4.2%	1.0%
20	0.2%	0.2%	0.3%	1.2%	1.8%	4.2%	5.5%	2.3%
21	0.0%	0.2%	0.7%	0.8%	1.9%	4.3%	6.7%	3.0%
22	0.0%	0.3%	0.5%	0.9%	2.3%	5.3%	8.2%	4.1%
23	0.0%	0.1%	0.2%	0.3%	1.4%	4.4%	5.1%	5.0%
24	0.0%	0.2%	0.3%	0.3%	0.9%	4.0%	9.1%	4.9%

Table B2 (cont'd) Blackwater study area

elevation class	surface temperature (°C)							
	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
25	0.0%	0.2%	0.3%	0.1%	0.5%	2.9%	9.8%	5.8%
26	0.0%	0.2%	0.2%	0.1%	0.1%	0.6%	5.7%	7.7%
27	0.0%	0.1%	0.2%	0.1%	0.1%	0.3%	3.8%	8.9%
28	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.3%	5.8%
29	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.8%
30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%

Table B3 Sovereign Creek study area

elevation class	surface temperature (°C)							
	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
1	0.2%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
2	1.0%	0.2%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%
3	2.5%	0.8%	0.6%	0.1%	0.0%	0.0%	0.0%	0.0%
4	8.2%	2.8%	0.8%	0.1%	0.0%	0.0%	0.0%	0.0%
5	10.0%	7.4%	2.9%	0.2%	0.0%	0.0%	0.0%	0.0%
6	4.0%	15.7%	3.9%	0.5%	0.0%	0.0%	0.0%	0.0%
7	1.4%	14.4%	6.4%	1.6%	0.1%	0.0%	0.0%	0.0%
8	0.6%	9.3%	9.8%	4.1%	0.4%	1.2%	2.1%	0.0%
9	3.4%	3.4%	9.1%	10.8%	3.0%	1.6%	0.7%	0.0%
10	7.5%	3.3%	9.5%	8.1%	8.1%	6.5%	3.7%	0.0%
11	8.2%	3.4%	8.6%	7.0%	10.1%	7.1%	8.3%	0.4%
12	7.8%	3.8%	6.6%	6.0%	7.7%	2.9%	4.3%	1.4%
13	8.2%	4.0%	4.9%	7.7%	8.6%	4.1%	3.0%	1.4%
14	6.5%	3.3%	4.4%	7.2%	7.7%	5.6%	2.3%	1.3%
15	4.5%	2.9%	3.9%	6.6%	6.6%	8.3%	4.3%	2.1%
16	4.7%	2.8%	2.5%	6.5%	6.5%	9.1%	4.1%	2.2%
17	4.5%	5.1%	3.8%	4.3%	6.7%	7.9%	5.7%	7.4%
18	4.4%	4.2%	5.1%	3.6%	5.2%	5.5%	6.8%	6.0%
19	4.2%	2.2%	4.4%	2.6%	4.2%	5.0%	5.5%	5.7%
20	2.7%	1.9%	2.3%	1.9%	5.6%	4.5%	4.6%	9.6%
21	2.2%	2.1%	2.3%	2.2%	4.2%	5.3%	5.1%	7.8%
22	1.3%	2.3%	2.0%	2.4%	3.0%	4.6%	6.5%	7.1%
23	0.5%	1.7%	2.1%	3.3%	3.4%	5.1%	7.7%	7.9%
24	0.1%	0.9%	1.9%	3.9%	3.8%	5.4%	7.6%	11.4%
25	0.2%	0.6%	1.0%	2.5%	2.0%	3.8%	4.9%	10.9%
26	0.4%	0.8%	0.7%	2.1%	0.7%	1.8%	3.4%	4.8%
27	0.4%	0.4%	0.1%	1.4%	1.2%	2.0%	2.9%	4.3%
28	0.3%	0.2%	0.1%	1.1%	0.4%	1.9%	2.1%	4.3%
29	0.1%	0.1%	0.0%	1.0%	0.4%	0.4%	1.4%	2.5%
30	0.0%	0.1%	0.0%	1.1%	0.3%	0.3%	3.1%	1.3%
31	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%

Table B4 Big Creek study area

elevation class	surface temperature (°C)							
	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.9%	1.4%	1.0%	1.1%	1.7%	1.9%	0.7%	0.5%
3	0.4%	2.1%	2.8%	3.2%	4.6%	7.1%	1.6%	1.0%
4	0.2%	1.4%	1.6%	2.4%	1.8%	2.1%	1.0%	0.2%
5	0.6%	1.2%	2.3%	2.3%	2.0%	1.3%	1.4%	0.1%
6	0.3%	1.6%	2.6%	2.9%	3.0%	2.9%	1.8%	0.2%
7	0.2%	1.3%	2.8%	3.1%	3.4%	3.2%	2.0%	0.2%
8	0.4%	1.4%	3.0%	4.4%	4.7%	5.3%	2.9%	0.1%
9	2.3%	2.3%	3.9%	5.6%	6.2%	6.3%	3.3%	0.1%
10	0.7%	1.1%	2.5%	4.1%	3.6%	5.2%	3.2%	0.6%
11	0.6%	0.9%	1.4%	4.1%	4.4%	7.3%	3.2%	0.6%
12	3.3%	3.5%	2.9%	2.7%	4.3%	6.7%	3.6%	0.9%
13	18.6%	8.6%	7.0%	5.1%	6.0%	5.9%	4.0%	1.6%
14	22.1%	11.9%	13.2%	11.3%	4.4%	3.6%	1.3%	0.4%
15	26.4%	22.8%	9.5%	8.3%	3.3%	2.4%	0.6%	0.1%
16	11.6%	16.1%	8.4%	4.6%	1.8%	1.3%	0.3%	0.3%
17	1.5%	3.6%	5.6%	5.2%	2.7%	2.2%	1.4%	0.6%
18	1.8%	2.5%	3.0%	3.4%	3.7%	4.4%	3.5%	1.4%
19	4.2%	3.5%	3.8%	4.0%	4.0%	3.7%	4.7%	1.2%
20	1.0%	1.5%	2.1%	2.4%	1.9%	1.9%	2.7%	1.5%
21	0.1%	0.3%	0.9%	1.5%	1.7%	2.3%	3.7%	2.4%
22	0.0%	0.1%	0.6%	0.8%	2.1%	1.9%	4.0%	3.6%
23	0.2%	0.1%	0.2%	0.4%	0.9%	1.6%	3.3%	4.0%
24	0.1%	0.0%	0.1%	0.1%	0.6%	0.6%	1.8%	4.4%
25	0.2%	0.1%	0.2%	0.1%	0.6%	0.6%	1.9%	4.6%
26	0.0%	0.0%	0.1%	0.2%	0.9%	0.6%	1.6%	4.7%
27	0.0%	0.0%	0.2%	0.5%	1.7%	1.1%	2.6%	3.0%
28	0.0%	0.0%	0.1%	0.2%	0.9%	0.5%	2.1%	3.0%
29	0.0%	0.1%	0.3%	0.3%	0.5%	0.4%	1.0%	2.5%
30	0.1%	0.4%	0.6%	0.7%	0.7%	0.3%	0.8%	2.1%
31	0.2%	0.7%	0.8%	0.8%	1.0%	0.7%	1.4%	2.1%
32	0.0%	0.2%	0.4%	0.7%	1.0%	1.0%	1.5%	1.8%
33	0.0%	0.0%	0.2%	0.5%	0.8%	0.8%	0.9%	1.2%
34	0.0%	0.1%	0.3%	0.5%	0.6%	0.6%	0.8%	0.9%
35	0.0%	0.1%	0.3%	0.6%	1.1%	0.7%	0.9%	0.9%
36	0.0%	0.1%	0.2%	0.4%	0.8%	0.8%	1.1%	1.0%
37	0.0%	0.1%	0.3%	0.4%	0.6%	0.7%	1.1%	1.2%
38	0.0%	0.1%	0.3%	0.4%	0.7%	0.6%	0.8%	1.5%
39	0.0%	0.1%	0.2%	0.4%	0.9%	0.6%	0.7%	1.6%
40	0.0%	0.1%	0.3%	0.5%	1.0%	0.6%	0.7%	1.6%
41	0.0%	0.0%	0.4%	0.9%	1.4%	0.4%	0.8%	1.6%
42	0.0%	0.1%	0.7%	1.1%	1.0%	0.4%	1.0%	1.2%

Table B4 (cont'd) Big Creek study area

elevation class	surface temperature (°C)							
	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
43	0.0%	0.1%	1.1%	1.1%	0.9%	0.4%	1.2%	1.3%
44	0.0%	0.2%	0.8%	1.1%	0.9%	0.4%	1.4%	1.3%
45	0.0%	0.5%	0.9%	0.8%	1.1%	0.5%	1.1%	1.1%
46	0.0%	0.7%	0.9%	0.7%	0.9%	0.6%	1.2%	1.3%
47	0.8%	0.8%	0.8%	0.3%	0.6%	0.6%	1.4%	1.9%
48	0.7%	0.9%	0.7%	0.4%	0.5%	0.4%	1.9%	2.1%
49	0.2%	0.5%	0.5%	0.4%	0.4%	0.2%	0.9%	1.9%
50	0.0%	0.6%	0.6%	0.2%	0.5%	0.3%	1.0%	1.2%
51	0.0%	0.4%	0.5%	0.2%	0.5%	0.3%	0.8%	1.3%
52	0.0%	0.2%	0.5%	0.3%	0.5%	0.3%	0.8%	1.3%
53	0.0%	0.1%	0.2%	0.3%	0.6%	0.3%	0.7%	1.3%
54	0.0%	0.1%	0.2%	0.3%	0.7%	0.4%	0.7%	1.0%
55	0.0%	0.1%	0.2%	0.3%	0.7%	0.5%	1.0%	0.9%
56	0.0%	0.1%	0.5%	0.2%	0.5%	0.5%	1.4%	0.7%
57	0.0%	0.2%	0.6%	0.1%	0.3%	0.4%	1.3%	0.8%
58	0.0%	0.2%	0.5%	0.1%	0.2%	0.2%	1.5%	1.1%
59	0.0%	0.3%	0.3%	0.1%	0.1%	0.1%	0.8%	1.1%
60	0.0%	0.3%	0.4%	0.1%	0.1%	0.1%	0.4%	1.3%
61	0.0%	0.3%	0.4%	0.1%	0.1%	0.1%	0.2%	1.1%
62	0.0%	0.3%	0.3%	0.1%	0.1%	0.3%	0.3%	1.2%
63	0.0%	0.3%	0.3%	0.1%	0.0%	0.3%	0.7%	1.0%
64	0.0%	0.3%	0.4%	0.1%	0.1%	0.1%	0.6%	1.3%
65	0.0%	0.4%	0.5%	0.1%	0.2%	0.2%	0.5%	2.1%
66	0.0%	0.4%	0.5%	0.1%	0.2%	0.2%	0.4%	3.0%
67	0.0%	0.2%	0.3%	0.1%	0.2%	0.1%	0.2%	2.0%
68	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%
69	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%
70	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
71	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
72	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
73	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%

Table B5 Moffat Lakes study area

elevation class	surface temperature (°C)							
	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
3	0.0%	0.0%	0.0%	0.2%	0.1%	0.1%	0.0%	0.1%
4	0.0%	0.0%	0.0%	0.2%	0.1%	0.1%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.2%	0.1%	0.2%	0.1%	0.0%
6	0.0%	0.0%	0.0%	0.1%	0.2%	0.2%	0.0%	0.0%
7	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.1%	0.1%
8	0.0%	0.0%	0.1%	0.2%	0.1%	0.3%	0.1%	0.2%
9	0.0%	0.0%	0.0%	0.2%	0.1%	0.5%	0.1%	0.2%
10	0.0%	0.0%	0.0%	0.2%	0.1%	0.7%	0.1%	0.2%
11	0.0%	0.0%	0.0%	0.2%	0.3%	1.1%	0.2%	0.3%
12	0.0%	0.0%	0.1%	0.4%	0.5%	1.4%	0.2%	0.5%
13	0.1%	0.1%	0.2%	0.8%	0.7%	2.2%	0.4%	0.8%
14	0.1%	0.3%	0.2%	0.7%	0.6%	2.4%	0.8%	1.1%
15	0.1%	0.6%	0.2%	0.4%	0.4%	1.9%	0.7%	1.2%
16	0.6%	0.6%	0.2%	0.5%	0.5%	2.1%	0.7%	0.9%
17	0.2%	0.7%	0.8%	0.6%	0.4%	1.3%	0.9%	1.1%
18	0.1%	0.9%	1.2%	0.7%	0.4%	1.0%	1.7%	1.3%
19	0.6%	0.5%	0.5%	1.1%	0.8%	0.8%	1.4%	1.4%
20	2.1%	1.6%	0.9%	1.8%	1.5%	1.3%	2.0%	1.6%
21	0.9%	2.5%	1.4%	1.4%	1.3%	1.3%	1.4%	1.3%
22	3.4%	3.8%	2.7%	1.7%	2.6%	2.4%	1.7%	1.5%
23	4.4%	6.1%	7.7%	2.7%	2.9%	2.0%	1.7%	6.5%
24	17.2%	12.3%	14.0%	3.2%	2.6%	2.4%	2.9%	3.5%
25	17.5%	9.5%	12.2%	4.4%	4.5%	3.3%	3.6%	3.1%
26	13.4%	10.8%	8.7%	10.2%	7.7%	4.5%	3.9%	2.6%
27	16.1%	15.7%	9.6%	11.0%	8.9%	7.3%	4.4%	4.2%
28	6.5%	12.0%	7.8%	9.5%	9.4%	9.3%	7.1%	4.1%
29	1.0%	6.7%	4.8%	6.1%	5.6%	5.5%	10.1%	4.3%
30	0.1%	3.2%	3.5%	4.6%	4.4%	4.9%	5.5%	4.2%
31	0.0%	1.4%	2.6%	5.0%	4.1%	4.2%	3.2%	3.9%
32	0.0%	0.2%	1.5%	2.0%	2.1%	2.9%	2.9%	3.6%
33	0.0%	0.1%	1.6%	1.2%	1.0%	1.6%	2.2%	3.1%
34	0.0%	0.2%	1.2%	0.8%	0.8%	0.7%	1.7%	2.9%
35	0.0%	0.1%	0.9%	0.7%	0.8%	0.8%	1.9%	2.7%
36	0.0%	0.1%	0.6%	0.5%	0.9%	0.7%	1.8%	2.6%
37	0.0%	0.0%	0.4%	0.6%	1.3%	0.8%	1.8%	2.6%
38	0.1%	0.1%	0.5%	0.8%	1.1%	0.7%	1.9%	2.6%
39	0.1%	0.2%	1.0%	1.2%	1.5%	1.3%	3.0%	2.2%
40	0.0%	0.3%	1.3%	1.4%	1.7%	1.2%	2.3%	1.4%
41	0.5%	0.6%	1.0%	1.6%	2.0%	1.3%	1.5%	1.2%
42	12.7%	3.1%	2.7%	2.3%	2.3%	1.6%	1.4%	2.3%

Table B5 (cont'd) Moffat Lakes study area

elevation class	surface temperature (°C)							
	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
43	1.2%	2.0%	3.0%	3.2%	3.4%	1.7%	1.1%	1.0%
44	0.4%	0.6%	0.9%	2.3%	3.3%	1.8%	1.1%	0.9%
45	0.0%	0.5%	0.7%	0.9%	1.9%	2.9%	1.7%	0.9%
46	0.0%	0.5%	0.4%	1.1%	1.2%	1.6%	1.6%	1.2%
47	0.1%	0.6%	0.3%	0.9%	1.0%	0.8%	1.2%	1.4%
48	0.3%	0.8%	0.3%	1.0%	1.1%	0.8%	0.9%	1.5%
49	0.0%	0.1%	0.1%	0.6%	0.9%	1.0%	0.9%	1.6%
50	0.0%	0.0%	0.0%	0.7%	0.7%	0.8%	0.9%	1.4%
51	0.0%	0.0%	0.1%	0.6%	0.9%	0.7%	0.8%	1.2%
52	0.0%	0.0%	0.2%	0.7%	0.7%	0.6%	0.7%	1.2%
53	0.0%	0.0%	0.1%	0.8%	0.6%	0.7%	0.8%	1.0%
54	0.0%	0.0%	0.1%	0.7%	0.9%	0.8%	0.9%	0.8%
55	0.0%	0.0%	0.1%	0.7%	1.3%	0.9%	1.0%	0.7%
56	0.0%	0.0%	0.1%	0.7%	1.2%	1.5%	1.2%	0.5%
57	0.0%	0.1%	0.2%	0.5%	1.1%	1.2%	1.3%	0.5%
58	0.0%	0.4%	0.3%	0.7%	1.0%	1.0%	1.6%	0.6%
59	0.0%	0.1%	0.1%	0.5%	0.9%	1.0%	1.5%	0.7%
60	0.0%	0.1%	0.2%	0.6%	0.8%	0.7%	1.1%	0.5%
61	0.0%	0.0%	0.2%	0.5%	0.4%	0.5%	1.1%	0.4%
62	0.0%	0.0%	0.2%	0.3%	0.2%	0.2%	0.6%	0.5%
63	0.0%	0.0%	0.2%	0.1%	0.1%	0.2%	0.4%	0.6%
64	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%	0.1%	0.5%
65	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
66	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
67	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
68	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
69	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
70	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
71	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
72	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
73	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Appendix C - Cross-tabulation of Soil Composition with Surface Temperature

Table C1 Soil Classification codes and modifiers

AIX - Alix soil - orthic dystric brunisol ALZ - Aleza soil - orthic luvic gleysol ARH - Archie soil - podzolic gray luvisols ART - Art soil - brunisolic gray luvisol BGC - Big Creek soil - orthic eutric brunisol BGR - Big Bar soil - chernozem (orthic dark brown) BRT - Barret soil - orthic gray luvisol CHM - Chasm soil - eluviated eutric luvisol CIF - Chief soil - typic mesisol CMY- Chimney soil - hernozem (orthic dark brown) DAG - Dragon soil - orthic humo-ferric podzol DES - Deserters soil - gleyed brunisolic gray luvisol DMI - Dominion soil - luvisolic humo-ferric podzol DZK - Dezaiko soil - orthic humo-ferric podzol ELT - Elliot soil - carbonated rego-humic gleysol GUI - Guilford soil - gleyed cumulic regosol HWK - Hawk soil - eluviated eutric brunisol KEI - Keithly soil - typic mesisol	KNK Keno Lake soil - orthic humo-ferric podzol LDN - Lynn soil - lithic orthic humo-ferric podzol MOF - Moffat Lakes soil - ortho humo-ferric podzol ORM - Ormond soil - orthic dystric brunisol PTZ - Piltz soil - orthic gray luvisol RAM - Ramsey soil - orthic humo-ferric podzol RKL - exposed bedrock ROA - Roaring soil - orthic dystric brunisol SEW - Shemwell soil - orthic gray luvisol SLL - Salt Lake soil - orthic gray luvisol SOU - Spout soil - podzolic gray luvisol STK - Stellako soil - gelyed regosol TEE - Tyee soil - orthic gray luvisoil TGP - Telegraph soil - eluviated dystric brunisol VWM - Vedan Meadow soil - orthic gray luvisol WLA - Williams Lake soil - orthic gray luvisol WSD - West Road soil - eluviated dystric brunisol ZZZ - Zezaiko soil - chernozem (orthic dark brown)
Modifiers: (symbolized by an * in the tables below)	
1 - gleyed subgroups 5 - lithic soils - shallow to bedrock within 100 cm 7 - saline phase 8 - carbonated phase	9 - very shallow lithic soils; bedrock within 50 cm 11 - terric (shallow) organics 14 - eroded phase 17 - bouldery phase; stony class = 5 or 3

Table C2 Blackwater study area

Soil composition										surface temperature (°C)							
ID#	soil1	*	%	soil2	*	%	soil3	*	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
1	AIX		85	CIF		15			0	5.6%	36.1%	30.9%	15.5%	3.3%	4.3%	0.9%	0.7%
2	CHM		60	CHM	9	40			0	0.0%	0.4%	0.9%	1.8%	0.3%	0.1%	0.0%	0.0%
3	CIF		70	CIF	11	15	ALZ		15	25.2%	9.2%	5.3%	2.4%	0.5%	0.7%	0.8%	0.7%
4	ORM	5	40	BRT		30	ORM	9	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.4%
5	ROA		80	ROA	14	20			0	0.0%	1.7%	4.4%	4.1%	6.8%	0.8%	0.0%	0.0%
6	STK		70	AIX		15	CIF	11	15	8.7%	14.1%	7.7%	3.5%	4.0%	3.3%	1.1%	1.4%
7	WSD		65	BRT		35			0	16.9%	30.4%	37.9%	63.7%	80.5%	86.0%	96.1%	55.2%
8	WSD		50	AIX		35	CIF		15	43.4%	8.1%	12.7%	8.9%	4.4%	4.1%	0.0%	0.0%
9	ZZZ		100			0			0	0.2%	0.1%	0.0%	0.0%	0.2%	0.6%	1.0%	37.6%

Table C3 Pantage Creek study area

Soil composition										surface temperature (°C)							
ID#	soil1	*	%	soil2	*	%	soil3	*	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
1	BRT		100			0			0	0.0%	0.2%	1.6%	1.0%	0.4%	0.4%	0.2%	0.6%
2	BRT		70	AIX		30			0	0.6%	0.7%	0.3%	0.6%	0.9%	0.9%	2.0%	0.1%
3	CHM		60	CHM	9	40			0	0.0%	1.8%	1.5%	2.7%	1.8%	0.4%	0.0%	0.0%
4	CIF		70	CIF	11	15	ALZ		15	22.7%	12.2%	2.8%	1.9%	2.2%	0.3%	0.1%	0.0%
5	ORM	5	40	BRT		30	ORM	9	30	0.3%	2.0%	2.2%	1.6%	3.3%	5.4%	10.2%	10.0%
6	TGP		85	SLL		15			0	7.1%	14.5%	38.5%	35.6%	24.7%	36.4%	35.2%	21.0%
7	TGP		60	ORM	5	25	ORM	9	15	41.4%	15.9%	21.4%	19.9%	18.2%	22.9%	18.0%	63.0%
##										27.8%	52.5%	31.7%	36.8%	48.6%	33.4%	34.3%	5.2%

Table C4 Sovereign Creek study area

Soil composition										surface temperature (°C)							
ID#	soil1	*	%	soil2	*	%	soil3	*	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
1	CIF		70	ALZ		30			0	2.9%	1.4%	0.8%	0.2%	0.1%	1.5%	2.6%	0.0%
2	DES		65	DMI		35			0	20.8%	15.5%	23.9%	32.2%	18.9%	26.9%	10.5%	9.5%
3	DMI		85	DMI	1	15			0	13.5%	29.8%	42.9%	47.2%	58.3%	51.8%	47.6%	45.8%
4	DMI		60	ALZ		25	CIF		15	55.8%	49.2%	24.0%	9.4%	7.5%	4.2%	3.3%	5.5%
5	DMI		60	DAG	5	25	DAG	9	15	1.3%	1.6%	5.0%	9.7%	15.0%	14.9%	34.6%	36.3%
6	DZK	9	70	RKL		30			0	0.0%	0.0%	0.1%	0.2%	0.1%	0.1%	0.0%	0.0%
7	RAM		70	GUI		15	GUI	1	15	4.7%	1.2%	3.0%	0.8%	0.1%	0.0%	0.0%	0.0%
8	ZZZ		100			0			0	1.0%	1.2%	0.3%	0.3%	0.1%	0.5%	1.4%	2.9%

Table C5 Big Creek study area

Soil composition										surface temperature (°C)							
ID#	soil1	*	%	soil2	*	%	soil3	*	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
1	BGC		100			0			0	1.4%	1.9%	3.9%	6.7%	5.8%	3.9%	1.6%	0.3%
2	CMY		60	WLA		25	CMY	7	15	0.0%	0.5%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%
3	ELT	8	100			0			0	5.1%	3.1%	2.1%	1.7%	1.4%	1.1%	0.8%	0.5%
4	HWK		100			0			0	3.3%	7.7%	11.5%	13.8%	13.2%	14.6%	6.4%	2.0%
5	PTZ		85	PTZ	5	15			0	0.0%	0.3%	0.4%	0.9%	2.3%	2.7%	8.0%	21.1%
6	SEW		100			0			0	48.5%	55.8%	35.4%	36.9%	25.5%	20.6%	25.0%	14.6%
7	SEW		70	ELT	8	30			0	3.6%	2.7%	2.6%	2.3%	2.2%	1.6%	3.5%	0.1%
8	TEE		100			0			0	13.6%	17.4%	27.5%	30.0%	41.3%	45.0%	45.7%	50.0%
9	TEE		80	BGR		20			0	12.2%	7.4%	8.8%	6.4%	7.2%	8.9%	8.5%	10.9%
10	VWM		60	TEE		25	BGR		15	9.5%	2.0%	7.0%	1.0%	0.6%	1.2%	0.3%	0.4%
11	WLA		85	WLA	17	15			0	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%	0.0%	0.0%
12	ZZZ		100			0			0	2.8%	1.2%	0.3%	0.3%	0.2%	0.2%	0.0%	0.2%

Table C6 Moffat Lakes study area

Soil composition										surface temperature (°C)							
ID#	soil1	*	%	soil2	*	%	soil3	*	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
1	ARH		70	MOF		30	0			17.8%	37.1%	17.3%	27.5%	30.6%	44.2%	37.2%	30.0%
2	ARH		60	ARH	5	40	0			0.1%	1.3%	3.1%	7.3%	11.8%	11.3%	15.9%	17.4%
3	ART		70	LDN	5	30	0			10.5%	14.0%	16.2%	10.7%	5.5%	5.4%	8.2%	8.4%
4	KEI		100			0	0			15.4%	10.2%	5.0%	6.6%	4.1%	3.5%	2.0%	1.3%
5	KNK		60	KEI		40	0			11.7%	5.4%	4.8%	2.4%	1.5%	0.0%	0.0%	0.0%
6	LDN	5	60	ARH		40	0			0.2%	1.2%	5.7%	17.5%	24.6%	17.1%	23.5%	25.5%
7	MOF		50	KNK		50	0			42.7%	28.9%	44.1%	26.8%	20.0%	18.1%	12.8%	12.9%
8	MOF		50	SOU		50	0			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
9	ZZZ		100			0	0			1.6%	1.8%	3.7%	1.3%	1.8%	0.5%	0.4%	4.3%

Appendix D - Cross-tabulation of Forest Species Composition with Surface Temperature

Table D1 Forest Species composition codes used in the following tables

Forest Species codes	
AC - Balsam/poplar/ Cottonwood	PL - Lodgepole pine
AT - Aspen	S - spruce
B - True fir	SB - Black spruce
BL - Alpine fir	SE - Engelmann spruce
EP - common paper birch	SW - White spruce
FD - Douglas fir	

The abbreviatons spc1, spc2 and spc3 (in the following tables) refer to primary, secondary and tertiary forest species, respectively

Table D2 Pantage Creek study area

Forest species composition							Surface temperature (°C)							
ID#	spc1	%	spc2	%	spc3	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
0	-	-	-				23.7%	15.3%	5.7%	2.7%	1.1%	1.2%	1.0%	0.5%
1	BL	100		0		0	0.0%	0.0%	0.7%	2.8%	0.3%	0.2%	0.1%	0.1%
2	BL	84	PL	10	S	6	1.2%	1.9%	1.3%	0.4%	0.2%	0.5%	0.2%	0.0%
3	BL	50	PL	30	S	20	0.0%	2.6%	1.8%	0.6%	0.6%	0.7%	0.2%	0.1%
4	PL	100		0		0	71.3%	60.0%	37.9%	43.6%	55.8%	42.6%	43.3%	33.8%
5	PL	99	S	1		0	0.0%	2.1%	9.4%	7.3%	3.1%	1.8%	0.2%	0.0%
6	PL	97	AT	3		0	0.0%	0.6%	2.8%	2.2%	1.7%	0.8%	0.2%	0.0%
7	PL	90	BL	10		0	0.0%	2.6%	5.2%	6.8%	1.7%	1.4%	0.4%	0.1%
8	PL	90	FD	10		0	0.0%	0.0%	0.1%	0.5%	0.6%	0.6%	0.7%	0.0%
9	PL	90	S	10		0	0.0%	0.0%	0.1%	0.4%	0.5%	2.0%	4.3%	3.4%
10	PL	80	BL	20		0	0.0%	3.3%	7.2%	6.8%	0.9%	1.0%	0.3%	0.0%
11	PL	80	EP	10	AT	10	0.3%	2.8%	1.1%	0.7%	0.9%	0.1%	0.0%	0.0%
12	PL	80	S	20		0	0.0%	0.3%	0.7%	0.1%	0.1%	0.0%	0.0%	0.0%
13	PL	80	S	10	B	10	0.0%	1.8%	3.3%	7.7%	15.5%	27.4%	28.6%	47.4%
14	PL	77	BL	19	S	4	0.0%	0.1%	3.2%	3.5%	1.3%	0.7%	0.2%	0.0%
15	PL	73	BL	21	S	6	0.0%	0.1%	1.5%	0.3%	0.0%	0.0%	0.0%	0.0%
16	PL	70	AT	30		0	0.0%	0.0%	0.0%	0.0%	0.1%	0.4%	0.6%	0.5%
17	PL	70	BL	30		0	0.0%	1.0%	3.1%	0.8%	0.1%	0.1%	0.0%	0.0%
18	PL	62	S	38		0	0.0%	0.0%	1.6%	1.0%	0.9%	0.7%	0.1%	0.0%
19	PL	60	BL	30	AT	10	2.8%	1.7%	4.5%	5.6%	4.8%	3.5%	0.6%	0.0%
20	PL	60	BL	30	S	10	0.0%	0.2%	0.6%	0.9%	0.9%	0.4%	0.1%	0.1%
21	PL	60	FD	40		0	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.3%	0.4%
22	PL	60	S	40		0	0.0%	0.0%	1.5%	0.6%	0.4%	0.9%	5.4%	4.1%
23	PL	60	S	30	BL	10	0.0%	0.0%	0.9%	0.3%	0.1%	0.1%	0.0%	0.0%
24	PL	60	S	20	BL	20	0.0%	0.1%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%
25	PL	60	S	30	B	10	0.0%	0.1%	0.3%	0.4%	0.9%	3.2%	3.9%	2.4%
27	PL	59	S	41		0	0.0%	0.0%	1.8%	1.0%	0.2%	0.2%	0.1%	0.0%

Table D2 (cont'd) Pantage Creek study area

Forest species composition							Surface temperature (°C)							
ID#	spc1	%	spc2	%	spc3	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
28	PL	50	BL	50		0	0.0%	0.0%	0.0%	0.2%	0.1%	0.1%	0.0%	0.0%
29	PL	50	S	30	B	20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
30	S	100		0		0	0.0%	0.0%	0.2%	0.8%	0.8%	0.7%	0.1%	0.1%
31	S	60	B	30	PL	10	0.0%	0.0%	0.1%	0.3%	1.2%	1.6%	1.8%	2.4%
32	S	60	B	40		0	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
33	S	60	PL	30	B	10	0.0%	0.0%	0.2%	0.7%	2.1%	3.3%	4.2%	2.5%
34	S	60	PL	40		0	0.0%	0.1%	0.3%	0.7%	2.7%	3.6%	3.5%	1.6%
35	S	40	PL	33	BL	27	0.0%	0.0%	1.0%	0.1%	0.0%	0.0%	0.0%	0.0%
36	SB	100		0		0	0.7%	2.8%	1.7%	0.6%	0.5%	0.1%	0.0%	0.0%

Table D3 Blackwater study area

Forest species composition							Surface Temperature (°C)							
ID#	spc1	%	spc2	%	spc3	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
0							41.3%	27.0%	11.1%	4.8%	4.8%	7.2%	4.9%	44.5%
1	AC	100		0		0	0.0%	0.1%	0.1%	0.2%	0.1%	0.1%	0.0%	0.0%
2	AT	100		0		0	0.0%	0.6%	1.0%	0.2%	0.6%	2.4%	3.8%	0.4%
3	AT	60	PL	40		0	0.0%	0.3%	0.8%	0.8%	3.6%	0.3%	0.0%	0.0%
4	AT	60	S	40		0	0.0%	0.1%	0.1%	0.5%	0.8%	0.2%	0.0%	0.0%
5	AT	60	PL	30	S	10	0.0%	0.0%	0.4%	0.3%	0.5%	0.1%	0.0%	0.0%
6	FD	100		0		0	0.0%	0.0%	0.0%	0.0%	1.3%	0.6%	0.0%	0.0%
7	FD	60	PL	40		0	0.0%	0.0%	0.0%	0.2%	0.5%	0.0%	0.0%	0.0%
8	FD	60	PL	30	AT	10	0.0%	0.0%	0.0%	0.3%	2.4%	0.5%	0.4%	0.0%
9	PL	100		0		0	52.5%	64.7%	80.4%	83.3%	67.7%	56.6%	66.3%	41.0%
10	PL	93	S	7		0	0.6%	1.1%	0.4%	0.3%	0.2%	0.3%	0.0%	0.0%
11	PL	90	S	10		0	1.1%	1.8%	1.0%	0.2%	0.8%	3.4%	2.7%	3.1%
12	PL	90	AT	10		0	0.0%	0.0%	0.2%	0.7%	1.4%	0.0%	0.0%	0.0%
13	PL	90	FD	10		0	0.0%	0.0%	0.0%	0.3%	1.2%	1.0%	0.0%	0.0%
14	PL	88	S	12		0	3.1%	1.7%	1.8%	0.6%	0.5%	1.1%	1.4%	0.5%
15	PL	80	AT	10	FD	10	0.0%	0.0%	0.1%	0.2%	0.5%	3.3%	0.0%	0.0%
16	PL	70	S	30		0	0.7%	0.5%	0.3%	0.0%	0.4%	0.4%	0.4%	0.0%
17	PL	60	AT	40		0	0.0%	0.0%	0.1%	0.9%	0.6%	0.1%	0.0%	0.0%
18	PL	60	S	40		0	0.1%	0.7%	1.1%	2.8%	2.1%	2.8%	5.4%	0.3%
19	PL	60	FD	40		0	0.0%	0.0%	0.0%	0.1%	3.0%	0.3%	0.0%	0.0%
20	PL	60	S	30	AT	10	0.0%	0.1%	0.2%	0.0%	0.4%	2.1%	1.5%	0.0%
21	S	100		0		0	0.6%	0.9%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
22	S	60	PL	40		0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.5%
23	S	60	AT	40		0	0.0%	0.2%	0.2%	0.3%	0.0%	0.0%	0.0%	0.0%
24	S	60	AC	40		0	0.0%	0.0%	0.0%	0.3%	0.4%	0.2%	0.0%	0.0%
25	S	60	PL	30	AT	10	0.0%	0.1%	0.4%	2.2%	3.4%	2.6%	13.1%	9.8%
26	S	60	AT	30	PL	10	0.0%	0.0%	0.0%	0.3%	2.8%	14.4%	0.0%	0.0%

Table D4 Sovereign Creek study area

Forest species composition									Surface temperature (°C)							
ID#	spc 1	%	spc 2	%	spc 3	%	spc 4	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
0									19.1%	14.7%	8.9%	9.4%	7.1%	6.8%	6.7%	8.4%
1	AT	40	AC	30	S	20	BL	10	0.5%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	BL	100		0		0			0.0%	0.2%	0.2%	0.1%	0.2%	0.1%	0.0%	0.0%
3	BL	90	SW	10		0			0.2%	0.7%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%
4	BL	85	AT	9	SW	6			0.7%	0.5%	0.6%	0.3%	0.2%	0.3%	0.0%	0.0%
5	BL	80	SW	20		0			0.3%	0.3%	0.4%	0.3%	1.1%	1.7%	0.8%	2.0%
6	BL	80	SW	10	AT	10			0.1%	0.2%	0.5%	0.8%	2.0%	2.9%	4.6%	0.2%
7	BL	70	SW	30		0			0.1%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8	BL	69	SW	25	PL	4	AT	2	1.5%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
9	BL	60	PL	20	SW	20			0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
10	BL	60	SW	40		0			1.7%	0.8%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
11	PL	100		0		0			4.9%	3.6%	2.2%	0.5%	0.3%	0.2%	0.1%	0.3%
12	PL	90	AT	10		0			0.1%	0.6%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%
13	PL	90	SW	10		0			3.1%	8.6%	11.6%	7.7%	12.5%	4.0%	3.3%	2.8%
14	PL	90	SW	5	BL	5			0.0%	0.0%	0.1%	0.1%	0.5%	1.7%	1.3%	1.8%
15	PL	90	SW	5	AT	5			0.2%	2.2%	2.9%	1.8%	0.3%	0.0%	0.0%	0.0%
16	PL	89	SW	11		0			0.7%	0.3%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%
17	PL	85	SW	15		0			5.4%	9.3%	1.6%	0.1%	0.1%	0.0%	0.0%	0.0%
18	PL	80	AT	10	SW	10			0.7%	1.2%	0.7%	0.1%	0.2%	0.0%	0.0%	0.0%
19	PL	80	SW	20		0			1.2%	0.2%	0.3%	0.4%	1.5%	1.1%	0.6%	0.0%
20	PL	80	SW	10	AT	10			0.0%	0.9%	0.4%	1.1%	0.0%	0.0%	0.0%	0.0%
21	PL	70	S	20	AT	10			0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
22	PL	70	SW	30		0			2.6%	4.2%	10.0%	6.8%	6.9%	2.8%	12.0%	5.3%
23	PL	70	SW	20	AT	10			0.4%	0.1%	0.6%	0.2%	0.0%	0.0%	0.0%	0.0%
24	PL	70	SW	20	FD	10			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
25	PL	70	SW	20	BL	10			0.0%	0.4%	2.7%	0.8%	0.0%	0.0%	0.0%	0.0%
27	PL	65	SW	30	BL	5			1.8%	0.3%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
28	PL	60	AC	20	S	10	BL	10	1.2%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
29	PL	60	AT	20	SW	20			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
30	PL	60	S	20	BL	10	AC	10	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
31	PL	60	SB	40		0			0.3%	0.7%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%
32	PL	60	SW	40		0			5.1%	5.0%	7.8%	1.8%	1.4%	0.0%	0.0%	3.1%
33	PL	60	SW	20	AT	20			0.1%	0.2%	0.4%	0.5%	0.0%	0.0%	0.0%	0.0%
34	PL	60	SW	30	BL	10			0.0%	0.0%	1.0%	0.0%	0.3%	0.5%	2.3%	9.7%
35	PL	60	SW	30	AT	10			0.0%	1.1%	0.2%	2.9%	1.5%	0.4%	0.0%	0.0%
36	PL	57	SW	38	BL	5			0.4%	1.2%	3.5%	4.3%	2.7%	3.5%	1.3%	0.0%
37	PL	52	SW	48		0			1.6%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
38	PL	50	AC	30	S	10	BL	10	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
39	PL	50	SW	40	BL	10			0.2%	0.1%	0.2%	0.1%	0.4%	0.7%	0.8%	2.0%
40	PL	50	SW	30	FD	20			0.0%	0.1%	0.3%	0.2%	0.5%	0.8%	0.5%	2.1%
41	PL	50	SW	50		0			0.0%	0.5%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D4 (cont'd) Sovereign Creek study area

Forest species composition									Surface temperature (°C)							
ID#	spc 1	%	spc 2	%	spc 3	%	spc 4	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
42	PL	40	FD	30	S	20	AT	10	0.4%	0.8%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%
43	S	100		0		0			1.8%	0.6%	1.1%	6.4%	1.2%	0.5%	0.0%	0.0%
44	S	92	BL	3	AT	2	EP	3	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%
45	S	90	BL	10		0			1.7%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
46	S	90	PL	10		0			0.3%	0.5%	0.4%	1.0%	0.0%	0.0%	0.0%	0.0%
47	S	87	AC	9	BL	3	AT	1	1.0%	1.0%	0.7%	3.0%	0.5%	0.5%	0.0%	0.0%
48	S	87	BL	11	AC	2			0.0%	0.0%	0.0%	0.4%	0.1%	0.1%	0.0%	0.0%
49	S	80	BL	20		0			1.5%	1.4%	0.6%	0.2%	0.2%	0.3%	0.5%	0.4%
50	S	80	BL	10	AC	10			0.5%	0.3%	0.2%	0.0%	0.0%	0.1%	0.0%	0.0%
51	S	80	PL	10	FD	10			0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
52	S	70	AC	10	PL	10	BL	10	2.1%	1.4%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
53	S	70	BL	20	AC	10			1.2%	0.6%	0.5%	0.3%	0.1%	0.1%	0.0%	0.0%
54	S	70	BL	30		0			1.3%	0.7%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
55	S	65	BL	35		0			0.9%	1.2%	0.8%	1.4%	0.4%	0.1%	0.0%	0.0%
56	S	60	AC	30	BL	10			0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
57	S	60	B	40		0			0.4%	1.1%	0.5%	0.4%	0.1%	0.1%	0.0%	0.0%
58	S	60	BL	30	AC	10			0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	1.3%	0.0%
59	S	60	BL	40		0			0.2%	1.0%	1.2%	1.5%	0.4%	0.4%	0.0%	0.0%
60	S	60	PL	20	AC	20			0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
61	S	60	PL	20	BL	10	AC	10	0.3%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
62	S	50	PL	50		0			0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
63	SB	60	PL	40		0			0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
65	SW	100		0		0			11.1%	3.0%	1.6%	0.8%	1.0%	1.0%	0.5%	0.2%
66	SW	94	PL	6		0			2.5%	0.4%	0.4%	0.0%	0.0%	0.1%	0.0%	0.0%
67	SW	90	BL	10		0			0.4%	0.7%	1.8%	1.7%	0.4%	1.4%	0.2%	0.0%
68	SW	88	PL	12		0			0.4%	0.9%	0.4%	0.2%	0.2%	0.4%	0.1%	0.0%
69	SW	86	BL	14		0			0.8%	1.8%	3.1%	4.7%	9.2%	8.4%	3.4%	0.0%
70	SW	85	BL	15		0			0.1%	0.4%	0.8%	0.3%	0.8%	0.5%	0.4%	0.0%
71	SW	81	PL	13	BL	6			1.1%	0.2%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%
72	SW	80	AT	10	PL	10			0.0%	0.5%	0.5%	4.4%	4.3%	6.5%	11.5%	2.3%
73	SW	80	BL	20		0			0.6%	1.2%	4.0%	2.7%	6.4%	8.2%	12.7%	7.7%
74	SW	80	FD	20		0			0.0%	0.1%	0.1%	0.1%	0.2%	0.5%	0.4%	3.0%
75	SW	80	FD	10	BL	10			0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%
76	SW	80	PL	20		0			0.5%	0.4%	0.9%	0.4%	0.6%	0.2%	0.0%	0.0%
77	SW	80	PL	10	AT	10			0.3%	0.4%	0.5%	0.4%	0.4%	1.4%	0.1%	0.0%
78	SW	80	PL	10	AC	10			2.8%	1.6%	1.9%	6.4%	4.8%	3.2%	0.4%	0.0%
79	SW	70	BL	30		0			1.7%	1.4%	4.1%	5.0%	5.2%	6.1%	5.4%	1.6%
80	SW	70	FD	30		0			0.0%	0.1%	0.2%	3.2%	1.1%	2.0%	1.1%	0.0%
81	SW	70	FD	20	PL	10			0.0%	0.2%	0.4%	0.8%	0.4%	0.6%	0.9%	0.1%
82	SW	70	PL	20	BL	10			0.1%	0.4%	1.5%	0.4%	0.8%	1.7%	1.1%	1.1%
83	SW	70	PL	30		0			0.6%	0.8%	0.5%	2.6%	6.0%	2.2%	5.2%	6.2%

Table D4 (cont'd) Sovereign Creek study area

Forest species composition									Surface temperature (°C)							
ID#	spc 1	%	spc 2	%	spc 3	%	spc 4	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
84	SW	70	PL	20	SB	10			0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
85	SW	70	PL	20	AT	10			0.1%	0.1%	0.3%	0.2%	1.1%	1.2%	0.3%	0.0%
86	SW	65	BL	29	AT	4	AC	2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%
87	SW	60	AT	30	PL	10			0.1%	0.5%	1.1%	1.7%	1.4%	1.0%	0.0%	0.0%
88	SW	60	BL	40		0			1.3%	3.0%	1.9%	0.6%	1.5%	2.4%	1.9%	3.2%
89	SW	60	BL	20	PL	20			0.0%	0.0%	0.0%	0.1%	0.1%	0.5%	0.1%	0.0%
90	SW	60	BL	30	PL	10			0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
91	SW	60	BL	35	AT	5			0.0%	0.0%	0.0%	0.0%	0.4%	0.9%	5.3%	5.6%
92	SW	60	FD	20	BL	20			0.0%	0.0%	0.0%	0.1%	0.2%	0.6%	0.5%	4.1%
93	SW	60	FD	20	PL	20			0.1%	0.5%	0.4%	1.7%	1.2%	8.3%	4.3%	13.6%
94	SW	60	PL	20	BL	20			0.4%	0.5%	0.2%	0.0%	0.1%	1.3%	2.2%	2.6%
95	SW	60	PL	40		0			0.6%	0.8%	0.3%	1.2%	0.6%	0.7%	0.0%	0.0%
96	SW	60	PL	30	BL	10			0.4%	1.9%	3.1%	0.7%	4.3%	2.2%	1.3%	5.5%
97	SW	56	BL	44		0			0.2%	0.3%	0.5%	1.4%	1.3%	3.3%	0.0%	0.0%
98	SW	55	PL	45		0			0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
99	SW	54	PL	24	AT	11	BL	11	1.2%	1.5%	0.6%	1.4%	0.8%	0.7%	1.2%	0.0%
100	SW	50	AC	50		0			0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
101	SW	50	BL	20	FD	20	PL	10	0.0%	0.0%	0.1%	0.0%	0.0%	0.2%	0.3%	1.8%
102	SW	50	BL	50		0			0.0%	0.1%	0.5%	1.1%	1.8%	1.3%	1.8%	0.1%
103	SW	50	PL	30	BL	20			0.0%	0.0%	0.1%	0.1%	0.1%	0.6%	0.9%	1.6%
104	SW	50	PL	50		0			0.6%	3.4%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
105	SW	50	PL	40	AT	10			0.5%	0.3%	0.3%	0.5%	0.0%	0.0%	0.0%	0.0%
106	SW	50	PL	40	BL	10			0.1%	1.1%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%

Table D5 Big Creek study area

forest specices composition							surface temperature (°C)							
ID#	spc1	%	spc2	%	spc3	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
0							24.9%	23.8%	25.3%	17.0%	15.2%	9.7%	11.4%	16.2%
1	AC	100		0		0	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
2	AC	90	S	10		0	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%
3	AC	70	AT	20	PL	10	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%
4	AC	70	S	20	AT	10	0.0%	0.1%	0.1%	0.1%	0.2%	0.2%	0.1%	0.0%
5	AC	70	S	30		0	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
6	AC	50	AT	50		0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7	AT	80	PL	20		0	0.5%	0.4%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%
8	AT	80	SW	20		0	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.1%	0.1%
9	AT	75	PL	25		0	0.6%	0.1%	0.0%	0.1%	0.1%	0.4%	0.0%	0.0%
10	AT	70	PL	20	S	10	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.3%	0.0%
11	AT	70	PL	30		0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%

Table D5 (cont'd) Big Creek study area

forest specices composition							surface temperature (°C)							
ID#	spc1	%	spc2	%	spc3	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
12	AT	70	S	20	PL	10	0.0%	0.1%	0.1%	0.3%	0.2%	0.2%	0.1%	0.0%
13	AT	62	PL	30	FD	8	0.1%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
14	AT	60	FD	20	PL	20	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.4%
15	AT	60	PL	40		0	2.3%	0.6%	0.5%	0.0%	0.1%	0.0%	0.0%	0.0%
16	AT	50	PL	30	S	20	0.1%	0.5%	0.6%	0.2%	0.1%	0.0%	0.0%	0.0%
17	AT	50	PL	50		0	4.8%	0.6%	0.2%	0.0%	0.0%	0.1%	0.2%	0.1%
18	AT	40	PL	30	FD	30	0.1%	0.3%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%
19	FD	100		0		0	0.8%	2.7%	4.3%	5.9%	9.0%	12.5%	10.1%	7.2%
20	FD	92	PL	8		0	0.0%	0.0%	0.0%	0.0%	0.2%	1.6%	1.2%	0.2%
21	FD	90	PL	10		0	0.4%	0.7%	1.3%	2.3%	3.1%	2.3%	2.7%	1.0%
22	FD	88	PL	12		0	0.1%	2.0%	1.3%	0.3%	0.2%	0.1%	0.1%	0.2%
23	FD	80	PL	15	AT	5	0.0%	0.1%	0.7%	0.6%	0.9%	0.9%	0.3%	0.0%
24	FD	80	PL	20		0	0.6%	1.3%	1.6%	1.1%	1.4%	1.8%	2.8%	3.7%
25	FD	80	PL	10	AT	10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
26	FD	74	PL	26		0	0.0%	0.0%	0.0%	0.1%	0.7%	0.5%	0.6%	0.0%
27	FD	73	AT	25	PL	2	0.0%	0.0%	0.1%	0.2%	0.5%	0.7%	0.3%	0.1%
28	FD	72	AT	23	PL	5	0.0%	0.1%	0.1%	0.1%	0.4%	0.2%	0.1%	0.1%
29	FD	70	PL	30		0	0.0%	0.2%	0.3%	0.4%	0.8%	0.8%	0.4%	0.4%
30	FD	60	PL	40		0	0.3%	1.9%	4.0%	2.5%	4.0%	6.7%	2.1%	1.1%
31	FD	50	PL	50		0	0.0%	0.3%	1.1%	3.5%	3.7%	2.2%	0.5%	0.1%
32	FD	50	PL	40	AT	10	1.0%	1.2%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
33	PL	100		0		0	43.9%	38.9%	39.1%	43.3%	32.3%	32.5%	39.8%	50.3%
34	PL	90	AT	10		0	0.7%	1.0%	0.5%	0.4%	0.6%	0.8%	0.3%	0.1%
35	PL	90	FD	10		0	1.7%	4.0%	3.5%	4.0%	4.7%	6.7%	3.4%	6.2%
36	PL	90	S	10		0	0.0%	0.3%	0.4%	0.4%	0.1%	0.2%	0.3%	0.2%
37	PL	90	SW	10		0	0.0%	0.0%	0.0%	0.0%	0.3%	0.1%	0.6%	0.1%
38	PL	87	AT	12	FD	1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
39	PL	80	AT	10	S	10	0.1%	0.6%	0.4%	0.8%	1.0%	2.3%	1.2%	1.0%
40	PL	80	AT	20		0	0.0%	0.0%	0.1%	0.2%	0.1%	0.1%	0.1%	0.0%
41	PL	80	FD	20		0	0.2%	0.1%	0.6%	0.9%	0.8%	1.8%	0.6%	3.1%
42	PL	80	FD	10	AT	10	2.9%	1.0%	1.6%	0.7%	0.9%	0.5%	0.4%	0.1%
43	PL	80	SW	10	AT	10	0.3%	0.2%	0.4%	0.6%	0.2%	0.2%	0.1%	0.2%
44	PL	75	AT	25		0	0.6%	0.5%	0.4%	0.1%	0.1%	0.0%	0.0%	0.0%
45	PL	73	AT	27		0	2.2%	0.5%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
46	PL	70	AT	30		0	0.0%	0.5%	0.1%	0.0%	0.0%	0.0%	0.1%	0.2%
47	PL	70	AT	20	FD	10	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
48	PL	70	FD	30		0	0.0%	0.0%	0.0%	0.0%	0.1%	0.3%	0.2%	0.7%
49	PL	67	FD	33		0	0.2%	0.2%	0.2%	0.8%	1.5%	1.2%	0.0%	0.0%
50	PL	60	AT	40		0	4.9%	2.5%	1.1%	0.3%	0.4%	0.7%	0.5%	0.1%
51	PL	60	FD	40		0	0.2%	0.0%	0.1%	0.4%	1.1%	2.7%	0.6%	0.2%
52	PL	50	AT	40	FD	10	0.5%	0.8%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
53	PL	50	AT	30	S	20	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%

Table D5 (cont'd) Big Creek study area

forest specices composition							surface temperature (°C)							
ID#	spc1	%	spc2	%	spc3	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
54	PL	50	S	30	AT	20	0.3%	0.2%	0.3%	0.5%	0.3%	0.4%	0.0%	0.0%
55	PL	50	S	30	FD	20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
56	PL	48	AT	45	FD	7	1.3%	0.5%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
57	PL	40	AT	30	S	30	0.0%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
58	PL	40	S	40	AT	20	0.0%	0.1%	0.5%	0.5%	0.4%	0.2%	0.1%	0.0%
59	S	100		0		0	1.6%	8.5%	5.0%	6.5%	8.7%	3.4%	12.4%	5.2%
60	S	90	PL	10		0	0.3%	0.4%	0.6%	0.9%	1.6%	1.8%	3.4%	0.0%
61	S	70	AC	30		0	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
62	S	70	AT	20	PL	10	0.0%	0.0%	0.3%	0.3%	0.5%	0.4%	0.3%	0.0%
63	S	70	AT	30		0	0.5%	0.3%	0.2%	0.7%	0.6%	0.6%	0.4%	0.0%
64	S	70	PL	30		0	0.1%	0.5%	0.5%	0.7%	0.9%	0.6%	0.3%	0.0%
65	S	70	PL	20	AT	10	0.0%	0.0%	0.0%	0.2%	0.2%	0.2%	0.0%	0.0%
66	S	60	FD	30	PL	10	0.0%	0.1%	0.1%	0.1%	0.2%	0.2%	0.3%	0.0%
67	S	60	PL	20	AT	20	0.0%	0.0%	0.0%	0.2%	0.1%	0.0%	0.0%	0.0%
68	S	60	PL	30	FD	10	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%
69	S	50	PL	40	FD	10	0.0%	0.0%	0.0%	0.3%	0.2%	0.1%	0.2%	0.2%
70	S	50	PL	30	AT	20	0.0%	0.0%	0.2%	0.2%	0.0%	0.0%	0.1%	0.1%
71	S	50	PL	30	FD	20	0.0%	0.0%	0.0%	0.0%	0.1%	0.3%	0.1%	0.0%
72	SW	100		0		0	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
73	SW	80	PL	20		0	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%
74	SW	60	PL	40		0	0.0%	0.2%	0.4%	0.3%	0.4%	0.1%	0.2%	0.6%
75	SW	50	PL	50		0	0.0%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%

Table D6 Moffat Lakes study area

Forest species composition									Surface temperature (°C)							
ID#	spc 1	%	spc 2	%	spc 3	%	spc 4	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
0									34.2%	27.0%	13.5%	12.0%	10.6%	7.3%	6.7%	10.0%
1	AT	60	S	20	AC	10	PL	10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
2	AT	40	PL	40	S	10	FD	10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%
3	B	100		0		0		0	0.0%	0.1%	0.1%	0.8%	0.5%	0.8%	0.7%	0.1%
4	B	90	S	10		0		0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
5	B	80	S	20		0		0	0.0%	0.0%	0.0%	0.1%	0.2%	0.5%	1.2%	0.6%
6	B	70	S	30		0		0	0.0%	0.0%	0.1%	0.3%	0.6%	0.2%	0.2%	0.2%
7	B	65	S	35		0		0	0.0%	0.0%	0.0%	0.1%	0.7%	0.6%	0.8%	0.2%
8	B	60	PL	30	S	10		0	0.0%	0.0%	0.0%	0.1%	0.3%	0.3%	0.8%	0.5%
9	B	60	S	40		0		0	0.0%	0.1%	1.1%	0.5%	0.7%	0.8%	0.9%	0.1%
10	B	60	S	30	AT	10		0	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%
11	BL	100		0		0		0	0.0%	0.0%	0.1%	1.9%	1.0%	2.4%	0.2%	0.0%
12	BL	75	S	25		0		0	0.0%	0.0%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%
13	BL	70	S	30		0		0	0.4%	3.4%	2.2%	3.1%	3.1%	1.3%	1.0%	0.5%

Table D6 (cont'd) Moffat Lakes study area

Forest species composition									Surface temperature (°C)							
ID#	spc 1	%	spc 2	%	spc 3	%	spc 4	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
14	BL	65	S	35		0		0	0.0%	0.0%	0.5%	1.9%	2.7%	2.0%	1.5%	0.7%
15	BL	60	PL	40		0		0	0.0%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
16	BL	60	S	40		0		0	0.4%	2.9%	1.3%	0.8%	0.3%	0.1%	0.1%	0.0%
17	BL	50	S	50		0		0	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
18	BL	40	PL	40	SW	20		0	0.0%	0.6%	0.6%	0.7%	2.5%	0.6%	0.2%	0.0%
19	PL	100		0		0		0	6.7%	14.6%	8.8%	13.2%	14.3%	29.2%	21.6%	25.6%
20	PL	96	SW	4		0		0	0.7%	3.0%	1.0%	0.1%	0.1%	0.0%	0.0%	0.0%
21	PL	95	AT	5		0		0	0.2%	0.7%	2.1%	0.1%	0.1%	0.6%	0.8%	0.6%
22	PL	95	S	5		0		0	0.0%	0.1%	1.1%	0.1%	0.0%	0.0%	0.0%	2.6%
23	PL	94	S	3	BL	3		0	1.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
24	PL	90	AT	10		0		0	6.6%	3.1%	1.5%	0.4%	0.0%	0.0%	0.0%	0.0%
25	PL	90	AT	5	S	5		0	0.5%	1.0%	2.7%	0.7%	0.2%	0.0%	0.0%	0.0%
26	PL	90	B	10		0		0	0.0%	0.0%	0.0%	0.2%	0.2%	0.4%	0.2%	0.4%
27	PL	90	S	10		0		0	10.9%	1.9%	3.5%	2.8%	2.2%	4.2%	3.8%	4.7%
28	PL	80	AT	10	BL	10		0	1.8%	0.4%	0.2%	0.2%	0.1%	0.1%	0.0%	0.1%
29	PL	80	AT	10	S	10		0	0.9%	0.6%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
30	PL	80	B	10	S	10		0	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
31	PL	80	S	10	B	10		0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%
32	PL	80	S	20		0		0	3.6%	2.5%	2.1%	0.7%	0.4%	0.6%	0.6%	2.3%
33	PL	80	S	15	B	5		0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
34	PL	80	S	10	BL	10		0	7.1%	2.5%	1.5%	1.4%	2.1%	0.5%	0.1%	0.0%
35	PL	80	S	15	BL	5		0	0.0%	0.1%	0.4%	1.6%	1.3%	1.1%	0.1%	0.0%
36	PL	75	S	25		0		0	1.0%	0.8%	2.7%	2.8%	1.8%	0.8%	0.2%	0.0%
37	PL	75	S	15	AT	10		0	0.6%	0.8%	0.3%	0.2%	0.1%	0.0%	0.0%	0.0%
38	PL	70	AT	20	S	10		0	0.0%	0.0%	0.0%	0.4%	0.1%	0.1%	0.0%	0.0%
39	PL	70	AT	20	SW	10		0	3.6%	2.6%	0.6%	0.3%	0.1%	0.1%	0.0%	0.1%
40	PL	70	AT	20	FD	10		0	0.0%	0.1%	0.4%	2.3%	1.4%	2.8%	0.4%	0.3%
41	PL	70	BL	20	S	10		0	0.2%	0.3%	0.5%	0.3%	0.1%	0.1%	0.1%	0.0%
42	PL	70	BL	30		0		0	0.3%	2.1%	1.3%	2.0%	2.5%	3.3%	0.8%	0.0%
43	PL	70	S	20	B	10		0	0.0%	0.0%	0.0%	0.0%	0.2%	0.6%	0.5%	0.4%
44	PL	70	S	30		0		0	0.5%	0.3%	0.4%	1.6%	1.0%	1.9%	1.6%	4.4%
45	PL	70	S	20	AT	10		0	0.4%	1.5%	3.7%	1.9%	1.7%	0.4%	0.6%	0.8%
46	PL	70	S	10	AT	10	B	10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
47	PL	60	AT	20	BL	20		0	0.0%	0.1%	0.1%	0.3%	0.1%	0.0%	0.0%	0.0%
48	PL	60	AT	20	FD	15	S	5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	1.3%
49	PL	60	AT	40		0		0	0.0%	0.0%	0.0%	0.2%	0.1%	0.1%	0.0%	0.8%
50	PL	60	AT	30	S	10		0	0.0%	0.0%	0.0%	0.3%	1.8%	1.5%	4.6%	0.8%
51	PL	60	S	25	B	15		0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
52	PL	60	S	30	B	10		0	0.0%	0.0%	1.0%	0.2%	0.0%	0.0%	0.0%	0.0%
53	PL	60	S	40		0		0	0.8%	1.4%	1.3%	4.6%	11.6%	11.1%	19.2%	17.6%
54	PL	60	S	30	AT	10		0	0.0%	0.0%	0.0%	0.3%	0.3%	0.1%	0.1%	0.9%

Table D6 (cont'd) Moffat Lakes study area

Forest species composition									Surface temperature (°C)							
ID#	spc 1	%	spc 2	%	spc 3	%	spc 4	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
55	PL	60	S	30	B	5	AT	5	0.1%	0.1%	2.1%	3.4%	1.3%	0.5%	0.1%	0.0%
56	PL	60	S	20	AT	20		0	0.0%	0.0%	0.0%	0.2%	0.4%	0.1%	0.2%	0.1%
57	PL	60	S	30	FD	10		0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
59	PL	57	S	43		0		0	0.8%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
60	PL	56	S	39	BL	5		0	0.1%	1.0%	1.1%	0.7%	0.1%	0.0%	0.0%	0.2%
61	PL	51	S	49		0		0	0.1%	0.5%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
62	PL	50	S	40	B	10		0	0.0%	0.1%	0.7%	0.3%	0.0%	0.0%	0.2%	1.5%
63	PL	50	S	50		0		0	2.3%	2.5%	1.3%	0.8%	0.5%	0.2%	0.2%	0.4%
64	PL	50	S	35	B	15		0	0.0%	0.0%	0.0%	0.0%	0.1%	0.5%	0.3%	0.3%
65	PL	50	S	20	BL	20	AT	10	0.1%	0.6%	0.2%	0.2%	0.1%	0.1%	0.0%	0.0%
66	PL	45	S	30	AC	25		0	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
67	PL	40	AT	30	S	20	FD	10	0.0%	0.0%	0.0%	0.0%	0.2%	0.1%	0.2%	0.1%
68	PL	40	BL	30	S	20	AT	10	2.5%	1.3%	0.9%	0.9%	1.2%	0.6%	1.4%	0.0%
69	PL	40	S	30	BL	30		0	1.0%	0.3%	0.1%	0.2%	0.1%	0.1%	0.0%	0.0%
70	S	97	PL	3		0		0	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
71	S	90	AT	10		0		0	0.0%	0.0%	0.0%	0.0%	0.2%	0.1%	0.1%	0.0%
72	S	90	B	10		0		0	0.0%	0.1%	0.3%	0.6%	1.2%	1.2%	1.9%	0.9%
73	S	90	BL	10		0		0	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%
74	S	90	PL	10		0		0	0.0%	0.3%	0.8%	0.7%	0.5%	0.3%	0.3%	0.4%
75	S	85	B	10	PL	5		0	0.1%	0.4%	0.7%	1.2%	0.5%	0.3%	0.1%	0.0%
76	S	85	PL	15		0		0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
77	S	80	B	15	PL	5		0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
78	S	80	B	20		0		0	0.0%	0.1%	0.2%	0.5%	0.7%	1.1%	2.8%	2.1%
79	S	80	B	10	PL	10		0	0.0%	0.0%	0.0%	0.4%	0.2%	0.1%	0.0%	0.0%
80	S	80	PL	10	B	10		0	0.1%	0.7%	0.5%	0.1%	0.3%	0.1%	0.0%	0.0%
81	S	80	PL	20		0		0	0.0%	1.6%	2.9%	0.1%	0.1%	0.1%	0.0%	0.3%
82	S	70	B	30		0		0	0.0%	0.0%	0.0%	0.1%	0.5%	0.1%	0.3%	1.3%
83	S	70	B	20	PL	10		0	0.0%	0.0%	0.4%	1.2%	0.7%	0.3%	0.5%	0.3%
84	S	70	B	25	PL	5		0	0.0%	0.2%	0.4%	0.2%	0.1%	0.0%	0.0%	0.0%
85	S	70	BL	20	PL	10		0	0.0%	0.1%	1.9%	0.7%	0.0%	0.0%	0.0%	0.0%
86	S	70	BL	30		0		0	0.3%	1.0%	2.0%	1.9%	1.2%	0.4%	0.2%	0.1%
87	S	70	PL	20	B	10		0	0.1%	1.2%	2.8%	2.0%	2.0%	1.6%	2.4%	0.8%
88	S	70	PL	20	BL	10		0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
90	S	69	PL	31		0		0	0.4%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
92	S	65	B	30	PL	5		0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
93	S	65	BL	35		0		0	0.0%	0.0%	0.5%	2.5%	2.9%	1.3%	0.9%	0.3%
94	S	60	AT	20	PL	20		0	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.3%	0.8%
95	S	60	B	40		0		0	0.1%	0.3%	0.7%	3.8%	5.6%	6.2%	7.1%	4.0%
96	S	60	B	20	PL	20		0	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%
97	S	60	B	30	PL	10		0	0.0%	0.0%	0.0%	0.0%	0.4%	0.1%	0.2%	0.2%
98	S	60	B	20	AC	10	PL	10	0.0%	0.0%	0.0%	0.1%	0.2%	0.3%	0.5%	0.3%

Table D6 (cont'd) Moffat Lakes study area

Forest species composition									Surface temperature (°C)							
ID#	spc 1	%	spc 2	%	spc 3	%	spc 4	%	< -6	-6 to -4	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	> 6
99	S	100		0		0		0	0.2%	0.5%	2.9%	2.5%	1.4%	2.0%	2.1%	0.5%
100	S	60	BL	40		0		0	0.4%	1.4%	1.5%	2.0%	1.5%	0.4%	0.2%	0.1%
101	S	60	BL	20	PL	20		0	0.0%	0.0%	0.1%	0.6%	0.3%	0.0%	0.0%	0.0%
102	S	60	PL	30	B	10		0	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.2%
103	S	60	PL	20	B	20		0	3.0%	1.9%	2.1%	1.0%	0.5%	0.3%	0.6%	0.4%
104	S	60	PL	30	EP	10		0	0.0%	0.1%	0.1%	0.0%	0.0%	0.1%	0.1%	0.0%
105	S	60	PL	30	AT	10		0	0.0%	0.1%	1.8%	1.0%	2.1%	0.3%	0.2%	0.0%
106	S	60	PL	40		0		0	0.0%	0.3%	1.0%	0.7%	0.7%	2.3%	3.8%	2.8%
107	S	60	PL	20	AT	10	FD	10	0.0%	0.2%	1.0%	0.3%	0.1%	0.0%	0.0%	0.0%
108	S	60	PL	20	B	10	EP	10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%
110	S	58	PL	42		0		0	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
111	S	55	B	45		0		0	0.0%	0.0%	0.1%	0.2%	0.3%	0.2%	0.1%	0.0%
112	S	55	PL	45		0		0	0.3%	1.9%	4.1%	0.8%	0.0%	0.0%	0.0%	0.0%
113	S	54	PL	46		0		0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
114	S	53	PL	47		0		0	3.5%	2.9%	1.8%	0.4%	0.1%	0.0%	0.1%	0.1%
115	S	50	B	40	PL	10		0	0.1%	1.0%	1.8%	1.0%	1.5%	0.7%	1.0%	0.1%
116	S	50	BL	50		0		0	0.8%	0.3%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
117	S	50	PL	30	B	20		0	0.0%	0.0%	0.2%	0.6%	0.5%	0.4%	0.2%	0.0%
118	S	50	PL	45	AT	5		0	0.0%	0.1%	0.3%	0.5%	0.4%	0.3%	0.6%	0.2%
119	S	50	PL	50		0		0	0.0%	0.0%	0.5%	0.8%	0.7%	0.0%	0.0%	0.0%
120	S	40	AT	30	PL	25	B	5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.6%
121	S	40	BL	30	PL	30		0	0.7%	0.1%	0.1%	0.6%	0.3%	0.0%	0.0%	0.0%
122	S	40	BL	40	PL	10	AT	10	0.0%	0.0%	0.2%	0.2%	0.4%	0.1%	0.1%	0.0%
123	S	40	PL	30	FD	20	AT	10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
124	S	30	BL	30	PL	20	AT	20	0.0%	0.1%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%
125	S	50	BL	40	PL	10		0	0.0%	0.2%	0.8%	1.3%	0.1%	0.0%	0.0%	0.0%

Appendix E - Multiple Regression Outputs and Prediction Results

The following table (Table D1) gives an explanation of the abbreviated variables in the following regression outputs. The OLS regression output, the interval regression output and the prediction results from the interval regression are given for each study area.

Table E1 explanation of the abbreviated variables used in the regression outputs

abbreviated variable	explanation
stand_ht	stand height (metres)
st_ht_sq	stand height - squared polynomial transformation
st_ht_cu	stand height - cubic polynomial transformation
crown_cl	crown closure (%)
cr_cl_sq	crown closure - squared polynomial transformation
cr_cl_cu	crown closure - cubic polynomial transformation
rel_elev	local relative elevation (metres)
r_elv_sq	local relative elevation - squared polynomial transformation
r_elv_cu	local relative elevation - cubic polynomial transformation
slp_mid	mid values of slope classes
slpmidsq	slope - squared polynomial transformation
slpmidcu	slope - cubic polynomial transformation
aspect1	north aspect
aspect2	northeast aspect
aspect3	east aspect
aspect4	southeast aspect
aspect5	south aspect
aspect6	southwest aspect
aspect7	west aspect
aspect8	northwest aspect
concave	concave terrain curvature
convex	convex terrain curvature
log	logged areas
wildfire	wildfire areas
flood	flooded areas
insects	insect affected areas
grs_seed	grass seeded areas
spacing	juvenile spacing
scarify	scarified areas
sani	sanitation treated areas
water	water (lakes, rivers)
clearing	cleared areas (meadows, non-productive brush)
road	roads
rock	rock
gravelbr	gravelbars
swamp	swamp
decidu	deciduous forest composition
con_dec	coniferous/deciduous mix forest composition
brunisol	brunisolic soils
chernoz	chernozemic (orthic dark brown) soils
gleysol	gleysolic soils

Table E1 (cont'd) explanation of the abbreviated variables used in the regression outputs

abbreviated variable	explanation
luvisol	luvisolic soils
mesisol	mesisol soils
podzol	podzol soils
regosol	regosol soils
brun_luv	brunisolic/luvisolic mixed soil
luv_gley	luvisolic/gleysolic mixed soil
luv_pod	luvisolic/podzolic mixed soil
mes_gley	mesisolic/gleysolic mixed soil
pod_mes	podzolic/mesisolic mixed soil
pod_gley	podzolic/gleysolic mixed soil
pod_reg	podzolic/regosolic mixed soil
pod_rock	podzolic/rock mixed soil

Table E2 Pantage Creek study area - ordinary least squares regression

-analytically weighted on the area field
(sum of wgt is 5.6437e+007)
-outputs beta coefficients

Source	SS	df	MS
Model	1624435.26	33	49225.3108
Residual	655912.733	108499	6.04533437
Total	2280347.99	108532	21.0108354

Number of obs	= 108533
F(33,108499)	= 8142.69
Prob > F	= 0.0000
R-squared	= 0.7124
Adj R-squared	= 0.7123
Root MSE	= 2.4587

temp_mid	Coef.	Std. Err.	t	P>|t|	Beta
stand_ht	.2236136	.0132473	16.880	0.000	.4475546
crown_cl	.0842559	.0071177	11.838	0.000	.4714797
log	-3.250216	.0627817	-51.770	0.000	-.32599
weed	5.729244	.1893583	30.256	0.000	.0547582
water	10.48625	.2108612	49.731	0.000	.088263
clearing	3.920738	.1293259	30.317	0.000	.0644973
swamp	2.288549	.1087098	21.052	0.000	.059661
road	3.930225	.3342768	11.757	0.000	.0197451
aspect1	.8789993	.1178492	7.459	0.000	.067675
aspect2	.5086196	.1176665	4.323	0.000	.0407891
aspect3	.2147797	.1173805	1.830	0.067	.0173098
aspect4	.2743989	.117663	2.332	0.020	.0217475
aspect5	.6748753	.1185619	5.692	0.000	.0431169
aspect6	.3284854	.1192401	2.755	0.006	.0189251
aspect7	.2752318	.118198	2.329	0.020	.0186927
aspect8	.8554182	.1187975	7.201	0.000	.0535142
concave	-.1641717	.018475	-8.886	0.000	-.0162592
convex	.0923575	.0179941	5.133	0.000	.0094128
slp_mid	.1754915	.0096094	18.262	0.000	.3113603
rel_elev	.1017755	.0009874	103.070	0.000	2.735271
r_elv_sq	-.0002893	4.10e-06	-70.516	0.000	-3.830091
r_elv_cu	2.77e-07	5.31e-09	52.255	0.000	1.59917
st_ht_sq	-.0047632	.0007863	-6.058	0.000	-.2632411
cr_cl_sq	.0002163	.0001722	1.256	0.209	.1105405
slpmidsq	-.0048643	.0006907	-7.042	0.000	-.2860751
con_dec	7.319443	.1434377	51.029	0.000	.0858324
brunisol	-.7516861	.0341559	-22.008	0.000	-.078367
luvisol	.0626298	.0966765	0.648	0.517	.0010988
brun_luv	3.337018	.0377699	88.351	0.000	.1863188
mesisol	.2471506	.0697306	3.544	0.000	.0070529
st_ht_cu	-.0000404	.0000144	-2.798	0.005	-.0614071
cr_cl_cu	-8.74e-06	1.21e-06	-7.241	0.000	-.3690114
slpmidcu	.0000528	.0000141	3.739	0.000	.0950338
_cons	-12.44375	.1517868	-81.982	0.000	.

Table E3 Pantage Creek study area - interval regression

```
-analytically weighted on the area field
(sum of wgt is  5.6437e+007)

Iteration 0:  Log Likelihood = -213030.21
Iteration 1:  Log Likelihood = -200114.13
Iteration 2:  Log Likelihood =  -198910.1
Iteration 3:  Log Likelihood = -198909.18
Iteration 4:  Log Likelihood = -198909.18
Iteration 5:  Log Likelihood = -198909.18
Iteration 0:  Log Likelihood = -156826.21
(nonconcave function encountered)
Iteration 1:  Log Likelihood = -146303.41
Iteration 2:  Log Likelihood = -139325.01
Iteration 3:  Log Likelihood = -138901.94
Iteration 4:  Log Likelihood = -138901.08
Iteration 5:  Log Likelihood = -138901.08
Iteration 6:  Log Likelihood = -138901.08
Interval Regression                               Number of obs   =  108533
                                                  Model chi2(33)  =120016.22
                                                  Prob > chi2     =  0.0000
Log Likelihood =-138901.0762882
```

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
model						
stand_ht	.1922384	.0161297	11.918	0.000	.1606248	.223852
crown_cl	.1302647	.0088102	14.786	0.000	.112997	.1475324
log	-3.843855	.0805281	-47.733	0.000	-4.001687	-3.686022
weed	6.052016	.2404756	25.167	0.000	5.580693	6.52334
water	11.32293	.2718512	41.651	0.000	10.79011	11.85575
clearing	4.590311	.1538745	29.832	0.000	4.288723	4.8919
swamp	2.960707	.1309852	22.603	0.000	2.70398	3.217433
road	3.935524	.3943655	9.979	0.000	3.162581	4.708466
aspect1	1.095885	.1399789	7.829	0.000	.8215312	1.370238
aspect2	.5884915	.1395515	4.217	0.000	.3149757	.8620074
aspect3	.1993739	.1390638	1.434	0.152	-.0731862	.4719339
aspect4	.2304921	.1394772	1.653	0.098	-.0428782	.5038624
aspect5	.718057	.14098	5.093	0.000	.4417413	.9943727
aspect6	.2666976	.1420419	1.878	0.060	-.0116993	.5450946
aspect7	.1996099	.1403318	1.422	0.155	-.0754353	.4746551
aspect8	1.055875	.141558	7.459	0.000	.7784268	1.333324
concave	-.199228	.0235206	-8.470	0.000	-.2453274	-.1531285
convex	.1398475	.0233257	5.995	0.000	.0941299	.1855651
slp_mid	.1629084	.0119242	13.662	0.000	.1395373	.1862794
rel_elev	.1058145	.0012279	86.173	0.000	.1034078	.1082212
r_elv_sq	-.0002926	5.31e-06	-55.094	0.000	-.000303	-.0002822
r_elv_cu	2.82e-07	7.10e-09	39.700	0.000	2.68e-07	2.96e-07
st_ht_sq	-.0027213	.0009856	-2.761	0.006	-.0046529	-.0007896
cr_cl_sq	-.0004142	.0002182	-1.898	0.058	-.0008419	.0000135
slpmidsq	-.0028191	.0008746	-3.223	0.001	-.0045333	-.001105
con_dec	8.01216	.2009791	39.866	0.000	7.618248	8.406072
brunisol	-.8202522	.0407256	-20.141	0.000	-.900073	-.7404315
luvisol	.2300632	.1217034	1.890	0.059	-.008471	.4685974
brun_luv	3.763293	.0505929	74.384	0.000	3.664133	3.862453
mesisol	.3744043	.0817482	4.580	0.000	.2141808	.5346279
st_ht_cu	-.0000996	.0000183	-5.434	0.000	-.0001356	-.0000637
cr_cl_cu	-6.43e-06	1.55e-06	-4.135	0.000	-9.48e-06	-3.38e-06
slpmidcu	.0000147	.0000181	0.811	0.417	-.0000208	.0000502
_cons	-13.44036	.1825194	-73.638	0.000	-13.79809	-13.08263
sigma						
_cons	2.79137	.0083488	334.345	0.000	2.775007	2.807734

Table E4 Pantage Creek Study Area - Interval Regression Prediction Results (input for Figure 6.1)

variable	mean	min.	max.	condition	hypoth. sfc. temp.	predicted sfc. temp.	std.err.	-(std.err.)	predicted - hypoth.
stand_ht	14.16	0	33.2	avg. stand height + 10m	3.86	5.41	0.16	-0.16	1.55
				avg. stand height + 20m	3.86	5.82	0.16	-0.16	1.96
crown_cl	50.14	0	80	avg. crown closure + 15%	3.86	5.70	0.17	-0.17	1.84
				avg. crown closure + 30%	3.86	7.22	0.19	-0.19	3.36
rel_elev	218.94	10	520	avg. elevation + 50m	3.86	8.45	0.16	-0.16	4.59
				avg. elevation + 100m	3.86	11.80	0.17	-0.17	7.94
slp_mid	14.35	2	30	slope at 0%	3.86	2.20	0.14	-0.14	-1.65
				slope at 5%	3.86	2.95	0.14	-0.14	-0.91
				slope at 10%	3.86	3.57	0.14	-0.14	-0.29
				slope at 15%	3.86	4.06	0.14	-0.14	0.21
aspect1	0	0	1	N aspect	3.86	4.95	0.05	-0.05	1.10
aspect2	0	0	1	NE aspect	3.86	4.45	0.05	-0.05	0.59
aspect3	0	0	1	E aspect	3.86	4.06	0.05	-0.05	0.20
aspect4	0	0	1	SE aspect	3.86	4.09	0.05	-0.05	0.23
aspect5	0	0	1	S aspect	3.86	4.58	0.05	-0.05	0.72
aspect6	0	0	1	SW aspect	3.86	4.12	0.06	-0.06	0.27
aspect7	0	0	1	W aspect	3.86	4.06	0.05	-0.05	0.20
aspect8	0	0	1	NW aspect	3.86	4.91	0.05	-0.05	1.06
concave	0	0	1	concave curvature	3.86	3.66	0.14	-0.14	-0.20
convex	0	0	1	convex curvature	3.86	4.00	0.14	-0.14	0.14
log	0	0	1	logged	3.86	0.01	0.15	-0.15	-3.84
weed	0	0	1	weeded	3.86	9.90	0.27	-0.27	6.04
water	0	0	1	water	3.86	15.18	0.30	-0.30	11.32
clearing	0	0	1	cleared	3.86	8.45	0.20	-0.20	4.59
swamp	0	0	1	swamp	3.86	6.82	0.18	-0.18	2.96
road	0	0	1	roads	3.86	7.79	0.42	-0.42	3.94
con_dec	0	0	1	coniferous/deciduous	3.86	11.87	0.24	-0.24	8.01
brunisol	0	0	1	brunisolic	3.86	3.04	0.14	-0.14	-0.82
luvisol	0	0	1	luvisolic	3.86	4.09	0.19	-0.19	0.23
brun_luv	0	0	1	brunisolic/luvisolic	3.86	7.62	0.15	-0.15	3.76
mesisol	0	0	1	mesisolic	3.86	4.23	0.17	-0.17	0.37

Table E5 Blackwater study area - ordinary least squares regression

-analytically weighted on the area field
(sum of wgt is 6.1131e+007)
-outputs beta coefficients

Source	SS	df	MS
Model	713787.786	35	20393.9367
Residual	575676.661	123791	4.65039188
Total	1289464.45	123826	10.4135193

Number of obs	= 123827
F(35,123791)	= 4385.42
Prob > F	= 0.0000
R-squared	= 0.5536
Adj R-squared	= 0.5534
Root MSE	= 2.1565

temp_mid	Coef.	Std. Err.	t	P>|t|	Beta
stand_ht	-.4282625	.0215336	-19.888	0.000	-1.090558
crown_cl	.0976384	.0063266	15.433	0.000	.7715265
log	-2.665015	.0992707	-26.846	0.000	-.1086965
weed	-.3347118	.0975494	-3.431	0.001	-.0066597
wildfire	.7278303	.0798504	9.115	0.000	.0444471
water	5.845457	.1170982	49.919	0.000	.2920129
clearing	1.743472	.1118395	15.589	0.000	.1280371
rock	4.604015	.3643043	12.638	0.000	.0252569
swamp	-.3923797	.1119179	-3.506	0.000	-.0236329
aspect1	.1565765	.0405723	3.859	0.000	.0145946
aspect2	.2850652	.0404984	7.039	0.000	.0271255
aspect3	.3061	.0390384	7.841	0.000	.032313
aspect4	.5228179	.0418516	12.492	0.000	.0430881
aspect5	.1449486	.041855	3.463	0.001	.0118954
aspect6	.2544589	.0399405	6.371	0.000	.0248889
aspect7	.5551339	.0379989	14.609	0.000	.0730914
aspect8	.5967828	.0397669	15.007	0.000	.0612221
convex	.150269	.0153848	9.767	0.000	.0202098
concave	-.0381895	.0156983	-2.433	0.015	-.005031
slp_mid	-.0131347	.0070402	-1.866	0.062	-.027508
rel_elev	.040881	.0010865	37.625	0.000	.7686315
r_elv_sq	-.0003716	9.11e-06	-40.803	0.000	-1.754509
r_elv_cu	1.23e-06	2.22e-08	55.344	0.000	1.400893
st_ht_sq	.0423869	.001443	29.375	0.000	2.620779
cr_cl_sq	-.0022968	.0001883	-12.197	0.000	-1.274139
slpmidsq	.0115177	.0006199	18.580	0.000	.6569983
decidu	.9476197	.0765406	12.381	0.000	.0268581
con_dec	1.140816	.038428	29.687	0.000	.062283
regosol	.3421771	.0383659	8.919	0.000	.0257146
brun_luv	1.17454	.0176239	66.645	0.000	.1805869
mesisol	-.782413	.0372891	-20.982	0.000	-.0505632
chernoz	6.741124	.075409	89.394	0.000	.2266743
st_ht_cu	-.0009432	.0000306	-30.793	0.000	-1.395373
cr_cl_cu	.0000209	1.52e-06	13.778	0.000	.8154119
slpmidcu	-.0003205	.0000142	-22.595	0.000	-.5144465
_cons	-6.966592	.1173744	-59.354	0.000	.

Table E6 Blackwater study area - interval regression

```
-analytically weighted on the area field
(sum of wgt is  6.1131e+007)

Iteration 0:  Log Likelihood = -227378.73
Iteration 1:  Log Likelihood = -227048.77
Iteration 2:  Log Likelihood = -227048.72
Iteration 3:  Log Likelihood = -227048.72
Full model:
Iteration 0:  Log Likelihood = -178220.55
Iteration 1:  Log Likelihood = -177203.05
Iteration 2:  Log Likelihood = -177195.86
Iteration 3:  Log Likelihood = -177195.86
Iteration 4:  Log Likelihood = -177195.86
                                                    Number of obs =  123827
                                                    Model chi2(35)=99705.73
Log Likelihood = -177195.86                         Prob > chi2   =  0.0000
```

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
stand_ht	-.422987	.0213184	-19.841	0.000	-.4647703	-.3812036
crown_cl	.0947041	.0062168	15.234	0.000	.0825193	.1068888
log	-2.639928	.0982617	-26.866	0.000	-2.832517	-2.447339
weed	-.3492075	.0955922	-3.653	0.000	-.5365648	-.1618503
wildfire	.6529189	.0787203	8.294	0.000	.4986301	.8072078
water	5.740204	.1156577	49.631	0.000	5.513519	5.966889
clearing	1.703745	.1105364	15.413	0.000	1.487098	1.920392
rock	4.54725	.357673	12.713	0.000	3.846224	5.248276
swamp	-.3818208	.1107856	-3.446	0.001	-.5989566	-.1646849
aspect1	.1629224	.0411005	3.964	0.000	.0823668	.2434779
aspect2	.2888294	.0410144	7.042	0.000	.2084426	.3692162
aspect3	.309651	.0396796	7.804	0.000	.2318804	.3874217
aspect4	.5135007	.0423054	12.138	0.000	.4305837	.5964177
aspect5	.1354957	.0423376	3.200	0.001	.0525156	.2184759
aspect6	.2540478	.0405372	6.267	0.000	.1745964	.3334992
aspect7	.5561853	.0386475	14.391	0.000	.4804376	.631933
aspect8	.5833955	.0403118	14.472	0.000	.5043858	.6624052
convex	.1479193	.0151617	9.756	0.000	.1182029	.1776357
concave	-.03851	.0154718	-2.489	0.013	-.0688342	-.0081858
slp_mid	-.0069699	.0069403	-1.004	0.315	-.0205726	.0066328
rel_elev	.0450123	.0011	40.921	0.000	.0428564	.0471683
r_elv_sq	-.0004065	9.39e-06	-43.304	0.000	-.0004249	-.0003881
r_elv_cu	1.31e-06	2.33e-08	56.200	0.000	1.27e-06	1.36e-06
st_ht_sq	.0412095	.0014317	28.784	0.000	.0384035	.0440155
cr_cl_sq	-.0021932	.000185	-11.854	0.000	-.0025558	-.0018306
slpmidsq	.0108171	.0006114	17.692	0.000	.0096187	.0120154
decidu	.9349161	.0750216	12.462	0.000	.7878765	1.081956
con_dec	1.126748	.0376975	29.889	0.000	1.052862	1.200633
regosol	.3715839	.0377151	9.852	0.000	.2976637	.4455041
brun_luv	1.123192	.017318	64.857	0.000	1.08925	1.157135
mesisol	-.8001196	.0369114	-21.677	0.000	-.8724646	-.7277745
chrenoz	7.19689	.0911273	78.976	0.000	7.018284	7.375496
st_ht_cu	-.0009098	.0000305	-29.870	0.000	-.0009695	-.0008501
cr_cl_cu	.0000201	1.49e-06	13.442	0.000	.0000171	.000023
slpmidcu	-.0003043	.000014	-21.752	0.000	-.0003318	-.0002769
_cons	-6.968849	.1164953	-59.821	0.000	-7.197176	-6.740523
_sigma	2.032408	.0045645	445.264	0.000	2.023462	2.041355

Table E7 Blackwater Study Area - Interval Regression Prediction Results (input for Figure 6.2)

variable	mean	min.	max	condition	hypoth. sfc. temp.	predicted sfc. temp.	std. err.	-(std. err.)	predicted - hypoth.
stand_ht	13.68	0	30.2	avg. stand height + 10 m.	-3.00	-4.01	0.09	-0.09	-1.02
				avg. stand height + 20m.	-3.00	-2.25	0.09	-0.09	0.75
crown_cl	38.95	0	80	avg. crown closure + 15 %	-3.00	-2.00	0.07	-0.07	0.99
				avg. crown closure + 30 %	-3.00	-1.59	0.07	-0.07	1.41
rel_elev	90.87	10	300	avg. relative elevation + 50m.	-3.00	-1.60	0.06	-0.06	1.40
				avg. relative elevation + 100m.	-3.00	-1.25	0.06	-0.06	1.75
slp_mid	7.91	2	30	slope = 0	-3.00	-3.48	0.05	-0.05	-0.49
				slope = 5 %	-3.00	-3.29	0.04	-0.04	-0.29
				slope = 10 %	-3.00	-2.78	0.05	-0.05	0.22
				slope = 15 %	-3.00	-2.18	0.05	-0.05	0.81
aspect1	0	0	1	N aspect	-3.00	-2.83	0.03	-0.03	0.16
aspect2	0	0	1	NE aspect	-3.00	-2.71	0.03	-0.03	0.29
aspect3	0	0	1	E aspect	-3.00	-2.69	0.03	-0.03	0.31
aspect4	0	0	1	SE aspect	-3.00	-2.48	0.03	-0.03	0.51
aspect5	0	0	1	S aspect	-3.00	-2.86	0.03	-0.03	0.14
aspect6	0	0	1	SW aspect	-3.00	-2.74	0.03	-0.03	0.25
aspect7	0	0	1	W aspect	-3.00	-2.44	0.03	-0.03	0.56
aspect8	0	0	1	NW aspect	-3.00	-2.41	0.03	-0.03	0.58
concave	0	0	1	concave curvature	-3.00	-3.03	0.05	-0.05	-0.04
convex	0	0	1	convex curvature	-3.00	-2.85	0.05	-0.05	0.15
log	0	0	1	logged	-3.00	-5.64	0.09	-0.09	-2.64
wildfire	0	0	1	wildfire	-3.00	-2.34	0.07	-0.07	0.65
weed	0	0	1	weeded	-3.00	-3.34	0.10	-0.10	-0.35
water	0	0	1	water	-3.00	2.74	0.10	-0.10	5.74
clearing	0	0	1	cleared	-3.00	-1.29	0.10	-0.10	1.70
rock	0	0	1	rock	-3.00	1.55	0.35	-0.35	4.55
swamp	0	0	1	swamp	-3.00	-3.38	0.10	-0.10	-0.38
decidu	0	0	1	deciduous	-3.00	-2.06	0.09	-0.09	0.93
con_dec	0	0	1	coniferous/deciduous mix	-3.00	-1.87	0.06	-0.06	1.13
regosol	0	0	1	regosolic	-3.00	-2.62	0.06	-0.06	0.37
brun_luv	0	0	1	brunisolic/luvisolic	-3.00	-1.87	0.05	-0.05	1.12
mesisol	0	0	1	mesisolic	-3.00	-3.80	0.05	-0.05	-0.80
chernoz	0	0	1	orthic brown (chernozem)	-3.00	4.20	0.10	-0.10	7.20

Table E8 Big Creek study area - ordinary least squares regression

-analytically weighted on the area field
(sum of wgt is 1.3312e+08)
-outputs beta coefficients

Source	SS	df	MS
Model	3753744.54	42	89374.87
Residual	5052627.81	297926	16.9593383
Total	8806372.35	297968	29.5547587

Number of obs	=	297969
F(42,297926)	=	5269.95
Prob > F	=	0.0000
R-squared	=	0.4263
Adj R-squared	=	0.4262
Root MSE	=	4.1182

temp_mid	Coef.	Std. Err.	t	P>|t|	Beta
stand_ht	.3850095	.015171	25.378	0.000	.5758878
crown_cl	.0710091	.0046917	15.135	0.000	.2688235
aspect1	1.454238	.0525032	27.698	0.000	.1126071
aspect2	1.09139	.0529473	20.613	0.000	.0841035
aspect3	.6682947	.0545569	12.250	0.000	.0396466
aspect4	.3911246	.0566065	6.910	0.000	.0195177
aspect5	-.1363073	.0574205	-2.374	0.018	-.0064407
aspect6	-.192204	.0593209	-3.240	0.001	-.008064
aspect7	.3870854	.0575865	6.722	0.000	.0176493
aspect8	1.190731	.0540444	22.032	0.000	.0734853
concave	-.0674974	.0193495	-3.488	0.000	-.0051563
convex	.4300277	.0188417	22.823	0.000	.0338387
log	.499414	.0332053	15.040	0.000	.0361101
wildfire	1.091312	.0943998	11.561	0.000	.0186655
flood	-.8737497	.59946	-1.458	0.145	-.0020263
insects	.1774894	.0206109	8.611	0.000	.0145575
grs_seed	2.116922	.0953195	22.209	0.000	.0321169
spacing	-2.867305	.0618809	-46.336	0.000	-.0774026
scarify	-1.476142	.0767413	-19.235	0.000	-.0306189
sani	.3344983	.0808815	4.136	0.000	.0074524
water	1.965171	.0567702	34.616	0.000	.0684063
clearing	3.944614	.0554305	71.163	0.000	.1476067
road	7.113649	.1204511	59.058	0.000	.0875027
rock	3.640217	.3622874	10.048	0.000	.0140442
gravelbr	6.12424	.2089632	29.308	0.000	.0414879
swamp	3.027194	.0573903	52.747	0.000	.1063051
decidu	.1004397	.1080704	0.929	0.353	.0013357
con_dec	-1.225877	.0518118	-23.660	0.000	-.0442332
brunisol	1.152374	.0382855	30.099	0.000	.06617
chernoz	-2.012023	.0888621	-22.642	0.000	-.0321958
gleysol	-4.436998	.0571828	-77.593	0.000	-.1101177
luv_gley	-.7230625	.0553064	-13.074	0.000	-.0187886
slp_mid	.3031506	.0087848	34.509	0.000	.358044
slpmidsq	-.0038021	.0007764	-4.897	0.000	-.116635
slpmidcu	-2.60e-06	.000018	-0.145	0.885	-.0021887
rel_elev	.0088831	.0006249	14.216	0.000	.2666194
r_elv_sq	.0000329	1.95e-06	16.832	0.000	.6646395
r_elv_cu	-4.85e-08	1.83e-09	-26.461	0.000	-.6092056
st_ht_sq	-.0190275	.0011561	-16.459	0.000	-.6477811
st_ht_cu	.0004175	.0000259	16.137	0.000	.3446704
cr_cl_sq	-.0002015	.0001253	-1.608	0.108	-.0484321
cr_cl_cu	-5.52e-06	1.06e-06	-5.193	0.000	-.0881682
_cons	-9.183253	.0901366	-101.882	0.000	.

Table E9 Big Creek study area - interval regression

```
-analytically weighted on the area field
(sum of wgt is   1.3312e+08)

Iteration 0:  Log Likelihood =  -639637.8 Iteration 0:  Log Likelihood = -561545.21
Iteration 1:  Log Likelihood = -613689.62 Iteration 1:  Log Likelihood = -530098.16
Iteration 2:  Log Likelihood = -611765.79 Iteration 2:  Log Likelihood = -527659.49
Iteration 3:  Log Likelihood = -611763.63 Iteration 3:  Log Likelihood = -527656.74
Iteration 4:  Log Likelihood = -611763.63 Iteration 4:  Log Likelihood = -527656.74
Iteration 5:  Log Likelihood = -611763.63 Iteration 5:  Log Likelihood = -527656.74
continued...

Log Likelihood =-527656.7413373                   Number of obs    =  297969
                                                  Model chi2(42)   =168213.77
                                                  Prob > chi2      =  0.0000
```

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
model						
stand_ht	.3951427	.018467	21.397	0.000	.358948	.4313373
crown_cl	.106252	.0057433	18.500	0.000	.0949953	.1175087
aspect1	1.772647	.0644008	27.525	0.000	1.646423	1.89887
aspect2	1.270598	.0649596	19.560	0.000	1.14328	1.397917
aspect3	.7260028	.066847	10.861	0.000	.5949851	.8570205
aspect4	.4213172	.0694035	6.071	0.000	.285289	.5573455
aspect5	-.1726067	.0705579	-2.446	0.014	-.3108977	-.0343157
aspect6	-.2868935	.0728933	-3.936	0.000	-.4297617	-.1440254
aspect7	.4899169	.0705883	6.940	0.000	.3515663	.6282674
aspect8	1.458369	.0662653	22.008	0.000	1.328491	1.588246
concave	-.1319154	.0239209	-5.515	0.000	-.1787995	-.0850314
convex	.544953	.0234494	23.240	0.000	.498993	.590913
log	.4651919	.0397484	11.703	0.000	.3872864	.5430973
wildfire	2.237923	.1163171	19.240	0.000	2.009946	2.465901
flood	-1.928718	.7760001	-2.485	0.013	-3.44965	-.4077856
insects	.2596441	.0255156	10.176	0.000	.2096344	.3096538
grs_seed	2.266233	.1145114	19.790	0.000	2.041795	2.490671
spacing	-4.273741	.0859569	-49.720	0.000	-4.442213	-4.105268
scarify	-1.838419	.1001127	-18.364	0.000	-2.034637	-1.642202
sani	.6419366	.102767	6.247	0.000	.4405169	.8433563
water	2.243937	.0688145	32.608	0.000	2.109063	2.378811
clearing	4.767631	.0672848	70.857	0.000	4.635755	4.899506
road	9.437521	.1723938	54.744	0.000	9.099636	9.775407
rock	4.098891	.4263766	9.613	0.000	3.263208	4.934574
gravelbr	9.662309	.3653832	26.444	0.000	8.946171	10.37845
swamp	3.629882	.07081	51.262	0.000	3.491097	3.768667
decidu	.0928678	.1318966	0.704	0.481	-.1656448	.3513804
con_dec	-1.599831	.0653649	-24.475	0.000	-1.727944	-1.471718
brunisol	1.081527	.0455321	23.753	0.000	.9922855	1.170768
chernoz	-2.559486	.1124248	-22.766	0.000	-2.779834	-2.339137
gleysol	-5.446001	.0713326	-76.347	0.000	-5.585811	-5.306192
luv_gley	-.9704806	.0668051	-14.527	0.000	-1.101416	-.8395451
slp_mid	.2684538	.0111287	24.123	0.000	.2466419	.2902657
slpmidsq	.0023822	.001013	2.352	0.019	.0003968	.0043676
slpmidcu	-.000079	.000024	-3.295	0.001	-.0001261	-.000032
rel_elev	.0048461	.000768	6.310	0.000	.0033409	.0063513
r_elv_sq	.0000547	2.45e-06	22.297	0.000	.0000499	.0000595
r_elv_cu	-6.79e-08	2.34e-09	-28.949	0.000	-7.25e-08	-6.33e-08
st_ht_sq	-.0179999	.0014158	-12.714	0.000	-.0207748	-.0152251
st_ht_cu	.0003752	.0000317	11.822	0.000	.000313	.0004374
cr_cl_sq	-.0006432	.0001557	-4.131	0.000	-.0009484	-.0003381
cr_cl_cu	-4.30e-06	1.34e-06	-3.221	0.001	-6.92e-06	-1.68e-06
_cons	-10.12606	.109476	-92.496	0.000	-10.34063	-9.911488
sigma						
_cons	4.766403	.0082864	575.205	0.000	4.750162	4.782645

Table E10 Big Creek Study Area - Interval Regression Prediction Results (input for Figure 6.3)

variable	mean	min.	max.	condition	hypoth. sfc. temp.	predicted sfc. temp.	std. err.	-(std. err.)	predicted - hypoth.
stand_ht	11.13	0	29.5	avg. stand height + 10 m.	-0.97	1.56	0.10	-0.10	2.53
				avg. stand height + 20 m.	-0.97	2.73	0.09	-0.09	3.70
crown_cl	27.84	0	90	avg. crown closure + 15%	-0.97	0.46	0.09	-0.09	1.43
				avg. crown closure + 30%	-0.97	1.52	0.10	-0.10	2.49
rel_elev	215.12	10	730	avg. relative elevation + 50 m.	-0.97	-0.60	0.07	-0.07	0.37
				avg. relative elevation + 100 m.	-0.97	-0.01	0.08	-0.08	0.96
slp_mid	7.49	2	30	slope = 0	-0.97	-3.08	0.07	-0.07	-2.11
				slope = 5 %	-0.97	-1.68	0.07	-0.07	-0.71
				slope = 10 %	-0.97	-0.23	0.07	-0.07	0.74
				slope = 15 %	-0.97	1.22	0.07	-0.07	2.19
aspect1	0	0	1	N aspect	-0.97	0.80	0.03	-0.03	1.77
aspect2	0	0	1	NE aspect	-0.97	0.30	0.03	-0.03	1.27
aspect3	0	0	1	E aspect	-0.97	-0.24	0.04	-0.04	0.73
aspect4	0	0	1	SE aspect	-0.97	-0.55	0.04	-0.04	0.42
aspect5	0	0	1	S aspect	-0.97	-1.14	0.04	-0.04	-0.17
aspect6	0	0	1	SW aspect	-0.97	-1.26	0.05	-0.05	-0.29
aspect7	0	0	1	W aspect	-0.97	-0.48	0.04	-0.04	0.49
aspect8	0	0	1	NW aspect	-0.97	0.49	0.03	-0.03	1.46
concave	0	0	1	concave curvature	-0.97	-1.10	0.07	-0.07	-0.13
convex	0	0	1	convex curvature	-0.97	-0.43	0.07	-0.07	0.54
log	0	0	1	logged	-0.97	-0.51	0.07	-0.07	0.47
wildfire	0	0	1	wildfire	-0.97	1.27	0.13	-0.13	2.24
flood	0	0	1	flooded	-0.97	-2.90	0.78	-0.78	-1.93
insects	0	0	1	insect affected	-0.97	-0.71	0.07	-0.07	0.26
grs_seed	0	0	1	grass seeded	-0.97	1.30	0.13	-0.13	2.27
spacing	0	0	1	spacing	-0.97	-5.24	0.11	-0.11	-4.27
scarify	0	0	1	scarified	-0.97	-2.81	0.12	-0.12	-1.84
sani	0	0	1	sanitation treated	-0.97	-0.33	0.12	-0.12	0.64
water	0	0	1	water	-0.97	1.27	0.08	-0.08	2.24
clearing	0	0	1	cleared	-0.97	3.80	0.08	-0.08	4.77
road	0	0	1	roads	-0.97	8.47	0.18	-0.18	9.44
rock	0	0	1	rock	-0.97	3.13	0.43	-0.43	4.10
gravelbr	0	0	1	gravelbars	-0.97	8.69	0.37	-0.37	9.66
swamp	0	0	1	swamp	-0.97	2.66	0.09	-0.09	3.63
decidu	0	0	1	deciduous	-0.97	-0.88	0.15	-0.15	0.09

Table E10 (cont'd) Big Creek Study Area - Interval Regression Prediction Results (input for Figure 6.3)									
variable	mean	min.	max.	condition	hypoth. sfc. temp.	predicted sfc. temp.	std. err.	-(std. err.)	predicted - hypoth.
con_dec	0	0	1	coniferous/deciduous mix	-0.97	-2.57	0.09	-0.09	-1.60
brunisol	0	0	1	brunisolic	-0.97	0.11	0.07	-0.07	1.08
chernoz	0	0	1	chernozemic	-0.97	-3.53	0.13	-0.13	-2.56
gleysol	0	0	1	gleysolic	-0.97	-6.42	0.10	-0.10	-5.45
luv_gley	0	0	1	luvisolic/gleysolic	-0.97	-1.94	0.09	-0.09	-0.97

Table E11 Sovereign Creek study area - ordinary least squares regression

-analytically weighted on the area field
(sum of wgt is 1.0002e+08)
-outputs beta coefficients

Source	SS	df	MS
Model	2516783.16	38	66231.1358
Residual	1455333.33	159339	9.13356634
Total	3972116.49	159377	24.9227711

Number of obs	= 159378
F(38,159339)	= 7251.40
Prob > F	= 0.0000
R-squared	= 0.6336
Adj R-squared	= 0.6335
Root MSE	= 3.0222

temp_mid	Coef.	Std. Err.	t	P>|t|	Beta
stand_ht	.0420269	.0191016	2.200	0.028	.117293
crown_cl	-.5893012	.0071178	-82.792	0.000	-2.367833
aspect1	-.8294693	.07339	-11.302	0.000	-.0433914
aspect2	-1.072066	.0709811	-15.104	0.000	-.0778839
aspect3	-.9123639	.0708713	-12.874	0.000	-.0663946
aspect4	-.6368658	.072196	-8.821	0.000	-.0366484
aspect5	-.0829396	.0714493	-1.161	0.246	-.0055333
aspect6	-.043773	.0705319	-0.621	0.535	-.0034026
aspect7	-.2491293	.0712082	-3.499	0.000	-.0166626
aspect8	-.6711008	.0735468	-9.125	0.000	-.0343401
concave	-.0554976	.0193917	-2.862	0.004	-.0045852
convex	.1152864	.0187139	6.160	0.000	.0099101
water	1.911689	.1466221	13.038	0.000	.0422611
clearing	-3.746287	.1324109	-28.293	0.000	-.1822439
swamp	-5.445143	.1369845	-39.750	0.000	-.1766318
road	-5.296744	.1626867	-32.558	0.000	-.0814907
log	-5.070229	.1192772	-42.508	0.000	-.4286499
wildfire	2.184171	.0597952	36.528	0.000	.1006154
sani	-2.122993	.0975802	-21.756	0.000	-.0347154
weed	1.883292	.0696063	27.056	0.000	.047135
rel_elev	-.0006235	.0016114	-0.387	0.699	-.0079564
slp_mid	-.0884526	.0087771	-10.078	0.000	-.1127093
r_elv_sq	.000309	.0000116	26.597	0.000	1.19071
r_elv_cu	-6.27e-07	2.51e-08	-24.955	0.000	-.6454073
st_ht_sq	-.0057584	.0009794	-5.880	0.000	-.5241513
cr_cl_sq	.0165397	.0002303	71.831	0.000	3.893448
slpmidsq	.0131374	.0007438	17.662	0.000	.4296429
decidu	-2.00469	.1802376	-11.122	0.000	-.0170366
con_dec	3.115852	.0954546	32.642	0.000	.0514119
mes_gley	-2.862467	.0646176	-44.299	0.000	-.0713979
luv_pod	-2.0909	.0222277	-94.067	0.000	-.1665428
pod_gley	-2.702464	.0215808	-125.225	0.000	-.2570118
pod_rock	-5.358263	.400319	-13.385	0.000	-.0203384
pod_reg	-2.035497	.0572857	-35.532	0.000	-.0601323
chernoz	-1.511445	.0813558	-18.578	0.000	-.0299603
st_ht_cu	.0001869	.0000154	12.152	0.000	.573427
cr_cl_cu	-.0001243	2.20e-06	-56.638	0.000	-1.707991
slpmidcu	-.0002388	.0000171	-13.934	0.000	-.2079625
_cons	-1.197498	.1617201	-7.405	0.000	.

Table E12 Sovereign Creek study area - interval regression

```
-analytically weighted on the area field
(sum of wgt is   1.0002e+08)

Iteration 0:  Log Likelihood = -322199.87
Iteration 1:  Log Likelihood = -303924.98
Iteration 2:  Log Likelihood = -302231.86
Iteration 3:  Log Likelihood = -302230.34
Iteration 4:  Log Likelihood = -302230.34
Iteration 5:  Log Likelihood = -302230.34
Iteration 0:  Log Likelihood = -251489.14
Iteration 1:  Log Likelihood = -228738.61
Iteration 2:  Log Likelihood = -226071.03
Iteration 3:  Log Likelihood =  -226056.6
Iteration 4:  Log Likelihood =  -226056.6
Iteration 5:  Log Likelihood =  -226056.6
Interval Regression                                 Number of obs    =  159378
                                                    Model chi2(38)   =152347.47
Log Likelihood =-226056.5994494                     Prob > chi2      =  0.0000
```

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
model						
stand_ht	.0875092	.0237077	3.691	0.000	.0410431	.1339754
crown_cl	-.7879205	.0091996	-85.647	0.000	-.8059514	-.7698897
aspect1	-.9611288	.0936311	-10.265	0.000	-1.144642	-.7776152
aspect2	-1.195755	.0904568	-13.219	0.000	-1.373047	-1.018463
aspect3	-.9373836	.0901963	-10.393	0.000	-1.114165	-.7606021
aspect4	-.535516	.0915431	-5.850	0.000	-.7149372	-.3560949
aspect5	.0476843	.0906844	0.526	0.599	-.1300539	.2254225
aspect6	-.060336	.0897531	-0.672	0.501	-.2362488	.1155768
aspect7	-.3016287	.0907731	-3.323	0.000	-.4795407	-.1237166
aspect8	-.7790892	.0938093	-8.305	0.000	-.9629521	-.5952263
concave	-.0824996	.0243549	-3.387	0.000	-.1302343	-.0347648
convex	.1510211	.0232493	6.496	0.000	.1054533	.196589
water	1.483642	.1824562	8.131	0.000	1.126035	1.84125
clearing	-4.85689	.1672702	-29.036	0.000	-5.184734	-4.529047
swamp	-7.399575	.1761143	-42.016	0.000	-7.744753	-7.054398
road	-6.560192	.2024999	-32.396	0.000	-6.957085	-6.1633
log	-6.038529	.1503436	-40.165	0.000	-6.333197	-5.743861
wildfire	2.201735	.0778988	28.264	0.000	2.049056	2.354414
sani	-2.55197	.1630657	-15.650	0.000	-2.871573	-2.232367
weed	2.011235	.0825641	24.360	0.000	1.849412	2.173057
rel_elev	.0002461	.0021457	0.115	0.909	-.0039593	.0044515
slp_mid	-.1343482	.0109533	-12.266	0.000	-.1558163	-.1128802
r_elv_sq	.0003315	.0000152	21.868	0.000	.0003018	.0003612
r_elv_cu	-6.46e-07	3.23e-08	-19.989	0.000	-7.09e-07	-5.83e-07
st_ht_sq	-.0055364	.0012049	-4.595	0.000	-.0078979	-.0031749
cr_cl_sq	.0213242	.0002932	72.738	0.000	.0207496	.0218987
slpmidsq	.0176111	.0009216	19.109	0.000	.0158047	.0194175
decidu	-3.25685	.3075916	-10.588	0.000	-3.859718	-2.653982
con_dec	3.48806	.1164509	29.953	0.000	3.259821	3.7163
mes_gley	-3.124617	.0827613	-37.755	0.000	-3.286826	-2.962408
luv_pod	-2.202525	.0270733	-81.354	0.000	-2.255588	-2.149463
pod_gley	-3.329479	.0269431	-123.575	0.000	-3.382287	-3.276672
pod_rock	-6.001896	.4554057	-13.179	0.000	-6.894475	-5.109317
pod_reg	-2.552719	.0786632	-32.451	0.000	-2.706896	-2.398542
chernoz	-1.512834	.0987328	-15.323	0.000	-1.706346	-1.319321
st_ht_cu	.0001715	.0000188	9.105	0.000	.0001346	.0002084
cr_cl_cu	-.0001572	2.77e-06	-56.634	0.000	-.0001626	-.0001517
slpmidcu	-.0003255	.0000211	-15.412	0.000	-.0003669	-.0002841
_cons	-.5008254	.2110895	-2.373	0.018	-.9145533	-.0870975
sigma						
_cons	3.387109	.0083218	407.016	0.000	3.370798	3.403419

Table E13 Sovereign Creek Study Area - Interval Regression Prediction Results (input for Figure 6.4)

variable	mean	min.	max.	condition	hypoth. sfc. temp.	predicted sfc. temp.	std.err.	-(std. err.)	predicted - hypoth.
stand_ht	18.54	0	38	avg. stand height + 10m	0.81	1.31	0.13	-0.13	0.49
				avg. stand height + 20m	0.81	1.72	0.15	-0.15	0.91
crown_cl	31.65	0	70	avg. crown closure + 15%	0.81	-6.74	0.13	-0.13	-7.55
				avg. crown closure + 30%	0.81	-7.87	0.14	-0.14	-8.69
rel_elev	140.46	10	310	avg. relative elevation + 50m	0.81	1.57	0.12	-0.12	0.76
				avg. relative elevation + 100m	0.81	3.51	0.14	-0.14	2.69
slp_mid	9.43	2	30	slope = 0	0.81	0.50	0.11	-0.11	-0.32
				slope at 5%	0.81	0.22	0.10	-0.10	-0.59
				slope at 10%	0.81	0.59	0.11	-0.11	-0.23
				slope at 15%	0.81	1.34	0.11	-0.11	0.53
aspect1	0	0	1	N aspect	0.81	-0.15	0.07	-0.07	-0.96
aspect2	0	0	1	NE aspect	0.81	-0.38	0.06	-0.06	-1.20
aspect3	0	0	1	E aspect	0.81	-0.12	0.06	-0.06	-0.94
aspect4	0	0	1	SE aspect	0.81	0.28	0.07	-0.07	-0.54
aspect5	0	0	1	S aspect	0.81	0.86	0.06	-0.06	0.05
aspect6	0	0	1	SW aspect	0.81	0.75	0.06	-0.06	-0.06
aspect7	0	0	1	W aspect	0.81	0.51	0.06	-0.06	-0.30
aspect8	0	0	1	NW aspect	0.81	0.04	0.07	-0.07	-0.78
concave	0	0	1	concave curvature	0.81	0.73	0.11	-0.11	-0.08
convex	0	0	1	convex curvature	0.81	0.97	0.11	-0.11	0.15
water	0	0	1	water	0.81	2.30	0.15	-0.15	1.48
clearing	0	0	1	cleared	0.81	-4.04	0.14	-0.14	-4.86
swamp	0	0	1	swamp	0.81	-6.59	0.16	-0.16	-7.40
road	0	0	1	roads	0.81	-5.75	0.19	-0.19	-6.56
log	0	0	1	logged	0.81	-5.22	0.13	-0.13	-6.04
wildfire	0	0	1	wildfire	0.81	3.02	0.12	-0.12	2.20
sani	0	0	1	sanitized	0.81	-1.74	0.19	-0.19	-2.55
weed	0	0	1	weeded	0.81	2.83	0.12	-0.12	2.01
decidu	0	0	1	deciduous	0.81	-2.44	0.32	-0.32	-3.26
con_dec	0	0	1	coniferous/deciduous	0.81	4.30	0.16	-0.16	3.49
mes_gley	0	0	1	mesosolic/gleysolic	0.81	-2.31	0.12	-0.12	-3.12
luv_pod	0	0	1	luvosolic/podzolic	0.81	-1.39	0.10	-0.10	-2.20
pod_gley	0	0	1	podzolic/gleysolic	0.81	-2.52	0.10	-0.10	-3.33
pod_rock	0	0	1	podzolic/rock	0.81	-5.19	0.47	-0.47	-6.00
pod_reg	0	0	1	podzolic/regosolic	0.81	-1.74	0.12	-0.12	-2.55
chernoz	0	0	1	chernozem	0.81	-0.70	0.14	-0.14	-1.51

Table E14 Moffat Lakes study area - ordinary least squares regression

-analytically weighted on the area field
(sum of wgt is 1.1383e+08)
-outputs beta coefficients

Source	SS	df	MS
Model	4696353.66	34	138128.049
Residual	3132008.55	268203	11.6777536
Total	7828362.20	268237	29.1844981

Number of obs	= 268238
F(34,268203)	=11828.31
Prob > F	= 0.0000
R-squared	= 0.5999
Adj R-squared	= 0.5999
Root MSE	= 3.4173

temp_mid	Coef.	Std. Err.	t	P>|t|	Beta
stand_ht	.2698274	.0122255	22.071	0.000	.5800353
crown_cl	-.0838795	.0035477	-23.643	0.000	-.4670983
aspect1	.4746259	.0659401	7.198	0.000	.0297351
aspect2	-.1049987	.0688375	-1.525	0.127	-.0042451
aspect3	-.1600582	.0690029	-2.320	0.020	-.0063536
aspect4	-.743134	.0664089	-11.190	0.000	-.0398533
aspect5	-.4490107	.0649079	-6.918	0.000	-.0322447
aspect6	-.1227074	.0645291	-1.902	0.057	-.0099657
aspect7	.3477774	.0654057	5.317	0.000	.0214332
aspect8	.8724319	.0664374	13.132	0.000	.0470396
concave	-.1140595	.016327	-6.986	0.000	-.0092895
convex	.0785524	.0160465	4.895	0.000	.0065308
rel_elev	-.0028179	.0009042	-3.116	0.002	-.0592489
r_elv_sq	.0000118	2.55e-06	4.637	0.000	.1904271
r_elv_cu	-1.12e-08	2.23e-09	-5.018	0.000	-.1161035
slp_mid	.102074	.0074703	13.664	0.000	.1330382
slpmidsq	.0079431	.0006194	12.823	0.000	.290751
slpmidcu	-.000223	.0000139	-16.067	0.000	-.2298181
st_ht_sq	-.0082754	.0007487	-11.053	0.000	-.4916112
st_ht_cu	.0001241	.0000136	9.112	0.000	.2092187
cr_cl_sq	.0011466	.0000774	14.804	0.000	.5459462
cr_cl_cu	-2.95e-06	5.27e-07	-5.604	0.000	-.1209629
water	9.015561	.0641035	140.641	0.000	.2902918
clearing	-1.766173	.0758357	-23.289	0.000	-.0328772
road	-.261189	.6151203	-0.425	0.671	-.0005206
swamp	-2.78511	.0552692	-50.392	0.000	-.1188622
log	-4.840197	.0437895	-110.533	0.000	-.3888989
wildfire	-6.010411	.5185359	-11.591	0.000	-.0142401
con_dec	.8680906	.0444378	19.535	0.000	.0245442
luvisol	4.685866	.0277479	168.873	0.000	.2694941
mesisol	.5151441	.0368901	13.964	0.000	.0196581
luv_pod	4.897849	.018988	257.945	0.000	.4487021
pod_mes	-3.033093	.0476947	-63.594	0.000	-.0827906
chernoz	-.0360496	.0474247	-0.760	0.447	-.0010838
_cons	-2.652997	.1321154	-20.081	0.000	.

Table E15 Moffat Lakes study area - interval regression

```
-analytically weighted on the area field
(sum of wgt is   1.1383e+08)

Iteration 0:  Log Likelihood = -557252.53
Iteration 1:  Log Likelihood = -522055.08
Iteration 2:  Log Likelihood = -518290.57
Iteration 3:  Log Likelihood = -518288.82
Iteration 4:  Log Likelihood = -518288.82
Iteration 5:  Log Likelihood = -518288.82
Iteration 0:  Log Likelihood = -451689.78
Iteration 1:  Log Likelihood = -408910.21
Iteration 2:  Log Likelihood = -404070.02
Iteration 3:  Log Likelihood = -403851.23
Iteration 4:  Log Likelihood =  -403851.1
Iteration 5:  Log Likelihood =  -403851.1
Log Likelihood =-403851.0955865                   Number of obs      =  268238
                                                  Model chi2(34)     =228875.44
                                                  Prob > chi2        =  0.0000

------------------------------------------------------------------------------
         |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
model    |
stand_ht |   .3741158   .0160869     23.256   0.000       .3425859    .4056456
crown_cl |  -.1219909   .0045646    -26.725   0.000      -.1309375   -.1130444
 aspect1 |   .4416848   .0934485      4.727   0.000        .258529    .6248405
 aspect2 |  -.1434999    .097466     -1.472   0.141      -.3345297    .0475299
 aspect3 |  -.2228823   .0975345     -2.285   0.022      -.4140465   -.0317181
 aspect4 |  -.9607688   .0940345    -10.217   0.000      -1.145073   -.7764646
 aspect5 |  -.5685299   .0921357     -6.171   0.000      -.7491126   -.3879473
 aspect6 |  -.0918852   .0916361     -1.003   0.316      -.2714887    .0877183
 aspect7 |   .4388201   .0928812      4.725   0.000       .2567764    .6208639
 aspect8 |   1.165691   .0942684     12.366   0.000       .9809286    1.350454
   curv1 |   -.169597   .0216737     -7.825   0.000      -.2120767   -.1271174
   curv3 |   .1294439   .0214286      6.041   0.000       .0874447    .1714431
rel_elev |   .0100513   .0012424      8.090   0.000       .0076161    .0124864
r_elv_sq |  -.0000274   3.58e-06     -7.667   0.000      -.0000344   -.0000204
r_elv_cu |   2.37e-08   3.20e-09      7.394   0.000       1.74e-08    3.00e-08
 slp_mid |   .0933715   .0100743      9.268   0.000       .0736263    .1131168
slpmidsq |   .0116502   .0008645     13.476   0.000       .0099558    .0133447
slpmidcu |   -.000228     .00002    -11.393   0.000      -.0002672   -.0001888
st_ht_sq |  -.0167469   .0010154    -16.493   0.000       -.018737   -.0147567
st_ht_cu |   .0003204   .0000189     16.911   0.000       .0002833    .0003576
cr_cl_sq |   .0020038   .0001014     19.761   0.000       .0018051    .0022026
cr_cl_cu |  -7.44e-06   6.97e-07    -10.667   0.000      -8.81e-06   -6.07e-06
   water |   13.55416   .1029474    131.661   0.000       13.35239    13.75594
clearing |  -2.387508   .0946809    -25.216   0.000      -2.573079   -2.201937
    road |  -.3097883   .7446158     -0.416   0.677      -1.769208    1.149632
   swamp |  -3.173962   .0694786    -45.683   0.000      -3.310137   -3.037786
     log |  -5.786539   .0552639   -104.707   0.000      -5.894854   -5.678223
wildfire |  -6.806786   .6293917    -10.815   0.000      -8.040371   -5.573201
 con_dec |   .8503888   .0587474     14.475   0.000        .735246    .9655316
 luvisol |   6.039409   .0394947    152.917   0.000       5.962001    6.116818
 mesisol |   .9646895   .0473211     20.386   0.000       .8719418    1.057437
 luv_pod |   6.157623   .0259859    236.960   0.000       6.106692    6.208555
 pod_mes |  -3.533927   .0622527    -56.767   0.000       -3.65594   -3.411914
 chernoz |  -.5673411   .0672662     -8.434   0.000      -.6991804   -.4355018
   _cons |  -4.464243   .1791375    -24.921   0.000      -4.815346    -4.11314
---------+--------------------------------------------------------------------
sigma    |
   _cons |   4.094106   .0079692    513.742   0.000       4.078487    4.109725
```

Table E16 Moffat Lakes Study Area - Interval Regression Prediction Results (input for Figure 6.5)

variable	mean	min.	max.	condition	hypoth. sfc. temp.	predicted sfc. temp.	std.err.	-(std.err.)	predicted - hypoth.
stand_ht	15.37	0	38	avg. stand height + 10 m	-0.18	2.21	0.12	-0.12	2.39
				avg. stand height + 20 m	-0.18	3.17	0.12	-0.12	3.35
crown_cl	36.10	0	90	avg. crown closure + 15 %	-0.18	-1.58	0.11	-0.11	-1.40
				avg. crown closure + 30 %	-0.18	-2.24	0.12	-0.12	-2.06
rel_elev	318.07	10	730	avg. elevation + 50 m	-0.18	0.26	0.11	-0.11	0.44
				avg. elevation + 100 m	-0.18	0.58	0.13	-0.13	0.75
slp_mid	8.87	2	30	slope = 0 %	-0.18	-1.94	0.10	-0.10	-1.76
				slope = 5 %	-0.18	-1.21	0.09	-0.09	-1.03
				slope = 10 %	-0.18	-0.07	0.10	-0.10	0.11
				slope = 15 %	-0.18	1.31	0.10	-0.10	1.49
aspect1	0	0	1	N aspect	-0.18	0.26	0.04	-0.04	0.44
aspect2	0	0	1	NE aspect	-0.18	-0.32	0.05	-0.05	-0.14
aspect3	0	0	1	E aspect	-0.18	-0.40	0.05	-0.05	-0.22
aspect4	0	0	1	SE aspect	-0.18	-1.14	0.04	-0.04	-0.96
aspect5	0	0	1	S aspect	-0.18	-0.75	0.04	-0.04	-0.57
aspect6	0	0	1	SW aspect	-0.18	-0.27	0.04	-0.04	-0.09
aspect7	0	0	1	W aspect	-0.18	0.26	0.04	-0.04	0.44
aspect8	0	0	1	NW aspect	-0.18	0.99	0.04	-0.04	1.17
concave	0	0	1	concave curvature	-0.18	-0.35	0.10	-0.10	-0.17
convex	0	0	1	convex curvature	-0.18	-0.05	0.10	-0.10	0.13
log	0	0	1	logged	-0.18	-5.96	0.10	-0.10	-5.79
wildfire	0	0	1	wildfire	-0.18	-6.99	0.63	-0.63	-6.81
water	0	0	1	water	-0.18	13.38	0.12	-0.12	13.55
clearing	0	0	1	cleared	-0.18	-2.57	0.13	-0.13	-2.39
swamp	0	0	1	swamp	-0.18	-3.35	0.10	-0.10	-3.17
road	0	0	1	roads	-0.18	-0.49	0.75	-0.75	-0.31
con_dec	0	0	1	coniferous/deciduous mix	-0.18	0.67	0.11	-0.11	0.85
luvisol	0	0	1	luvisolic	-0.18	5.86	0.10	-0.10	6.04
mesisol	0	0	1	mesisolic	-0.18	0.79	0.10	-0.10	0.96
luv_pod	0	0	1	luvisolic/podzolic	-0.18	5.98	0.09	-0.09	6.16
pod_mesi	0	0	1	podzolic/mesisolic	-0.18	-3.71	0.11	-0.11	-3.53
chernoz	0	0	1	chernozem	-0.18	-0.75	0.11	-0.11	-0.57

Appendix F - Definition of Acronyms and Symbols used in this Research

GIS - Geographic Information System(s)
UTM - Universal Transverse Mercator map projection
NAD27 - North American Datum 1927
NAD83 - North American Datum 1983
GRS80 - global reference system 1980
IGDS - interactive graphic design system
FC1 - forest cover map files
FIP - forest inventory planning files
TRIM - terrain resource information mapping
CanSIS - Canada Soil Inventory Survey
DEM - digital elevation model
DTM - digital terrain model
AML - ArcInfo Macro Language
TIN - triangulated irregular network
LUT - lookup table
LST - local standard time
W/m^2 - watts per meter^2
TFOV - total field of view
IFOV - instantaneous field of view
A.S.L. - above mean sea level
LST - local standard time
BCGS - British Columbia Geographic System
MOEP - Ministry of Environment, Lands and Parks (British Columbia)
S - direct beam solar radiation
S_i - flux density normal to the beam
Θ - angle between the beam and the normal to the horizontal surface
Θ' - angle between the incident solar rays and the normal to the sloping surface
ι - angle between the sloping surface and a horizontal surface
S^I - instantaneous flux of direct beam solar radiation on a sloping surface
G - ground heat flux density
k - thermal conductivity of the soil (the rate at which heat energy passes through the soil for a given temperature gradient) assuming no temperature change in the ∂z layer of the soil.
$\partial T/\partial z$ - temperature gradient taken downward from the soil surface
κ - thermal diffusivity
$\rho_b c_s$ - volumetric heat capacity
$L\uparrow$ - emitted longwave radiation (W/m^2)
σ - Stefan-Boltzmann constant (5.67×10^{-08} $W/m^2 K^4$)
T - absolute temperature of the emitting material (K)
ε - emissivity of the object.
$L\downarrow$ - re-emitted longwave radiation (W/m^2)

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