University of Alberta

THE EFFECTS OF LIGHTNING ON STAND AGE IN NORTH CENTRAL ALBERTA

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Dated: DEC 2 1 1998

DEDICATED TO

The one who started me on my journey into post-secondary education, Mr. Donald Wilkinson, in loving memory (1901 - 1986).

"I finally know what an albatross is!"

ABSTRACT

The central objective of this study was to explore possible relationships between lightning strikes and lightning fires, and vegetation types and stand age-classes in Weyerhaeuser Canada Limited's Forest Management Area located near Grande Prairie, Alberta. The effects of several other factors, including Aspect and Elevation, on the density of lightning strikes and lightning fires were also examined. Results obtained were mixed. In some cases, areas in which the density of lightning strikes and lightning fires was high, the younger stand age-class were more prevalent. Similarly, areas of high lightning fire density were more frequently dominated by pine species. The results of this study were frequently inconclusive. This was due to a limitation in data pertaining to weather, the number of lightning strikes, size of the research areas or number of lightning-caused fires in the research areas. The results obtained by this study however, may have significant implications for forest management if research questions identified are answered.

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Chapter 1

INTRODUCTION

Lightning is considered to be one of the most wide spread, and spectacular meteorological phenomena affecting Alberta's boreal forests. During the period between 1984 and 1996, there was an average of 427,000 lightning discharges throughout the forested regions of this Province. Of the total number of fires reported during this period, just over half were attributed to lightning. However, these fires accounted for over 80 % of the 45,600 hectares burned by fires each year. Consequently, lightning fires have played a significant role in defining the form and function, and the resultant biodiversity, of the boreal forests throughout Alberta (Johnson 1992, Chesterman and Stelfox 1995).

Alberta's boreal forest is a complex mosaic of vegetation associations, which have a wide range of successional stages (Beckingham et al. 1996) and stand age distributions (Johnson et. al. 1995, Murphy 1985). It is widely accepted that the diversity in both the patterns and species of vegetation found in these forests, and the age-class distributions seen throughout the boreal is primarily due to the effects of natural disturbance regimes (Slaughter et al. 1971, Forman and Gordon 1986). This contention is supported by much scientific research, a list of which would include Kelsall et al. (1977), Murphy (1985), Johnson (1992), Oliver (1992), Duchesne (1994), Stelfox (1995), Johnson et al. (1995) and Weir and Johnson (1998).

Miller and Clark (1994) define a natural disturbance regime as the "periodicity and pattern of a natural disturbance". This definition takes into account such factors as the intensity, severity, size, and frequency of the natural disturbance. Outbreaks of insects and disease, high winds and the attendant blow down, flooding and herbivory are all disturbances capable of affecting large areas of the boreal forest. However, fire is considered to be the primary mechanism by which the characteristics of age-class and plant community diversity are maintained (Brown and Davis 1973, Rowe and Scotter 1973, Chandler et. al. 1983, Pyne 1984, Johnson 1992, Duchesne1994, Ward and Tithecotte 1994).

It is widely believed that over the last 50 years, forest management policies and practices have resulted in changing in the biodiversity commonly found in the boreal forests (Anon. 1997). Historically, the main objective of woodland managers in this and other biomes was to the maximize the profits associated with timber harvesting. Not much attention was paid to the effects timber extraction has on the other goods and services commonly found in the forest. Most foresters assumed timber harvesting had little or no long-term effect on the indigenous plant and animal associations where cutting was occurring. Also, most management strategies were aimed at the level of individual forest stands. In general, the oldest aged stands, which are often the most diverse, were preferentially harvested due to the high economic value of the timber, and in an attempt to minimize the possible losses in wood fiber due to natural factors, (i.e. disease, insects, fire, wind). Additionally, forest managers attempted to suppress or eliminate any agents (insects, disease, fire or water), that would negatively impact on forest health and associated timber production potential. In general, the goal was to capture the maximum amount of wood volume at the earliest age possible, while maintaining evenness of flow (Figure 1-1). Over time there would be no old-aged stands and even younger stands would become more uniform in structure and composition. Heinselman (1981) and Mutch et. al. (1993) suggest that this type of forest management has, in part, impaired the of the form and function, and associated biodiversity of the forest stands (plant communities) regardless of where they are found.

Concerns were expressed over the loss of biodiversity from boreal ecosystems during the United Nations Conference on Environment and Development[1] (Barton, 1992). Subsequently, the conservation of ecological diversity has become a key issue in forestry and forest management. This new emphasis on the maintenance and enhancement of biological diversity has been accompanied by significant changes in forest management strategies (Hunter 1991, Lieffers and Beck 1994, Lieffers et al. 1996, Lieffers and Woodard 1997). New strategies, which are being used by forest managers, are based on an ecosystem approach to forest management in an attempt to maintain and enhance boreal biodiversity (Duchesne 1994). In conjunction with this new approach there is strong support for the suggestion that natural fire regimes common to the boreal forest be used as a template for forest management (Hunter 1991, Weber and Taylor 1992, Duschesne 1994, Ott 1994, Duchesne and Thompson 1995, Bergeron et. al. 1998, Delong, 1998). However, very little research has been conducted on the role fire in the boreal forest. Even less is know about the role of lightning.

It might seem logical to assume that most lightning strikes result in fires. But that is not true as evidenced by the fact that there are fewer lightning fires than lightning strikes. Various factors that are known to influence the occurrence of a lightning fire are shown in Figure 1-2. In general, it is well known that not all lightning discharges result

[1] Held in Rio de Janeiro in 1992, also referred to as the Earth Summit

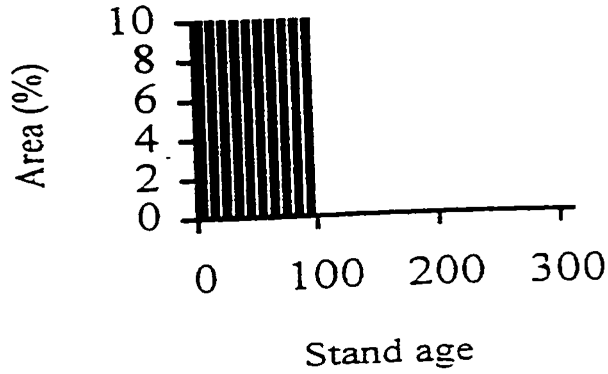

Figure 1-1 The theoretical age class distribution of a forested area under intensive harvesting and management regimes. (Source: Bergeron et. al. 1998).

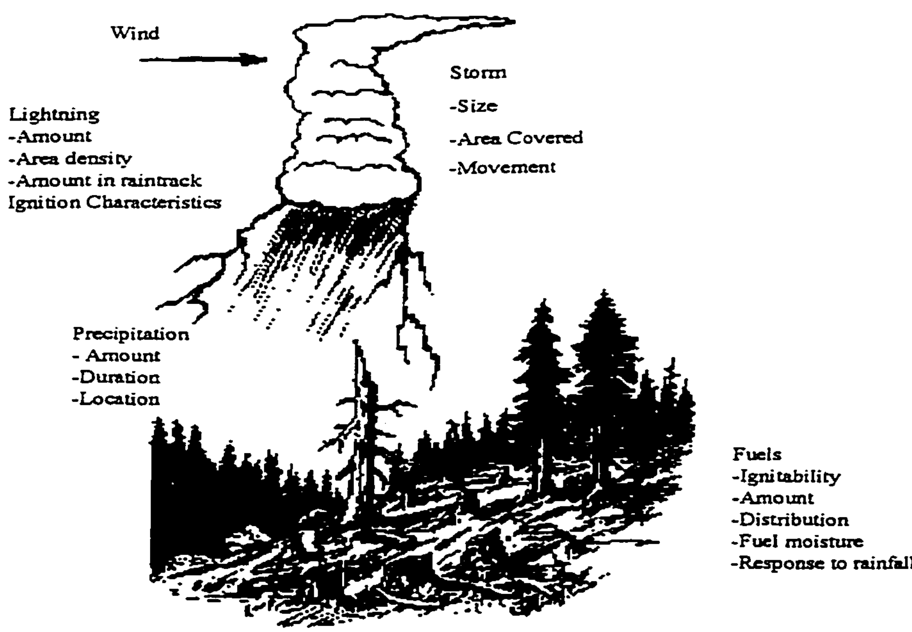

Figure 1-2 Various factors known to influence the ignition of a lightning fire (Source: Fuquay et. al 1972).

in an electrical pulse capable of igniting a fire (Schroeder and Buck 1975, Fuquay 1980, Anderson 1991). This due to three main facts. (1) Not all lightning discharges result in a pulse that will ignite forest fuels, (2) fuels are not always receptive to ignition and (3) weather is sometimes not conducive to the spread of fires ignited by lightning. Further, evidence suggests that only Cloud to Ground (C-G) discharges during which a Long Continuing Current (LCC) is observed are capable of ignitions (Fuquay 1980). Additionally, these long, continuing currents have been found to be more frequently associated with positive lightning discharges that strike the ground, than negative strikes to ground (Schroeder and Buck 1975, Fuquay, 1980, Anderson 1991). Yet, even strikes with an LCC will not always result in a fire if fuels are wet (Schroeder and Buck 1975, Ward 1977).

Research has identified other factors that seem to be related to the higher occurrence of lightning fires at specific locations when compared to others. It is well known that lightning fires are more common at higher elevation (Show and Kotok 1929, Barrows 1951, Kourtz 1967, Aselson 1975, Pickford et. al. 1980, Barden and Woods 1983, Uman and Krider 1989, Vasquez and Moreno 1998) and on south and southwest facing slopes (Barrows 1951, Vankat 1982, Aselson 1975). Some studies suggest that taller trees are struck more frequently than shorter trees in close proximity (Kourtz 1967). Trees with tap-roots or in well watered soils also seem to be hit more frequently (Kourtz 1967, Shipley 1946). However, all previous studies pertaining to lightning strike locations have used fire reports or past fire occurrences to develop these statistics. In this study, data pertaining to the actual occurrence and location of lightning determined from lightning location devices strategically throughout Alberta, British Columbia, Saskatchewan and the Northwest Territories (Figure 1-3 and Table 1-1) were used to answer the question: "Is there a pattern to the location of lightning strikes and lightning fires in the various "management areas" in Weyerhaeuser Forest Management Area (FMA) near Grande Prairie, Alberta?". If lightning is more common at some sites than others then forest managers might expect that stands will be younger where lightning is more frequent. The results of this study have important implications for forest management decision because stands that burn frequently because of an increase in lightning activity will not likely become old-aged stands.

Using this previous knowledge and lightning strike, lightning fire occurrence and vegetation data from "management areas" in Alberta, we test the following hypotheses:

Ho_1: The density of lightning strikes, positive lightning strikes, and lightning fires, as measured by the number of occurrences per square kilometer, is the same for all Aspect Classes.

Ho_2: The density of lightning strikes, positive lightning strikes, and lightning fires, as measured by the number of occurrences per square kilometer, is the same at all elevations.

Ho_3: The density of lightning strikes, positive lightning strikes, and lightning fires, as measured by the number of occurrences per square kilometer, is the same in all vegetation types.

Ho_4: Forest stands in areas of high lightning, positive lightning, or lightning fire density are the same age as stands in areas of low or moderate lightning, positive lightning, or lightning fire densities.

For reader clarity it should be noted that the word "effect" is used throughout this thesis. However, it is used to refer to the statistically significant relationships identified in the present study. Use of the word "effect" is not intended to imply a causal relationship

This thesis is presented in the traditional format. As such, it includes separate chapters including the present introduction, a brief description of the research areas used in the analysis, methods used to conduct the analysis, and a discussion of the results obtained. The next to last chapter of this thesis presents the conclusions about the results obtained, and the implications of these results for forest management practices in Weyerhaeuser Canada Limited's Grande Prairie FMA. The final chapter of the thesis discusses possible directions that future research should take.

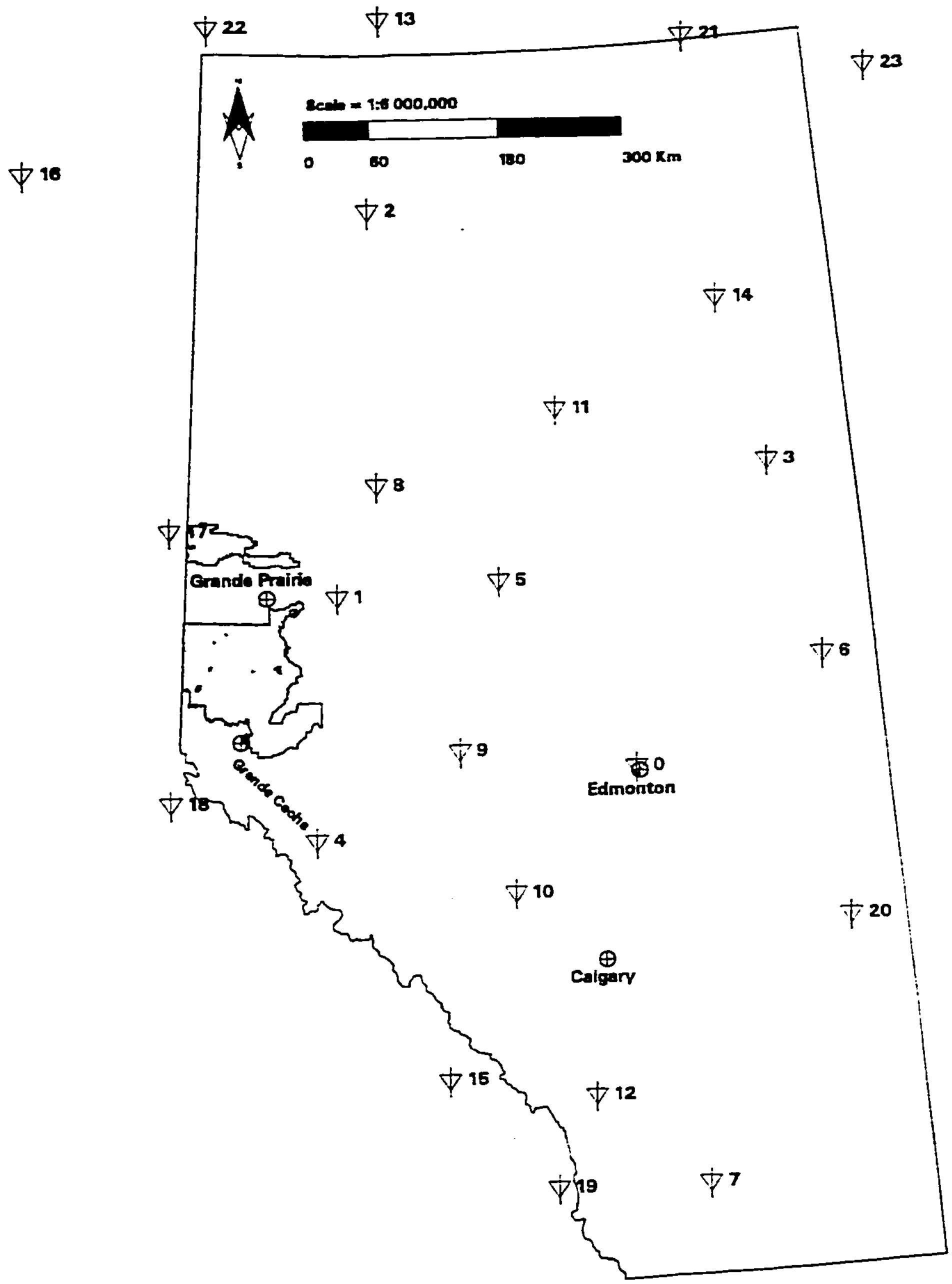

Figure 1-3 The location of the 24 Lightning Direction Finders (DFs) which comprised the Provincial Lightning Detection Network during the between1984 to 1996. The geographic coordinates and the place names are shown in Table 1-1.

Table 1-1 Geographic coordinates and place name locations of the Lightning Direction Finders which make up the Alberta Lands and Forest Service Provincial Lightning Detection System.

Unit Number	Latitude	Longitude	Location*	Agency Responsible**
0	53.58	-113.51	Edmonton	AB
1	55.16	-117.78	Debolt	AB
2	58.60	-117.29	Footner Lake	AB
3	56.21	-111.28	Anzac	AB
4	52.99	-118.06	Jasper	AB
5	55.28	-115.40	Kinuso	AB
6	54.45	-110.77	La Corey	AB
7	49.81	-112.92	Park Lake	AB
8	56.16	-117.19	Peace River	AB
9	53.77	-116.04	Peers	AB
10	52.50	-115.32	Rocky Mountain House	AB
11	56.80	-114.42	Trout Mountain	AB
12	50.65	-114.32	Turner Valley	AB
13	60.30	-117.06	Cameron Hills	NWT
14	57.69	-111.82	Birch Creek	AB
15	50.83	-116.29	Brisco	BC
16	58.85	-122.83	Fort Nelson	BC
17	55.73	-120.26	Dawson Creek	BC
18	53.30	-120.10	McBride	BC
19	49.83	-114.88	Sparwood	BC
20	52.12	-110.75	Gooseberry Lake	AB
21	60.03	-111.94	Fort Smith	NWT
22	60.21	-119.94	Redknife	NWT
23	59.61	-109.01	Wellington	SK
24	55.84	-108.43	Buffalo Narrows	SK

* Located at the A.L.F.S Provincial Forest Fire Centre

** AB = Alberta
BC = British Columbia
NWT = Northwest Territory
SK = Saskatchewan

Chapter 2

STUDY AREA

Weyerhaeuser Canada Limited's Forest Management Area (FMA), near Grande Prairie, Alberta, served as the general study area. The FMA, as shown in Figure 2-1, is divided into two smaller regions located to the north and south of Grande Prairie, respectively. The northern portion of the FMA is 23,503 hectares (2,350 km^2), while the southern portion is significantly larger at 1,138,504 hectares (113,850 km^2). Within the FMA, six smaller research sites with a combined area of 2,857 km^2 served as the study area. Figure 2-2 shows the names and relative locations of each of the research sites while the areas of each research site is presented in Table 2-1.

The forest management area is situated in the transition zone between the Cordilleran and Boreal climatic regions. Consequently a variety of subregions are represented both within the FMA, and in each of the research sites. The area encompassed by each subregion, as well as the total area of each research site is summarized in Table 2-1. It should be noted that the vegetation classification scheme used by Weyerhaeuser Canada, and throughout this study is similar to that developed by Strong and Leggat (1992), and Achuff (1994). A brief description of the characteristics of the subregions represented within the six research sites follows.

The "Peace River Parkland" is the subregion with the smallest representative area in the research sites encompassing only 0.2 percent of the total area encompassed by the six research areas (Table 2-1). It is restricted to the Saddlehills research site located in the northern portion

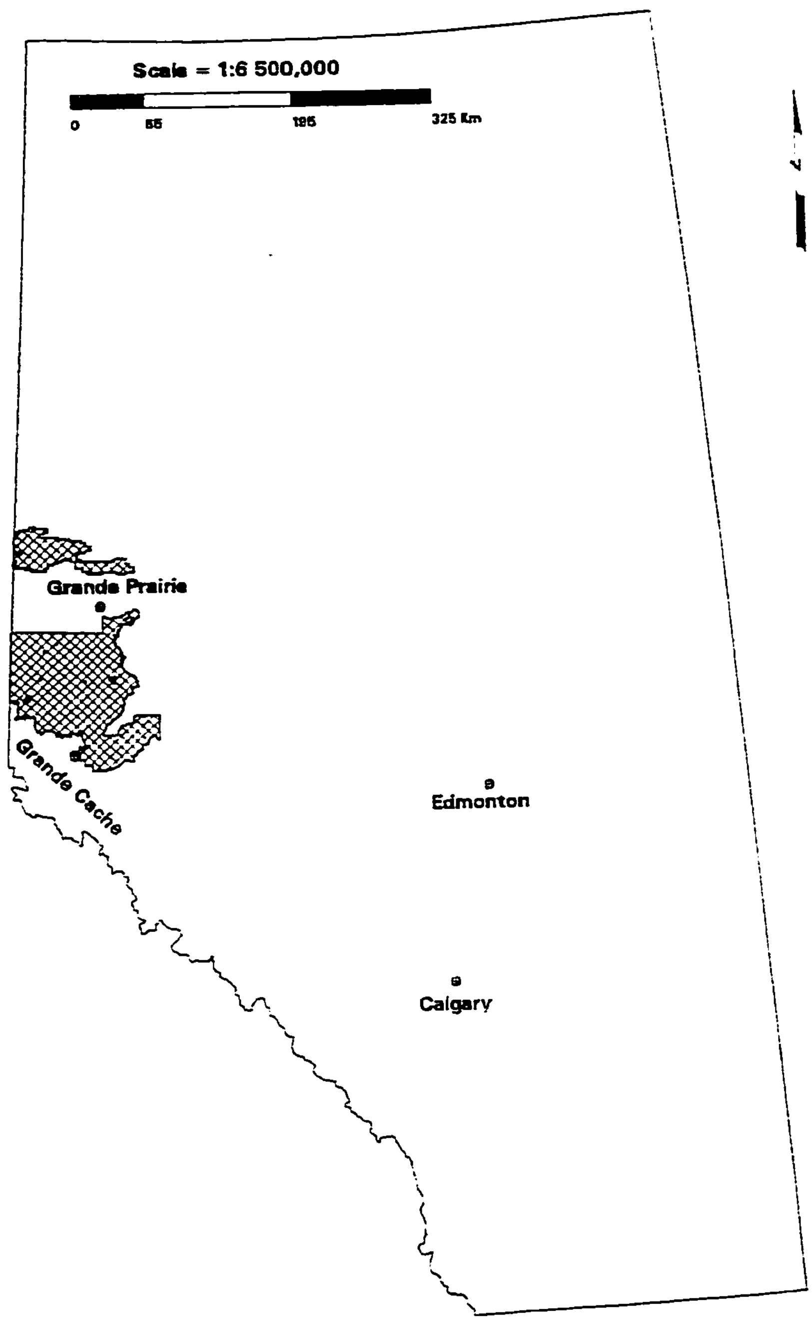

Figure 2-1 The location of Weyerhaeuser Canada Limited's Grande Prairie Forest Management Area (FMA) in Alberta.

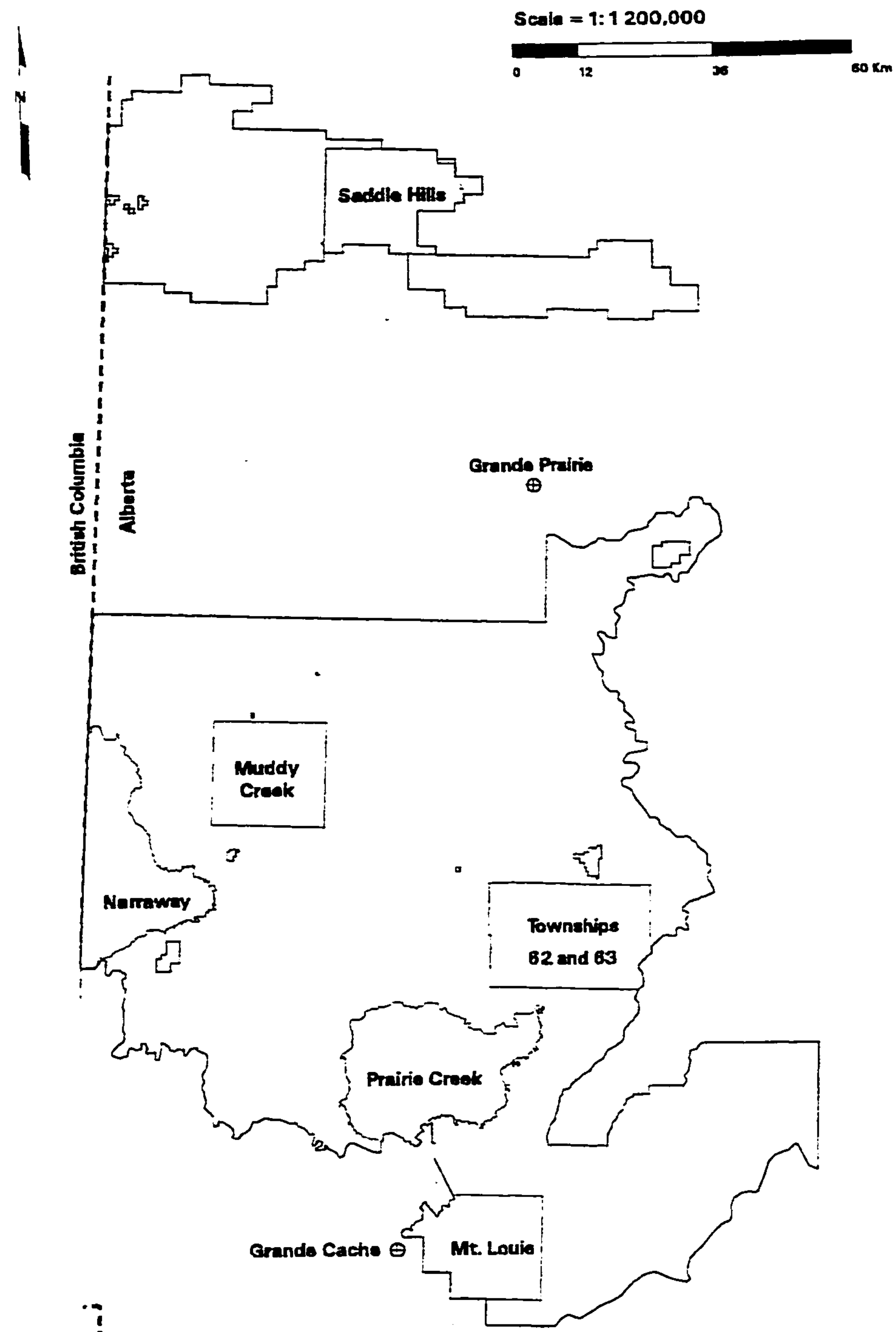

Figure 2-2 The names, and locations in Weyerhaeuser Canada Limited's Grande Prairie Forest Management Area, of the six research sites used in the study.

Table 2-1. A summary of the subregions, and their respective areas, represented in each of the six research sites.

Subregion	N	PC	MT.L	MC	SH	TWP	Total by Subregion	% of Total Res. Site Area
Lower Foothills	0.01	NR	NR	35.97	221.83	250.00	507.82	17.77
Upper Foothills	236.37	119.60	68.98	200.73	NR	307.63	933.32	32.66
Montane	NR	187.12	NR	NR	NR	NR	187.12	6.55
Subalpine	252.72	324.79	296.38	142.43	NR	2.72	1019.04	35.66
Alpine	19.73	NR	20.17	NR	NR	NR	39.90	1.40
Central Mixed wood	NR	NR	NR	NR	57.61	NR	57.61	2.02
Dry Mixedwood	NR	NR	NR	NR	107.53	NR	107.53	3.76
Peace River Parkland	NR	NR	NR	NR	5.53	NR	5.53	0.19
Total Research Site Area (km2)	508.83	631.52	385.54	379.13	392.50	560.35	2857.88	100.00

NR = NOT REPRESENTED
N = Narraway
PC = Prairie Creek
Mt. L. = Mount Louie
MC = Muddy Creek
SH = Saddle Hills
TWP = Townships 62 & 63

* *N. B. All area values are expressed in* Km^2

of the FMA. Climate in this subregion is predominately boreal (Achuff, 1994). The mean annual precipitation for this subregion ranges between 350 to 440 mm and the mean May to September temperature is 13°C. The topography is gentle in this subregion. Soil composition varies between Solonetzic in grassland areas, and Luvisolic in forested areas. The overstory vegetation in this subregion is dominated by trembling aspen *(Populus tremuloides* Michx.*)* and white spruce (*Picea glauca* [Moench] Voss) although balsam popular *(Populus balsamea* L.*)* may be found in smaller amounts on wetter sites (Achuff, 1994).

The "Alpine" subregion, which encompasses only 1.4% of the combined area of the six research sites, is only represented in Narraway and Mount Louie (Table 2-1). Both Strong and Leggat (1992) and Achuff (1994) suggest the alpine subregion is the coldest and potentially the wettest of Alberta's subregions. The mean May to September temperature in the alpine subregion is 6°C while winter temperatures in this subregion are significantly lower than summer mean temperatures. Mean annual precipitation in the alpine subregion may range between 420 and 850 mm (Achuff 1994, Strong and Leggat 1992). Soils are poorly developed and occur in minimal amounts; however Brunisols are considered to be the reference soil for the alpine region. Despite the harsh physiography of this subregion, floristic diversity is considered to be high. The most common plant types are sedges, forbs, and a variety of lichens at higher elevations (Achuff 1994, Strong and Leggat 1992). Strong and Leggat (1981, 1992) report that trees may be present in the alpine subregion. However, due to prevailing physiographic conditions, individual trees are usually stunted and deformed (Strong and Leggat 1981, 1992). The tree species most commonly found at these higher elevations include subalpine sir (*Abies lasiocarpa* (Hook)

Nutt.), engelmann spruce (*Picea engelmannii* Parry ex Engelm.), whitebark pine (*Pinus albicaulis* Engelm.), and alpine larch (*Larix lyallii* Parl.).

Two percent of the combined area of the research sites is classified as the "Central Mixedwood subregion". The climate of this subregion is described as continental with long cold winters and short summers (Achuff 1994, Strong and Leggat 1992). The mean annual precipitation is 380 mm, and the mean summer and winter temperatures are 13.5°C and -7.7°C, respectively (Achuff 1994; Strong and Leggat 1992). Soil type varies topographically with Gray Luvisols and Eutric Brunisols dominating on uplands and Organic and Gleysolic soils commonly found in depressed or hydric sites (Achuff 1994). Vegetation has also been found to be highly variable in this subregion. In early successional stages aspen, balsam poplar and paper birch (*Betula papyrifera* Marsh.) occur in pure and mixed stands. Late successional stands are dominated by white spruce and balsam fir although pure stands of either species are reported to be rare due to the frequent occurrence of fires and other natural disturbances (Achuff 1994).

The "Dry Mixedwood" subregion encompasses nearly 4% of the research area. Dry mixedwood is considered to be a transition zone between the "Central mixedwood" and "Central Parkland" subregions. The transitional nature of the Dry Mixedwood subregion is reflected in the physiographic conditions that are similar to those found in the Central Mixedwood subregion previously described (Strong and Leggat, 1992; Achuff, 1994).

The "Montane" subregion covers 6% of the research area. This subregion represents a transition between the Upper foothills region to the east, and the Subalpine region to the west. Topography and climate are highly variable. Annual precipitation can range from 300 to 1280 mm, averaging at 600 mm (Achuff 1994). Summer and winter average temperatures are 11.9°C and -5.5°C, respectively (Strong and Leggat 1992). This physiographic variability is reflected in vegetation patterns, which are also complex. Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco.), limber pine (*Pinus flexilis* James), and lodgepole pine (*Pinus contorta* Dougl. ex. Loud.) are considered to be characteristic of this region. However, late successional forests are dominated by white spruce and Douglas-fir (Achuff 1994, Strong and Leggat 1992).

Half of the area contained within the research sites is considered to be in the "Foothills Natural Region" (Table 2-1) (Achuff 1994). Seventeen percent of this area is categorized as the "Lower Foothills" subregion, while the remaining 33% is classified as the "Upper Foothills" subregion. Achuff (1994) states the prevailing climatic conditions of the lower foothills subregion is continental. The average summer temperature may range between 11 to 13°C; while the mean winter temperature is -7.8°C. Mean summer temperatures in the Upper foothills subregion are slightly cooler at 11.5°C and the mean winter temperatures are slightly warmer are -6.0°C (Strong and Leggat 1992). Mean annual precipitation in the "Lower Foothills" is approximately 380 mm. The Upper Foothills is slightly wetter, with an annual average precipitation of 439 mm. In both subregions, Luvisolic and Brunisolic soils dominate well drained sites However, as Achuff (1994) reports, Gleysols are thought to characterize poorly drained sites in the lower foothills, while Gleysol and Organic soils dominate hydric sites in the Upper foothills.

The characteristic vegetation of both subregions is very similar. In the lower foothills, stands are generally mixtures of deciduous and coniferous species. White and black spruce (*Picea mariana* (Mill.) B. S. P.), lodgepole pine and balsam fir are the main coniferous species in these stands. Deciduous tree species common to this subregion are aspen, balsam poplar and paper birch. In the upper foothills, the species are similar, but mixed stands are not common. Achuff (1994) states that stands in the upper foothills subregion are nearly all coniferous. In both the upper and lower foothills subregions, vegetation patterns vary with elevation (Achuff 1994, Strong and Leggat 1992).

The "Subalpine" subregion encompasses the largest single portion, some 35%, of the combined area of the six research sites. This subregion is highly variable topographically and this variation is reflected in the soil composition, which is dominated by Eutric Brunisols although other soil types represented may include: Regosols, Podzolics, and Cryosolics (Achuff 1994, Strong and Leggat 1992). Climatic factors, such as "Mean Annual Temperatures" and "Mean Annual Precipitation", are also significantly affected by the complex topography of this subregion. Mean annual temperatures in the subalpine region range between -1°C to 3°C. As a result the number of frost-free days is less than 30 (Achuff 1994, Strong and Leggat 1992). The Mean Annual Precipitation is 415 mm for this subregion (Strong and Leggat 1992). Early successional vegetation is characterized by lodgepole pine, while late successional forests have been reported to be dominated by Englemann spruce, and subalpine fir. However, elevational and geographic variations have been noted (Achuff 1994, Strong and Leggat 1992).

The eight subregions represented in the research sites comprise larger, more general natural regions (Achuff, 1994). For example, both the central and dry mixedwood subregions are part of the larger boreal forest natural region. The Rocky Mountain natural region contains the montane, subalpine and alpine subregions; while the Foothills Natural region consists of the upper and lower foothills subregions. The smallest subregion, the

Peace River Parkland subregion, is part of the larger Parkland Natural Region (Achuff 1994). Information, from the FMA, about the understory composition is available only for the larger natural regions (Kansas et. al. 1990). Consequently, information about the understory vegetation within the research sites is limited and extremely generalized. However, a summary of the composition of the understory vegetation for each of the natural regions represented in the research sites is presented in Table 2-2, while Appendix A contains a complete listing of all scientific and common names of the vegetation listed. Unfortunately, no data are available concerning the fuel structure and composition in either the FMA, or the research sites. The lack of information about the structure, composition and loading of fuels in the FMA indicates the need for more future research, and will be discussed in a later section.

Table 2-2. Common and Scientific names of Understory vegetation commonly associated with each of the Natural Regions represented in the six research sites (Kansas et. al. 1990).

Natural Region/Subregion	Common Name	Scientific Name
Boreal Forest Natural Region	Saskatoon	*Amelanchier alnifolia* Nutt.
Central Mixedwood	Prickly Rose	*Rosa acicularis* Lind.
Dry Mixedwood	Red Osier Dogwood	*Cornus stolinifera* Michx.
	Alder	*Alnus* Spp.
	Buffulo berry	*Sphedria canadensis* (L.) Nutt.
	Labrador tea	*Ledum groenlandicum* Oeder
	Sphagnum mosses	*Sphagnum* Spp.
	Sedges	*Carex* Spp.
Foothills Natural Region	Buffalo berry	*Sphedria canadensis* (L.) Nutt.
Upper Foothills	Low bush cranberrry	*Viburnum edule* (Michx.) Raf.
Lower Foothills	Sasparilla	*Aralia nudicaulis* L.
	Labrador tea	*Ledum groenlandicum* Oeder
	Mosses	
Rocky Mountain Natural Region		
Montane	Rhododendron	*Rhododendron albiflorum*
Subalpine	Tall Billberry	*Vaccinium membranaceum* Dougl. ex Hook.

Chapter 3

METHODS

3.0 Data Acquisition

The data for this study were obtained from two main sources. Databases containing the lightning strike information (1984-1996) and fire records (1961-1996) for the province were obtained from the Forest Protection Branch of the Alberta Lands and Forest Service (A.L.F.S) in Edmonton. Weyerhaeuser Canada Limited provided all necessary geographic information data pertaining to each of the six research sites located in the Grande Prairie Forest Management Area.

Geographic information, in the form of Arc/Info™ coverage[2] layers, provided by Weyerhaeuser Canada Limited, included: boundary lines (outlines) of each of the six research sites and the FMA; road coverages for each of the six research sites and hydrological features (lakes, major and minor drainages). Information concerning the locations of the seismic lines and harvested areas, Ecoregion and Subregion classifications for each of the six research sites within the FMA, Phase III Inventory data, and Digital Elevation Models (D.E.M) for the entire FMA was also provided. This geographic information was provided pre-formatted for use in the Arc/Info™ Geographic Information System (GIS), which served as the main analysis platform for the study. However, the data provided by Weyerhaeuser Canada required some changes in order to achieve the objectives of the study. These modifications are discussed in a later section of this chapter. Similarly, it was necessary to make several major modifications to the

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[2] Coverage is an Arc/Info™ technical term used to describe a data file containing geographically referenced data.

databases obtained from the A.L.F.S prior to the use in the study. The modifications made to both the provincial lightning strike database, and the provincial fire database, although similar, are discussed separately.

3.1 Provincial Lightning Database

Although the principles involved in detecting lightning are relatively simple, the engineering and mathematical algorithms involved in actually locating the position and determining the type of a lightning strike, are extremely complicated. Hence, for more insight on how lightning strikes are located and interpreted, the reader should see Krider et al. (1980), and Uman (1987).

The provincial lightning database contains detailed information about lightning strikes to ground that occur each year in Alberta beginning in 1984. This information is recorded on a daily basis. Included in the data are information about the date, time, relative signal strength, multiplicity, and geographic location of lightning strikes to ground from across the province. These data were recorded through a series of interconnected Lightning Detection Devices (LDD), or Direction Finders, strategically located throughout Alberta, British Columbia, Saskatchewan, and the Northwest Territories. Each direction finder antennae is linked via modem to a positional analyzer centrally located in Edmonton. There are 24 lightning detection finders currently covering the province of Alberta. However, not all of these detectors are located in the province (Figure 1-2). Information pertaining to the geographic location, place name location, and unit identification numbers of the 24 direction finders is summarized in Table 1-1.

The data recorded by each of the direction finders are automatically compiled and analyzed by the positional analyzer, located at the Provincial Forest Fire Centre (PFFC) in Edmonton. The lightning records are normally stored by year as database files (*.dbf extension). For this study, however, the provincial lightning strike records were obtained from A.L.F.S as ASCII text files (*.txt extension). This allowed for rapid editing using a UNIX based text editor.

Although the lightning database contains lightning strike records from across the province, only the records corresponding to the geographic extent of the Grande Prairie FMA were required. Additionally, only certain record fields from the lightning files were required. These included all fields with the exception of the multiplicity of individual lightning strikes. Consequently, it was necessary to excise the salient records from the original database, and covert the pertinent records into Arc/Info™ point coverages.

The original data provided by A.L.F.S used cartesian coordinates (latitude and longitude, expressed in decimal degrees). However, the geographic data provided by Weyerhaeuser was represented by Zone 12 of the Universal Transverse Mercator (UTM) map projection system. As a result a change was made to the coordinate system used to represent the lightning strike locations. This change to the map projection system of the lightning strike records ensured proper registration with the geographic data provided by Weyerhaeuser.

The changes made to the projection system of the lightning strike data, as well as the removal of those lightning strike records not pertaining to the research areas were conducted simultaneously on each year of lightning strike data. This resulted in 14 individual Arc/Info™ point coverages each representing a year of lightning strike data from 1984 to 1996. To conserve disk space and to increase the efficiency of the analysis, it was decided to append each year of lightning strike data into a single Arc/Info coverage containing all the lightning strikes recorded in the Grande Prairie FMA between 1984 and 1996. Lightning strike data for each of the six research areas was then clipped out of this larger data file, using a "cookie-cutter" approach.

3.2 Provincial Fire Records

The provincial fire records, dating from 1961 to 1996, were obtained from the Forest Protection Branch of the Alberta Lands and Forest Service. Each year of data was obtained individually, as a database (*.dbf extension) file. However, as with provincial lightning database, modifications were necessary prior to using the fire records in the study.

In Alberta, each time a fire is detected, a corresponding fire report is started. Each report contains detailed information concerning the date, time, and approximate geographic location of the specific fire. Information about the size, general and specific causes of each fire, and suppression resources and efforts is also included on the fire report. An example of the fire records from the 1996-fire season is provided in Appendix C (Table C-1).

Forest fires in Alberta are fully investigated to determine the exact cause. Subsequently the general, and the sometimes the specific cause of each fire can be determined and is recorded using a series of numeric categories. The classification of each fire is based on the physical evidence and/or the judgement of the fire boss assigned to each fire. A brief description of each general cause category as used by staff in the

Protection Branch of the A.L.F.S. is summarized in Table 3-1. Although the specific cause of each fire is important, it was not a concern for the present study. In this study, I only examined fires due to lightning, which are represented with a general cause of 1 (Table 3-1).

The provincial fire records are stored by year, and cover the period between 1961 and 1984. However, the provincial lightning database only contains records from 1984, which corresponds to the establishment of the lightning detection system. Any lightning fires detected and recorded prior to 1984 were considered to be inaccurate, as the information could not be verified by the lightning detection system. Because of this, all fire records prior to 1984 were eliminated from the study.

A preliminary examination of the fire records, by year, was conducted using version 7.0 of Microsoft Excel™. This was necessary to determine the structure of each year of data, which was variable from year to year, and to select the relevant record fields to use in the analysis. Much of the data included in each fire record was irrelevant to the study and was therefore disregarded.

As with the lightning records, the fire database contains records of fires detected throughout Alberta. However, only the fire records pertaining to Weyerhaeuser's FMA in Grande Prairie were required. In a procedure similar to that used to extract the pertinent lightning strike records and prepare them for use in the analysis, lightning fire records corresponding to the geographic boundary of the Grande Prairie FMA were clipped out of the provincial database and converted into Arc/Info™ point coverages. It was also necessary, as with the lightning strike records, to change the map projection system used to describe the location of lightning fires. Each of The UTM Arc/Info point coverages showing the locations of lightning fires within the FMA for period between 1984 and 1996 were then appended into a single data file. The lightning fires recorded in each of the six research areas during the period between 1984 and 1996 were then clipped from this single data file.

It is important to note that several assumptions were made about the accuracy of both the provincial lightning strike and provincial fire data prior to the use of the data in the study. With regard to the lightning strike data, it was assumed that there were no consistent errors (bias) associated with the recorded location of the lightning strike. Essentially, the location at which any lightning strike was recorded was thought to be the true location for that strike. Additionally, it was initially assumed that the number and type (positive or negative) of lightning strikes recorded was accurate. Similarly, both the recorded location of any lightning fire contained in the fire database, as well as the total number of lightning fires were assumed to be accurate.

3.3 Weyerhaeuser Data

Given the fact that the data provided by Weyerhaeuser is used for the planning of timber harvesting, and other forest management needs, it was assumed the original geographic data was error free or at least very accurate. However, despite the number of Arc/Info coverages provided by Weyerhaeuser Canada Limited, the information required to meet the objectives of the study was not readily available in the data provided. Consequently, it was necessary to use the Arc/Info™ coverages provided to derive the new coverages to fulfill the project objectives. The Phase III vegetation data base was

Table 3-1 The Alberta Lands and Forest Service General Cause Category Codes and Descriptions forest fires in the Green Protection Zone of Alberta *.

General Cause Category Number	Description of General Cause
0	**Other Industry** (other than Forestry/Railroad; includes: Mining, Oil and Gas, Utility, Waste Disposal, Trapping, Commercial fishery, Commercial Transportation, Commercial Tourism)
1	**Lightning**
2	**Residential** (fires due to activities related to agriculture or living in Rural Areas)
3	**Forest Industry**
4	**Railway**
6	**Recreation** (Hunting, Fishing Camping and all associated activities)
7	**Incendiary** (fires willfully started for the purpose of mischief, profit, vengeance, or because of mental disposition)
8	**Known** (Cause of fire is known, but is other than those listed)
9	**Unknown** (Cause Indeterminable)

* **Source**: Alberta Lands and Forest Service Individual Fire Report Form Handbook (FR48) , Revised March 1994).

the only information that proved to be the most useful of the original coverages initially provided.

3.3.1 Stand Origin and Vegetation Type

The phase III vegetation data represents the third installment of the three part Alberta Phase III inventory completed in 1984. The main objective of the inventory was to create and maintain a comprehensive database pertaining to the structure, composition and physiography of forest stands throughout Alberta's Green Zone for the purposes of forest harvesting and related activities (Alberta Lands and Forest Service 1988). Data about individual forest stands, represented graphically as polygons, was assessed through the interpretation of aerial photographs in conjunction with frequent ground truthing studies (Alberta Lands and Forest Service 1988). Information about the structure, stand age, composition and general physiography of each forest stand was collected, compiled, and encoded into a special format. This encoded information is referred to as the P3 Label and each forest stand, or polygon, within the Green Zone covered by the Phase III inventory is assigned an appropriate P3 Label. Figure 3-1 represents an example of a P3 Label. By breaking the P3 label down into individual components information about the stand age, and dominant and secondary tree species within each forest stand (polygon) was obtained.

This procedure was performed in the Info module of Arc/Info by editing each component of the Phase III polygon attribute table (*.pat). For example, stand origin values, for each research site, were determined by selecting for, and copying the stand origin component for each polygon in the research site from the Phase III polygon attribute table and pasting these values to a separate polygon attribute table containing only the stand origin values. This resulted in the development of a new Arc/Info™ coverage, for each research site, in which each polygon in the new coverage had associated with it a polygon identification number, the area and perimeter of the polygon (measured in meters squared, and meters respectively), and the stand origin value. The origin dates were then recalculate to reflect age classes of 20 years. It should be noted that the area, as measured in square meters, of each polygon was variable and reflected the true size of the original forest stand.

A similar procedure was conducted to obtain the dominant vegetation type of each forest stand (polygon) in all six research sites. This involved cutting and pasting the codes used to represent the dominant and secondary tree species in each forest stand to a separate polygon attribute table attribute table (*.pat) (output file). The alphabetic codes used to represent different species of vegetation in the Phase III polygon label are listed in Table 3-2. However, the reclassification was slightly different. Table 3-3 and Table 3-4 represents a summary of the system used to reclassify the primary and secondary tree species, as listed in the Phase III polygon label, for each forest polygon. As listed in Table 3-4, vegetation classes 2 and 3 were used to represent the economically important softwood Spruce and Pine Species. Although vegetation class 1 was used to classify hardwood species such as Aspen and Poplar, the class also included some softwood species such as Larch and Fir (Table 3-4).

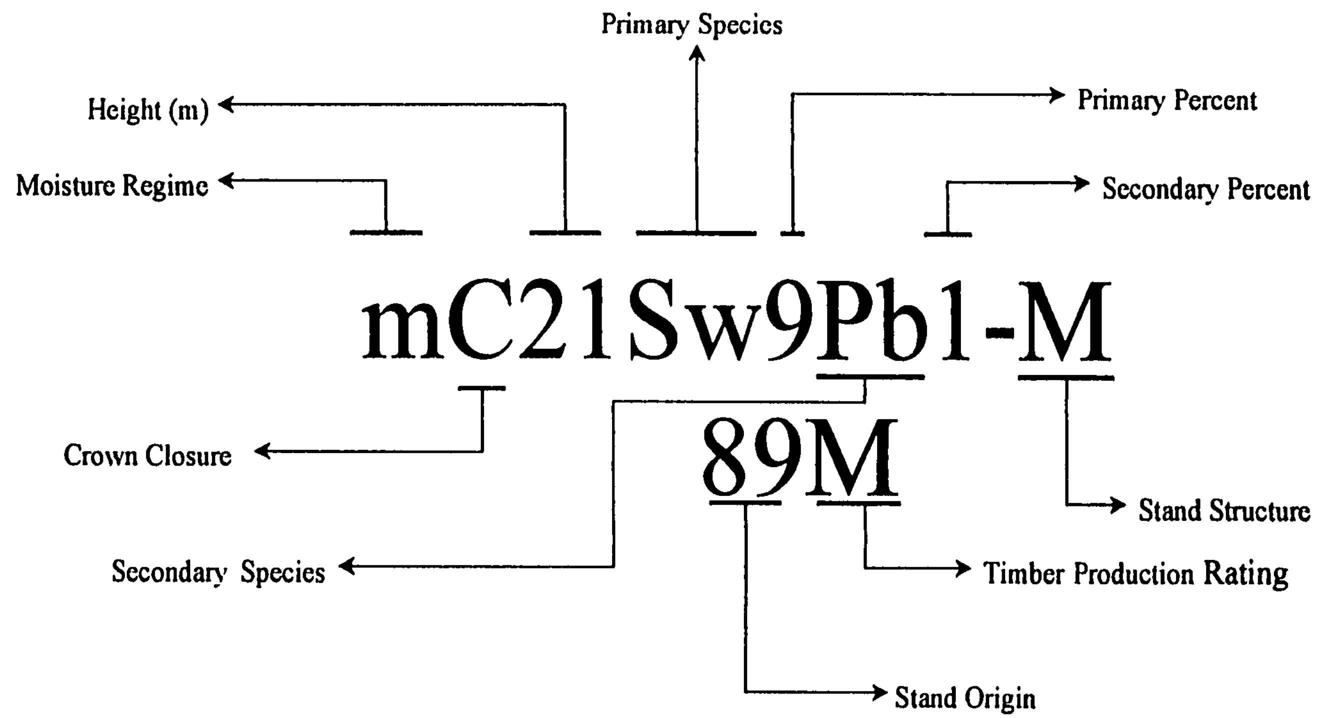


Figure 3-1 An interpretation of a Phase III (P3) Vegetation Inventory Polygon Label used by the Alberta Lands and Forest Service, Alberta Environment (Alberta Lands and Forest Service, 1988).

3.3.2 Aspect and Elevation Coverages

Elevation

The Aspect and Elevation coverages, for each research site, were derived from the Digital Elevation Model (D.E.M) of the entire FMA that was included in the original data set from Weyerhaeuser. The Digital Elevation Model, as the name implies, is a digital representation of 3 dimensional topographic features in 2 dimensions. In some cases, the DEM may be used to represent any continuous surface. Essentially, the DEM is a series of raster cells (squares) each containing a single elevation value. The spatial resolution of each of the grid cells comprising the DEM was 25 meters. Consequently, accuracy of the original DEM data was also assumed to be very high. A special module of the Arc/Info™, referred to as GRID, was used to manipulate the Digital Elevation Model. As the research areas were the main focus of the study it was necessary to clip the full DEM using the boundaries of the research sites and thereby obtain the digital elevation models for each of the six research sites. The "CLIPGRID" command of the GRID module was used (Appendix B). This resulted in a digital elevation model for each of the research sites. However, using the original digital elevation model data would have required significant amounts of disk space. Consequently, it was necessary to reclassify the DEM for each research site thereby reducing the size of the files required. Reclassification of the elevation data for the research sites also served to simplify the statistical analysis.

Reclassification of the Digital Elevation Models was accomplished using a GRID module command called "RECLASS" (Appendix B) in conjunction with a special remap table. The RECLASS command changes the grid cell values, on a cell by cell basis, to the values specified in the remap table. In this study, the original DEM data for the research sites was reclassified into 100-meter elevation classes based on the minimum and maximum values of the research Digital Elevation Models. The remap table that was used in association with the RECLASS procedure is presented in Appendix C.

After the reclassification of the elevation grids, each reclassified grid was then converted from a grid, or raster coverage, into a polygon coverage. This was due to the fact that all other coverages, provided by Weyerhaeuser or derived, were in the form of polygons. This step was completed using the GRIDPOLY command of the Grid module (Appendix B). The result was a series of small polygons within the boundaries of each study site. Each smaller polygon contained an associated elevation value, expressed in 100-meter classes.

Aspect

The original D.E.M also served as the template for the Aspect coverages derived for each research site. The elevation grids, previously describe, for each research site were modified into aspect grids using the ASPECT command of the Grid module (Appendix B). The aspect grids for each research site were also reclassified using a remap table as in the elevation coverages. However, the reclassification scheme was based on the points of a compass. For example, any negative values were considered to be level and were automatically considered to have a zero value. Values ranging from 0 to 90 degrees were reclassified as Northeast Aspects; 90 to 180 degrees were reclassified as Southeast Aspects; 180 to 270 degrees became Southwest aspects; and 270 to 360 degrees were reclassified to be Northwest Aspects. It should be noted that the weather in

Table 3-2 A summary and description of the alphabetic codes used to represent different vegetation species in the Phase III polygon label.

Alphabetic Symbol	Species Represented
A	populus spp. (undifferentiated)
Aw	trembling aspen
Bw	paper birch
Fa	subalpine fir
Fb	balsam fir
Fd	Douglas-fir
Lt	eastern larch
Lt	western larch
Lt	tamarack
Pa	white bark pine
Pl	lodgepole pine
Sb	black spruce
Sw	Englemann spruce
Sw	white spruce

Source: Alberta Forestry Lands and Wildlife (1988). Alberta Phase 3 Forest Inventory: Forest Cover Type Specifications.

Table 3-3 The reclassification scheme used in this Thesis to recategorize the primary and secondary species of the Phase III polygon labels.

If	**Primary Species**	*And*	*Secondary Species*	*Then*	*Reclassed Species*
If	**Non-Forested (No Vegetation)**	*And*	**Any**	*Then*	**None**
If	**Other than Spruce or Pine**	*And*	**Any**	*Then*	**Other**
If	**Spruce species**	*And*	**Any**	*Then*	**Spruce**
If	**Pine species**	*And*	**Any**	*Then*	**Pine**
If	**Non-Forested (No Vegetation)**	*And*	**Spruce**	*Then*	**Spruce**
If	**Non-Forested (No Vegetation)**	*And*	**Pine**	*Then*	**Pine**
If	**Other than Spruce or Pine**	*And*	**Spruce**	*Then*	**Spruce**
If	**Other than Spruce or Pine**	*And*	**Pine**	*Then*	**Pine**
If	**Other than Spruce or Pine**	*And*	**Not Spruce or Pine**	*Then*	**Other**
If	**Non-Forested (No Vegetation)**	*And*	**Not Spruce or Pine**	*Then*	**None**

Table 3-4 Vegetation classes derived from the reclassified primary and secondary species of the Phase III polygon labels.

Reclassified Species Name *	Representative Vegetation Class
None (Non-vegetated area)	0
Other (Species other than Spruce or Pine)	1
Spruce Species	2
Pine Species	3

** Based on values presented in Table 3-3* this Province moves from northwest to southeast as a general rule. The system used to account for aspect was designed to accommodate this weather pattern. Appendix C contains a copy of the remap table was used to reclassify the aspect values for each research site. As with the reclassified elevation grids, the reclassified Aspect grids were converted into a polygon format using the GridPoly command of the Grid module (Appendix B). In both cases, this conversion was necessary, as it is not possible, in Arc/Info™, to work with both Grid and Polygon coverages simultaneously.

3.4 Calculation of Density Variables

Once all the necessary coverages for the study had been derived, it was necessary to overlay both the lightning and fire coverages onto these newly derived coverages and calculate the number of positive and negative lightning strikes, and lightning fires per unit area. This was done using a series of steps in the Arc module. However, one important step was necessary prior to beginning this procedure. This was the addition of fields to contain the calculated values of lightning strikes, fires, and positive lightning strikes densities as measured in the number strikes or fires per square kilometer. These three fields were added to the polygon attribute table (*.pat) of each coverage in each research site using the "ADDITEM" function of the Arc module (Appendix B). It should be noted that these fields were added only to the coverages being used in the analysis. Having completed this step for each coverage, the overlay procedure was started.

The initial step in this procedure was to overlay the lightning and fire coverages on to the coverages involved in the analysis. Essentially, this overlay procedure combined the features and respective attributes from one coverage with the features and attributes from another coverage, and resulted in the formation of a new coverage containing the features and attributes of both original coverages. The overlay, or IDENTITY, procedure is represented graphically in Figure 3-2. This was done using the "IDENTITY" command of the Arc module (Appendix B). To conserve disk space it was decided to use the appended lightning (ltg84-96) and fire (ltgfires84-96) coverages for each research site in this step, rather than performing separate overlays for individual years of lightning and fire data. The identity commands were performed separately for the lightning and fire coverages. However, in each separate identity command the same base coverage was used (Figure 3-2). For example, in order to be able to calculate the lightning strike and lightning fire densities for the Aspect coverage of the Narraway area, two individual identity commands involving the separate lightning strike and lightning fire coverages were required. However, the Aspect coverage of the Narraway site was used as the base, or identity coverage (Figure 3-2 and Appendix B).

The second step in this procedure was to calculate the frequency of the lightning strikes, fires and positive lightning strikes. This was conducted using the "STATISTICS" command of the Arc module (Appendix B). Essentially, this calculates the number of points that fall into each polygon. A second statistics command was necessary in order to determine the area of each polygon. The results of these statistics are stored in a separate output file (attribute table). Overall, four separate statistics commands were performed for each coverage in each research site. These include: 2 for the lightning overlays, and 2 for the fire overlays.

The information stored in the separate output files (attribute tables) was then related back to the product of the overlays performed initially. This was performed using a special command called "RELATE", which temporarily combines information from two attribute tables (see Appendix B). For each overlay, it was only necessary to perform three relates. The first "RELATE" involved determining the frequency of lightning strikes, and positive strikes per polygon while the second relate was associated with determining the frequency of lightning fires per polygon in each separate coverage. The third relate pertained to the area of each polygon contained in a specific coverage. By knowing the frequency, or number of lightning strikes, fires, or positive lightning strikes within an individual polygon, and the respective area of that polygon, it was possible to calculate the density of the lightning strikes, lightning fires, or positive lightning strikes for each polygon in the coverage. The density refers to the number of observations per unit area.

The final step in the procedure, conducted in the ArcEdit module, involved the calculation of lightning strike, lightning fires, and positive lightning densities in each coverage. This involved combining the results of the relates in a mathematical formula constructed to obtain the desired output. Figure 3-3 illustrates the general structure of each separate calculation. These procedures were conducted for all the coverages to be analyzed, in each of the six research sites.

After having calculated all of the values for the required coverages in each research site, the resulting attribute tables were converted from Arc/Info information files to database files (*.dbf extension). This was done using the "INFODBASE" command of the Arc module (Appendix B). The conversion was conducted in order to export the results to the SPSS™ statistical program for further analysis. This step allowed for statistical analysis, without having to re-enter any of the results manually.

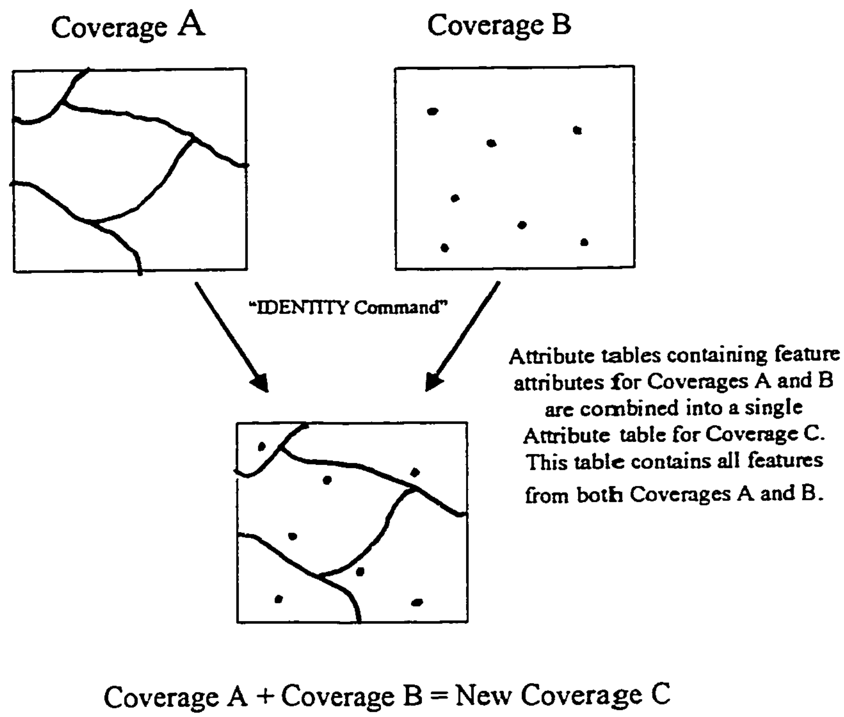


Figure 3-2 A representation of the Arc/Info IDENTITY command.

The calculation is based on the Attribute tables resulting from the IDENTITY and associated RELATE Command. The general structure is as follows:

$$\text{Lightning Strike Density (strikes/Km}^2\text{)} = \frac{LSF^*}{AP} \times 1{,}000{,}000^{**}$$

Where LSF = lightning strike frequency per polygon (obtained during the RELATE command)

AP = Area of each individual polygon (obtained during the RELATE command)

** Multiplication factor to convert square meters to square kilometers

Figure 3-3 An example of the general structure of the calculation of the Lightning Density.

3.5 Reclassification of Density Variables

As previously mentioned, certain assumptions were made about the lightning strike, and lightning fire data in relation to the null hypotheses to be tested as stated in chapter one. Specifically, the occurrence of both lightning strikes and lightning fires were assumed to be randomly distributed. As shown in Figure 3-4, this assumption was seen to be valid. Consequently, the number of lightning strikes and lightning fires in a given area were assumed to have Poisson distribution (Ross 1984). As a result, the variance in both lightning strike and lightning fire densities was expected to be inversely related to the square root of the area of the polygon in which any lightning strike or lightning fire was recorded. This indicated that the variance in the lightning strike and lightning fire densities was extremely large and variable. This fact contradicted the assumption, that all data have equal variance, for the analysis of variance procedures used to analyze the data.

Analysis of Variance (ANOVA) procedures require certain assumptions to be made about the data used in an analysis and include: random, normally distributed data having constant variance among the sample data. However, because of the area of the polygons in which lightning strikes or lightning fires were recorded was variable, so to was the variance among the lightning strike and lightning fire density values. Consequently, a reclassification of the original lightning strike and lightning fire density values was required in order to meet the requirements associated with the ANOVA procedures.

The reclassification was based on the value of the theoretical population mean for each density variable which, in turn, was representative of the overall mean value for each of the density variables. The theoretical mean values for each of the density variables was calculated from a scatter plot of the density variable multiplied by the square root of the area for each polygon in which the density value was recorded. By multiplying the density variable by the square root of the area of for each polygon in which the density value was recorded a constant variance among the resulting values was expected. As. illustrated in Figure 3-5, this procedure generally resulted in a straight line scatter plot with constant variance, confirming our assumptions on the lightning strike and lightning fire distributions. Although only one scatter plot is represented, the same procedure was used for the density of lightning fires in which similar results were obtained. Calculating the general linear equation (given by: $y = mx + b$; where y = value of the dependent variable, x = value of the independent variable; b = y-axis intercept; and m = slope of the line) of the line of best fit provided a value of the slope of the line. Theoretically, the slope of the line is an estimate of the population mean and the intercept of the line should be zero for Poisson variables (Figure 3-5). The slope of the scatter plot was used as the value of the theoretical population mean for the lightning strike density. The regression line was used to reclassify the lightning strike density data. Those points that fell above the straight line were reclassified as high, while the points falling below the liner were classified as low. The end result was a reclassification of lightning, positive lightning, and lightning fire densities into high or low categories based on a the value of the theoretical population mean for each density variable. This reclassification procedure was performed on all the coverages in each of the research sites.

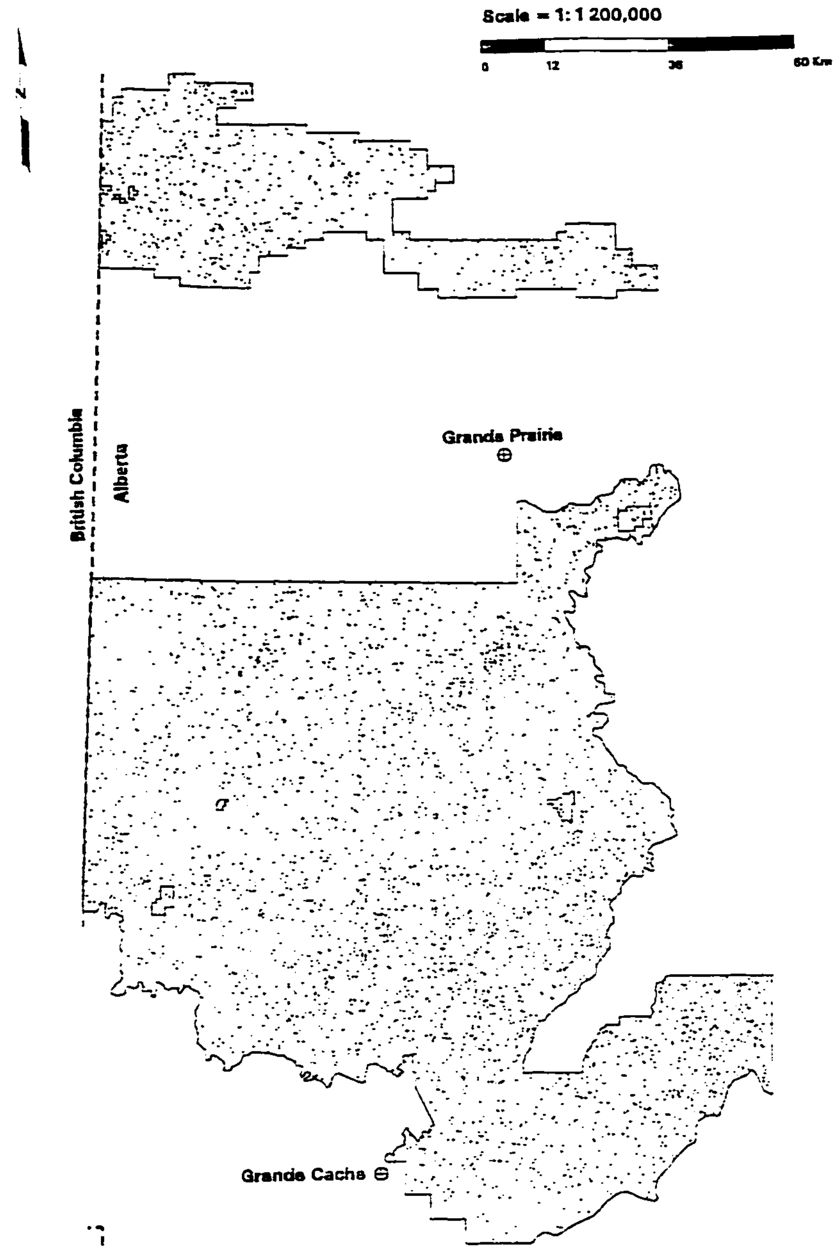


Figure 3-4 Location of lightning strikes recorded in Weyerhaeuser's Grande Prairie FMA in 1990.

It should be noted that the use of high and low, or categories 1 and 2, categories for the reclassification of the lightning strike and lightning fire densities is binary (Ross 1984). However, because the degrees of freedom in the error terms associated with the lightning strike and lightning fire data were so high, there was reasonable confidence that, based on the Central Limit Theorem, a normal distribution of the errors as required by the analysis of variance procedure could be assumed (Ross 1984).

3.6 Statistical Analyses

The recategorized data obtained from the Arc/Info™ manipulations were analyzed for statistically significant relationships, as outlined in the study objectives, using SPSS™ (version 7.5) statistical analysis software. It should be noted that in the Aspect and Elevation coverages for each research site, the density variables were considered to be the dependent variables, while in the Origin and Vegetation coverages, the density variables were used as the independent variables. Initial statistical analysis of the data involved the use of Partial Correlation procedures that allowed for the identification of statistically significant relationships between and among the dependent and independent variables in each of the coverages. However, due to the questionable robustness of this statistical procedure as reported by Meyers and Wells (1995) any discussion of the results obtained from the Partial Correlation procedures has been omitted. The results obtained during the Analysis of Variance procedures conducted on the data are presented and discussed in Chapters 4 and 5, respectively.

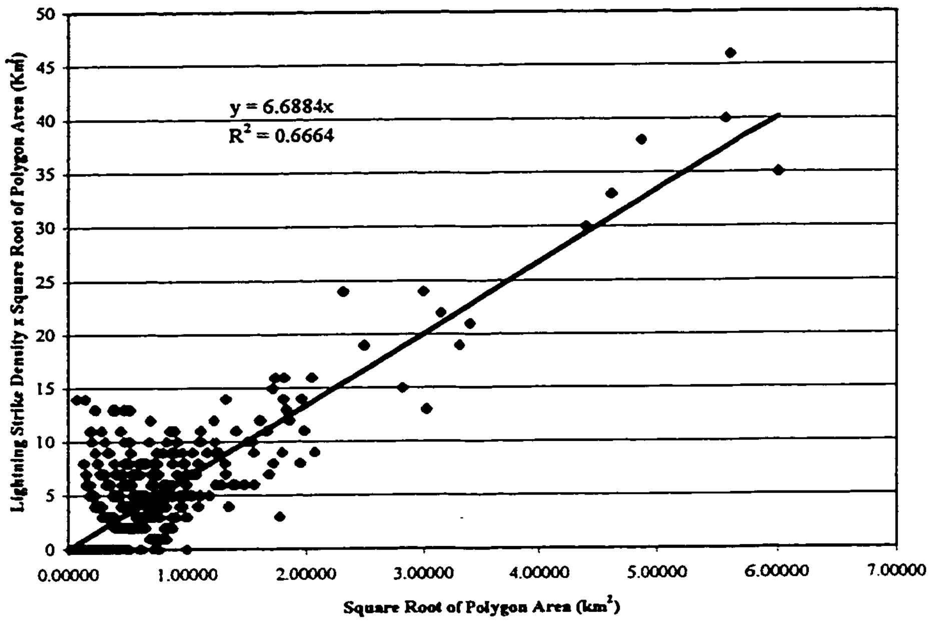


Figure 3-5 An example of a Scatter plot of the product of the lightning strike density multiplied by the square root of the area of each polygon versus the square root of the area of each polygon in the Narraway Stand Origin Coverage.

The equation of the straight line, given by the equation: $y = mx + b$

Where y= Value of the Dependent Variable

x = Value of the Independent Variable

m = Slope of the line,

b = Y-axis intercept value, which is equal to 0

The slope of the line approximated the value of the mean lightning strike density of the theoretical Population (μ) which was used as the point of reclassification of the original lightning density values into high (category 1) or low (category 2) values.

Chapter 4

RESULTS

4.1 Summary of Lightning Strike data

Approximately 2 % (92, 317) of the 5, 551, 562 lightning strikes to ground recorded throughout Alberta during the period between 1984 and 1996 were recorded within Weyerhaeuser's Grande Prairie FMA. This represents an average of only 7,101 (standard deviation, s.d. = 4,939) lightning strikes annually. The high standard deviation in the mean annual lightning within the FMA is indicative of the extreme variability in lightning occurrence from year to year. Appendix D contains tabular and graphical summaries of the cumulative positive, negative, total lightning by month and by year for the entire FMA. Although the occurrence of a lightning strike is thought to be random, when the density of lightning strikes is considered over long temporal or large spatial scales, certain patterns do appear. Figure 4-1 presents the density of lightning strikes, calculated for 9 km^2 grid cells, as recorded in the FMA between 1984 and 1996.

The mean annual number of positive, negative, and total lightning strikes, for the entire FMA, is plotted in Figure 4-2(A). All categories of lightning strikes show an increasing trend from 1984 to 1996. Mean annual positive lightning strikes appeared to peak in 1989. However, the average number of negative and cumulative lightning strikes was greatest in 1994. Figure 4-2(B) illustrates the average number of positive, negative, and cumulative lightning strikes by month for the FMA over the 14-year period. Mean lightning activity in the FMA was seen to increase from April, peaking in July, and then

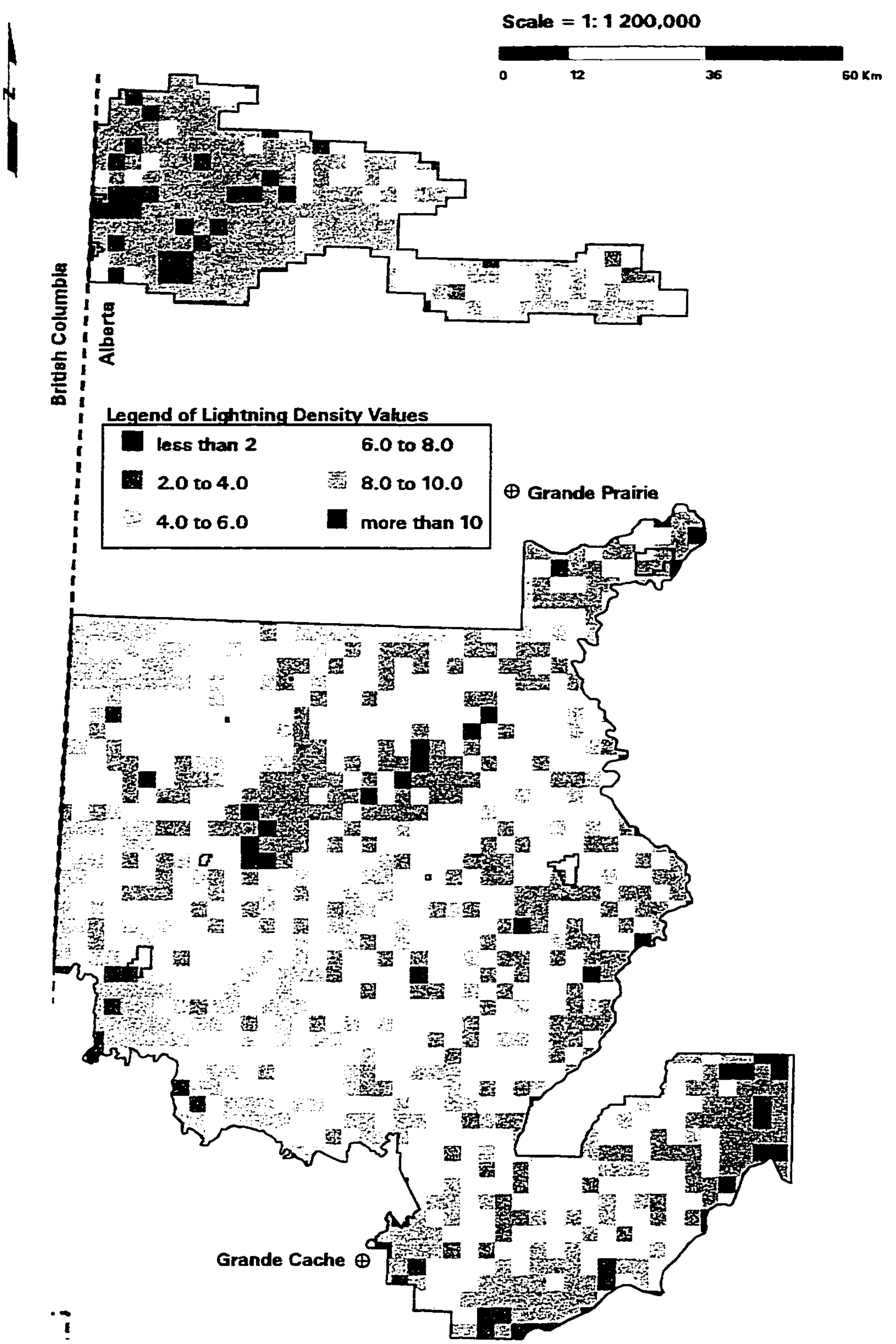


Figure 4-1 Cummulative lightning strike density, as measured by the number of strikes per square kilometer, in Weyerhaeuser Canada Limited's Grande Prairie FMA. Based on lightning strikes recorded between 1984 and 1996 input into a 3 Km x 3 Km raster grid.

Table 4-1 Cummulative number of Positive, Negative, and Total Lightning Strikes recorded in each research area between 1984 and 1996.

	Narraway			Prairie Creek			Mount Louie			Muddy Creek			Saddle Hills			Townships 62 & 63		
Year	Positive	Negative	Total	Positive	Negative	Total	Positive	Negative	Total	Positive	Negative	Total	Positive	Negative	Total	Positive	Negative	Total
1984	3	88	91	12	181	193	5	68	73	6	153	159	1	106	107	13	84	97
1985	10	31	41	5	29	34	8	55	63	12	38	50	10	46	56	12	133	145
1986	5	32	37	5	46	51	8	46	54	6	59	65	1	23	24	9	51	60
1987	15	180	195	17	191	208	7	139	146	6	132	138	10	70	80	17	290	307
1988	10	216	226	15	158	173	5	33	38	14	137	151	11	48	59	31	177	208
1989	41	300	341	42	348	390	14	202	216	42	329	371	69	473	542	37	536	573
1990	9	94	105	24	227	251	15	80	95	13	69	82	15	66	81	26	176	202
1991	18	63	81	38	186	224	17	254	271	14	70	84	25	117	142	45	246	291
1992	10	297	307	24	473	497	11	337	348	9	296	305	13	206	219	36	445	481
1993	33	296	329	33	351	384	25	274	299	32	292	324	36	295	331	34	455	489
1994	31	1139	1170	49	1089	1138	6	367	373	26	613	639	26	244	270	48	911	959
1995	13	114	127	15	194	209	8	156	164	21	73	94	19	102	121	9	186	195
1996	21	243	264	34	299	333	14	197	211	22	326	348	27	204	231	26	310	336

Table 4-2 Total and Average number of lightning fires, and associated area burned by research area and in the FMA between 1984 and 1996.

Research Site	Total No. Ltg Fires	Ave No. Fires	St. Dev	Total Area Burned (Ha)	Ave Area Burned (Ha)	Stdev
Narraway	3.00	1.50	0.71	0.50	0.17	0.71
Prairie Creek	14.00	2.33	1.21	1.40	0.10	1.21
Mount Louie	7.00	1.17	0.41	1.60	0.23	0.41
Muddy Creek	1.00	1.00	N/A	0.10	0.10	0.00
Saddlehills	2.00	1.00	0.00	0.20	0.10	0.00
Townships 62 and 63	21.00	2.63	1.60	2.60	0.12	1.60
FMA	225.00	17.31	18.28	77.17	3.34	9.74

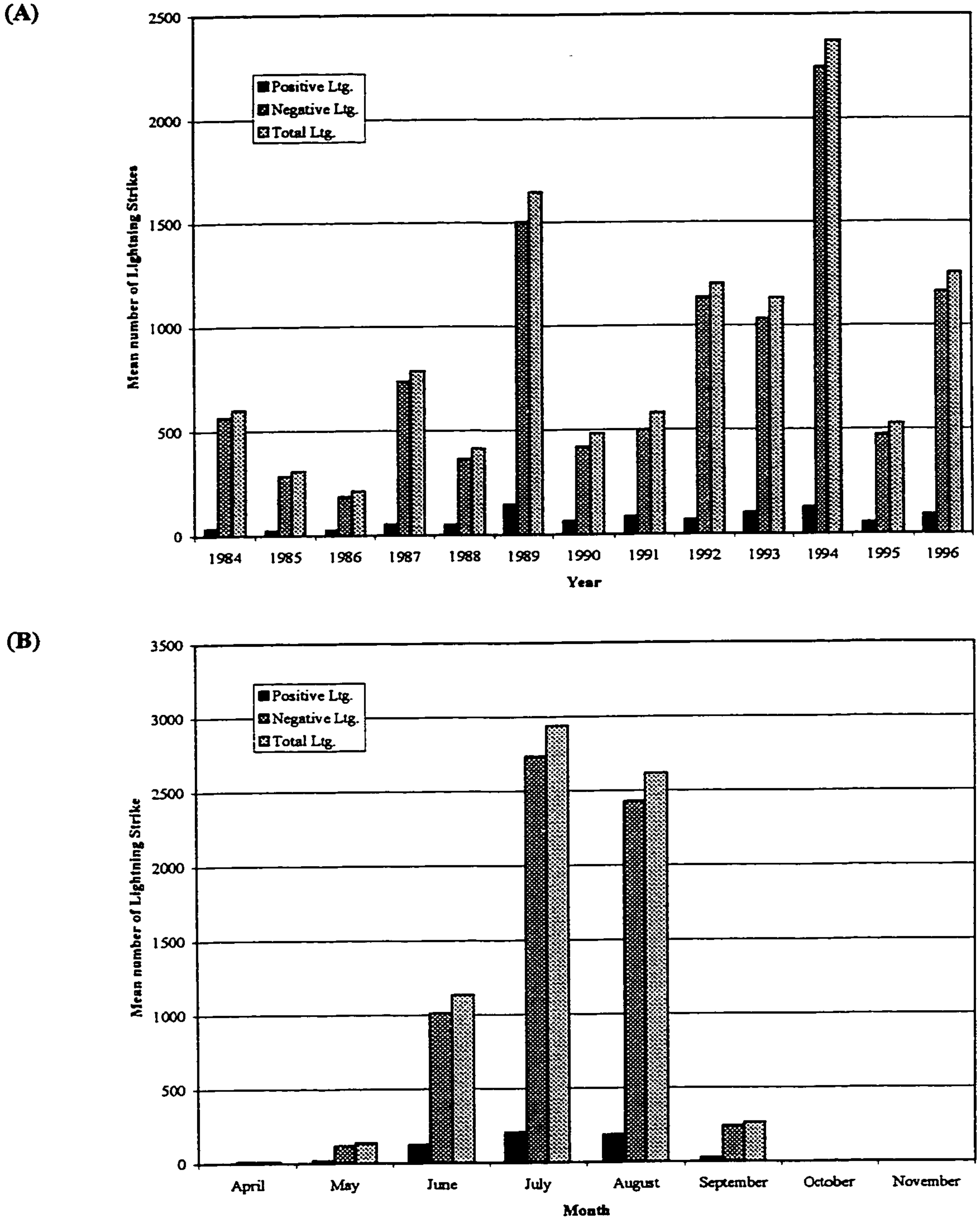


Figure 4-2 Mean Number of Lightning strikes by Year (A) and by Month (B) recorded in the FMA between 1984 and 1996.

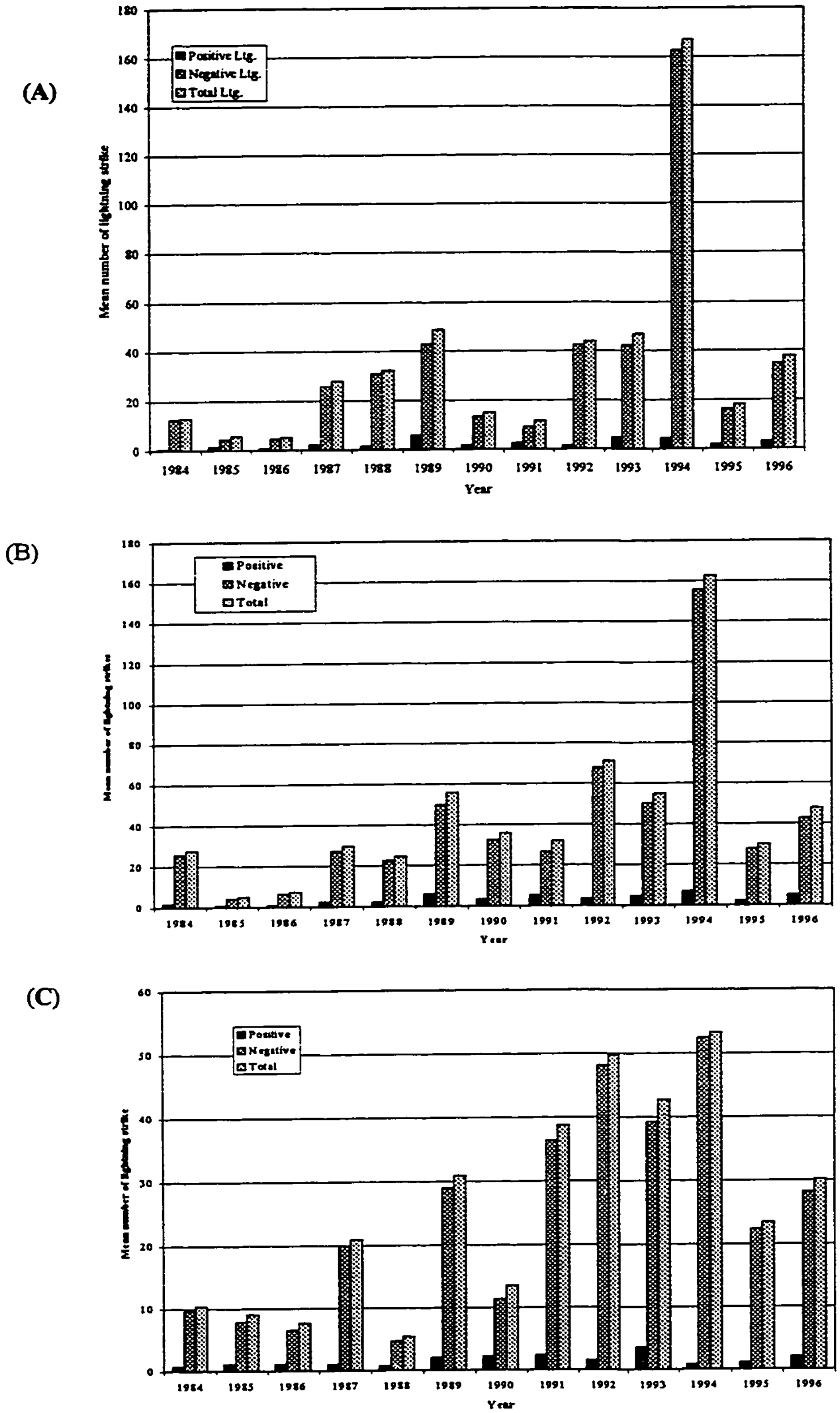
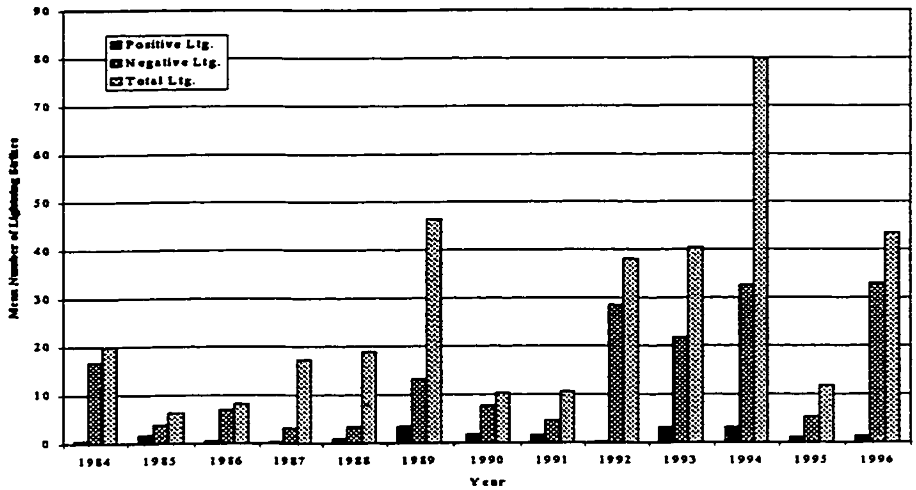
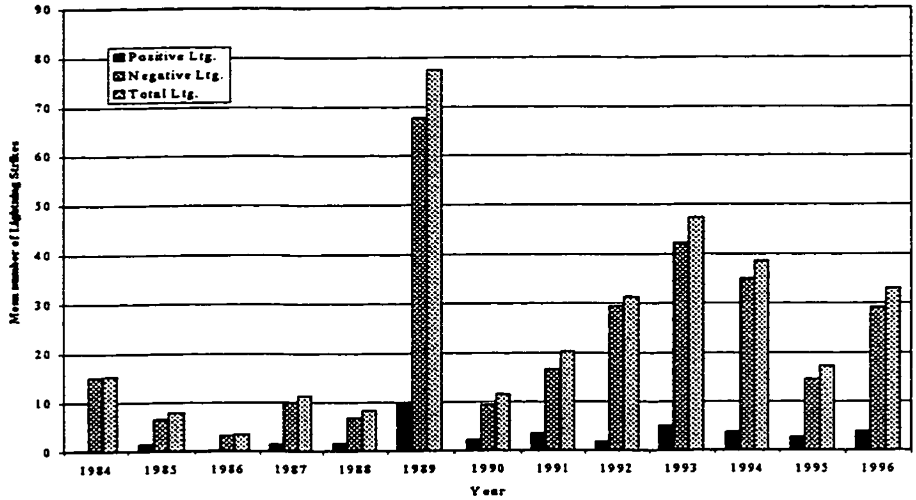


Figure 4-3. Mean number of lightning strikes, by year, recorded in the Narraway **(A)**, Prairie Creek **(B)**, and Mount Louie **(C)** research areas between 1984 and 1996.

(D)



(E)



(F)

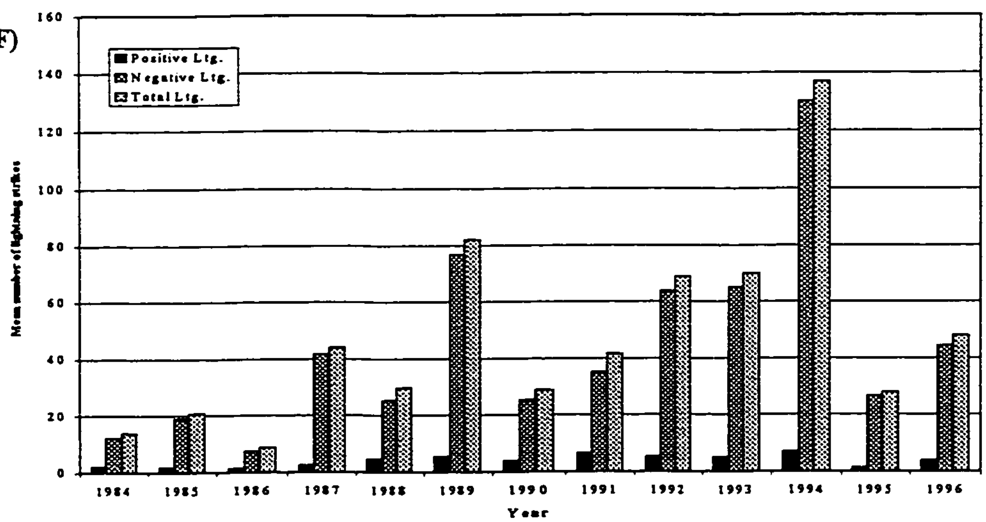


Figure 4-3. Mean number of lightning strikes, by year, recorded in the Muddy Creek **(D)**, Saddle Hills **(E)**, and Townships research **(F)** areas between 1984 and 1996.

decreasing to minimum levels in November (Figure 4-2B). Similar trends in both the mean annual and mean monthly lightning activity were observed in each of the six research areas, although total, and subsequently the mean, number of positive, negative, and cumulative lightning strikes were significantly lower.

Although tabular and graphical summaries of the total number of lightning strikes recorded, by year and by month, in each of the six research areas are contained in Appendix D, Table 4-1 contains a summary of the total number of lighting strikes by research area. Table 4-1 presents the number of observations on which the average number of positive, negative, and total lightning strikes, currently being discussed, are based.

Mean annual lightning activity in all of the research areas exhibited the same increasing trend seen in the FMA (Figure 4-3 (A) through 4-3 (F)). The largest mean number of lightning strikes occurred in 1994 for all but one of the research areas. In the Saddle Hills research area, mean annual lightning activity was greatest in 1989 (Figure 4-3(E)). However, as in the FMA, mean annual lightning activity in all of the research areas was associated with a great deal of variability from year to year. Interestingly, when the relative location, and area of each research area are considered in conjuction with the mean annual lightning activity, various trends were observed. For example, when the relative position of each research area from south to north was plotted against the mean lightning strike density; the mean annual number of negative, and total lightning strikes exhibited a decreasing trend (Figure 4-4). However, variations were noted which may reflect varying meteorological conditions prevalent in each research area (Figure 4-4). Mean annual positive lightning, however, showed a slightly

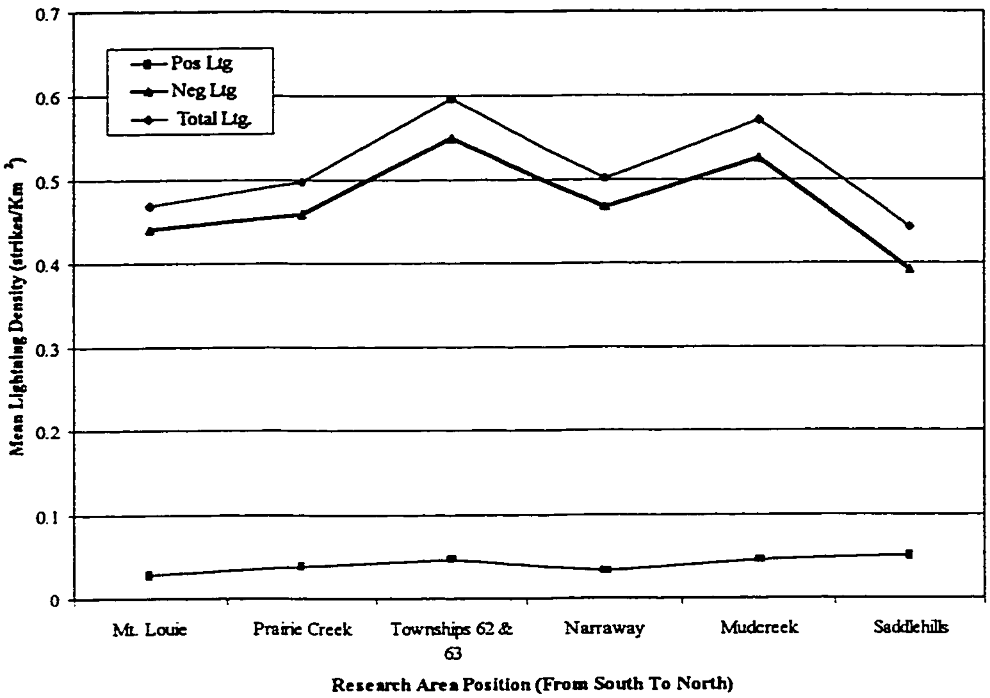


Figure 4-4 Mean lightning strike density (1984-1996) by relative location of research areas from south to north within the Grande Prairie FMA.

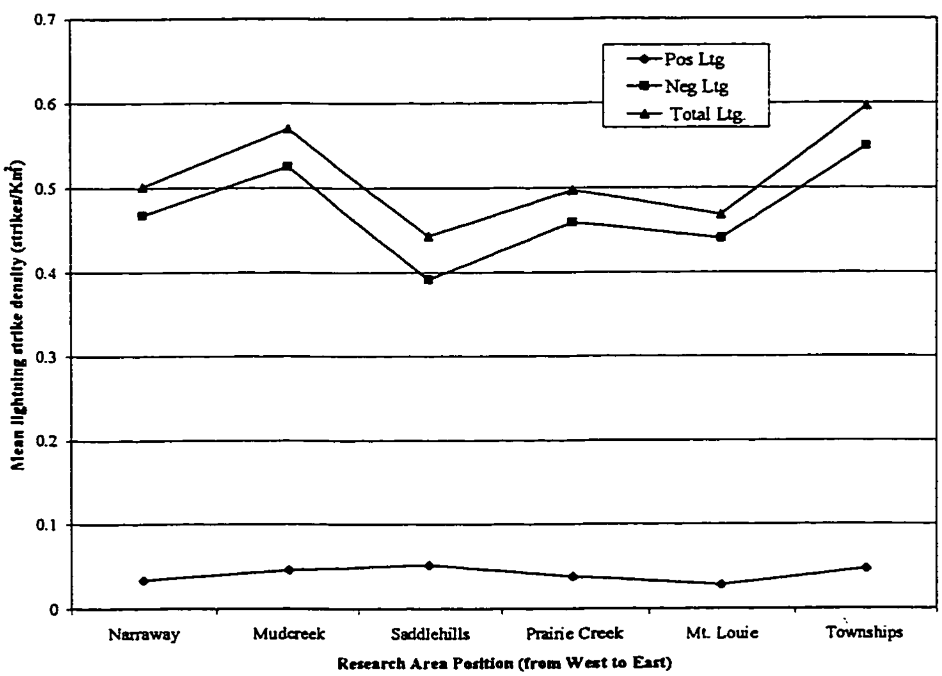


Figure 4-5 Mean lightning strikes density (1984-1996) by the relative location of the research areas from West to East within the FMA.

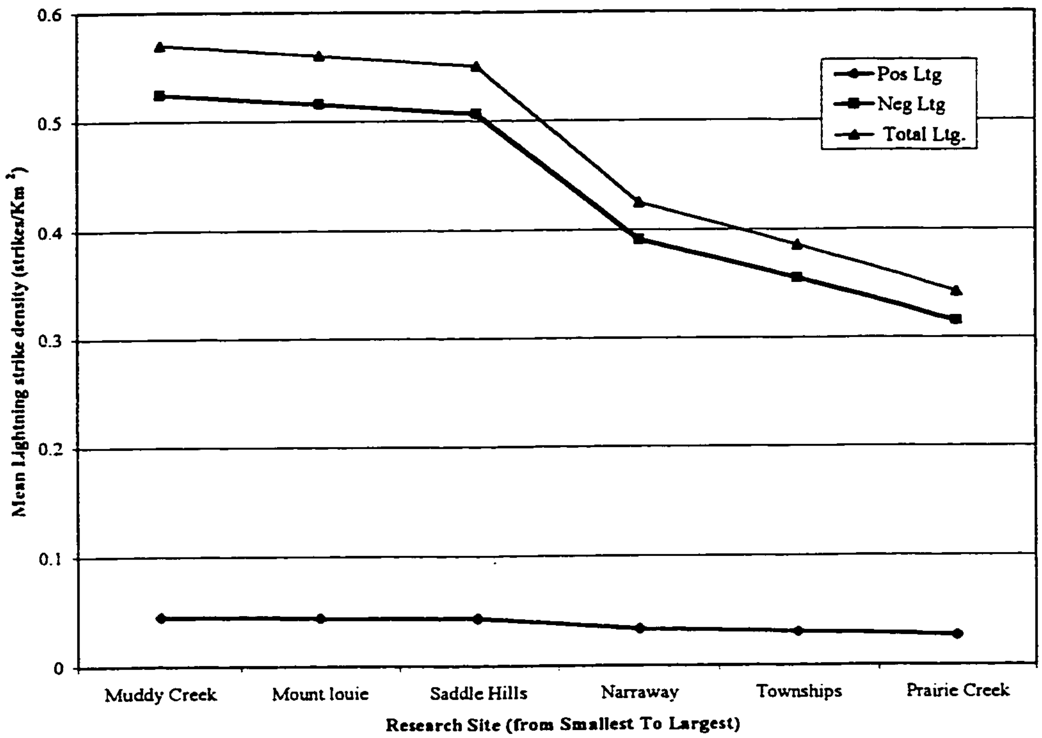


Figure 4-6 Mean lightning strike density (1984 -1996) by research area size (from smallest to largest).

increasing trend from south to north. In the case of the relative position of the research areas from west to east was plotted, the mean annual lightning strike activity showed increasing trends for positive, negative and total lightning (Figure 4-5). The same result was obtained when the mean annual lightning activity was plotted against the research area area (Figure 4-6).

Figures 4-7(A) through 4-7(F) illustrate the mean lightning activity by month in each of the six research areas. Similar to the FMA, peak monthly lightning activity increased from April, peaked in July, and reached a minimum in October. No lightning activity was recorded in November in any of the research areas during the period between 1984 and 1996. In Mount Louie, unlike the remaining research areas, peak average monthly lightning activity occurred in August rather than in July. Unfortunately, it was not possible to plot the average number of lightning strikes by month relative to the geographic position (West to East, or South to North), or the areal extent of each research. Consequently, no inferences can be made.

4.2 Summary of Lightning Fire Data

Although a there were an average of 7, 101 (s.d. = 4,939) lightning strikes recorded annually within the FMA, there was only an average of 1, 731 (s.d. = 18.28) lightning fires reported each year. The distinction is made between reported fires and detected fires, as it may have been possible that detected fires were not always reported. On average, these lightning fires burned an area of 3.34 (s.d. = 9.74) km^2 annually. Figure 4-8 illustrates the mean number of lightning fires, and average area burned by year within the FMA for the period between 1984 and 1996. These data, combined with the

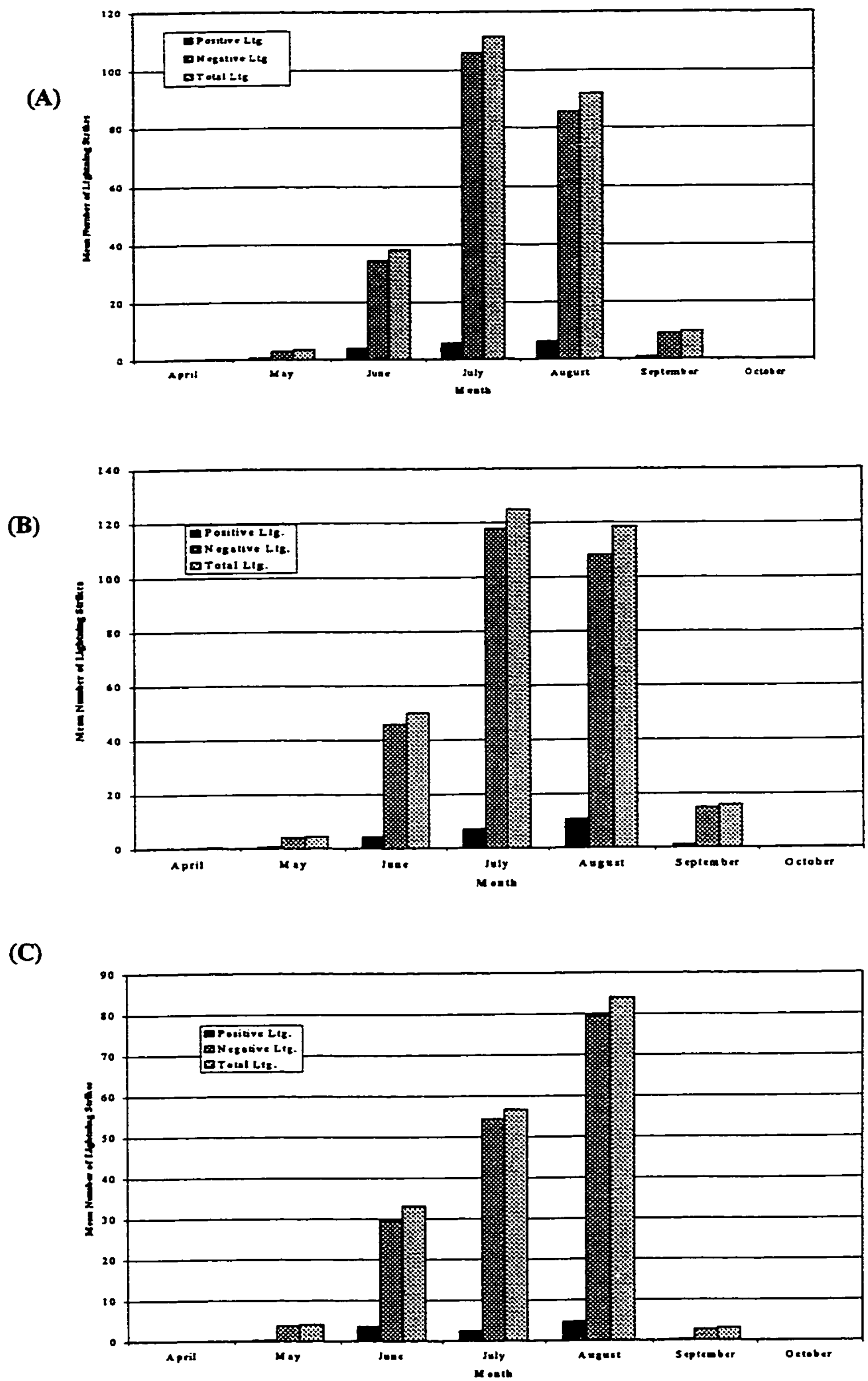


Figure 4-7. Mean number of lightning strikes, by month, recorded in the Narraway **(A)**, Prairie Creek **(B)**, and Mount Louie **(C)** research area between 1984 and 1996.

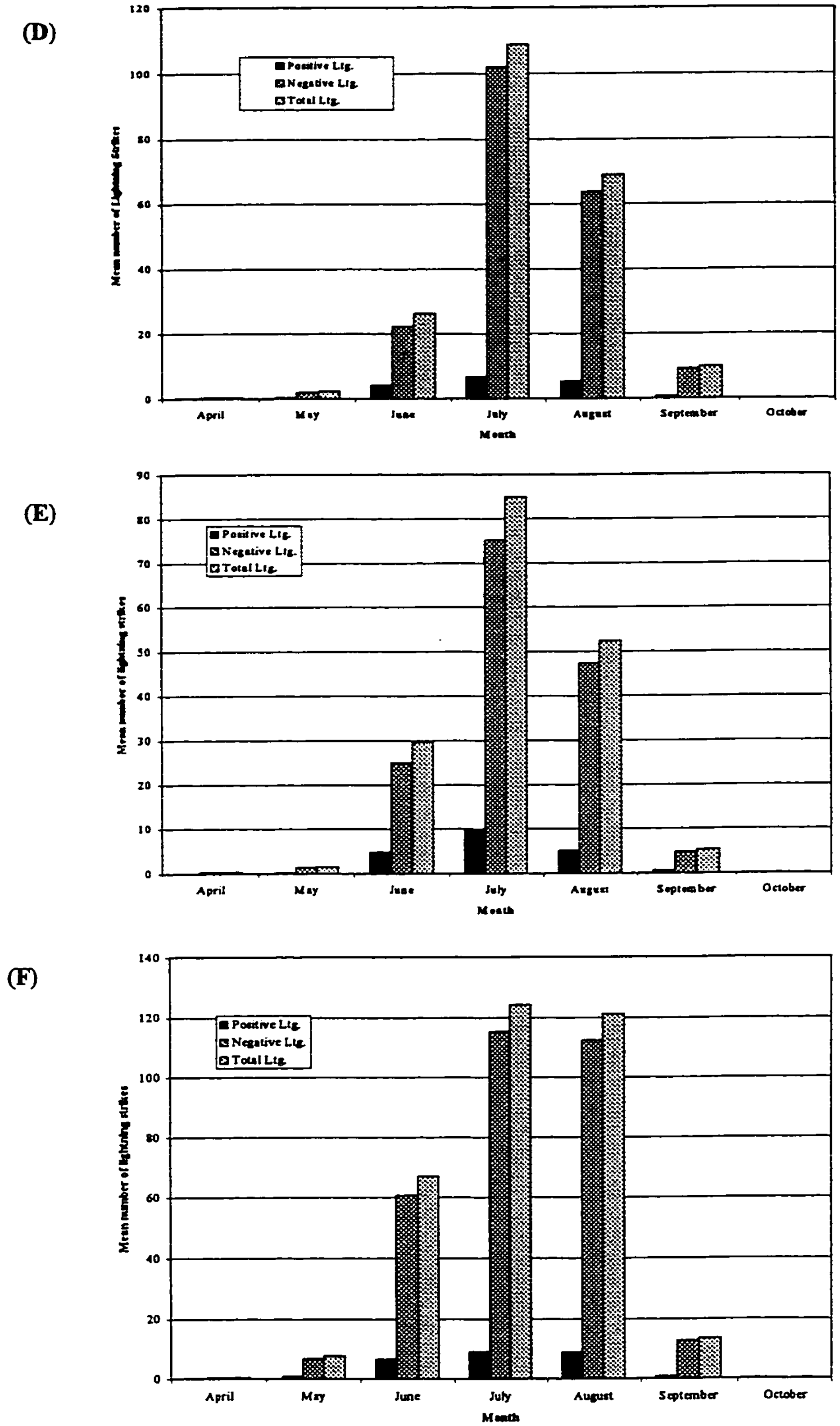


Figure 4-7 Mean number of lightning strikes, by month, recorded in the Muddy Creek **(D)**, Saddle Hills **(E)**, and Townships 62 & 63 **(F)** research area between 1984 and 1996.

total number of lightning fires and total area burned for the same time period is summarized in Table 4-2. Table 4-2 also summarizes the total and average number of lightning fires, and average area burned for each of the six research areas.

The highest average number of lightning fires recorded in the FMA was recorded in 1993 (Figure 4-8(A)). However, the largest average area burned in the FMA occurred in 1984 (Figure 4-8(A)). As portrayed in Figure 4-8(B), the largest mean number of lightning fires during the period between 1984 and 1996 occurred in the Prairie Creek research area, and the smallest average number of lightning fire occurred in the Muddy Creek research area. Conversely, the largest average area burned by lightning fires, for the same 14-year period, was seen in the Mount Louie research area (Figure 4-8(B)). This result is interesting as the Mount Louie research area had the third smallest average number of lightning fires. It may be that prevailing climatic conditions in the Mount Louie research area over the 14-year period were more conducive to burning and fire spread than in the other research areas. Three research areas: Prairie Creek, Muddy Creek, and Saddle Hills all represented the smallest average area burned by lightning fires (Figure 4-8(B)). The mean density of lightning fires and average area burned during the period from 1984 to 1996 by research area are plotted relative to the position of each research from South to North and West to East within the FMA, as well as by research area area from smallest to largest (Figure 4-9A to 4-9C). The resulting trends are quite different from the trends seen in similar plots of mean number of lightning strikes for each research area.

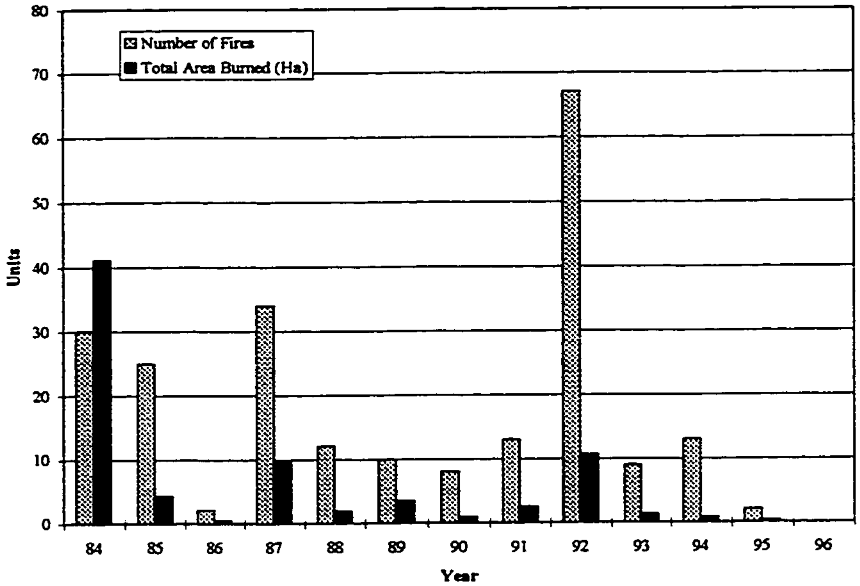


Figure 4-8A Mean annual number of lightning fires, and average area burned in the Grande Prairie Forest Management Area during the period between 1984 and 1996.

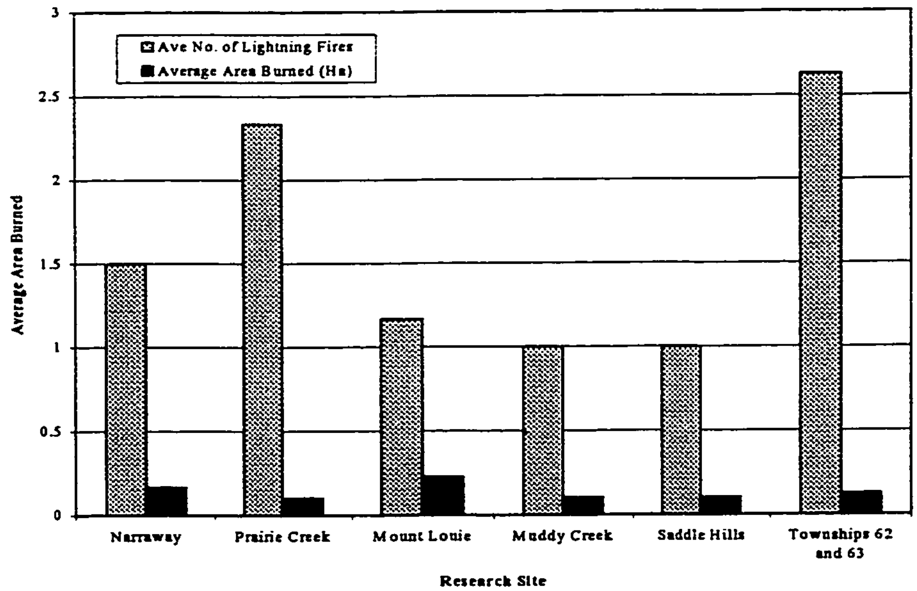
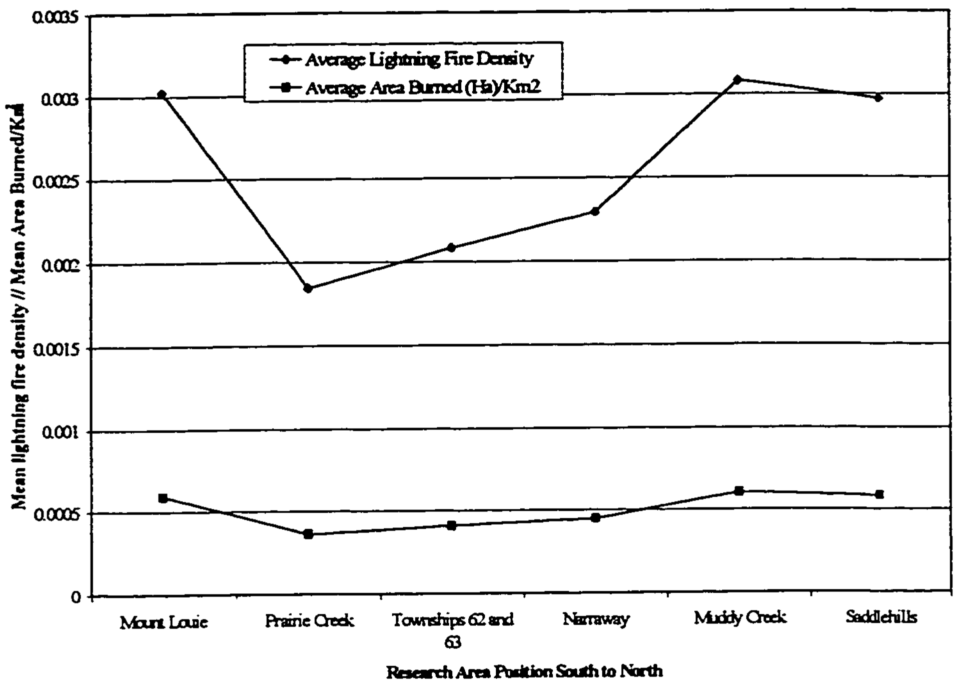


Figure 4-8B Mean number of lightning fires and average area burned by research area during the period between 1984 and 1996.

(A)



(B)

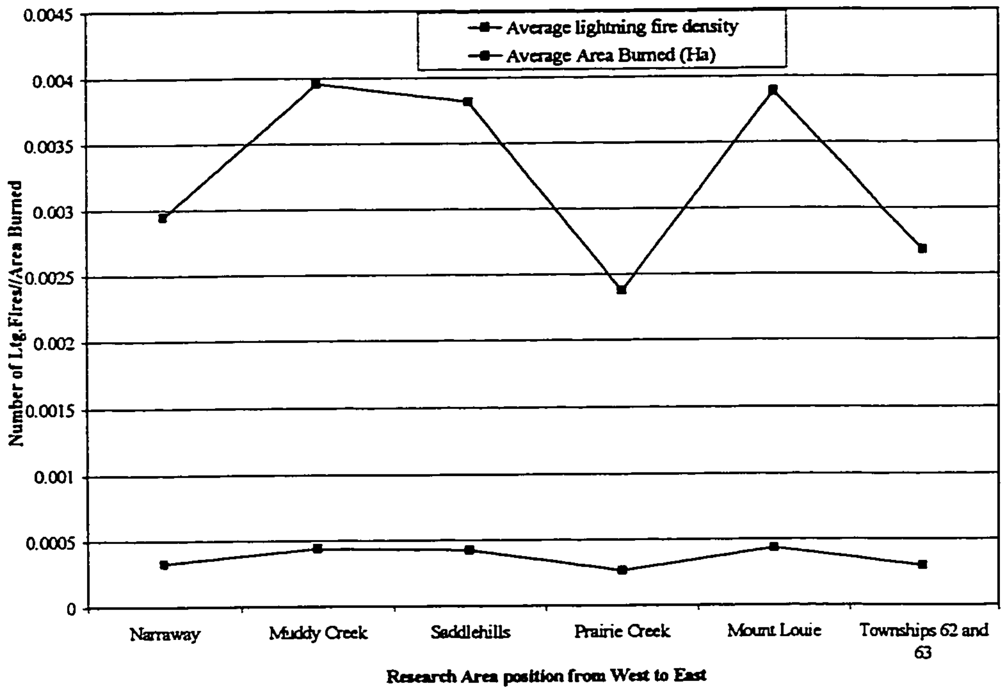


Figure 4-9 Mean lightning fires density, and average area burned per square kilometer by research area between 1984 and 1996 relative to the positions of the research areas within the FMA from **(A)** South to North, and **(B)** West to East.

(C)

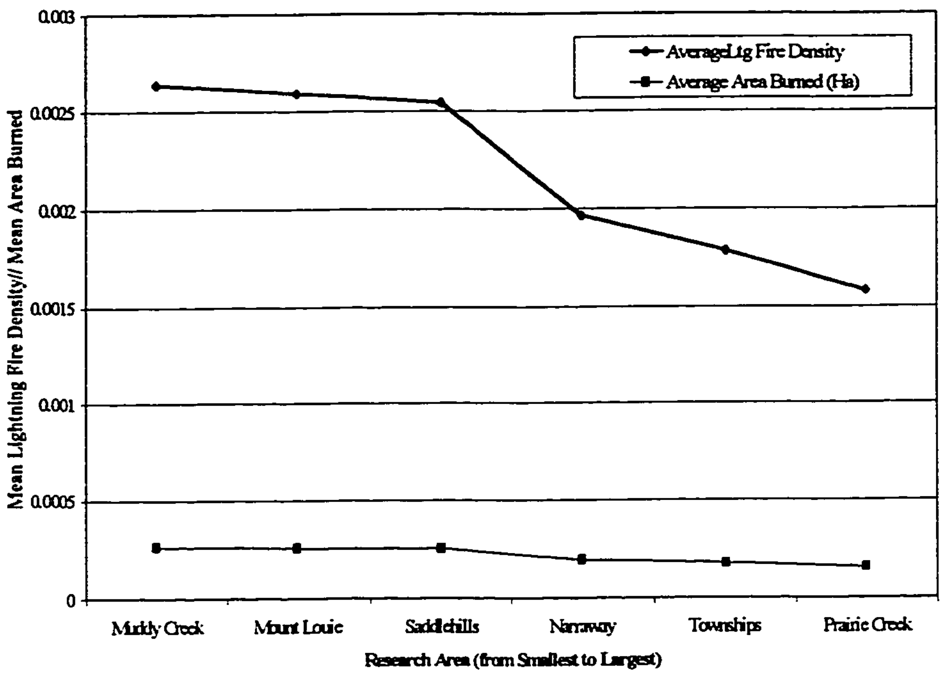


Figure 4-9 Mean lightning fires density, and average area burned per square kilometer by research area between 1984 and 1996 in relation to the areal extent of the research areas from smallest to largest.

Unlike the case of mean lightning strikes densities by research area there are no general trends in the mean density of lightning fires per square kilometer by research area from south to north. This is probably due to the low number of lightning fires recorded in the research areas. A very slight increasing trend was detected in the average area burned by lightning fires given the position of the research areas from south to north (Figure 4-9A). This may be an artifact of the weather or fuel related conditions in each of the six research areas.

Figure 4-9B portrays the mean number of lightning fires and average area burned by the relative location of each research area from west to east. Interestingly, a great deal of variation was noted in the average density of lightning fires. This variation, combined with the limited numbers of lightning fires recorded in each of the research areas may preclude definitive statements regarding trends. However, mean area burned by lightning fires exhibited a very slight decreasing trend (Figure 4-9B). Similarly, the mean lightning fire density, and average area burned per square kilometer recorded by research area, relative to the area of each site from smallest to largest, showed a decreasing trend (figure 4-9C). The significance of these results will be discussed in Chapter V.

4.3 Results from Statistical Analysis

For reader clarity, it should be noted that the word "effect" is widely used throughout this chapter. When used, however, it is used to refer to a statistically significant finding, or relationship between the variables rather than to imply a causal relationship. Given the extreme variability of the data used, it would be impossible to verify a causal nature of any of the statistically significant relationships identified in the present study.

Results obtained from the statistical analysis, including descriptive statistics, are presented according to each of the coverages generated from the Arc/Info™ procedures. For example, the results obtained from the analysis of the Aspect coverage data for each of the six research areas is presented together. A summary of the results obtained in the analysis of the data is presented. However, all the figures and tables pertaining to the results generated in the analysis are presented in detail in Appendices E and F.

4.3.1 Aspect

Narraway

Southeast was the dominant aspect class in the Narraway research area. Appendix E Figure E-1 shows the distribution of mean polygon area by aspect classes for the polygons contained within the Aspect coverage for Narraway (Appendix E). Descriptive statistics for the Narraway Aspect coverage are summarized in Appendix Table D-4 .

The Analysis of Variance procedures, conducted on the aspect coverage, involved using the Aspect class as the independent variable, and the density variables as the dependent variables. This seemed logical, as it was thought that each of the density variables would influenced by the aspect class and not vice versa. According to this study, as indicated in Table 4-3, aspect was not observed to have a statistically significant effect on the density of lightning, positive lightning or lightning fires. Possible reasons for the lack of a statistically significant effect will be discussed in Chapter V.

Prairie Creek

Northwest facing aspects, represented by an aspect class of 4, encompassed the largest average area of the Prairie Creek research area (Figure E-2). The mean lightning, positive lightning, and lightning fire densities were calculated to be 6.355 (s.d. = 70.18), 0.351 (s.d. = 17.42), and 0.00153 (s.d. = 0.078). These values, as well as other descriptive statistics for the Prairie Creek aspect coverage are presented in Appendix Table D-5. The large standard deviations in each of the mean density values reflects the high degree of variability associated with the lightning strike, and lightning fire data used in the analysis.

The results of the analysis of variance procedures conducted on the Prairie Creek Aspect coverage data are summarized in Table 4-3, and presented in detail in Appendix Table E-2. Aspect class in the Prairie Creek research area, as in Narraway, was considered to be the independent variable during the Analysis of Variance procedures. Unfortunately, in this study aspect class was not observed to have a significant effect on either of the lightning or positive lightning strike densities, or the density of lightning fires (Table 4-3).

Mount Louie

Mount Louie, out of all the research areas, had the aspect coverage containing the largest number of polygons. The Mount Louie aspect coverage was comprised of 41 899 polygons, with a mean area of 1.3 km^2, which would seem to indicate that Mount Louie had the most varied terrain of all of the research areas. As illustrated in Appendix E Figure E-3, Southwest and Northeast facing aspects, represented by aspect class 3 and 1

Table 4-3 Summary of the F-ratio values calculated during the Analysis of Variance Procedures (ANOVA) conducted on the Aspect Coverage in each of the 6 research areas.

		Aspect		
Research Area	**DF**	***Lightning Strike Density***	***Positive Lightning Strike Density***	***Lightning Fire Density***
Narraway	3	0.03	2.27	1.28
Prairie Creek	3	2.39	2.45	1.33
Mount Louie	3	1.07	2.49	2.30
Muddy Creek	3	1.98	1.43	0.91
Saddle Hills	3	0.07	0.39	2.03
Townships	3	0.71	2.00	1.51

DF = Degrees of Freedom (n-1)
* = Pr > F is significant at 95 % Confidence Interval
** = Pr > F is significant at 99 % Confidence Interval

respectively, dominated the Mount Louie research area. The mean values of lightning, positive lightning, and lightning fire densities, which are summarized along with other descriptive statistics in Appendix Table D-6, and the associated standard deviations reflect the high variability in the number of lightning strikes or lightning fires recorded per square kilometer.

Aspect class in Mount Louie , as in the Narraway and Prairie Creek areas, was not observed to have a statistically significant effect on the density of lightning strikes, positive lightning strikes or lightning fires. Table 4-3 presents a summary the results obtained from the ANOVA procedures conducted on the Mount Louie Aspect Coverage data. A detailed ANOVA table is present in Appendix Table E-3. Reasons for the lack of a significant finding will be discussed in the next chapter.

Muddy Creek

Northeast and Northwest facing aspects, represented by aspect classes 1 and 4 respectively, covered the largest average area of the Muddy Creek research area (Appendix E Figure E-4,). Descriptive statistics calculated for the coverage are presented in Appendix Table D-7. The mean lightning fire density, listed in Appendix Table D-7, for this coverage is extremely low and is related to the fact that only 1 lightning fire was recorded in Muddy Creek research area in the entire 14 year period between 1984 and 1996. This fact is true for all coverages in the Muddy Creek research area.

The results of the ANOVA procedures indicated that aspect class was not seen to have any statistically significant effects on the density variables (Table 4-3). This is the same result that was obtained in the other research areas. These findings will be discussed in Chapter V.

Saddle Hills

The mean area by aspect class for the aspect coverage of the Saddle Hills research area is plotted in Appendix E Figure E-4 and illustrates that Aspect Class 4 and 2 covered the largest average area of coverage respectively. This means that Northwest and Southeast facing aspects dominated the coverage. Descriptive statistics for this coverage are presented in Appendix Table D-8. The maximum value of the lightning fire density is 533 lightning fires per square kilometer. However, this high value is due to a single lightning fire having occurred in a polygon with an area of only 0.00188 km^2.

Appendix Table E-5 details the results obtained from the ANOVA procedures conducted on the Aspect coverage of the Saddle Hills area. However, as summarized in Table 4-3, the aspect class was not seen to have a significant effect on the density of lightning, positive lightning, or lightning fires (Table 4-3).

Townships 62 and 63 (Township)

The largest average area of this research area was encompassed by Northeast facing aspects, represented by an aspect class of 1. Appendix E Figure E-6 shows the mean area by aspect class for the Township research area. Descriptive statistics associated with the aspect coverage for the research area are contained in Appendix Table D-9. The results obtained from the Analysis of Variation conducted on the Aspect coverage for the Township research area are summarized in Table 4-3. However, as with the other research areas, aspect was not observed to have a statistically significant effect on the lightning strike, positive lightning strike, or lightning fire density (Table 4-3).

4.3.2 Elevation

The values of the F-ratios calculated during the ANOVA procedures conducted on the Elevation coverage in each research area are summarized in Table 4-4. As was the case with the Aspect coverages, detailed results obtained during the analysis of variance procedures for the Elevation coverage of each research area are presented in Appendix E. Appendix D contains descriptive statistics calculated for the elevation coverage of each research area.

Narraway

Elevation in the Narraway research area ranged from a minimum of 733 meters (a.s.l) to a maximum of 1690 meters (a.s.l). However, the average elevation was calculated to be 1,183 (s.d. = 146) meters (a.s.l). Appendix E Figure E-7 illustrates the mean polygon area by elevation class in the Narraway research area. The mean lightning, positive lightning, and lightning fire densities for the elevation coverage are summarized in Appendix Table D-10 in conjuction with other descriptive statistics calculated for the Narraway Elevation coverage. As with the Aspect coverage, the elevation class was considered to be the independent variable, while the density variables were all considered to be dependent.

Results from the ANOVA procedures, which are summarized in Table 4-4, conducted on the Elevation coverage of the Narraway research area indicate that no statistically significant effect of elevation class on the density of lightning fires was observed. However, a statistically significant effect of elevation class on both the density of lightning strikes $(0.0130 < p < \alpha = 0.05)$ and positive lightning strikes $(0.0023 < p < \alpha = 0.01)$ was seen (Appendix Table E-7). The total lightning strike density and positive lightning strike densities, plotted against elevation class are illustrated in Figures F-8(A) and F-8(B) respectively. Both the positive and the total lightning strike densities exhibited an increasing trend with increasing elevation. However, the total lightning strike density was largest in elevation class 5, while the total positive lightning strike density was largest in elevation class 6.

Prairie Creek

Appendix E Figure E-9 illustrates the distribution of mean area by elevation classes in the Prairie Creek research area. Elevation class 6, from 1200 to 1300 meters (a.s.l), was found to dominate this research area (Appendix E Figure E-9). Descriptive statistics calculated for this coverage are presented in Appendix Table D-11.

The results of the Analysis of Variance procedures conducted on the recategorized data revealed that elevation class did not have an effect of the density of either lightning strikes, positive lightning strikes or lightning fires (Table 4-4). The absence of a significant effect of elevation on the density variables in Prairie Creek may be due to the relative geographic location of the research area in the FMA, or reduced land area in the higher elevation classes. These possible explanations, as well as several others will be discussed in Chapter V.

Mount Louie

As illustrated in Appendix E Figure E-10, an elevation class of 8 covered the largest area, on average, of the Mount Louie Elevation coverage. The elevation class represented elevations ranging between 1400 and 1500 meters (a.s.l). Descriptive statistics calculated for the data associated with the Mount Louie Elevation coverage are presented in Appendix Table D-12. As in the coverages of other research areas, the high variability in the density of lightning and positive lightning strikes, and lightning fires is reflected in both the high standard deviations associated with each of the mean density values and the high variance values listed in Appendix Table D-12. This high variability in the density values, as previously mentioned, was predominantly due to the significant variability associated with lightning strike occurrence, and the accuracy of the detection systems used.

A statistically significant relationship between elevation and lightning density was observed when the results of the ANOVA procedures conducted on the elevation data were examined. These results, summarized in Table 4-4, indicate that the effect of elevation on lightning density was highly significant $(0.0001 < p < \alpha = 0.01)$ (Appendix Table E-9). Appendix E Figure E-11 presents the total lightning density by elevation class, and shows that total lightning density increases with elevation. The largest total lightning density occurred in elevation class 13, which also had the smallest average area. However, the possible effects of area on the lightning density had been controlled for

Table 4-4 Summary of the F-ratio values calculated during the ANOVA procedures conducted on the Elevation coverages in each of the six research areas.

		Elevation		
Research Area	**DF**	***Lightning Strike Density***	***Positive Lightning Strike Density***	***Lightning Fire Density***
Narraway	9	2.43*	3.04**	0.47
Prairie Creek	10	0.78	1.59	0.43
Mount Louie	10	5.59**	0.82	0.63
Muddy Creek	6	2.10	2.39*	0.93
Saddle Hills	3	0.89	0.65	0.78
Townships	5	3.40**	1.02**	1.18

DF = Degrees of Freedom (n-1)
* = Pr > F is significant at 95 % Confidence Interval
** = Pr > F is significant at 99 % Confidence Interval

prior to the Analysis of Variance procedures being conducted to the Mount Louie Elevation coverage. The significance of this will be discussed in Chapter V.

Although the effect of elevation on the lightning density was seen to be significant, elevation was not observed to have a significant effect on either the density of positive lightning strikes, or lightning fires (Tables 4-4, and Appendix Table E-9). This lack of a significant effect may have been due to several possible reasons, which will be discussed in the proceeding chapter.

Muddy Creek

The mean elevation in the Muddy Creek research area was found to be 956.21 meters (s.d. = 105.49 m), and the elevation ranged from a minimum of 745.97 meters to a maximum of 1396.58 meters. This range in elevation resulted in Muddy Creek having seven elevation classes after the reclassification procedures. Figure E-12, contained in Appendix E, illustrates the finding that the largest average area of the Muddy Creek elevation coverage was contained in elevation class 3 that included elevations between 900 and 1000 meters (a.s.l). Appendix Table D-13 summarizes the descriptive statistics for the Muddy Creek Elevation coverage.

An examination of the ANOVA results indicated that no significant relationship between the lightning strike, or lightning fire densities had been observed (Table 4-4). However, the results of the Analysis of Variance performed on the Elevation coverage data, and presented in detain in Table E-10, did reveal a significant effect of the Elevation class on the positive lightning strike density $(0.039 < p < \alpha = 0.05)$ (Appendix Table E-10). The graph of the total positive lightning strike density plotted against the elevation classes shows a slight increasing trend. However, the total number of positive lightning strikes was at a maximum level in the fourth elevation class (1,000 - 1, 100 meters (a.s.l)) (Appendix E Figure E-13). Possible reasons for this finding will be discussed later.

Saddle Hills

The Saddle Hills area exhibited the lowest degree of topographic variation of all six research areas. Only 4 classes were needed to cover the range in elevation, which ranged from a minimum of 755 meters (a.s.l) to a maximum of 1018 meters (a.s.l). The mean elevation was calculated to be 877 (s.d. = 41.37) meters (a.s.l). The mean area by elevation class for the Saddle Hills area is shown in Appendix E Figure F-14. As was found other in the coverages of other research areas, there was a high degree of variance associated with the mean values of the lightning, positive lightning, and lightning fire densities due to the effect of area. These values, as well as other descriptive statistics that were calculated for the Saddle Hills Elevation coverage are presented in Appendix Table D-14. There were no significant effects of elevation on the density variables observed in the results of the ANOVA procedures for the coverage (Table 4-4, and Appendix Table E-11).

Townships 62 and 63 (Township)

Only 6 elevation classes were required to cover the range in elevations in the Townships research area, which went from a minimum to a maximum value of 761 to1218 meters (a.s.l), respectively. The mean area by elevation class for the Township research area is portrayed in Appendix E Figure E-15, and reveals that an elevation class of 3 (900 to 1000 meters (a.s.l).) encompassed the largest average area. Descriptive statistics calculated for this coverage are summarized in Appendix Table D-15, while the ANOVA results are presented in detail in Appendix Table E-12. Elevation class was seen to have a highly significant effect on the density of lightning strikes ($0.007 < p < \alpha = 0.01$) (Table 4-4, and Appendix Table E-12). Appendix E Figure E-16 suggests the total lightning density was greatest in elevation class 2. Additionally, the total lightning density exhibited a slight decreasing trend with elevation (Appendix E Figure E-15). These findings represents a departure from the significant results obtained in the elevation coverages of the other research areas in which the total lightning density was found to be greatest in the mid to upper elevation classes. Unfortunately, the effect of elevation class on the density of lightning strikes was the only significant effect observed. Elevation class was not seen to have an effect on the density of positive lightning strikes or the density of lightning fires (Table 4-4, and Appendix Table E-12).

4.3.3 Vegetation

Narraway

Pine, principally lodgepole pine, was the dominant vegetation type in the Narraway research area, followed by spruce species. The mean area by vegetation class is shown in Appendix E Figure E-17. Descriptive statistics for the Narraway Vegetation coverage are summarized in Appendix Table D-16.

Based on the results of the ANOVA procedures conducted on the vegetation data summarized in Table 4-5, it was observed that both the lightning strike and lightning fire densities were seen to have a statistically significant effect on the vegetation class (Table

4-5 and Appendix Table E-13). The density of positive lightning, however, apparently did not have a significant effect on the vegetation class. Possible reasons for these findings are discussed in the following chapter. These significant relationships are presented in Appendix E Figures E-18(A) and Appendix E-18(B), respectively. Areas containing no vegetation experienced the greatest number of lightning strikes per square kilometer, while areas of spruce and pine species experienced the lowest lightning strike densities. (Appendix E Figure E-18A). Conversely, when the density of lightning fires was examined, the pine species experienced the largest number of lightning fires per square kilometer, while the other vegetation classes in the Narraway area experienced no fires between 1984 and 1996 (Appendix E Figure E-18B). The high density of lightning fires seen in those areas dominated by pine species may be related to the moisture conditions in those areas. However, this will be discussed in further detail in Chapter V.

Prairie Creek

Pine species, represented by a vegetation class of 3, dominated the vegetation coverage of the Prairie Creek research area, as in Narraway (Appendix E Figure E-19). Descriptive statistics, including the mean lightning, positive lightning, and lightning fire densities and the respective standard deviations, are presented in Appendix Table D-17.

The analysis of variance procedures, the results of which are summarized in Table 4-5, conducted on the Prairie Creek vegetation data revealed some interesting observations. Only the density of lightning fires was seen to have a highly significant effect (Table 4-5). Appendix E Figure E-20 represents a scatter plot of the vegetation class plotted against the density of lightning fires. This figure suggests that pine species (vegetation class 3) had a slightly greater density of lightning fires than other vegetation classes (Appendix E Figure E-20). Interestingly, this occurred despite the pine species encompassing the largest average area of the Prairie Creek research area. It would be logical to expect that large numbers of lightning fires occurring in the vegetation class with occupying the largest mean area should result in the smallest lightning fire densities. However, that was not the case in the Prairie Creek research area. The fact that a high density of lightning fires was also seen in areas dominated by species other than spruce or pine may be related to the large number of lightning fires that were recorded in the Prairie Creek research area between 1984 and 1996. The relatively low number of lightning fires recorded over the same time period in the other research areas may be part of the reason that lightning fires were not seen to occur in other vegetation types in other research areas. Possible reasons for these results will be discussed in Chapter V.

Mount Louie

Generally, the vegetation in the Mount Louie research area, as presented in Appendix E Figure E-21, was dominated by pine species. However, the mean area covered by species other than spruce or pine, represented by a vegetation class of 1. Species other than spruce or pine (vegetation class of 1) were not observed to comprise a large mean area in either the Narraway or Prairie Creek research areas. The significance of this finding, and its importance relative to other findings will be discussed in further detail in Chapter V.

Descriptive statistics for the vegetation coverage of the Mount Louie research area are presented in Appendix Table D-18, while the results of the Analysis of Variance

procedures conducted on this coverage are summarized in Appendix Table E-15, and are presented in detail in Appendix Table E-15. Unfortunately, neither the density of lightning or positive lightning
strikes, nor the density of lightning fires was found to have a statistically significant effect on the type of vegetation in the Mount Louie research area (Table 4-5).

Muddy Creek

Unlike other research areas, in which Pine species covered the largest average area, the Muddy Creek research area was dominated by species of vegetation other than spruce or pine. This is illustrated in Appendix E Figure E-22 by the dominance of a vegetation class of one. It should be noted that although this vegetation class includes predominantly deciduous tree species like aspen, poplar, and birch it does also include fir and larch species. As stated in Chapter III, vegetation class 1 includes any species other than spruce or pine. Appendix Table D-19 contains the descriptive statistics calculated for the Muddy Creek Vegetation Coverage. The Analysis of Variance procedures, the results of which are presented in Table 4-5, did not reveal any significant relationships (effects) between either the lightning and positive lightning strike densities, or the density of lightning fires and the type of vegetation seen (Table 4-5, and Appendix Table E-16).

Saddle Hills

Vegetation species other than spruce or pine, represented by a vegetation class of 1 was found to encompass the largest average area of the Saddle Hills research area (Appendix E Figure E-23). Descriptive statistics calculated for the vegetation coverage

Table 4-5 Summary of the F-ratio values calculated during the ANOVA procedures conducted on the Vegetation Type coverages in each of the six research areas.

		Vegetation Type		
Research Area	**DF**	*Lightning strike density*	*Positive lightning strike density*	*Lightning fire density*
Narraway	1	9.812**	0.012	4.78*
Prairie Creek	1	1.922	2.221	10.267**
Mount Louie	1	0.011	0.007	1.053
Muddy Creek	1	0.208	0.101	0.419
Saddle Hills	1	0.150	0.296	0.201
Townships	1	0.402	0.120	0.273

DF = Degrees of Freedom (n-1)

* = Pr > F is significant at 95 % Confidence Interval

** = Pr > F is significant at 99 % Confidence Interval

of the Saddle Hills research area are presented in Appendix Table D-20 while the results of the ANOVA procedures are summarized in Table 4-5. ANOVA results are presented in detail in Appendix Table E-17. The results of the ANOVA conducted on the coverage fail to show the presence of effects between the independent density variables and the dependent vegetation class variable that would be considered statistically significant (Table 4-5).

Township

Spruce species covered the largest area, on average, of the Township research area (Appendix E Figure E-24). Appendix E Figure E-24 illustrates the mean polygon area by vegetation class for the research Area. Descriptive statistics are contained in Appendix Table D-21, and the results of the ANOVA procedures are summarized in Table 4-5.

The largest annual and monthly average number of lightning strikes, and largest average number lightning fires were recorded in the Township research area over the 14-year period between 1984 and 1996. Despite this, however, the lightning, positive lightning, and lightning fire densities were not found to have a significant effect on vegetation class (Table 4-5, and Appendix Table E-18). Possible reasons for the lack of any significant results are discussed in Chapter V.

4.3.4 Stand Age Class

Narraway

In the Narraway research area, as illustrated in Appendix E Figure E-25, twelve 20-year stand age classes were represented, with the 100-year age class encompassing the largest average area. Appendix Table D-22 represents a summary of the descriptive statistics calculated for the Narraway stand age-class coverage. It is important to remember that the large maximum values of lightning, and positive lightning densities may have been due to the occurrence of numerous lightning strikes occurring in either a single polygon, or several polygons, having a small area. The small maximum value of lightning fire density seen in Appendix Table D-22 is due to the fact that only three lightning fires were reported in the Narraway research area during the period between 1984 and 1996.

The lightning strike, positive lightning strike, and lightning fire densities were considered to be the independent variables when the stand age-class data were considered. Logically, it makes more sense that lightning density will effect stand age-class, rather than vice versa. The ANOVA results, using the density variables as the independent variables, for the Narraway stand age-class coverage are presented in detail in Appendix Table E-19. However, a summary of the ANOVA results is presented in Table 4-6 When considered individually, the lightning, positive lightning, and lightning fire densities were not observed to have a statistically significant effect on the stand age class (Appendix Table E-19). However, when one or more of the independent variables were considered simultaneously with stand age-class a statistically significant effect was seen. For example, the effect of the interaction of all three independent variables on stand age class was highly statistically significant (Appendix Table E-19). Further examination revealed that the combined interaction of the lightning and positive lightning strike densities were responsible for the highly statistically significant interaction observed when all three variables were considered simultaneously (Appendix Table E-19). Although the relationship between the stand age-classes and the interaction of the two variables could not be plotted simultaneously, it was possible to plot the relationships between total lightning and positive lightning strike densities and stand age-class for Narraway only (Appendix Figures E-26 and E-27). In general, the density of lightning and positive lightning strikes decreased with increasing stand age. Consequently, the greatest lightning strike densities as well as the greatest positive lightning strike densities were recorded in the youngest stand age class in which stand age-class dates ranged from 1995 (Appendix E Figures E-26 and E-27).

Prairie Creek

Stand age-class dates in the Prairie Creek research area ranged from a minimum of 1995 to a maximum of 1735. After reclassification into 20-year age classes, the range in stand age classes was from 0 to a maximum of 260 years, with the 100-year-old age-class encompassing the largest mean area within the research area (Appendix E Figure E-28). Mean lightning, positive lightning, and lightning fire densities were found to be 6.58 (s.d. = 10.61), 0.42 (s.d. = 0.06), and 0.014 (s.d. = 0.37) respectively (Appendix Table D-23).

The results of the ANOVA procedures on the reclassified data are summarized in Table 4-6. As in the Narraway research area, when all the possible interactions of the independent density variables were considered together a highly statistically significant effect on stand age-class was observed $(0.008 < p < \alpha = 0.01)$. Further examination of the results indicated that it was the interaction between the lightning, and lightning fire densities that had resulted in the statistically significant result previously mentioned (Table 4-6). However, when the effects of both the densities of lightning strikes and lightning fires on stand age-class were considered separately no statistically significant effect was seen. In fact the significance values were just over the confidence limit at the 95 percent level (Table 4-6). The density of positive lightning was not observed to have a significant effect on the stand age-class for the Prairie Creek research area. Interestingly, as shown in Appendix Table E-20, the combined interaction of all three density variables did not have a significant impact on stand age class. It was not possible to plot the changes stand age class distribution in response to the simultaneous interaction of the density of lightning strikes and lightning fires. Therefore, the changes of the stand age class distribution in response to the lightning strike and lightning fire densities were plotted individually for the Prairie Creek research area (Appendix Figure E-29 and E-30). As in the case of the Narraway stand age-class coverage, the density of lightning strikes generally decreased with increasing stand age. However, some irregularities caused by outlier values were noted (Appendix E, Figure E-29). As illustrated in Figure E-30, contained in Appendix E, these occurred in the 60 and 80 year age classes, as well as in the 120 to 160 age classes. Most probably, these are merely outlier values. However, the association of these age-classes with such high lightning strike densities will be discussed in Chapter V. As illustrated, high values of lightning fire density occurred in the 60 and

100 year age classes. Possible reasons for this finding and the potential effect on the statistically significant results obtained in the ANOVA procedures will be discussed later.

Mount Louie

Stand age classes in the Mount Louie Stand age-class coverage ranged from 0 to a maximum of 240 years. Consequently, stand age-class dates ranged between 1995 and 1755. Appendix E Figure E-31 illustrates the distribution of stand age classes, by mean area, for the Mount Louie stand age-class coverage. Appendix Table D-24 contains the descriptive statistics for the stand age-class data, including the mean density values and their respective standard deviations.

The results of the ANOVA procedures conducted on the coverage data are presented in detail in Appendix Table E-21 and are summarized in Table 4-6. Unlike the ANOVA results for the stand age-class coverages in the Narraway and Prairie Creek research areas, the results of the analysis of variance for the Mount Louie stand age-class coverage did not reveal any statistically significant results. This lack of statistically significant findings was true when the effect of the density variables on stand age-class were considered in concert with other variables, or when each density variable was considered separately (Table 4-6).

Table 4-6 Summary of the F-ratio values calculated during the ANOVA procedures conducted on the Stand Age-Class coverages in each of the six research areas.

		Stand Age-Class		
Research Area	**DF**	*Lightning strike density*	*Positive lightning strike density*	*Lightning fire density*
Narraway	1	0.030	0.001	0.031
Prairie Creek	1	3.742	0.003	3.542
Mount Louie	1	1.138	1.425	0.831
Muddy Creek	1	2.587	2.099	0.469
Saddle Hills	1	0.023	0.420	0.358
Townships	1	0.080	0.000	4.577*

DF = Degrees of Freedom (n-1)
* = Pr > F is significant at 95 % Confidence Interval
** = Pr > F is significant at 99 % Confidence Interval

Muddy Creek

The distributions of mean area by stand age-classes represented in the Origin coverage for Muddy Creek is presented in Appendix E Figure E-23. The predominant stand age class was the 100 year age class, or stands with an origin between the years 1895 and 1905 (Figure E-32). Descriptive statistics calculated for the origin coverage are summarized in Appendix Table D-25, and the results of the Analysis of Variance procedures are contained in Appendix Table E-23. However, examination of the ANOVA results indicated that none of the density variables was observed to have a significant effect on the stand age class (Table 4-6, and Appendix Table E-23).

Saddle Hills

Compared to the other research areas, Saddle Hills exhibited the smallest overall range in both stand age-class dates and stand age classes (Appendix E Figure E-33). A stand age class of 80, covering stand age-class dates between 1895 and 1915, represented the largest average area of the research area. Descriptive statistics, including mean density values, are presented for review in Appendix Table D-26.

The results of the analysis of variation are summarized in Table 4-6. However, as with the other coverages in the Saddle Hills research area, the independent variables of lightning, positive, and lightning fire densities were not seen to have a significant effect on the stand age classes observed in the research area (Table 4-6, and Appendix Table E-23).

Township

Stand age-class dates for the Township research area ranged from 1995 to 1795. However, as shown in Appendix E Figure E-34, stands in the 20-year age class covered the largest average area of the coverage. This may be indicative of the recent occurrence of harvesting, or some other disturbance, however, this could not be confirmed. Appendix Table D-27 contains the descriptive statistics calculated for the stand age-class coverage of the Townships area.

The results of the Analysis of Variance tests conducted on the stand age-class data indicated that only lightning density had a significant effect on the stand age-class ($0.033 < p < 0.05$) (Appendix Table E-24). However, this significant effect was only seen when relationship between stand age-class and lightning density was considered alone, without the possible effects of the other variables (Table 4-6, and Appendix Table E-24). Appendix E Figure E-35 illustrates a scatter plot of the stand age-class by the total lightning density for the Township Stand age-class coverage. In general, the highest lightning density occurs in the oldest age classes. There were some exceptions, most notably in the 20, 40, year age-classes (Appendix E Figure E-35). Although these high values of lightning fire density occurring in the older stand age classes may be merely outlier values, it is interesting to consider that a similar result was obtained in the Prairie Creek research area. Positive lightning strike and lightning fire densities were not seen to have a statistical effect on the stand age-class class (Table 4-6, and Appendix Table E-24). The possible significance of this observation will be discussed in Chapter V.

Chapter 5

DISCUSSION

5.0 General

Prior to beginning any discussion of the results obtained in this study, it is necessary to emphasize several key points relating to the lightning strike data and lightning fire data. The locational accuracy of the lightning detection system used in Alberta has been reported to be variable depending on the factors involved in lightning detection (Jansichwskyj and Chisholm 1992). In the area surrounding Grande Prairie, Jansichwskyj and Chisholm (1992) reported the locational accuracy (random error) of the lightning detection system could be approximately 10 to 15 kilometers. This means that under ideal conditions, lightning strikes detected will be located within 10 to 15 kilometers of the true location of the lightning strike. A ground truthing study of lightning strike locations in Alberta, conducted in 1989, revealed that the random error associated in the location the lightning strike by the detection system varied between 4 and 8 kilometers, and 10 to 14 kilometers in Central and Northern Alberta, respectively (Gilbert et. al. 1987, Nimchuck, 1989). The detection efficiency of the lightning detection system in the area in question was reported to be between 90 and 100 percent (Jansichwskyj and Chisholm 1992). Based on the reported detection efficiencies and locational accuracy of Alberta's lightning detection system it was assumed that there was no systematic bias present in the lightning strike records used in the analysis. Essentially, there was an equal probability of a lightning strike being detected and located either inside or outside any one of the six research areas. However, the study conducted by Jansichwskyj and Chisholm (1992) was conducted for 1992. Consequently, estimates of the detection efficiency and locational accuracy of the lightning detection system in Alberta are not very accurate, particularly for the early operational years. Additionally, it has been suggested that the lightning detection system fails to detect large numbers of lightning strikes during intense thunderstorms (Nimchuck 1989, Beale 1997 Personal Communication). Combined, these facts suggest the number of lightning strikes, as well as the locations at which the strikes were recorded between 1984 and 1996 may be underestimated. This may have had a significant effect on the findings reported by the present study. However, more important are the concerns raised by the fire record data used in the analysis.

The occurrence and detection of a fire in Alberta, and associated suppression actions result in a fire report being filed. As stated previously, these fire reports include large amounts of information pertaining to the location, date, time, and suppression actions taken to quell the fire. Also included in any fire report is a category referred to as General Cause, to which the general cause of the fire is assigned. Although in some cases, the general cause of a fire can be confirmed, in many cases, the general cause code is assigned subjectively by the attending fire boss. The subjective nature of the general cause category may have resulted in an underestimation of the true number of fires due to lightning recorded in the region of the FMA between 1984 and 1996. Fires due to lightning generally occur in remote areas in which a human activity is low (Vasquez and Moreno 1998). Subsequently, the probability of a lightning fire in such an area being detect prior to natural extinction, via precipitation or other factors, is relatively low. These factors may have resulted in fewer fires due to lightning being recorded than actually occurred. For example, only one lightning fire was recorded in the Muddy Creek area during the period between 1984 and 1996. This in turn would have had a significant effect on the results presented in this study.

The areal extent of the polygons comprising the Aspect, Elevation, Vegetation Type, and Stand Age Class Arc/Info™ coverages was found to be highly variable. This can be seen within the descriptive statistics that were calculated by research area for each of the Aspect, Elevation, Vegetation Type and Stand Origin coverages, as presented in Appendix D. For instance, the mean area of the Aspect coverage in the Narraway research area was found to be 55,308 m^2 (s.d. = 496,479 m^2), while the mean area of the Narraway Elevation coverage was 3,036475 m^2 (s.d. = 13,54,6601 m^2). Additionally, the variation in mean area was also affected by the number of individual polygons comprising the separate coverages (Aspect, Elevation, Vegetation Type, and Stand Origin). In the case of the Narraway Aspect coverage, the number of polygons was 8, 839, while there were only 161 polygons in the Elevation coverage. Similar variations were also noted between the same coverages in each of the six research areas.

Some of the variability in the areal extent was due to the mathematical processes and algorithms used by the Arc/Info™ program in the manipulation of the coverages. The variability observed in the area and the number of polygons comprising the individual coverages between and among research areas may also have affected the variance in the lightning, positive lightning, and lightning fire densities. As describe in the methods section, however, attempts were made to maintain equal variance in the density values through reclassification.

5.1 Lightning Strike Data

Stashko (1972) was one of the first individuals to examined the variations in lightning strike density throughout Alberta. As illustrated in Figure 4-1 lightning densities in Weyerhaeuser's FMA are consistent with those reported by Stashko (1972). The frequency of lightning strike, both in the FMA and in each of the six research areas, exhibits a great deal of variation by month and by year. However, general trends are apparent. Although there were years of relatively high lightning activity, 1994 was the year in which peak lightning activity was recorded. This was found to be true in all but one of the six research areas. Specifically, in the northern most research area (Saddle Hills) the greatest lightning activity peaked in 1989, rather than 1994. This suggests that the weather patterns and associated patterns of thunderstorm generation may have been different in the Saddle Hills research area for that particular year, when compared to those recorded in the remaining areas.

The findings reported by Granström (1993) and Johnson (1995) support the results of this study that July and August were the months where lightning activity was commonly highest in all research areas (Schroeder and Buck 1975, Uman 1987). Additionally, the finding that although variations were noted, mean lightning density exhibited a general decreasing trend with the relative position of the research areas from south to north is also supported (Granström, 1993, Johnson 1995). This decrease in lightning activity with increasing latitude has been linked to latitudinal changes in synoptic weather conditions, specifically temperature, and associated patterns of thunderstorm generation (Schroeder and Buck 1975, Uman 1987, Takeuto et. al. 1983, Granström 1993, Nash and Johnson 1996).

As would be expected, the largest research areas also experienced the greatest frequency of lightning strikes during the period between 1984 and 1996. This is due to the fact these larger areas have the ability to capture more lightning strikes even if the probability of a lightning strike is constant across the Province because of their increased size. This is logical if one considers the analogous situation of throwing darts at a dartboard versus a football field. The chance of hitting an area the size of a football field should be greater than the chance of hitting the dartboard. In general, the density of lightning should be similar for areas of equal size. The interesting feature of the plot of mean lightning activity by research area is the fact that the Muddy Creek and Mount Louie research areas, which were the second and third smallest areas, recorded the second lowest and lowest levels of mean lightning activity. While this may merely reflect the natural variation in lightning activity, it seems interesting that both the Muddy Creek and Mount Louie areas are situated closer to the Rocky Mountains, which border the FMA to the west. This proximity to the Rocky Mountains may have produced different weather patterns than those occurring in the other research areas. However, these findings may also be due to the subjective nature of ranking the location and size of each of the research areas. Unfortunately, without weather data specific to each research area anything more than general statements regarding the patterns of lightning strike activity in the research areas should be considered speculation. Consequently, this suggests a need for significant future research.

5.2 Lightning Fire Data

There exists a possibility that more lightning fires may have been ignited over the 14-year period between 1984 and 1996 than were reported. It is possible that some fires ignited by lightning in the specific research areas of the FMA may have been extinguished naturally before being detected. Consequently, the average area burned by lightning fires may be underestimated.

Generally, both the mean number of lighting fires and average area burned recorded in each of the research areas during the period between 1984 and 1996 was relatively small. This may be an artifact of weather and fuel related conditions associated with the research areas within this FMA. The normal weather in this FMA may not support the occurrence of large naturally occurring (lightning) fires. Unfortunately, the veracity of this statement can not be assessed due to a lack of data relating to weather and fuel conditions in the research areas. Additionally, the fire suppression effectiveness of the Alberta Lands and Forest Service personnel responsible for the area in the vicinity of the FMA may be high, and may have contributed to the low average area burned by lightning fires between 1984 and 1996.

The largest average number of fires due to lightning for the period between 1984 and 1996 was recorded in the Township research area, which not surprisingly is also one of the largest in area. The largest and second largest research areas, Prairie Creek and the Township research areas respectively, recorded the greatest average area burned for the same time period. Although these findings may be linked to weather and fuel-related factors, the influence of the size of the research area can not be overlooked. For example, the largest areas generally have the highest possibility of receiving a lightning strike. It is logical to assume, therefore that a greater frequency of lightning strikes should also result in a higher chance of an ignition occurring. However, if the areal extent of the area was the only factor influencing the number of lightning fires then more lightning fires should have been recorded in the Prairie Creek area. This was not the case and implies that other factors besides research area may have had an effect.

The average density of lightning fires exhibited a great deal of variability, as did the average area burned by lightning fires given the relative position of the research areas from West to East (Figure 4-9 a-c). Variations in both the average lightning fire density, and average area burned by lightning fires may be related to area specific differences in weather patterns or fuel conditions. Similar variability in the average area burned by lightning fires was observed in the research areas from South to North. The mean density of lightning fires also showed significant variability from South to North. However, the average area burned by lightning fires seemed to exhibit slight increasing trend from south to north, as did the mean density of lightning fires (Figure 4-9A). However, it is important to note, that given the low numbers of lightning fires recorded in each of the six research areas; statements regarding the trends in mean lightning fire density or average area burned from south to north, or east to west in the FMA can not be fully substantiated.

Although slight, this increasing trend in number of lightning fires is surprising when the fact that the mean number of lightning strikes decreased with increasing position from South to North. However, Takeuto et al. (1983) stated that the percentage of positive lightning flashes relative to total lightning increased with latitude. The long continuing current characteristic of lightning capable of igniting a fire has been more frequently associated with positive rather than negative flashes to ground (Fuquay 1980). An increasing percentage of positive lightning strikes from south to north may explain why an increasing number of lightning fires were associated with a decreasing number of lightning strikes. Unfortunately, data relating to the electrical properties of the lightning strikes detected in Alberta was not included in the lightning strike records. Hence, this theory can not be confirmed. As with the other findings, these results may also be linked to differences in the prevailing weather and fuel conditions and yet this interaction, if it exists, can not be substantiated at the present time due to a lack of area specific data.

A superficial comparison of the figures presented in the preceding chapter reveals that the average number lightning fires recorded in each of the research areas does not correspond to the mean number of lightning strikes. This supports the initial assumption, made in this study, that not all lightning strikes are capable of igniting fires due to inherent characteristics or weather and fuel related conditions (Fuquay, 1980, Flannigan and Wotton 1990). These findings also suggest that other factors are exerting an influence. Consequently, additional future research is needed before specific conclusions can be drawn.

5.3 Aspect

There was no statistically significant effect of Aspect class on the density of lightning strikes or positive lightning strikes. This was true for all research areas studied. Consequently, these findings support the acceptance of the null hypotheses that the density of lightning and positive lightning strikes is the same for all Aspect classes. Only one other study could be found that that could confirm the veracity of results obtained in the present study regarding the possible effects of Aspect on the density of lightning strikes. Van Wagtendonk (1986, 1991) examined the potential effects of Aspect on a total of 7,250 lightning strikes recorded in the region of Yosemite National Park in the USA between 1985 and 1990, he reported finding that Aspect had no significant effect on the occurrence of lightning strikes. Additionally, he suggested that there was no "a priori" reason to believe that Aspect would affect the number of lightning strikes. Interestingly, Van Wagtendonk (1986, 1991) made no effort to control the possible effect that size of area might have on his analysis. Unfortunately, he also did not conduct any analysis on the likely role of Aspect on the density of positive lightning strikes. Given the findings reported by Van Wagtendonk (1986, 1991) it may be possible that a relationship between Aspect class and the density of either lightning or positive lightning does not exist in the areas under consideration, and therefore could not have been detected. Another possibility may be that the number of lightning strikes available for analysis was insufficient to allow for the detection of any significant relationships.

There were a combined total of only 19,166 lightning strikes detected in all of the research areas between 1984 and 1996. Of these only 1,054 were positive lightning strikes. However, if the number lightning strikes were insufficient to observe a significant relationship between Aspect and lightning or positive lightning; then it is doubtful that other significant relationships would be observed between Elevation and lightning. Yet, in some research areas, there was a significant correlation between Elevation class and lightning density. Unfortunately, without other research against which the results of this study can be compared, reasons for the absence of significant findings is purely speculative.

Aspect class was not found to have a significant effect on the density of lightning fires in any of the six research areas. As with the results obtained for lightning and positive lightning strike densities, this finding also supports the acceptance of the hypothesis that the density of lightning fires is the same in all Aspect classes. Other researchers, however, have reported results that indicate a significant effect of Aspect on the frequency of fires due to lightning. Specifically, Vankat (1982) observed that lightning fires occurred more frequently on South facing slopes than on North facing slopes. However, the results reported by Vankat (1982) were only preliminary and should be considered as such. Barrows (1951) reported that lightning fires occurred in greater numbers on South facing slopes than on slopes of other aspects. Of the 21,048 lightning ignitions studied by Barrows, between 1931 and 1944, 15 % occurred on South facing aspects, while only 14 % occurred on Southwest facing aspects and 12 % occurred on Southeast aspects. North, Northeast, and Northwest facing aspects only accounted for 10, 11 and 8 percent of the lightning ignitions, respectively (Barrows, 1951). Similarly, Aselson (1975) reported that 1,069 out of 2,088 lightning fires occurred on South, or Southerly, aspects. Unlike the results recorded by Barrows (1951), which for the most part were purely observational, Aselson (1975) found his results to be statistically significant. It should be further noted that Barrows (1951) made no attempt to account for the possible impact that size of area for each Aspect might have had on the outcome of his analysis. Aselson, on the other hand assumed that all aspects were represent by equal areas. This approach may account why they found a significant effect of Aspect on the density of lightning fires, and why I did not. The absence of a significant relationship between the aspect class and the density of lightning fires in the present study may also be related to area specific conditions.

Ignition of a fire is dependent on the simultaneous occurrence of several conditions. The most important of which are: a suitable ignition source and the receptivity of the fuel to ignition (Fuquay 1980, Pyne 1984, Nash and Johnson 1996). If it is assumed that both the density, and type of lightning strikes in the research areas was sufficient to result in the occurrence of lightning fires, then the key limiting factor to finding a significant relationship between Aspect and lightning fires could be the fuel condition. It may have been possible, although unlikely, that the fuel characteristics were similar on all Aspect classes and in all research areas, and further that the probability of an ignition due to lightning was extremely low. A list of these characteristics would include the loading, species and condition (i.e. rotten vs. sound), and architecture of the fuelbed. However, the most important variable is the "availability" of the fuel (Brown and Davis 1973, Pyne 1984, Nash and Johnson 1996). "Fuel availability" refers to the moisture content of the fuel species. Pyne (1984) suggests fuels with a moisture content of greater than 30 % will not ignite. In general, a 30 % moisture content, based on oven dry weight, is considered to be the moisture content of extinction (Rothermel 1972).

Local topography and weather directly influences fuel moisture content (Barrows 1951, Brown and Davis 1973, Schroeder and Buck 1975, Chandler et al. 1983, Pyne 1984). Topographic features, and prevailing climatic conditions in the research areas used in this study may have resulted in fuel, and burning conditions that were not conducive to the ignition of lightning fires (Arno 1980). However, no data on fuel characteristics or local weather conditions prevailing in the research areas were available for analysis. As a result, the importance of these, and other factors on the results of this study are based on speculation, and can not be substantiated without further research. The factors affecting fuel ignitability and combustionability may account for our inability to relate the numbers of lightning strikes to the number of lightning fires within the research areas of this FMA.

The most obvious difference between the results of the present study and those reported by Aselson (1975) and Barrows (1951) is the number of lightning fires available in the analysis. Aselson (1975) used 2,088 lightning fires recorded between 1961 and 1970, while Barrows (1951) had 21,048 lightning fires, between 1931 and 1944, for his analyses. Additionally, the study area used by Barrows (1951) consisted of all National Forests from within the continental United States. While Aselson's (1975) study area measured approximately 6,000 square kilometers. Comparatively, this study relied on 48 lightning fires recorded between 1984 and 1996 in the six research areas (combined area = 2,857 km^2). In the Muddy Creek research area (379 km^2) only 1 lightning fire was detected. Consequently, the limited numbers of lightning fires recorded is probably the most important reason for the lack of a significant finding between Aspect class and the density of lightning fires.

In retrospect, it may have been more appropriate, given the limited number of lightning strikes and lightning fires recorded in the six research areas, to combine the data from all six areas into a single data file and then perform the analysis. Although this would have provided sufficient numbers of lightning strikes and lightning fires for statistical analysis, comparison of the results obtained on a research area basis would not have been possible.

5.4 Elevation

Significant relationships between the Elevation class and at least one of either the density of lightning or positive lightning strikes were observed in four of the six research areas studied. Elevation class in the Muddy Creek and Township areas was seen to have significant effect on the density of lightning strikes, while in the Mount Louie area, only positive lightning strike density was seen to be significantly affected by Elevation class. Conversely, in the Narraway area Elevation class was observed to have a significant effect on the density of both total lightning and positive lightning strikes. Elevation class was not observed to have a significant effect on the density of lightning fires in any of the six research areas.

The absence of a significant relationship between Elevation class and lightning fires in this study is contradicted by the results of other studies. Barrows (1951) observed that lightning fires occurred more frequently in the 5,000 to 6,000 (1,524 –1,829 m) foot Elevation level west of the continental divide, and in the 3,000 to 4,000 (914 –1,219 m) foot Elevation level east of the continental divide. Although not directly discussed by Barrows (1951) this was probably due to limited topographic variation, and altered weather and fuel patterns associated with areas east of the continental divide. Kourtz (1967) reported that of 3,615 lightning fires record between 1961 and 1963 from across Canada, 60 % (2,169 fires) occurred in the top third of the slope. However, neither the Elevation ranges encompassed by the top third of the slope, nor the locations of these fires were provided (Kourtz, 1967). Aselson (1975) examined the frequency of 2,087 lightning fires in Elevations ranging from under 1,000 feet to over 7,000 feet in altitude. Unlike Kourtz (1967), Asleson (1975) found that lightning fires occurred more frequently in the 4,000 to 5,000 foot (1,219 – 1,524 m) Elevation range rather than in the highest altitudinal ranges (i.e. > 7,000 feet in elevation). A similar finding was reported by Barden and Woods (1973), who studied the frequency of lightning fires in Great Smokey Mountains National Park (USA). They found that lightning fires were less frequent at the highest possible elevations and more frequent at mid elevations. Barden and Woods

(1973) also found that a greater number of lightning fires in the Southern Appalachians occurred at higher elevations before the month of May, and at slightly lower elevations after the month of May. This finding may indicate the receptivity of fuels to ignition may change with the changing synoptic weather patterns at different elevations (Barden and Woods 1973). Pickford et al. (1980) stated that the occurrence of lightning fires in Olympic National Park varied with elevation. These researchers found that 82 % and 51 % of the lightning fires studied occurred above 914 metres and 1,220 meters in elevation respectively (Pickford et al. 1980). Vasquez and Moreno (1998) observed that, in Spain, lightning-caused fires occurred more frequently at higher elevations than those fires related to human activity. It should be noted that both Pickford (et al. 1980) and Vasquez and Moreno (1998) failed to state whether or not the observations reported were tested for statistical significance.

It appears that based on the results reported by the majority of these researchers, the occurrence of lightning fires is significantly affected by Elevation. Yet, no such relationship was observed in the results of this study. The absence of significant findings in this study may be due to several possible factors, some of which are interdependent. Specifically, when the range in Elevation classes examined by other researchers are compared to those examined in this study it becomes apparent that the Elevation classes used in this study were both smaller in range, and much fewer in number. For example, other researchers used 1,000 foot Elevation classes in their analyses, while in the present study, the elevations were re-categorized into classes of only 100 meters in range (Barrows, 1951, Kourtz, 1967, Aselson, 1975). Additionally, the range of elevations used by Barrows (1951), Kourtz (1967), and Aselson (1975) were much larger than those considered in this study. Both Aselson and Barrows examined elevations ranging from below 1,000 feet to over 7,000 feet (305 to 2,133 meters). Unfortunately, the true minimum and maximum values used by Barrows and Aselson were not available. Kourtz (1967) did not provide the total range in elevation used in his study. However, the elevations of all the research areas used throughout the present study only ranged from a minimum of 733 to a maximum of 1,987 meters (a.s.l.). Consequently, the minimum and maximum Elevations used in this study are larger and smaller than the minimum and maximum Elevations stated by Barrows and Aselson. Although it is very unlikely, this approach may have contributed to the absence of a significant finding.

A more probable reason for the lack of significance observed between the density of lightning fires and Elevation in this study was related to the low number of lightning fires available for analysis. Barrows (1951) used a sample size of 16,973 fires recorded in National Forests across the continental United States during the period between 1936 and 1944. Kourtz (1967) relied on the records of 3,615 lightning fires reported across Canada between 1961 and 1963, while Aselson (1975) used 2,087 recorded lightning fires as the basis of his analysis. Comparatively, a combined total of only 48 lightning fires were used in the present study. This low number of lightning fires may have been directly attributable to weather and fuel-related conditions specific to the research areas studied. Unfortunately, discussion of weather and fuel related factors must be limited due to the lack of weather and fuel data available for the research areas. The importance of weather and fuel related factors clearly can not be underestimated and is a prime consideration for future research needs.

The significant effect of Elevation on the density of lightning and positive lightning strikes found in the present study is echoed in the findings reported by other researchers. Van Wagtendonk (1986, 1991) also examined the frequency of lightning strikes by elevation class. He found that lightning frequency was significantly affected by Elevation, with the largest numbers of lightning strikes occurring in the 9,000 - 10,000 foot (2,743 - 3,048 m) Elevation zone. However, the range in Elevations examined by Van Wagtendonk included a maximum Elevation of 12,000 - 13,000 feet. This is surprisingly similar to Aselson's finding that lightning fires were more frequent in mid Elevation ranges rather than in the highest Elevation classes examined. As stated previously, however, Van Wagtendonk apparently did not take into account the effect of area, as the 9,000 to 10,000 foot Elevation class also encompassed the largest area and therefore had the highest probability of a lightning strike occurring. This may have had a significant impact on the reported results. Although questionable, this result was attributed to the topographic variation and associated patterns of thunderstorm development (Van Wagtendonk, 1986, 1991). This same reasoning could be applied to the significant findings for the Narraway, Mount Louie, Muddy Creek, and Township research areas.

It may have been possible that the research areas in which a significant observation was made between the Elevation and the lightning density could have been in the path of the majority of thunderstorms occurring in the FMA. This in turn could have lead to an increase in the number of both the lightning, and positive lightning strikes that may have occurred in these research areas, and would have also served to increase the calculated densities of lightning and positive lightning strikes. Unfortunately, although

Lawford (1970) provided a detailed analysis of the patterns and characteristics of thunderstorm generation over the forested regions of Alberta; no information concerning the general movements of thunderstorms over Alberta could be found to support the aforementioned hypothesis.

5.5 Vegetation

Statistically significant relationships were identified between the vegetation class and at least one of the independent density variables in just two of the six research areas studied. The density of lightning fires was found to be significantly related to vegetation class in both the Narraway and Prairie Creek areas. Areas dominated by pine species in both research areas were associated with the greatest lightning strike densities. In the Narraway area a second statistically significant relationship, not seen in the Prairie Creek research area, was observed between the density of lightning strikes and the vegetation class. In the Narraway research area, areas without vegetation generally had the greatest number of lightning strikes per square kilometer, while a progressive decrease in the density of lightning strikes in the areas dominated by other species, spruce species, and pine species was observed. There were no other statistically significant relationships observed between the density of lightning strikes and the vegetation class in any of the remaining research areas.

Other researchers have reported that certain vegetation types have been observed to experience greater frequencies of both lightning strikes and lightning fires than other types of vegetation. However, the reasons given by these researchers for the results obtained differ significantly. Show and Kotok (1929) postulated that areas dominated by fir could be expected to receive a greater frequency of lightning strikes than other species he studied. He suggested that because regions of higher elevation receive a greater number of lightning strikes, then any vegetation that preferred the environmental conditions associated with higher elevations were also subjected to greater numbers of lightning strikes (Show and Kotok 1929). Conversely, Shipley (1946) reported that, throughout the United Kingdom, oak trees were struck by lightning more frequently than any other tree species. He attributed this result to the presence of a deep taproot extending into damp soil. Shipley (1946) concluded oak species acted as a much better lightning conductor than other species of tree (Shipley 1946). Kourtz (1967) found that 45 percent of the individual trees struck by lightning were higher than the surrounding vegetation. Only 43 % and 12 % of the lightning struck trees were the same height or lower than the surrounding trees (Kourtz 1967). Although possible, it seems unlikely that the significant relationships observed in this study, between lightning strike densities (both total and positive) and the type of vegetation, were due to variations in the heights of the tree species, or differences in electrical conductivity of the vegetation types. This is supported by the observation of significant results in some research areas, but not in others in which the same types of vegetation was common. However, the possible influence of factors such as differences in tree heights, and properties associated with electrical conductivity could not be confirmed due to a lack of data. Despite the improbability of the influence of these and other factor on the results obtained, the possibility of the effect these factors may have had on the results obtained should not be underestimated.

Show and Kotok (1929), and Van Wagtendonk (1991) also found that lightning occurred more frequently in certain species of vegetation than in others. For example, 1,757 of 7,205 lightning strikes recorded between 1985 and 1990 in the region of Yosemite National Park occurred in areas dominated by lodgepole pine. Conversely, only 160 lightning strikes were recorded in the areas covered by chaparral (Van Wagtendonk 1991). Van Wagtendonk (1991) suggested that his findings were related to the patterns of spatial distribution of the vegetation species, which in turn were dependent on the area-specific environmental preferences of each vegetation species. Subsequently, these area-specific conditions were related to the topography, specifically the Elevation, of the study area (Van Wagtendonk, 1991). As a result, Van Wagtendonk (1991) stated that the observed effect of lightning strike frequencies on the vegetation was similar to the pattern of lightning strikes in relation to elevation. For example, Van Wagtendonk (1991) indicates that lodgepole pine dominated areas of higher elevation. As stated by Uman (1971, 1987), lightning tends to strike the highest point on the terrain. Consequently, the observation that lodgepole pine received a significantly higher proportion of the total number of lightning strikes than a vegetation species occurring at lower altitudes is logical (Van Wagtendonk, 1991). This is supported by the findings of several other researchers.

Van Wagtendonk's findings, although supporting the results of this study should be viewed cautiously. Unlike the present study, Van Wagtendonk did account for the relative areas encompassed by each vegetation type. The importance of this issue is illustrated by the statement made by Plummer (1912), and repeated by Kourtz (1967) that: "Any kind of tree is likely to be struck by lighting and the greatest number struck in any locality will be the dominant species". However, in the present study, non-vegetated zones in the Narraway area encompassed the smallest mean area overall

The significant effect of lightning density on the vegetation type that was observed in the Narraway research area also lends credence to the statements made by Van Wagtendonk (1991). As illustrated in the preceding chapter, areas dominated by no vegetation were associated with much higher lightning strike densities than areas dominated by spruce, pine, or other vegetation species. Given the findings of Kimmins (1981) and Uman (1971, 1987) it would be logical to associate areas with little or no vegetation with areas of higher Elevation, which are in turn associated with areas of greater lightning strike densities. The fact that this relationship was only identified in the Narraway research area may be significant given the proximity of the area to the Rocky Mountains. Greater variation in Elevation may have affected lightning densities, which in turn may have affected the type and distribution of vegetation observed in the research area. However, if this was the case, then similar relationships should have been identified in the Prairie Creek and Mount Louie areas, which were also characterized by increased Elevational variability. It is possible that relationships between lightning strike density and vegetation do exist in the Prairie Creek and Mount Louie areas, but were not significant enough to be detected using the Analysis of Variance procedures, which were preformed on the data. It may also be possible that other factors are responsible for the present study only finding a significant relationship between lightning strike density and vegetation type in the western most research area in the Grande Prairie FMA.

The significant result, between the density of lightning fires and vegetation type, was identified in both the Prairie Creek and Narraway research areas. In both cases, those areas dominated by pine species received the greatest number of lightning fires per square kilometer. However, in both the Narraway and Prairie Creek areas, pine encompassed the largest mean area of the respective vegetation coverage, which may account for the result noted. Consequently, it seems likely that other factors may be responsible for the observation that pine species received a greater number of lightning fires per square kilometer than other species of vegetation in both the Narraway and Prairie Creek research areas. It is recognized that the variability in area associated with each vegetation species, which was not accounted for by this study, may be responsible for the significant results obtained. However, I can not discount the fact that other researchers have reported that certain species do receive a disproportionate number of lightning fires, given the area encompassed by the vegetation, when compared to other species

It follows; lightning fires should be more prevalent in certain species of vegetation due primarily to area preferences and fuel conditions associated with that species of vegetation. This is supported by a variety of other studies. For example, Kourtz,(1967) found that ignitions due to lightning occurred more frequently in hardwood species than in softwood species, even when equal proportions of hard and softwood species were present in a given area. This difference was linked to differences in the electrical conductivity of hardwood species compared to softwood species. Because hardwoods were poor electrical conductors, greater resistance occurred to the electrical current associated with a lightning strike. This, in turn, resulted in the generation of greater amounts of heat thereby increasing the probability that a hardwood tree species would ignite (Kourtz 1967). Additionally, Kourtz (1967) suggested that the moisture content of the soil in which the vegetation occurred could have a contributing factor in the more frequent occurrence of lightning fires in certain types of vegetation.

Unfortunately, Kourtz (1967) did not include any data concerning the number of lightning fires by species type. Aselson (1975) stated that the increased number of lightning fires observed in areas dominated by certain species was a function of area preference, and associated conditions. He found that, based on the results of a Chi-Squared analysis, lightning fires occurred more frequently than would normally be expected in areas dominated by grand fir and Douglas-fir, than in other species. Interestingly, Aselson (1975) also accounted for the relative area encompassed by each tree species. As with other researchers, Aselson (1975) attributed the finding that certain species experience a greater number of lightning fires than others due to the area preferences of the species in question, and the patterns of lightning strikes in relation to these area preferences. In particular, lightning strike patterns relative to Elevation were thought be responsible (Asleson, 1975).

It would seem logical to assume that vegetation species on steep slopes or elevated areas not only receive a greater number of lightning strikes and therefore a higher possibility of ignition, but are also subjected to drier conditions and resultant lower fuel moistures. This should result in an increased receptivity to ignition due to lightning. Additionally, vegetation on elevated areas may receive less precipitation during a thunderstorm than vegetation situated in valley bottoms. Consequently, ignitions due to lightning occurring in elevated areas would have an increased chance of developing into a fire, rather than possibly being extinguished prior to transforming from a glowing to a flaming combustion at lower Elevations (Fuquay, 1980; Pyne, 1984). Although generalized weather data for the Northwest quadrant of Alberta was available, data pertaining to the precipitation levels and weather patters specific to the research areas was unavailable for analysis. Similarly, information detailing the fuel conditions (amount available, condition, species and arrangement) in the research areas was not available. Gathering such information, at a statistically reliable level, would necessitate several field seasons, but should be considered for possible future research.

5.6 Stand Age-Class

It should be noted that this study has made no attempt to link stand origin dates and the density of lightning strikes, or lightning fires. Given the facts that many of the stands found throughout the research areas originated in 1735, and only 14 years of lightning and lightning fire data were used in the analysis such a relationship would be impossible to uncover. However, statistically significant relationships between any of the density variables and the stand age class were observed in three of the six research areas. Additionally, the majority of the significant effects involved the interaction of more than one of the independent density variables on the stand age class. For example, in the Narraway area only the interaction between the lightning strike and positive lightning strike densities was positively correlated to the stand age-class variable. When the relationships were plotted, individually as presented in Appendix E Figures E-26 and E-27, the areas dominated by stand age-classes of 0, or the youngest stands, experienced the greatest lightning and positive lightning strike densities. It was not possible, based on the data available, to determine whether or not regions with a stand age class of 0 (stand origin dates 1995 to 1975) resulted from recent harvesting activity, fire, or some other disturbance event. In the Prairie Creek area, a combined effect of the density of lightning strikes and the density of lightning fires was observed to have a statistically significant effect on the stand age class distribution. Although a general decreasing trend was observed in the stand age class with an increase in the density of lightning strikes, some outlier values in the 60, 80, and 120 to 140 year stand age-classes were noted (Appendix E Figures E-29 and E-30). Similarly, although almost no trend was seen between stand age class and the density of lightning fires, outlier values were noted in the 60 and 100 year stand age classes (Appendix E Figure E-29 and E-30). The significant relationships identified in both the Narraway and Prairie Creek sites may be due to the outlier values noted. However, it is important to note that the significant results found were due to the interaction of closely related variables. Consequently, the results, and more importantly the implications of these results are extremely questionable.

The Township research area was the only area in which a single density variable was observed to have a significant effect on the stand age-class. A significant effect was observed for in the older stand age classes, which experience the greatest density of lightning fires. Additionally, a general trend of increasing stand age-class with increasing fire density was observed. This is contrary to what was hypothesized.

The finding that the density of lightning increases with decreasing stand age class, as was the case in the Narraway and Prairie Creek areas, are in general agreement with other stand age models (Johnson and Gutsell 1994, Van Wagner 1978. This implies that as the occurrence of a disturbance increases in frequency as the age distribution of a given area decreases. As a result, there should be a greater number of younger age stands in areas experiencing more frequent disturbance events, as compared to those areas which experience infrequent disturbance events. With the exception of outlier values, this is exactly what was observed. However, the stand age classes in which very high lightning strike densities were recorded are a source of concern.

The fact that the significant relationships between stand age-class and the density variables in both the Narraway and Prairie Creek areas was due to an interaction of two closely related variables is of significant concern. The high variance in two closely related variables may be the cause of the significant result. Consequently, significant results due to the interaction of two of the density variables, and the implications of such results, should be viewed cautiously. The significant relationship observed in the Narraway area, involving the interaction of the lightning and positive lightning strike densities, raises a concern over the simultaneous use of both of these variables. It may be possible that the relationship observed in this particular area was due to the doubling effect created by the use of the total, and positive lightning strike densities; rather than any statistically significant effect of the density variables on the stand age classes. Essentially, the density of positive lightning strikes is being counted twice. However, it is interesting that if this so-called doubling effect was responsible for the significant finding in the Narraway area, then why were similar results not obtained in the other research areas? Given this question, then it may be possible that other factors may be contributing to the significance of this relationship.

As with the results obtained for the other coverages, the potential effect of area, or the number of polygons encompassed by the stand age classes in which a significant result was obtained, as well as other factors can not be ruled out. Although attempts were made to control for the potential effect caused by differences in polygon area, it may have occurred that the procedures to reclassify the original density variables were insufficient to fully account for the effect of area. Similarly, no direct efforts were made to account for the number of individual polygons encompassed by a single stand age-class in each of the stand origin coverages. However, it was thought that the potential of this effect could also be minimized through the reclassification of the density variables to account for differences in area. Unfortunately, it may have been possible that attempts to control for such effects were insufficient.

It would seem logical to assume the significant effect on stand age-class observed in the Prairie Creek research area was due to the interaction of the lightning strike and lightning fire density, it was probably due more to the density of lightning fires, as in the Township research areas. In the case of the density of lightning fires in the Prairie Creek and Township areas, the opposite situation was observed. As previously stated, the older stand age classes in both areas received a greater density of lightning fires. This contradicts the models of stand age in relation to disturbance frequency suggested by Van Wagner (1978) and Johnson and Gutsell (1994).

Van Wagner (1983) suggested flammability increased with stand age, reaching a maximum at stand maturity and then decreasing at stand break-up. If this were true, then it would not be surprising to find that older stands could potentially experience a greater number of lightning fires. However, Van Wagner (1983) suggests there is very little evidence to support this idea. Furthermore, the hypothesis of increased flammability with increasing stand age does not explain why high densities of lightning fires were observed in stands of a younger age class in both the Prairie Creek and Township areas. Other factors, then, must have had an effect.

It may have been possible that the conditions for ignition, and sustained combustion were more appropriate in the stand age classes experiencing a greater density of lightning fires. Potentially, this could have been due to the topographic position of the stands in question and the related biotic and abiotic (weather, fuel moisture etc.) influences affecting those stands. This could also serve to explain why significant results between the density of lightning fires and the stand age classes were only obtained in the Prairie Creek and Township research areas. However, this raises an interesting point. The greatest number of lightning fires recorded in between 1984 and 1996 all of the research areas used in the study were recorded in the Prairie Creek and Township areas. Consequently, the total number of lightning fires recorded may have had a significant bearing on the results obtained, and could possibly explain the lack of significant findings in those areas which did not experience as many lightning fires between 1984 and 1996. This seems to be the most logical explanation for the findings of this portion of the present study.

Chapter 6
CONCLUSIONS

This thesis was the first attempt to determine if lightning strike data obtained from a sophisticated automatic lightning detection system could be used to predict stand age classes in a number of research areas in a working Forest Management Agreement area (FMA) in Alberta. The historical approaches to this problem have been to analyze historical fire records or to interpret post-burn evidence as part of fire history studies. Most of this previous work has been accomplished in the United States. In general, previous research would suggest that lightning-caused fires appear to be related to such wildland characteristics as: Aspect, Elevation, vegetation type, and stand age-classes. We were not able to duplicate all of these results in this study.

The results of this work suggest:

a. ***The density of lightning strikes, positive lightning strikes, or lightning fires did not differ significantly among Aspect classes.*** Aspect class was not observed to have had a statistically significant effect on the density of lightning or positive lightning strikes, or lightning fires. This result was found for all six of the research areas.

b. ***The density of lightning strikes, positive lightning strikes, or lightning fires varied significantly among Elevation classes.*** In the Narraway research area, there was a significant relationship between Elevation class and both the lightning and positive lightning strike densities. Both variables exhibited an increasing trend with increasing elevation. However, the greatest number of lightning and positive lightning strikes per square kilometer did not occur in the highest possible elevation class, but rather in the mid-elevation classes. Similar trends were detected in the significant relationships between Elevation class and the density of lightning strikes observed in both the Mount Louie and Township areas. In the Muddy Creek area, a significant effect was only observed between the Elevation class and the number of positive lightning strikes per square kilometer. Greatest positive lightning strike densities were found to occur in the mid-range elevation classes, rather than in the highest elevation classes possible.

*c. **Vegetation type was not always significantly affected by the density of lightning strikes, positive lightning strikes, or lightning fires.*** Significant results between the density of lightning strikes and lightning fires were only found to exist in the Narraway and Prairie Creek research areas. In both sites, areas dominated by pine species were associated with the greatest densities of lightning fires. This may have been due to the weather or fuel conditions specific to these areas. The effect of weather and fuel on this outcome could not be confirmed due to a lack of data specific to each of the research areas. A confounding outcome occurred in the Narraway site, which had areas in which no vegetation had been recorded and areas dominated by pine. In this area, the vegetation free areas received more lightning strikes per square kilometer, while the areas dominated by pine species generally received the fewest. It was conjectured that the results for this area were probably due to the influence of Elevation on the number of lightning strikes rather than the plants found at high strike locations.

*d. **The density of total lightning strikes, positive lightning strikes, or the number of lightning fires did not significantly affect stand age-class.*** However, three exceptions were noted. In the Narraway research area, a statistically significant effect on the stand age class was observed only when the densities of lightning strikes and lightning fires were considered simultaneously. Unfortunately, it was necessary to assess the significant relationship by analyzing the patterns associated with each individual density variable. In the Narraway research area, lightning strike density was observed to decrease as the stand age-class increased. Consequently, the stands in the youngest age-class also received the greatest number of lightning strikes per square kilometer. Similarly, the density of positive lightning strikes was also observed to decrease with increasing stand age-class in the Narraway research area. However, in both cases, the presence of outlier values and concerns over the interaction of closely related variables makes definitive statements about the nature of these relationships difficult.

Lightning strike density in the Prairie Creek research area also exhibited a decreasing trend as stand age-class increased. However, the 100-year stand age-classes received the greatest number of lightning fires per square kilometer. Interestingly, in the Township research area, the oldest stand age-classes were also associated with the greatest densities of lightning fires. These results may have been due to flammability characteristics inherent in the older stand age-classes, or they may have been the result of the influence of other variables. The low numbers of lightning fires used in the analysis make definitive statements about this result difficult, and additional research is required. Despite this, however, these results may have significant implications for forest management practices in Weyerhaeuser Canada Limited's Grande Prairie Forest Management Agreement area (FMA). It is readily apparent that relationship which may exist between Aspect and Elevation and lightning strike and lightning fire densities, or between the densities of lightning strikes and lightning fires and vegetation type or the distribution stand age-class are extremely complex and involve the influence of numerous variables. Consequently, changing management strategies in order to conserve biological diversity and old growth stands in Weyerhaeuser Canada Limited's Grande Prairie FMA will require an extremely complex model, which accounts for the role played by lightning and lightning fires on the distribution of stand age-classes and vegetation type.

This thesis sets the stage for future work by identifying the new approaches and the sample sizes that will be necessary to answer these kinds of questions. The values of this approach is that for the first time it allows science to isolate the influence of those factors that cause fires to start once lightning strikes. In so doing, science will be able to estimate the economic value of fuel treatments, if required, or the futility of any management treatment if weather is the controlling factor. But much more data will be required before these answers can be provided.

Chapter 7

FUTURE RESEARCH NEEDS

1. This study suffered from a lack of data pertaining to lightning strikes, aspect coverage, elevation groups, vegetation classes and age-class distributions caused by lightning. The next step in an attempt to understand more about what factors are controlling age-class distributions in this area would be to combine the Arc/Info™ coverage data for each of the research areas into a single data file. The procedures involved in calculating the lightning strike and lightning fire densities for the single coverage could then be redone. Rather than combining the lightning strike and lightning fire records from 1984 to 1996 into a single data file, it may be more appropriate to analyze the data in each year. Based on the results of the present study, this would require either increasing the size of the research area (i.e. using the entire FMA), or increasing the time period during which the lightning strike and lightning fire data is recorded. For example, rather than only having 14 years of lightning fire data, as in the present study, the research could be conducted at some future time when more records would be available. The resulting coverage could provide information about the simultaneous effects of lightning strike, and lightning fire densities on the stand age classes of a specific vegetation type occurring at a specific elevation, and with a preference for specific aspects or other site conditions. Such a task would necessitate the use of large amounts of computer disk space, which was a key limiting factor throughout the present study. Additionally, given the concerns over the statistical analysis and possible effects of area raised by the present, such a project could be conducted using an analysis based in Spatial Statistics.

2. An additional limiting factor to the results obtained in the present study was the lack of data concerning weather and fuel-related conditions specific to each of the research areas. These factors, as previously stated, probably had a highly significant effect on the results obtained. In order to be able to make definitive statements about the effect of lightning strike density on the distribution of stand age-classes or other factors, information about weather and fuel conditions in each research area is required. Data related to the condition of the fuel bed would necessarily include such things as the condition (sound vs. rotten) and species of fuel, fuel moisture conditions, and the architecture of the fuel bed (loading and arrangement). Other information would also be required. Gathering this information would involve conducting numerous transect studies in different locations in each of the research areas. Field studies could take place over several years to strengthen the database, and increase the statistical validity of the data. Information about the weather conditions specific to the research areas could be compiled through the use of Remote Automated Weather Stations (RAWS) situated throughout the research areas. These RAWS would provide key information about site-specific weather conditions, as well as data that could be used to calculate the various components used in the Canadian Forest Fire Danger Rating System (CFFDRS). The CFFDRS indices and codes could then be used in association with data concerning the condition of the fuel bed in each of the research areas. It may then possible to use spatial statistics to analyze these data with the lightning strike and other data used in this study to gain a better understanding of the role played by lightning and lightning fires on such things as the distribution of stand age classes in Weyerhaeuser's Grande Prairie FMA.

Such as study, however, may not be feasible given the long term nature and great expense involved in gathering the data.

3) Another possible consideration for future research would be an attempt to understand the role played by the multiplicity of a lightning strike on the occurrence of a lightning fire. It is a widely held misconception that lightning does not strike the same object twice. However, Uman (1987) states that a single lightning flash actually consists of multiple return strokes over the duration of the flash. Based on the lightning strike data obtained from the Forest Protection Branch of the Alberta Lands and Forest Service for use in the present study, it was seen than not all lightning strikes have the same number of return strokes. The number of return strokes in a single lightning strike is referred to as strike multiplicity. Fuquay (1980) found that lightning fires were more probable given a positive lightning strike with a Long Continuing Current (LCC). However, very little research is available which examines the possible effect of the multiplicity of a lightning strike on the occurrence of a lightning fire. Such a project, combined with the results of the present study would make for an interesting future project for the author provided funding could be obtained.

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APPENDIX A

- Contains a listing of Scientific and Common names for all species of vegetation discussed throughout the thesis

Table A-1 Common and Scientific names of vegetation species listed throughout the study (Source: Moss 1983).

Species Common Name	Species Scientific Name
Alder	*Alnus* Spp.
Balsam fir	*Abies balsamea* [L.] Mill
Balsam Poplar	*Populus balsamnifera* L.
Black Spruce	*Picea mariana* [Mill.] B.S.P.
Buffalo berry	*Sphedria canadensis* (L.) Nutt.
Douglas-Fir	*Pseudotsuga menziesii* [Mirb.] Franco
Englemann Spruce	*Picea engelmanni* Parry ex Engelm.
Labrador tea	*Ledum groenlandicum* Oeder
Limber Pine	*Pinus flexilis* James
Lodgepole Pine	*Pinus contorta* Dougl. ex. Loud.
Low bush cranberrry	*Viburnum edule* (Michx.) Raf.
Paper Birch	*Betula papyrifera* Marsh.
Prickly Rose	*Rosa acicularis* Lind.
Red Osier Dogwood	*Cornus stolinifera* Michx.
Rhododendron	*Rhododendron albiflorum*
Saskatoon	*Agrimonia alnifolia* Nutt.
Sasparilla	*Aralia nudicaulis* L.
Sedges	*Carex* Spp.
Sphagnum mosses	*Sphagnum* Spp.
Subalpine Fir	*Abies lasiocarpa* [Hook.] Nutt.
Tall Billberry	*Vaccinium membranaceum* Dougl. ex Hook.
Trembling Aspen	*Populus tremuloides* Michx.
Western Larch	*Larix lyallii* Parl.
White Pine	*Pinus albicaulis* Engelm.
White Spruce	*Picea glauca* [Moench] Voss.

APPENDIX B

Glossary of Arc/Info Commands used, including general syntax

APPENDIX B

DEFINITIONS AND GENERAL SYNTAX OF ARC/INFO COMMANDS USED[1]

Aspect: Identifies the direction of maximum rate of change in z value from each cell.
Syntax: Aspect <grid>

Additem: Adds a blank or zero item to an INFO data file.
Syntax: Additem <in_info_file> <out_info_file> <item_name> <item_width> <output_width> <item_type> {decimal places} (start item}.

Append: Combines up to 500 coverages in one coverage.
Syntax: APPEND <out_cover> {NOTEST | template_cover | feature_class .... feature_class} {NONE | FEATURES | TICS | ALL}

Build: Creates, or updates a feature attribute table for a specified coverage.
Syntax: Build <cover> {Poly | Line | Point | Node | Anno. <subclass>}

Clip: Extracts those features from an input coverage that overlap with a clip coverage
Syntax: CLIP <in_cover> <clip_cover> <out_cover> {point; poly; line; net; raw} {fuzzy tolerance}

Dropitem: Deletes an item or a subset of items from and existing INFO data file creating a new or revised INFO data file.
Syntax: DROPITEM <in_info_file> <out_info_file> {drop_item}

---

[1] Source: Environmental Systems Research Institute. 1992. Arc/Info User's Guide Version 6.1

Generate: Adds features to a coverage. Coordinates for each feature may be entered from the terminal or from a file.

Syntax: GENERATE <cover>

GridClip: Clips a grid using the outline of another polygon coverage

Syntax: GRIDCLIP <in_grid> <clip_cover> <out_grid>

GridPoly: Converts a grid to a polygon coverage. Polygons are built from groups of contiguous cells having the same cell values.

Syntax: GRIDPOLY <in_grid> <out_cover> {weed tolerance}.

Identity: Computes the geometric intersection of two coverages. All features of the input coverage, as well as those features of the identity coverage that overlap the input coverage are preserved in the output coverage.

Syntax: <in_cover> <identity_cover> <out_cover> {Poly | Line | Point} {fuzzy_tolerance} {JOIN | NOJOIN}.

INFODBASE: Copies an INFO data file to a DBASE data file.

Syntax: INFODBASE <info_file> <dbase_file> {DEFAULT | DEFINE}

PROJECT: Projects coordinates between two map projections.

Syntax: PROJECT <Cover | Grid | File> <input> <output> projection_file}{nearest | Bilinear | arbie}

RECLASS: Reclassifies, or changes, the value of the input cells using a remap table on a cell by cell basis within the analysis window

Syntax: RECLASS <grid> <remap table> {DATA; NODATA} {IN_ITEM} {OUT_ITEM}

RELATE: Establishes or modifies the relate environment. An existing relate environment may be listed or saved as an info data file.

Syntax: 1.) RELATE <ADD | DROP> 2.) RELATE <RESTORE> <info_file> 3.) RELATE LIST {relate}

STATISTICS: Generates summary statistics for items in an INFO data file and saves them in an output INFO data file.

Syntax: STATISTICS <info_file> <out_info_file> {case item}.

APPENDIX C

-Contains an example of the record fields in the 1996 Provincial Fire Record. Also contains a listing of the Remap tables used in the Reclassification of the Aspect and Elevation Grids.

Table C-1 An example of the record fields included in the 1996 Provincial Fire Record.

id
dr_id
fire_number
fire_location_latitude
fire_location_longitude
fire_type_code
fire_boss_name
signoff_indicator
last_updated_date
wil_id
id
wil_id
assessment_datetime
fire_spread_rate
fire_origin
prmt_fir_id
industry_identifier
responsible_group
true_cause
activity_class
discovered_size
fire_start_date
fire_fighting_start_size
fire_fighting_start_date
fire_type
fire_position_on_slope
weather_conditions_over_fire
ia_getaway_objective_time
initial_action_by
start_for_fire_date
wind_direction
wind_speed
comments
general_cause
fuel_type
other_fuel_type
assessment_datetime
requirements
billing_recommended_indicator
seen_area_1
seen_area_2
seen_area_3
last_updated_date
reported_date
discovered_date
uc_fs_date
ex_fs_date
fire_number
detection_report_id
year
cr_id
name
uc_hectares
total_area_burned
permit_number

Table C-2 An example of the remap table, used in association with the RECLASS command to reclassify the Aspect coverage data.

```
# This file will be used to convert GRID COVERAGE ASPECT TO ASPECT_4
#
# remap file for reclassifying aspects into 4 quadrants
# Note: in the input, 0 is north; and proceeds clockwise in degrees.
#  Classes: NE = 1, SE = 2, SW = 3, NW = 4.
# aspects of -1 are level
-1 -1 : 0
0 90 : 1
90 180 : 2
180 270 : 3
270 360 : 4
```

Table C-3 An example of the remap table, used in association with the RECLASS command to reclassify the Elevation coverage data.

```
# This AML is a remap file for reclassifying elevations into
# 100 m class intervals, based on the min. and max. values of
# 733 m and 1987 m, for the research areas.

700 800 : 1
800 900 : 2
900 1000 : 3
1000 1100 : 4
1100 1200 : 5
1200 1300 : 6
1300 1400 : 7
1400 1500 : 8
1500 1600 : 9
1600 1700 : 10
1700 1800 : 11
1800 1900 : 12
1900 2000 : 13
```

APPENDIX D

-Contains the Cumulative number of lightning strikes (by type) by year and month recorded in the FMA, and each of the research areas between 1984 and 1996. Also contains descriptive statistics which were calculated for each research area.

Table D-1 Total number of lightning strikes by month, and by year recorded in the FMA between 1984 and 1996.

Month	A			M			J			JL			AU			S			O			N		
	P	N	T	P	N	T	P	N	T	P	N	T	P	N	T	P	N	T	P	N	T	P	N	T
Year																								
1984	0	0	0	18	46	64	66	435	501	63	928	991	109	3055	3164	14	78	92	0	0	0	0	0	0
1985	0	0	0	16	238	254	10	867	877	53	287	340	106	882	988	0	3	3	0	1	1	0	0	0
1986	0	0	0	5	5	10	63	420	483	73	591	664	62	428	490	9	37	46	0	0	0	0	0	0
1987	0	0	0	15	49	64	113	2183	2296	256	3545	3801	12	53	65	10	83	93	4	2	6	0	0	0
1988	4	9	13	36	166	202	135	757	892	153	1847	2000	28	89	117	44	47	91	8	0	8	0	0	0
1989	4	13	17	8	55	63	136	452	588	472	6553	7025	516	4878	5394	22	72	94	0	0	0	2	0	2
1990	5	2	7	33	192	225	71	331	402	174	1555	1729	192	1223	1415	23	70	93	5	1	6	1	0	1
1991	7	10	17	32	69	101	172	1258	1430	178	1315	1493	289	1348	1637	0	0	0	0	0	0	0	0	0
1992	4	42	46	6	54	60	97	1016	1113	272	4479	4751	155	3496	3651	2	4	6	2	3	5	0	0	0
1993	7	22	29	31	342	373	433	2710	3143	201	2719	2920	96	2406	2502	47	62	109	0	1	1	0	0	0
1994	1	0	1	5	34	39	146	1006	1152	357	7960	8317	420	8186	8606	88	791	879	0	0	0	0	0	0
1995	0	14	14	33	100	133	135	1190	1325	191	1768	1959	64	443	507	5	286	291	0	1	1	0	2	2
1996	1	22	23	17	152	169	60	487	547	205	1982	2187	371	5093	5464	69	1567	1636	0	1	1	0	0	0

P= Positive Lightning
N = Negative Lightning
T = Total Lightning

Table D-2 Total number of lightning strikes by month, and by year recorded in each of the six research areas between 1984 and 1996.

	Nar			Pra			Mtl			Mud			Sad			Twp		
Year	P	N	T	P	N	T	P	N	T	P	N	T	P	N	T	P	N	T
1984	3	88	91	12	181	193	5	68	73	6	153	159	1	106	107	13	84	97
1985	10	31	41	5	29	34	8	55	63	12	38	50	10	46	56	12	133	145
1986	5	32	37	5	46	51	8	46	54	6	59	65	1	23	24	9	51	60
1987	15	180	195	17	191	208	7	139	146	6	132	138	10	70	80	17	290	307
1988	10	216	226	15	158	173	5	33	38	14	137	151	11	48	59	31	177	208
1989	41	300	341	42	348	390	14	202	216	42	329	371	69	473	542	37	536	573
1990	9	94	105	24	227	251	15	80	95	13	69	82	15	66	81	26	176	202
1991	18	63	81	38	186	224	17	254	271	14	70	84	25	117	142	45	246	291
1992	10	297	307	24	473	497	11	337	348	9	296	305	13	206	219	36	445	481
1993	33	296	329	33	351	384	25	274	299	32	292	324	36	295	331	34	455	489
1994	31	1139	1170	49	1089	1138	6	367	373	26	613	639	26	244	270	48	911	959
1995	13	114	127	15	194	209	8	156	164	21	73	94	19	102	121	9	186	195
1996	21	243	264	34	299	333	14	197	211	22	326	348	27	204	231	26	310	336

Nar = Narraway
Pra = Prairie Creek
Mtl = Mount Louie
Mud = Muddy Creek
Sad = Saddle Hills
Twp = Townships 62 & 63

P = Positive Lightning
N= Negative Lightning
T = Total Lightning

Table D-3 Total number of lightning strikes by month, recorded in each of the six research areas.

Month	A			M			J			JL			AU			S			O		
	P	N	T	P	N	T	P	N	T	P	N	T	P	N	T	P	N	T	P	N	T
Research Site																					
Narraway	0	2	2	7	39	46	49	447	496	74	1376	1450	80	1112	1192	10	117	127	1	0	1
Prairie Creek	5	1	6	8	52	60	56	592	648	91	1533	1624	136	1403	1539	14	191	205	3	0	3
Mount Louie	1	0	1	3	49	52	45	384	429	31	706	737	59	1033	1092	4	35	39	0	1	1
Muddy Creek	0	4	4	5	25	30	53	287	340	87	1326	1413	69	827	896	9	118	127	0	0	0
Saddle Hills	0	4	4	2	18	20	61	324	385	128	977	1105	64	615	679	8	61	69	0	1	1
Townships 62 & 63	2	4	6	11	88	99	84	786	870	117	1497	1614	115	1460	1575	11	165	176	3	0	3

Table D-4 Descriptive statistics calculated for the Aspect coverage of the Narraway research area.

	N	Range	Mean	Std. Deviation	Variance
AREA	8839.00	17243751.00	55308.58	496418.91	246431731028.72
Aspect Class	8839.00	3.00	2.48	1.11	1.24
LTGBA	8839.00	1600.00	7.73	81.54	6648.51
FBA	8839.00	177.78	2.09E-02	1.89	3.58
POSLTGBA	8839.00	1600.00	.68	23.58	555.78
Valid N (listwise)	8839.00				

Table D-5 Descriptive statistics calculated for the Aspect coverage in the Prairie Creek research area.

	N	Range	Mean	Std. Deviation	Variance
AREA	8953	24204999.00	67754.38	533253.96	284359788072.10
Aspect Class	8953	3.00	2.47	1.15	1.32
LTGBA	8953	1600.00	6.36	70.18	4925.42
FBA	8953	6.35	1.53E-03	7.80E-02	6.09E-03
POSLTGBA	8953	1600.00	.35	17.42	303.51
Valid N (listwise)	8953				

Table D-6 Descriptive statistics calculated for the Aspect coverage of the Mount Louie research area.

	N	Range	Mean	Std. Deviation	Variance
AREA	41899.00	21778751.00	13561.91	235406.95	55416429948.87
Aspect Class	41899.00	3.00	2.56	1.14	1.29
LTGBA	41899.00	1600.00	3.95	62.85	3949.74
FBA	41899.00	177.78	4.53E-03	.87	.76
POSLTGBA	41899.00	1600.00	.34	19.60	384.35
Valid N (listwise)	41899.00				

Table D-7 Descriptive statistics calculated for the Aspect coverage of the Muddy Creek research area.

	N	Range	Mean	Std. Deviation	Variance
AREA	7876.00	8186875.00	48137.78	322641.67	104097647803.02
Aspect Class	7876.00	3.00	2.51	1.15	1.32
LTGBA	7876.00	1600.00	7.93	85.09	7241.06
FBA	7876.00	.79	1.00E-04	8.88E-03	7.89E-05
POSLTGBA	7876.00	533.33	.22	7.76	60.27
Valid N (listwise)	7876.00				

Table D-8 Descriptive statistics calculated for the Aspect coverage of the Saddle Hills research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	5268.00	8538750.00	65513	349943.39	1.2246E+11
Aspect Class	5268.00	3.00	2.46	1.11	1.24
LTGBA	5268.00	1600.00	5.95	59.87	3584.46
FBA	5268.00	533.33	.10	7.35	54.01
POSLTGBA	5268.00	1600.00	.85	24.12	581.68
Valid N (listwise)	5268.00				

Table D-9 Descriptive statistics calculated for the Aspect coverage of the Township research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	7920.00	22872499.00	70621.92	535479.28	286738057404.42
Aspect Class	7920.00	3.00	2.49	1.13	1.28
LTGBA	7920.00	1600.00	5.98	64.27	4130.66
FBA	7920.00	5.33	1.95E-03	7.34E-02	5.38E-03
POSLTGBA	7920.00	320.00	.23	5.32	28.35
Valid N (listwise)	7920.00				

Table D-10 Descriptive statistics calculated for the Elevation coverage of the Narraway research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	161.00	107931871.00	3036475.16	13546601.85	183510421812684
Elevation Class	161.00	9.00	4.24	2.36	5.57
LTGBA	161.00	1600.00	12.05	126.02	15880.94
FBA	161.00	7.80	4.86E-02	.62	.38
POSLTGBA	161.00	1.35	5.52E-02	.19	3.46E-02
Valid N (listwise)	161.00				

Table D-11 Descriptive statistics calculated for the Elevation coverage in the Prairie Creek research area..

Variables	N	Range	Mean	Std. Deviation	Variance
AREA	124.00	121024999.00	4891980.83	19616509.90	384807460816641
Elevation Class	124.00	10.00	6.49	2.83	8.02
LTGBA	124.00	30.77	1.67	4.60	21.19
FBA	124.00	6.33E-02	1.47E-03	7.33E-03	5.38E-05
POSLTGBA	124.00	4.22	.11	.49	.24
Valid N (listwise)	124.00				

Table D-12 Descriptive statistics calculated for the Elevation coverage in the Mount Louie research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	555.00	80783127.00	1025230.86	5705011.12	3.254715E+13
Elevation Class	555.00	10.00	7.68	2.67	7.12
LTGBA	555.00	533.33	1.71	22.88	523.47
FBA	555.00	.11	5.39E-04	6.33E-03	4.01E-05
POSLTGBA	555.00	39.02	.11	1.70	2.88
Valid N (listwise)	555.00				

Table D-13 Descriptive statistics calculated for the Elevation coverage in the Muddy Creek research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	66.00	137389375.00	5744441.24	22577154.43	509727902213631
Elevation Class	66.00	6.00	3.33	1.82	3.30
LTGBA	66.00	45.71	4.67	7.31	53.42
FBA	66.00	9.27E-03	1.40E-04	1.14E-03	1.30E-06
POSLTGBA	66.00	3.88	.25	.64	.41
Valid N (listwise)	66.00				

Table D-14 Descriptive statistics calculated for the Elevation coverage in the Saddle Hills research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	52.00	233951871.00	6636983.12	33002483.58	1089163922440962
Elevation Class	52.00	3.00	2.48	1.02	1.04
LTGBA	52.00	48.48	3.40	7.61	57.87
FBA	52.00	2.12E-02	4.89E-04	2.98E-03	8.90E-06
POSLTGBA	52.00	3.54	.25	.64	.41
Valid N (listwise)	52.00				

Table D-15 Descriptive statistics calculated for the Elevation coverage in the Township research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	113.00	133080623.00	4949784.30	19410965.67	3.7678559E+14
Elevation Class	113.00	5.00	3.01	1.48	2.19
LTGBA	113.00	533.33	9.16	50.67	2567.10
FBA	113.00	.33	5.53E-03	3.43E-02	1.17E-03
POSLTGBA	113.00	3.56	.17	.49	.24
Valid N (listwise)	113.00				

Table D-16 Descriptive statistics calculated for the Vegetation coverage in the Narraway research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	800.00	143372655.10	647295.01	5636175.08	3.176647E+13
Vegetation Class	800.00	3.00	1.26	1.12	1.24
LTGBA	800.00	184.93	6.06	11.30	127.77
FBA	800.00	.23	3.02E-04	8.06E-03	6.50E-05
POSLTGBA	800.00	28.29	.48	2.53	6.42
Valid N (listwise)	800.00				

Table D-17 Descriptive statistics calculated for the Vegetation coverage in the Prairie Creek research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	783.00	79703404.31	769529.34	5040054.12	25402145577409.3
Vegetation Clas	783.00	3.00	1.28	1.13	1.28
LTGBA	783.00	115.52	6.96	11.20	125.50
FBA	783.00	5.04	1.04E-02	.19	3.55E-02
POSLTGBA	783.00	31.19	.48	2.45	5.98
Valid N (listwise	783.00				

Table D-18 Descriptive statistics calculated for the Vegetation coverage in the Mount Louie research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	957.00	42505562.7	358549.47	1989902.67	3.960E+12
Vegetation Class	957.00	3.00	1.66	1.16	1.34
LTGBA	957.00	655.95	5.92	24.74	612.10
FBA	957.00	1.51	2.11E-03	5.03E-02	2.53E-03
POSLTGBA	957.00	49.93	.41	2.89	8.33
Valid N (listwise)	957.00				

Table D-19 Descriptive statistics calculated for the Vegetation coverage in the Muddy Creek research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	656.00	141713168.46	564711.12	5772093.10	33317058791796.0
Vegetation Class	656.00	3.00	1.67	1.04	1.09
LTGBA	656.00	697.21	8.79	29.89	893.70
FBA	656.00	7.06E-03	1.08E-05	2.76E-04	7.60E-08
POSLTGBA	656.00	68.32	.71	4.07	16.58
Valid N (listwise)	656.00				

Table D-20 Descriptive statistics calculated for the Vegetation coverage in the Saddle Hills research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	537.00	105430843.89	627850.66	5809095.43	33745589719782.7
Vegetation Clas	537.00	3.00	1.51	1.05	1.11
LTGBA	537.00	122.66	5.88	11.82	139.75
FBA	537.00	6.96	1.30E-02	.30	9.01E-02
POSLTGBA	537.00	38.55	.61	3.01	537.00
Valid N (listwise)	537.00				

Table D-21 Descriptive statistics calculated for the Vegetation coverage in the Township research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	1029.00	77664632.33	553821.75	3071654.15	435059209958.85
Vegetation Class	1029.00	3.00	1.69	1.15	1.32
LTGBA	1029.00	503.21	6.86	19.70	388.06
FBA	1029.00	1275.01	1.31	39.78	1582.38
POSLTGBA	1029.00	91.23	.61	3.99	15.94
Valid N (listwise)	1029.00				

Table D-22 Descriptive statistics calculated for the Stand Origin coverage in the Narraway research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	1014.00	36050746.05	487241.16	2310251.16	5337260434100.66
Origin	1014.00	240.00	79.59	57.26	3279.20
LTGBA	1014.00	184.93	6.27	10.68	114.01
FBA	1014.00	1.71	1.99E-03	5.43E-02	2.95E-03
POSLTGBA	1014.00	28.29	.43	2.28	5.21
Valid N (listwise)	1014.00				

Table D-23 Descriptive statistics calculated for the Stand Origin coverage in the Prairie Creek research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	1289.00	37117904	467448.78	2075307.1	4.307E+12
Origin	1289.00	260.00	82.22	62.59	3917.12
LTGBA	1289.00	115.52	6.58	10.62	112.68
FBA	1289.00	12.78	1.40E-02	.37	.13
POSLTGBA	1289.00	31.19	.42	2.15	4.63
Valid N (listwise)	1289.00				

Table D-24 Descriptive statistics calculated for the Stand Origin coverage in the Mount Louie research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	1250.00	18800519.97	274613.76	1053254.01	1109344017126.14
PERIMETER	1250.00	170439.87	3805.94	9474.25	89761479.59
ORIGIN	1250.00	240.00	97.31	56.84	3230.56
LTGBA	1250.00	1159.95	7.25	39.73	1578.36
FBA	1250.00	9.60	1.00E-02	.28	7.67E-02
POSLTGBA	1250.00	49.93	.41	2.71	7.34
Valid N (listwise)	1250.00				

Table D-25 Descriptive statistics calculated for the Stand Origin coverage in the Muddy Creek research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	950.00	37002110.29	389947.89	2142090.54	4588551873739.09
ORIGIN	950.00	240.00	70.00	42.23	1783.56
LTGBA	950.00	697.21	8.55	25.44	647.33
FBA	950.00	3.90E-02	4.10E-05	1.26E-03	1.60E-06
POSLTGBA	950.00	68.32	.69	3.55	12.59
Valid N (listwise)	950.00				

Table D-26 Descriptive statistics calculated for the Stand Origin coverage in Saddle Hills research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	860.00	42663686.20	392041.63	2127049.45	4.52434E+12
Origin	860.00	180.00	76.07	39.93	1594.31
LTGBA	860.00	402.93	6.39	17.33	300.28
FBA	860.00	.12	1.42E-04	4.18E-03	1.75E-05
POSLTGBA	860.00	38.61	.65	3.39	11.51
Valid N (listwise)	860.00				

Table D-27 Descriptive statistics calculated for the Stand Origin coverage in the Township research area..

	N	Range	Mean	Std. Deviation	Variance
AREA	1404.00	28651144.33	360440.29	1157826.00	1340561037198.65
Origin	1404.00	200.00	102.29	64.79	4197.44
LTGBA	1404.00	147.84	6.57	11.05	122.18
FBA	1404.00	52.13	7.44E-02	1.51	2.27
POSLTGBA	1404.00	91.23	.52	3.33	11.09
Valid N (listwise)	1404.00				

Appendix E

-Contains detailed listings of the results obtained during the Analysis of Variance procedures conducted on the Aspect, Elevation, Vegetation, and Stand Age-Class coverages in all 6 of the research areas.

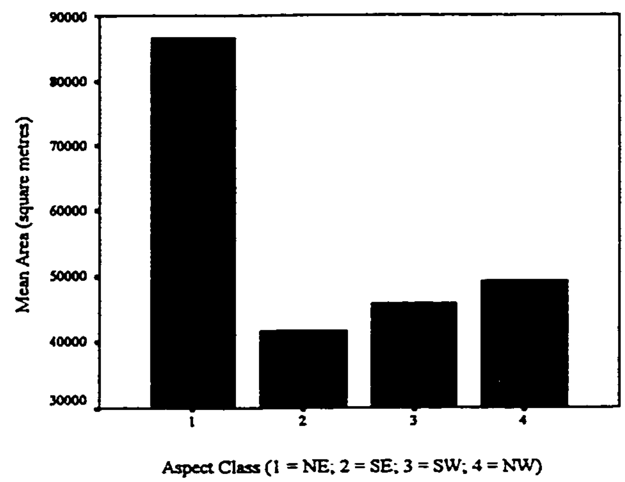

Figure E-1 The mean area by Aspect Class for the Aspect Coverage of the Narraway research area.

Table E-1. Summary of results of the Analysis of Variance procedures conducted on the Narraway Aspect Coverage.

Dependent Variable	Source	DF	Type III SS**	MS	F-Value	Pr > F
LTGBA	Aspect Class	3.000	0.006	0.002	0.030	0.995
FBA	Aspect Class	3.000	0.001	0.000	1.280	0.278
POSLTGBA	Aspect Class	3.000	0.093	0.031	2.270	0.079

* *LTGBA = Lightning Strike Density*
FBA = Lightning Fire Density
POSLTGBA = Positive lightning strike density

SS = Sum of Squares
MS = Mean Square
** *Type III SS was used data is assumed to be unbalanced*

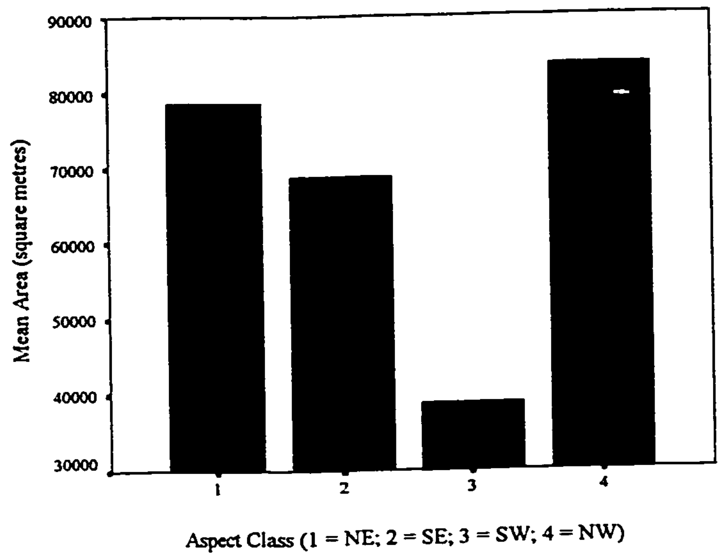

Figure E-2 The mean area by Aspect Class for the Prairie Creek Aspect Coverage

Table E-2. Summary of results of the Analysis of Variance procedures conducted on the Prairie Creek Aspect Coverage.

Dependent Variable	Source	DF	Type III SS**	MS	F-Value	Pr > F
LTGBA	Aspect Class	3.000	0.588	0.196	2.390	2.390
FBA	Aspect Class	3.000	0.004	0.001	1.330	0.263
POSLTGBA	Aspect Class	3.000	0.141	0.047	2.450	0.061

* *LTGBA = Lightning Strike Density*
FBA = Lightning Fire Density
POSLTGBA = Positive lightning strike density

SS = Sum of Squares
MS = Mean Square
** *Type III SS was used data is assumed to be unbalanced*

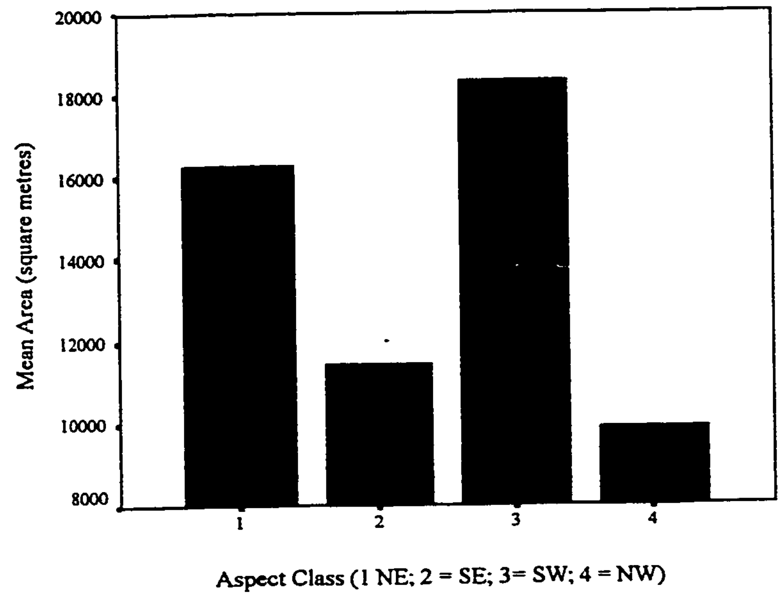

Figure E-3 The mean area by Aspect Class for the Mount Louie Aspect Coverage.

Table E-3. Summary of results of the Analysis of Variance procedures conducted on the Mount Louie Aspect Coverage.

Dependent Variable	Source	DF	Type III SS**	MS	F-Value	Pr > F
LTGBA	Aspect Class	3.000	0.057	0.019	1.070	0.359
FBA	Aspect Class	3.000	0.001	0.000	2.300	0.075
POSLTGBA	Aspect Class	3.000	0.017	0.006	2.490	0.058

* *LTGBA = Lightning Strike Density*
FBA = Lightning Fire Density
POSLTGBA = Positive lightning strike density

SS = Sum of Squares
MS = Mean Square
** *Type III SS was used as this assumes an unequal distribution of the dependent variable*

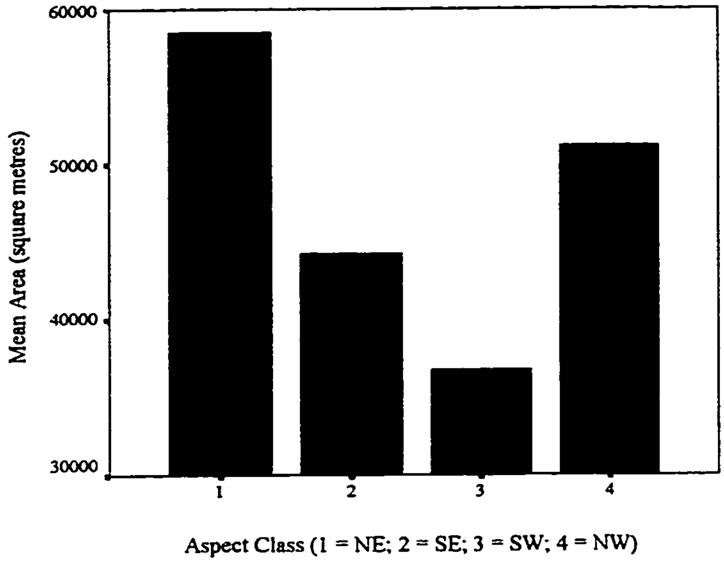

Figure E-4 The mean area by Aspect Class for the Muddy Creek Aspect Coverage.

Table E-4 Summary of results of the Analysis of Variance (ANOVA) procedures conducted on the Muddy Creek Aspect Coverage.

Dependent Variable	Source	DF	Type III SS**	MS	F-Value	Pr > F
LTGBA	Aspect Class	3	0.462	0.154	1.980	0.115
FBA	Aspect Class	3	0.000	0.000	0.910	0.433
POSLTGBA	Aspect Class	3	0.076	0.025	1.430	0.232

* *LTGBA = Lightning Strike Density*
FBA = Lightning Fire Density
POSLTGBA = Positive lightning strike density

SS = Sum of Squares
MS = Mean Square
** *Type III SS was used as this assumes an unequal distribution of the dependent variable*

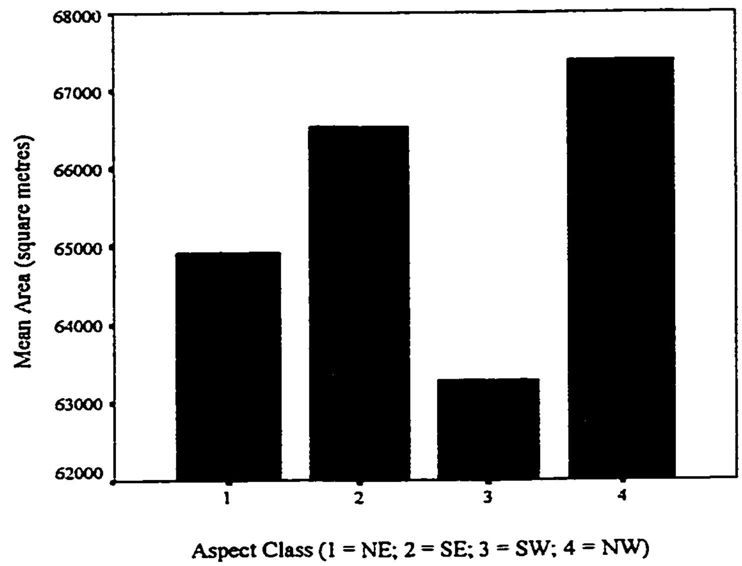

Figure E-5 The mean area by Aspect Class for the Saddle Hills Aspect Coverage.

Table E-5 Summary of results of the Analysis of Variance (ANOVA) procedures conducted on the Saddle Hills Aspect Coverage.

Dependent Variable	Source	DF	Type III SS**	MS	F-Value	Pr > F
LTGBA	Aspect Class	3	0.020	0.007	0.070	0.978
FBA	Aspect Class	3	0.002	0.001	2.030	0.107
POSLTGBA	Aspect Class	3	0.035	0.012	0.390	0.758

* *LTGBA = Lightning Strike Density*
FBA = Lightning Fire Density
POSLTGBA = Positive lightning strike density

SS = Sum of Squares
MS = Mean Square
** *Type III SS was used as this assumes an unequal distribution of the dependent variable*

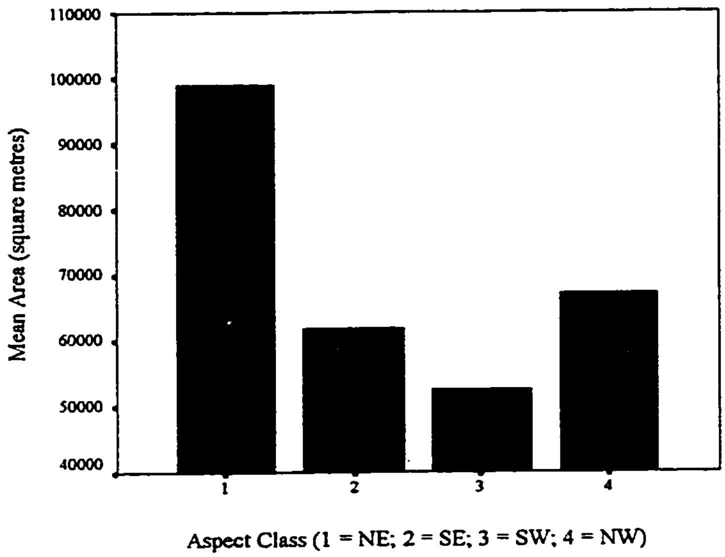

Figure E-6 The mean area by Aspect Class for the Township Aspect Coverage.

Table E-6 Summary of results of the Analysis of Variance (ANOVA) procedures conducted on the Township Aspect Coverage.

Dependent Variable	Source	DF	Type III SS**	MS	F-Value	Pr > F
LTGBA	Aspect Class	3	0.183	0.061	0.710	0.547
FBA	Aspect Class	3	0.009	0.003	1.510	0.208
POSLTGBA	Aspect Class	3	0.135	0.045	2.000	0.111

* *LTGBA = Lightning Strike Density*
FBA = Lightning Fire Density
POSLTGBA = Positive lightning strike density

SS = Sum of Squares
MS = Mean Square
** *Type III SS was used as this assumes an unequal distribution of the dependent variable*

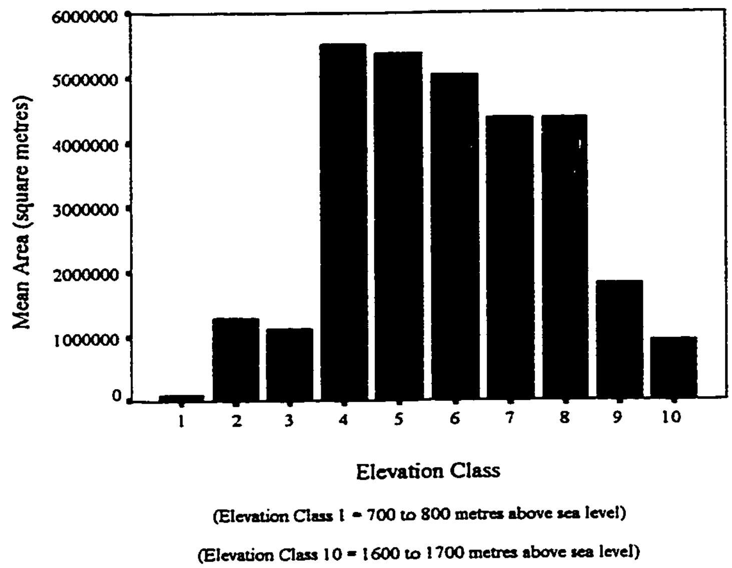

Figure E-7 The mean area by Elevation Class for the Elevation Coverage of the Narraway Research Area.

Table E-7. Summary of results of the Analysis of Variance procedures conducted on the Narraway Elevation Coverage.

Dependent Variable	Source	DF	Type III SS**	MS	F-Value	Pr > F
LTGBA	Elevation Clas	9.000	2.407	0.267	2.430	0.013
FBA	Elevation Clas	9.000	0.027	0.003	0.470	0.892
POSLTGBA	Elevation Clas	9.000	0.451	0.050	3.040	0.002

* *LTGBA = Lightning Strike Density*
FBA = Lightning Fire Density
POSLTGBA = Positive lightning strike density

SS = Sum of Squares
MS = Mean Square
** *Type III SS was used as this assumes an unequal distribution of the dependent variable*

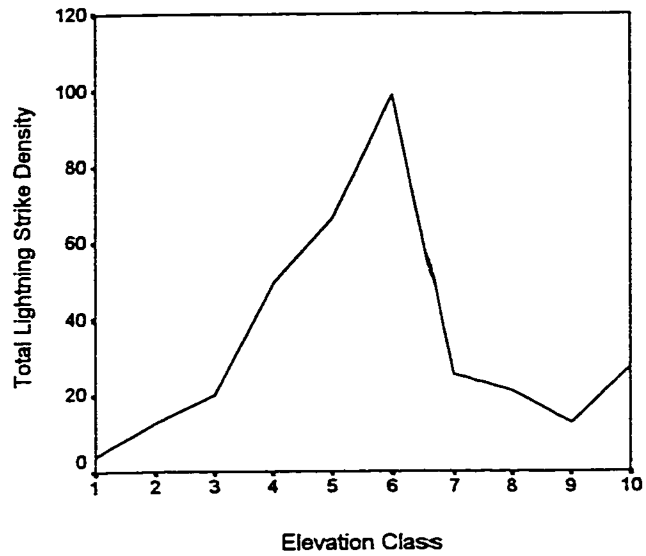

Figure E-8a Total lightning strike density by Elevation class in the Narraway research area.

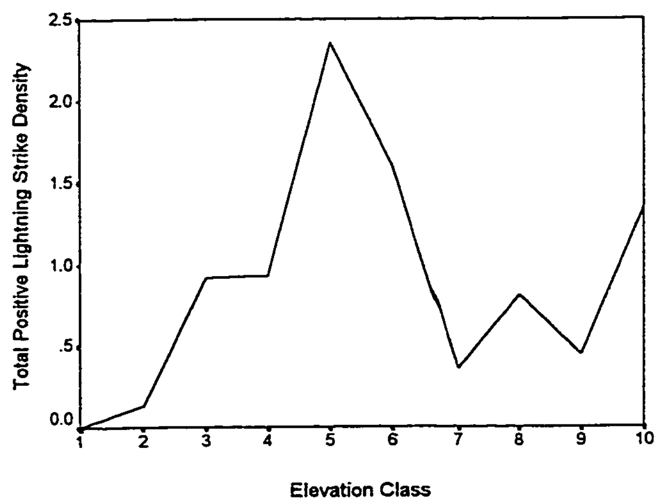

Figure E-8B Total Positive lightning strike density by Elevation class in the Narraway research area.

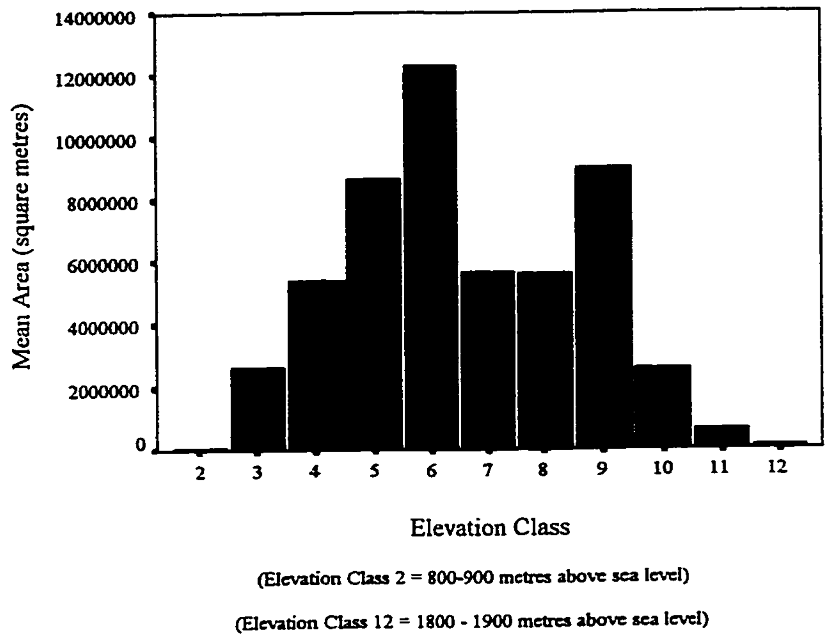

Figure E-9 The mean area by Elevation Class for the Prairie Creek Elevation Coverage.

Table E-8. Summary of results of the Analysis of Variance procedures conducted on the Prairie Creek Elevation Coverage.

Dependent Variable	Source	DF	Type III SS**	MS	F-Value	Pr > F
LTGBA*	Elevation Class	11	0.697	0.697	0.780	0.652
FBA	Elevation Class	11	0.016	0.011	0.430	0.932
POSLTGBA	Elevation Class	11	0.705	0.071	1.590	0.118

** LTGBA = Lightning Strike Density*
FBA = Lightning Fire Density
POSLTGBA = Positive lightning strike density

SS = Sum of Squares
MS = Mean Square
*** Type III SS was used as this assumes an unequal distribution of the dependent variable*

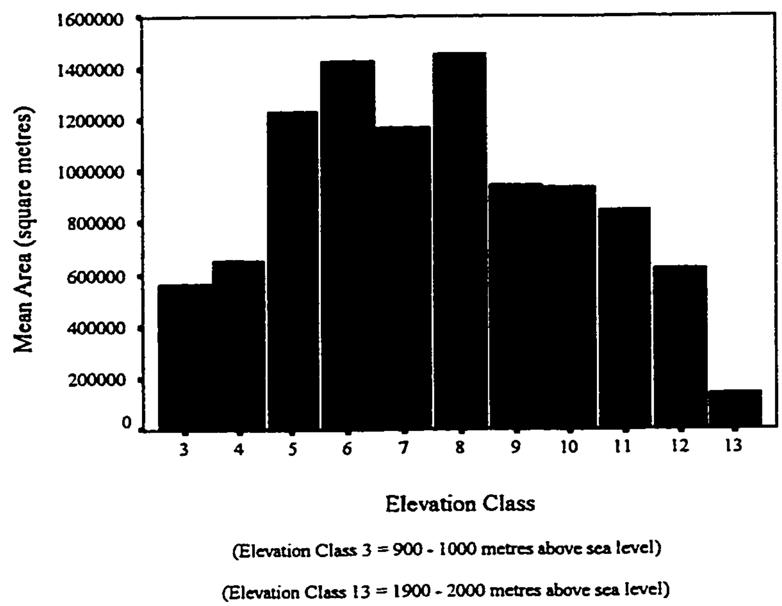

Figure E-10 The mean area by Elevation Class for the Mount Louie Elevation Coverage.

Table E-9. Summary of results of the Analysis of Variance procedures conducted on the Mount Louie Elevation Coverage.

Dependent Variable	Source	DF	Type III SS**	MS	F-Value	Pr > F
LTGBA	Elevation Class	10	3.138	0.314	5.590	0.000
FBA	Elevation Class	10	0.057	0.006	0.630	0.786
POSLTGBA	Elevation Class	10	0.230	0.023	0.820	0.613

* *LTGBA = Lightning Strike Density*
FBA = Lightning Fire Density
POSLTGBA = Positive lightning strike density

SS = Sum of Squares
MS = Mean Square
** *Type III SS was used as this assumes an unequal distribution of the dependent variable*

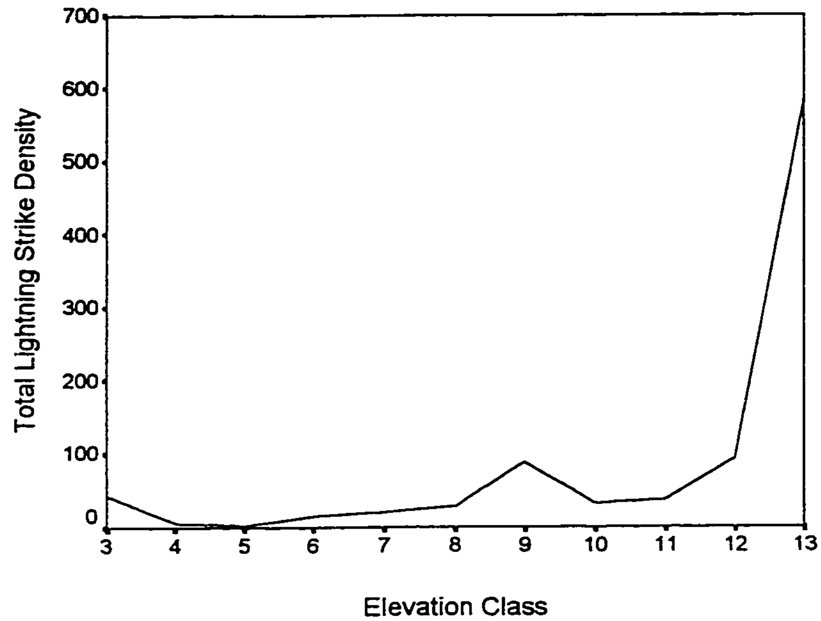

Figure E-11 The total number of lightning strikes per square kilometer by elevation class in the Mount Louie research area.

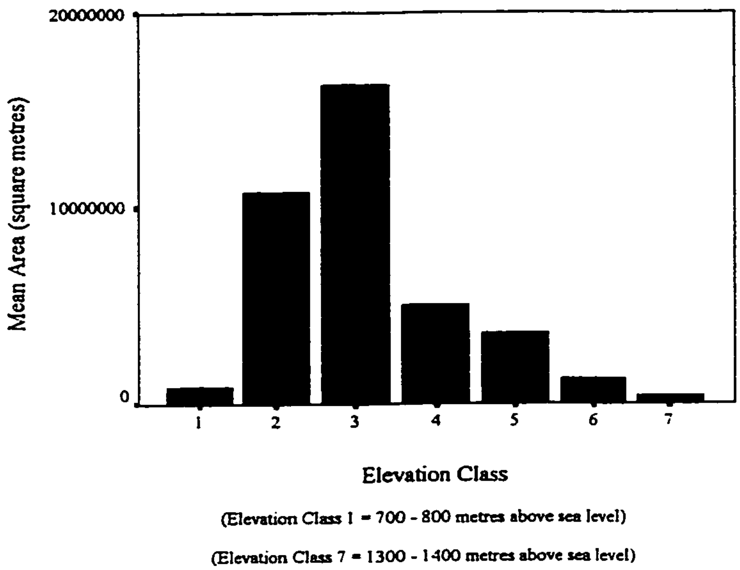

Figure E-12 The mean area by Elevation Class for the Muddy Creek Elevation Coverage.

Table E-10 Summary of results of the Analysis of Variance (ANOVA) procedures conducted on the Muddy Creek Elevation Coverage

Dependent Variable	Source	DF	Type III SS**	MS	F-Value	Pr > F
LTGBA	Elevation Class	6	1.836	0.306	2.100	0.067
FBA	Elevation Class	6	0.085	0.014	0.930	0.482
POSLTGBA	Elevation Class	6	0.734	0.122	2.390	0.039

* *LTGBA = Lightning Strike Density*
FBA = Lightning Fire Density
POSLTGBA = Positive lightning strike density

SS = Sum of Squares
MS = Mean Square
** *Type III SS was used as this assumes an unequal distribution of the dependent variable*

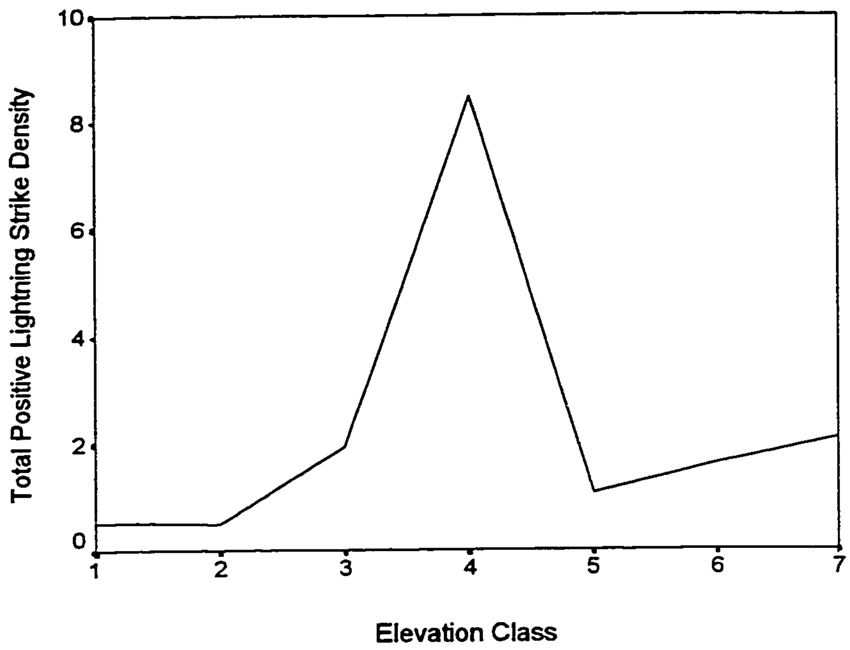

Figure E-13 Total Positive Lightning strike density by Elevation Class for the Muddy Creek Research area.

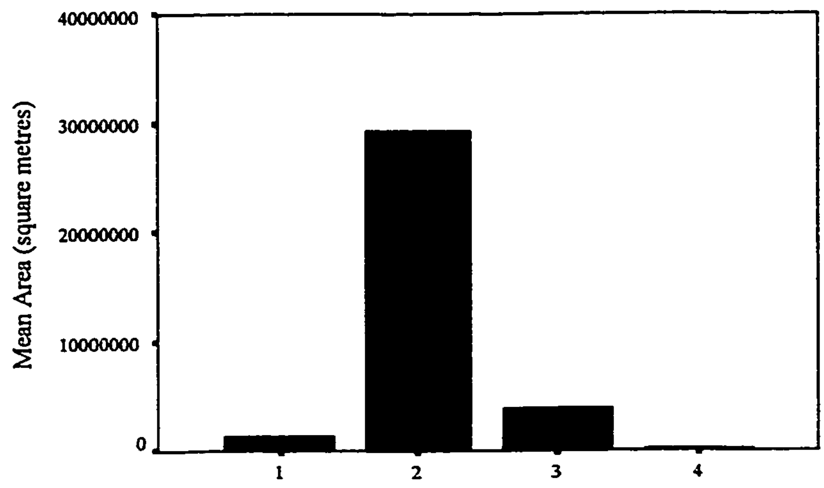

Figure E-14 The mean area by Elevation Class for the Saddle Hills Elevation Coverage.

Table E-11 Summary of results of the Analysis of Variance (ANOVA) procedures conducted on the Saddle Hills Elevation Coverage.

Dependent Variable	Source	DF	Type III SS**	MS	F-Value	Pr > F
LTGBA	Elevation Clas	3	0.319	0.106	0.890	0.453
FBA	Elevation Clas	3	0.090	0.030	0.780	0.509
POSLTGBA	Elevation Clas	3	0.144	0.048	0.650	0.587

* *LTGBA = Lightning Strike Density*
FBA = Lightning Fire Density
POSLTGBA = Positive lightning strike density

SS = Sum of Squares
MS = Mean Square
** *Type III SS was used as this assumes an unequal distribution of the dependent variable*

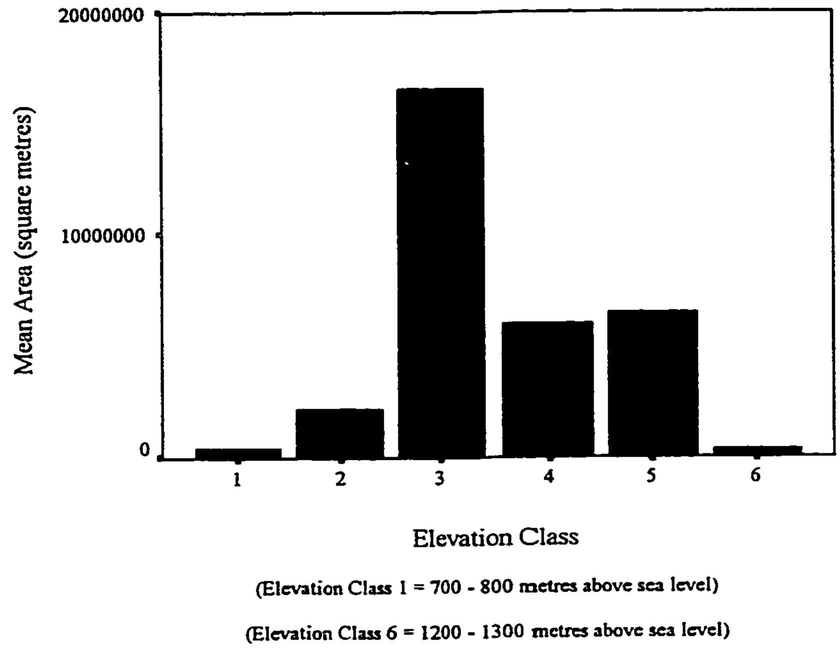

Figure E-15 The mean area by Elevation Class for the Township Elevation Coverage.

Table E-12 Summary of results of the Analysis of Variance (ANOVA) procedures conducted on the Township Elevation Coverage.

Dependent Variable	Source	DF	Type III SS**	MS	F-Value	Pr > F
LTGBA	Elevation Clas	5	3.656	0.731	3.400	0.007
FBA	Elevation Clas	5	0.103	0.021	1.180	0.325
POSLTGBA	Elevation Clas	5	0.781	0.156	1.020	0.407

** LTGBA = Lightning Strike Density*
FBA = Lightning Fire Density
POSLTGBA = Positive lightning strike density

SS = Sum of Squares
MS = Mean Square
*** Type III SS was used as this assumes an unequal distribution of the dependent variable*

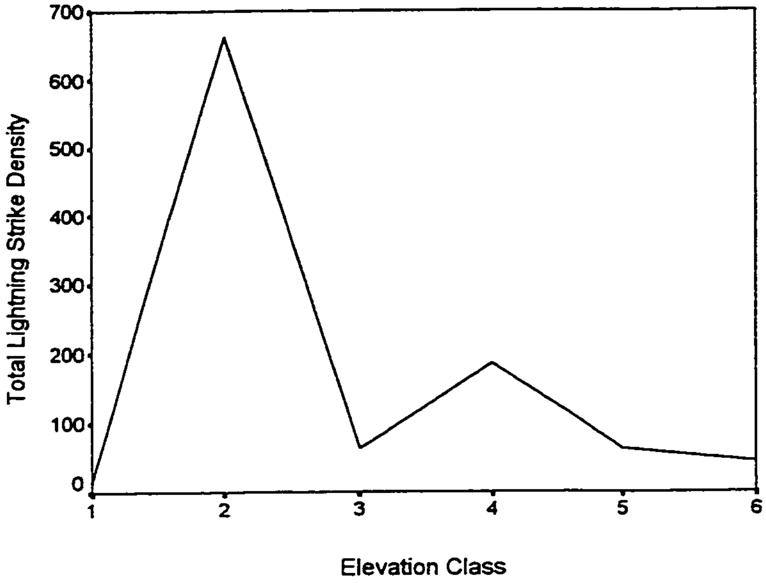

Figure E-16 Total Lightning Strike density, as measured by number of strikes per square kilometer, by Elevation Class in the Townships research area.

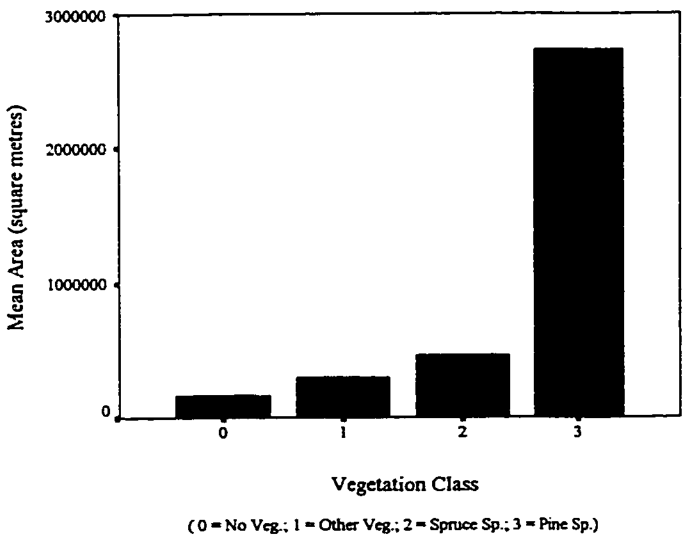

Figure E-17 The mean area by Vegetation Class for the Vegetation Coverage of the Narraway Research Area.

Table E-13. Summary of results of the Analysis of Variance (ANOVA) procedures conducted on the Narraway Vegetation Coverage.

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
Vegetation Class	Main Effects	(Combined)	19.30	3	6.433	5.24	.001
		LTGBA	12.04	1	12.044	9.81	.002
		FBA	5.87	1	5.867	4.78	.029
		POSLTGBA	.01	1	.014	.01	.914
	Model		19.30	3	6.433	5.24	.001
	Residual		985.64	803	1.227		
	Total		1004.94	806	1.247		

a. Vegetation Class by LTGBA, FBA, POSLTGBA

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

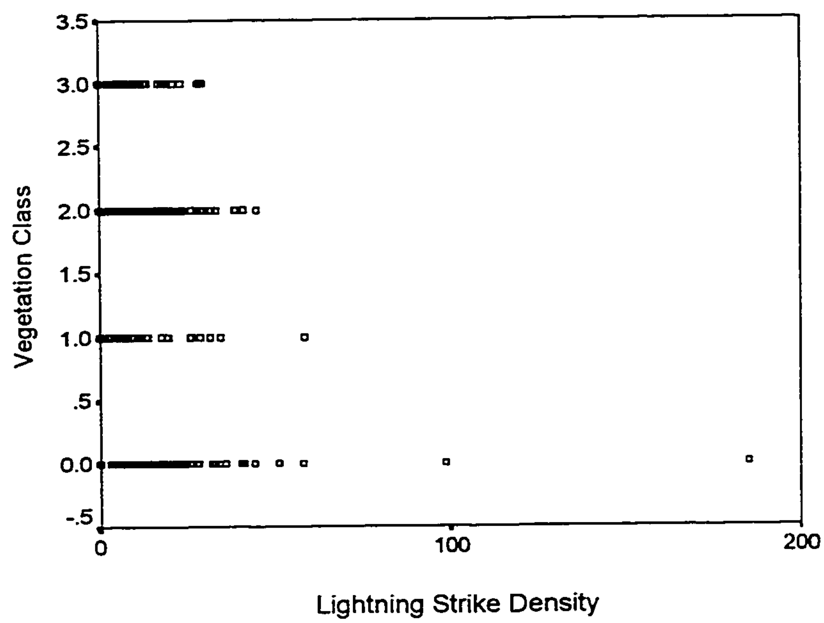

Figure E-18A Vegetation type by total lightning strike density in the Narraway research area.

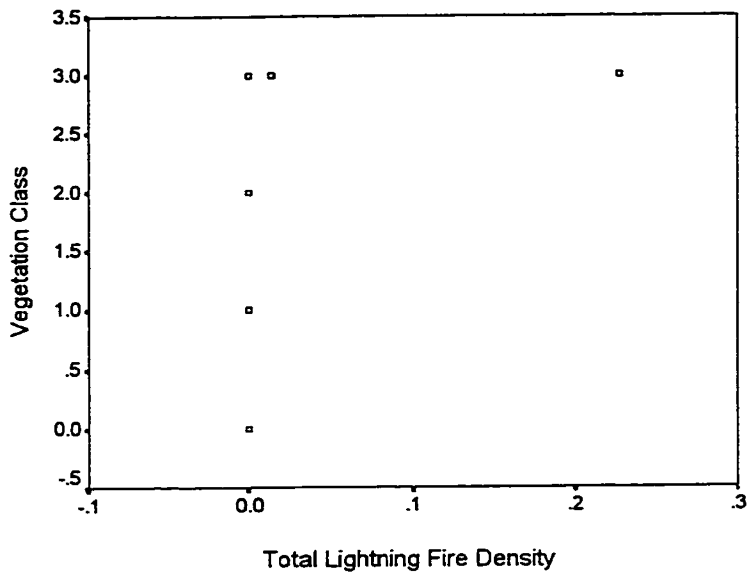

Figure E-18B Vegetation class by total lightning fire density in the Narraway research area.

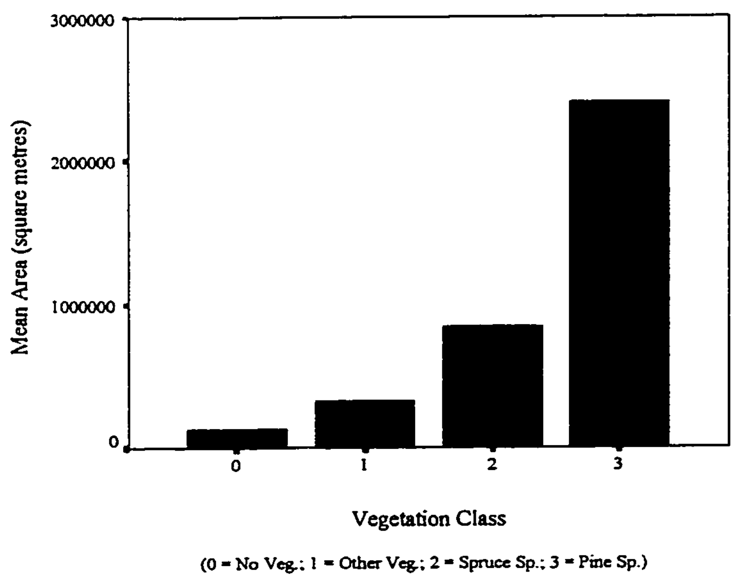

Figure E-19 The mean area by Vegetation Class for the Prairie Creek Vegetation Coverage.

Table E-14 Summary of results of the Analysis of Variance (ANOVA) procedures conducted on Prairie Creek Vegetation Coverage

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
Vegetation Class	Main Effects	(Combined)	19.44	3	6.48	5.16	.002
		LTGBA	2.41	1	2.41	1.92	.166
		FBA	12.89	1	12.89	10.27	.001
		POSLTGBA	2.79	1	2.79	2.22	.137
	Model		19.44	3	6.48	5.16	.002
	Residual		977.86	779	1.26		
	Total		997.31	782	1.28		

a. Vegetation Class by LTGBA, FBA, POSLTGBA

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

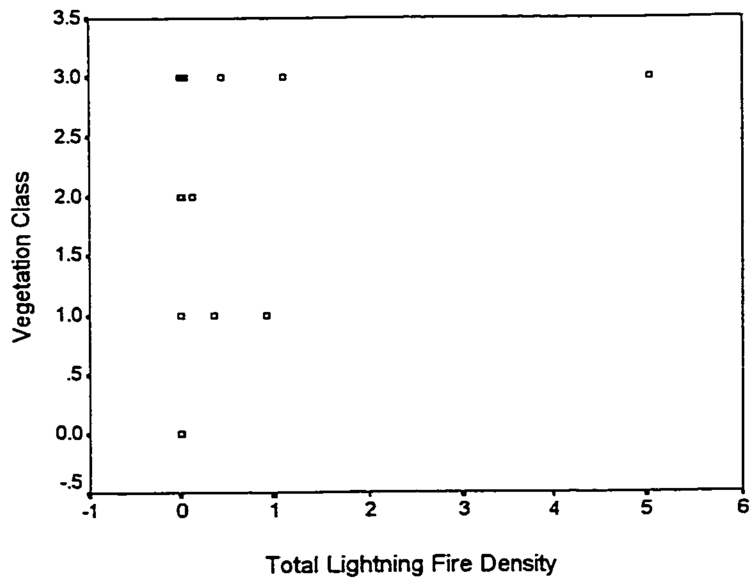

Figure E-20 Vegetation Class by the total density of lightning fires in the Prairie Creek Research area.

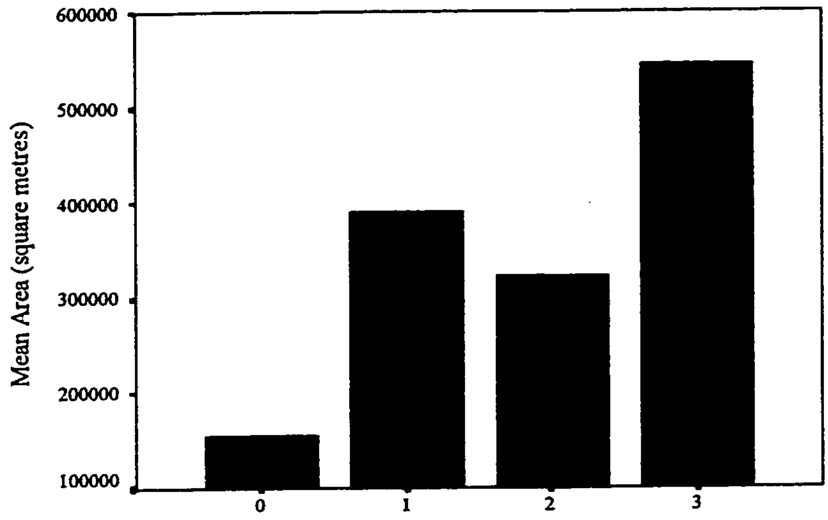

Figure E-21 The mean area by Vegetation Class for the Mount Louie Vegetation Coverage.

Table E-15 Summary of results of the Analysis of Variance (ANOVA) procedures conducted Mount Louie Vegetation Coverage

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
Vegetation Class	Main Effects	(Combined)	1.44	3	.48	.36	.785
		LTGBA	.01	1	.01	.01	.918
		FBA	1.42	1	1.42	1.05	.305
		POSLTGBA	.01	1	.01	.01	.935
	Model		1.44	3	.48	.36	.785
	Residual		1281.83	953	1.35		
	Total		1283.27	956	1.34		

a. Vegetation Class by LTGBA, FBA, POSLTGBA

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

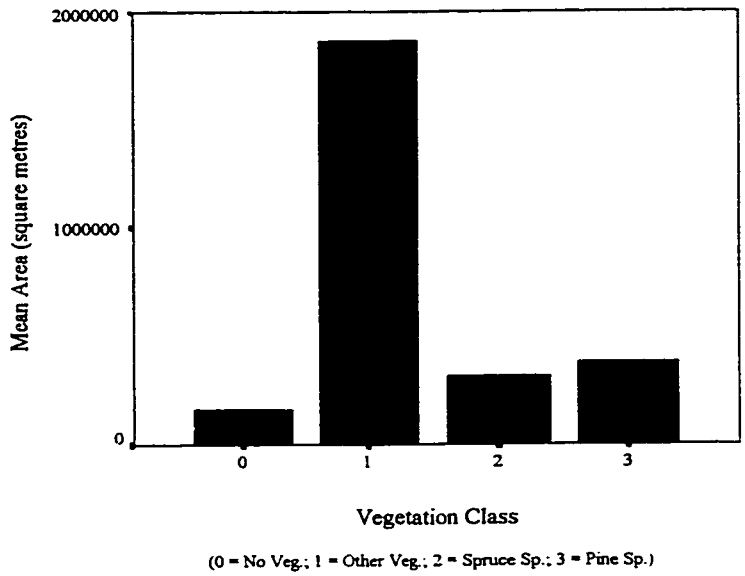

Figure E-22 The mean area by Vegetation Class for the Muddy Creek Vegetation Coverage.

Table E-16 Summary of results of the Analysis of Variance (ANOVA) procedures conducted on the Muddy Creek Vegetation Coverage

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
Vegetation Class	Main Effects	(Combined)	.73	3	.24	.22	.881
		LTGBA	.23	1	.23	.21	.648
		FBA	.46	1	.46	.42	.518
		POSLTGBA	.11	1	.11	.10	.751
	Model		.73	3	.24	.22	.881
	Residual		713.16	652	1.09		
	Total		713.89	655	1.09		

a. Vegetation Class by LTGBA, FBA, POSLTGBA

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

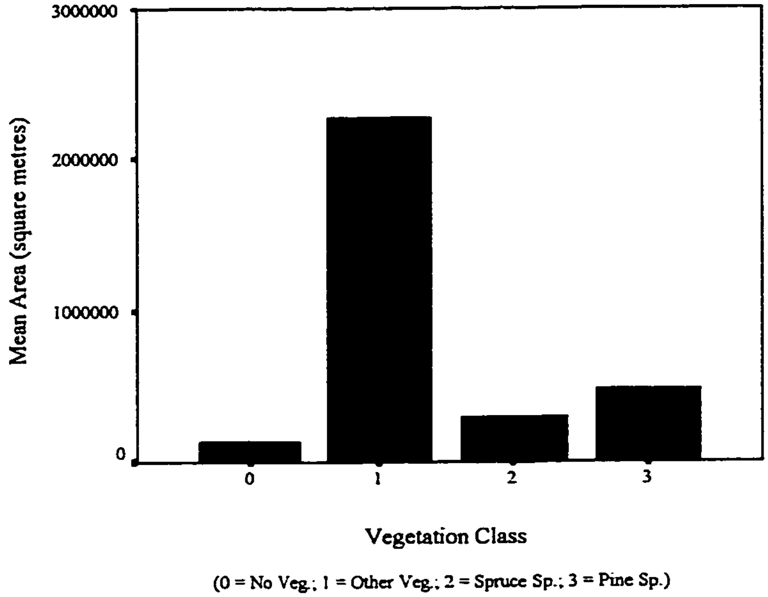

Figure E-23 The mean area by Vegetation Class for the Saddle Hills Vegetation Coverage.

Table E-17 Summary of results of the Analysis of Variance (ANOVA) procedures conducted on the Saddle Vegetation Coverage.

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
Vegetation Class	Main Effects	(Combined)	1.00	3	.33	.30	.826
		LTGBA	.17	1	.17	.15	.698
		FBA	.22	1	.22	.20	.654
		POSLTGBA	.33	1	.33	.30	.586
	Model		1.00	3	.33	.30	.826
	Residual		593.23	533	1.11		
	Total		594.23	536	1.11		

a. Vegetation Class by LTGBA, FBA, POSLTGBA

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

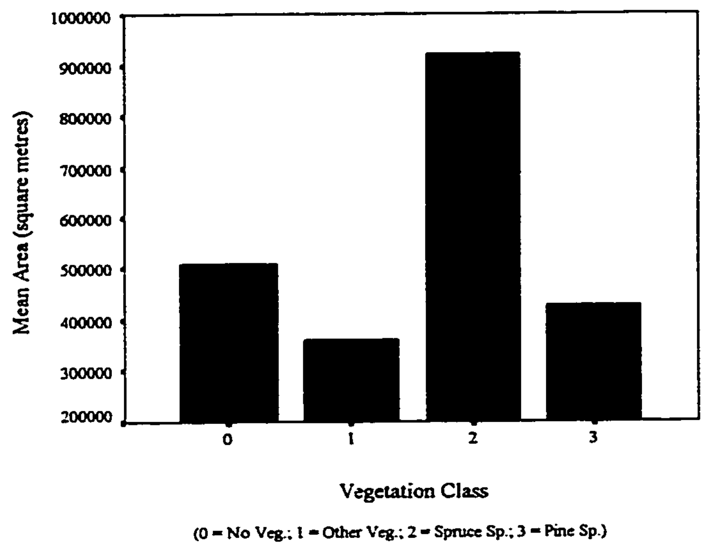

Figure E-24 The mean area by Vegetation Class for the Township Vegetation coverage.

Table E-18 Summary of results of the Analysis of Variance (ANOVA) procedures conducted on the Township Vegetation Coverage.

ANOVA [a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
Vegetation Class	Main Effects	(Combined)	1.10	3	.37	.28	.841
		LTGBA	.53	1	.53	.40	.526
		FBA	.36	1	.36	.27	.601
		POSLTGBA	.16	1	.16	.12	.729
	2-Way Interactions	(Combined)	3.02	3	1.01	.76	.514
		LTGBA * FBA	.84	1	.84	.64	.425
		LTGBA * POSLTGBA	1.87	1	1.87	1.42	.234
		FBA * POLSTGBA	.06	1	.06	.04	.834
	Model		7.80	6	1.30	.99	.432
	Residual		1344.39	1022	1.32		
	Total		1352.18	1028	1.32		

a. Vegetation Class by LTGBA, FBA, POSLTGBA

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

Figure E-25 The mean area by Stand Age Class for the Stand Origin Coverage of the Narraway research area.

Table E-19 Summary of results of the Analysis of Variance procedures conducted on the Narraway Stand Origin Coverage.

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
ORIGIN	Main Effects	(Combined)	397.66	3	132.55	.04	.989
		LTGBA	95.26	1	95.26	.03	.863
		POSLTGBA	3.50	1	3.50	.00	.974
		FBA	98.61	1	98.61	.03	.861
	2-Way Interactions	(Combined)	40589.4	3	13529.80	4.21	.006
		LTGBA * POSLTGBA	40302.0	1	40302.00	12.55	.000
		LTGBA * FBA	18.33	1	18.33	.01	.940
		POSLT * FIRE	1005.45	1	1005.45	.31	.576
	Model		88829.1	6	14804.85	4.61	.989
		Residual	3.E+06	1007	3210.52		.863
		Total	3.E+06	1013	3279.20		.974

a. Stand Age Class by LTGBA, FBA, POSLTGBA

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

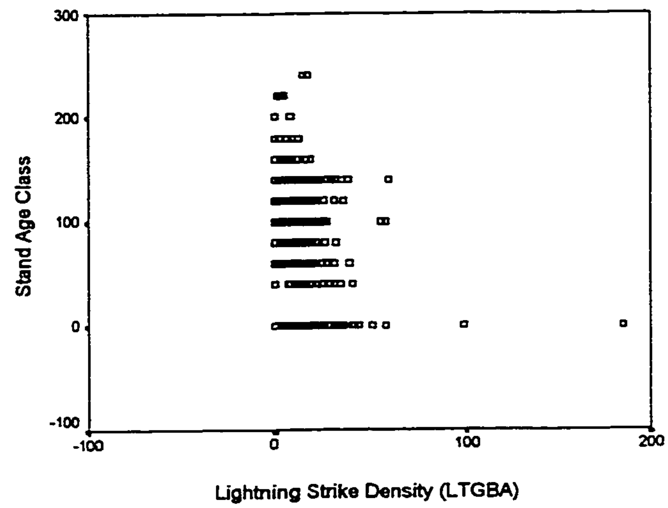

Figure E-26 A Scatter plot of stand age class by lightning strike density for the Narraway research area.

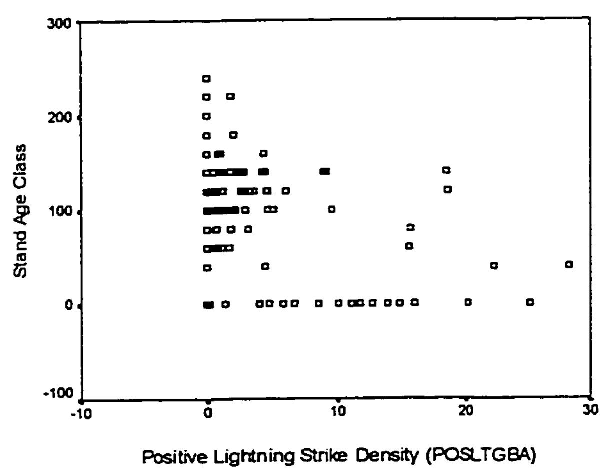

Figure E-27 A Scatter plot of stand age class by positive lightning strike density for the Narraway research area.

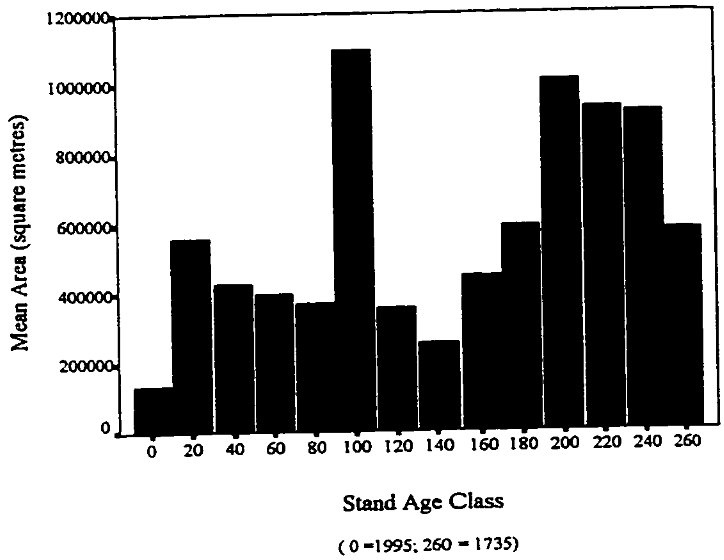

Figure E-28 The mean area by Stand Age Class for the Prairie Creek Stand Origin Coverage.

Table E-20 Summary of results of the Analysis of Variance (ANOVA) procedures conducted on Prairie Creek Stand Origin Coverage.

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
ORIGIN	Main Effects	(Combined)	119347	3	39782.5	10.378	.000
		LTGBA	28927.1	1	28927.1	7.546	.006
		FBA	97481.5	1	97481.5	25.430	.000
		POSLTGBA	1658.20	1	1658.20	.433	.511
	Model		119347	3	39782.5	10.378	.000
	Residual		5.E+06	1285	3833.39		
	Total		5.E+06	1288	3917.12		

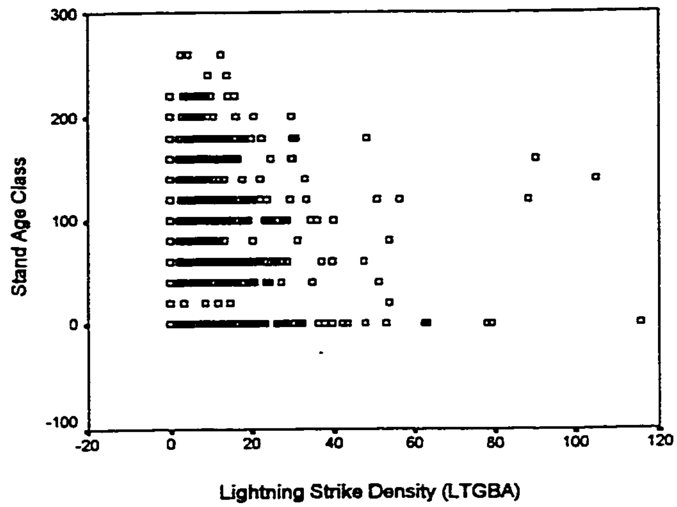

Figure E-29 A scatter plot of stand age class by lightning strike density for the Prairie Creek research area.

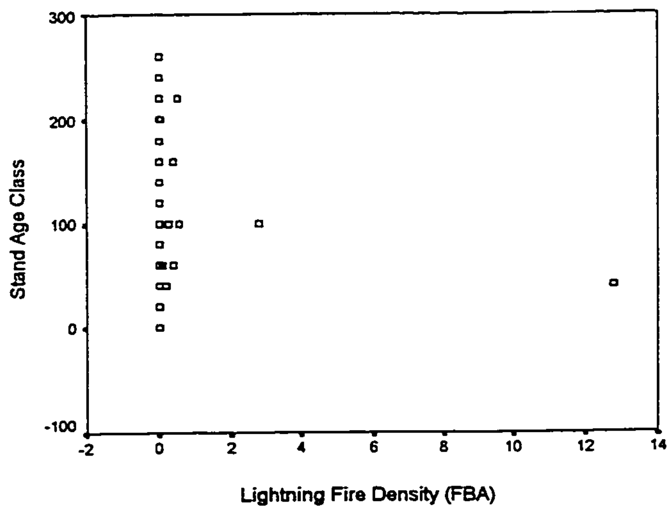

Figure E-30 A scatter plot of stand age class by lightning fire density for the Prairie Creek research area.

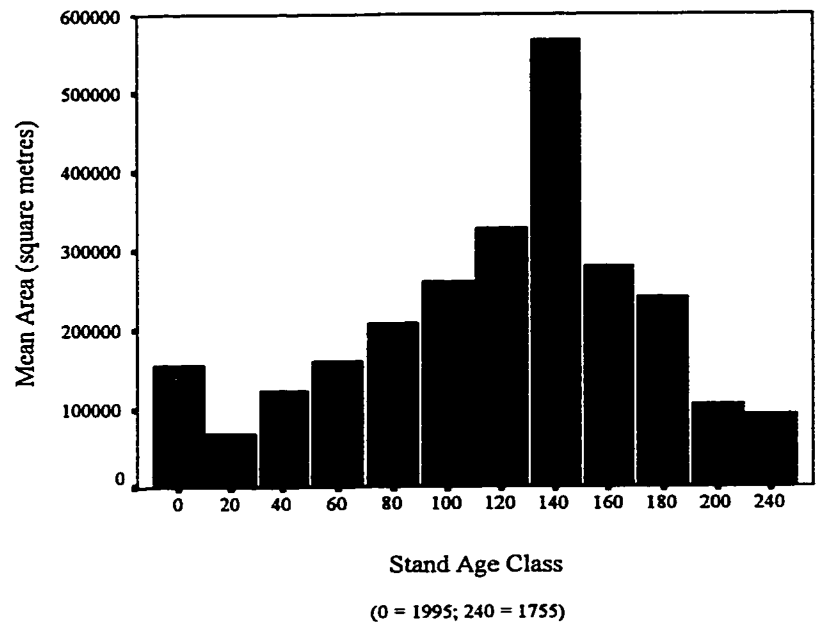

Figure E-31 The mean area by Stand Age Class for the Mount Louie Stand Origin Coverage.

Table E-21 Summary of results of the Analysis of Variance (ANOVA) procedures conducted Mount Louie Stand Origin Coverage.

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
ORIGIN	Main Effects	(Combined)	5739.07	3	1913.02	.59	.621
		LTGBA	3686.43	1	3686.43	1.14	.286
		FBA	2692.66	1	2692.66	.83	.362
		POSLTGBA	4615.23	1	4615.23	1.42	.233
	2-Way Interactions	(Combined)	6430.86	3	2143.62	.66	.576
		LTGBA * FBA	3842.29	1	3842.29	1.19	.276
		LTGBA * POSLTGBA	803.602	1	803.602	.25	.619
		FBA * POSLTGBA	4541.62	1	4541.62	1.40	.237
	Model		8329.93	6	1388.32	.43	.860
	Residual		4.E+06	1243	3239.45		
	Total		4.E+06	1249	3230.56		

a. Stand Age Class by LTGBA, FBA, POSLTGBA

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

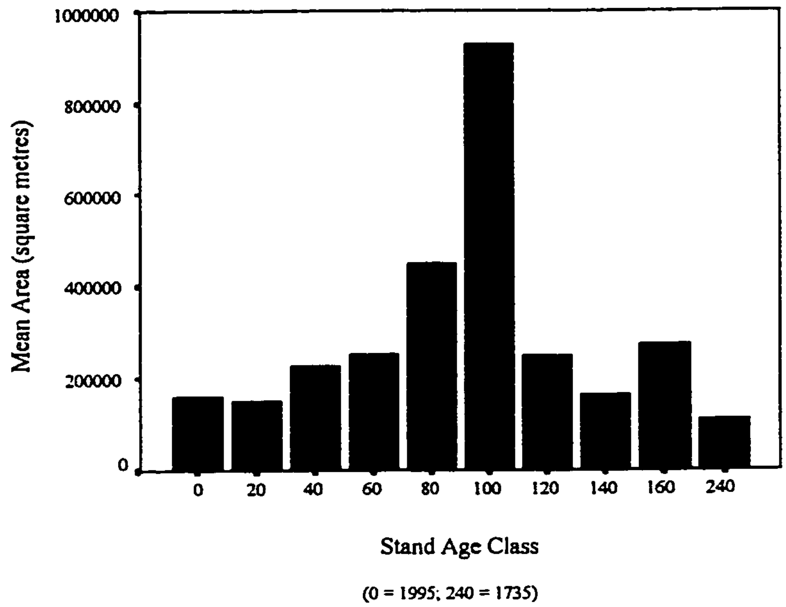

Figure E-22 The mean area by Stand Age Class for the Muddy Creek Stand Origin Coverage.

Table E-22 Summary of results of the Analysis of Variance (ANOVA) procedures conducted on the Muddy Creek Stand Origin Coverage.

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
ORIGIN	Main Effects	(Combined)	7596.98	3	2532.33	1.42	.235
		LTGBA	4608.52	1	4608.52	2.59	.108
		FBA	835.32	1	835.32	.47	.494
		POSLTGBA	3738.95	1	3738.95	2.10	.148
	Model		7596.98	3	2532.33	1.42	.235
	Residual		1685003.02	946	1781.19		
	Total		1692600.00	949	1783.56		

a. Stand Age Class by LTGBA, FBA, POSLTGBA

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

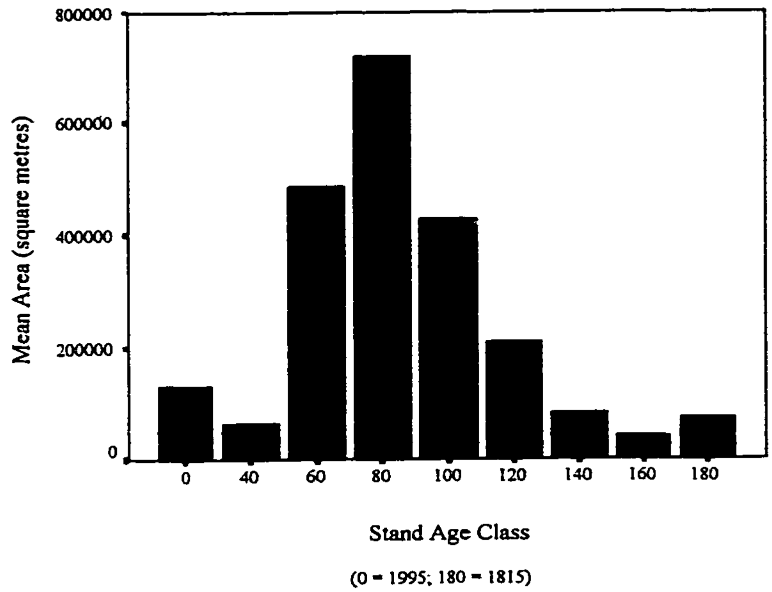

Figure E-33 The mean area by Stand Age Class for the Saddle Hills Stand Origin Coverage.

Table E-23 Summary of results of the Analysis of Variance (ANOVA) procedures conducted on the Saddle Hills Stand Origin Coverage.

ANOVA[a,b,c]

			Unique Method			
			Sum of Squares	Mean Square	F	Sig.
ORIGIN	Main Effects	(Combined)	1433.58	477.86	.30	.826
		LTGBA	36.53	36.53	.02	.880
		FBA	571.93	571.93	.36	.550
		POSLTGBA	671.04	671.04	.42	.517
	Model		1433.58	477.86	.30	.826
	Residual		1368082.24	1598.23		
	Total		1369515.81	1594.31		

a. Stand Age Class by LTGBA, FBA, POSLTGBA

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

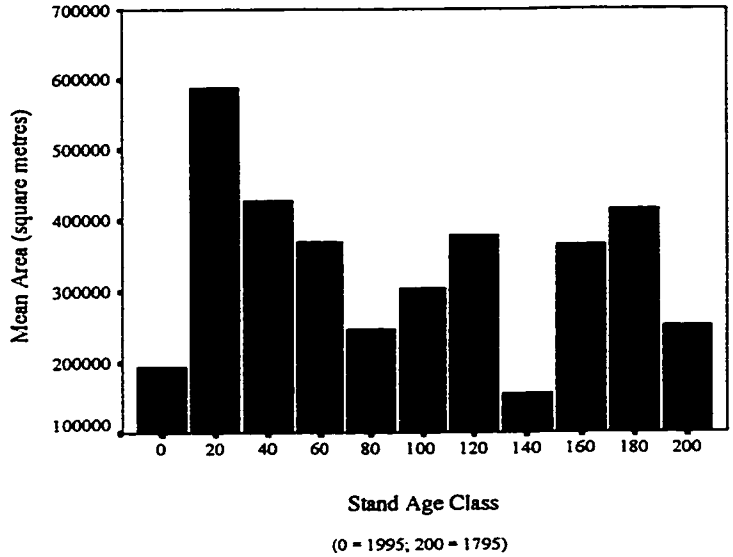

Figure E-34 The mean area by stand age class for the Township Stand Origin Coverage.

Table E-24 Summary of results of the Analysis of Variance (ANOVA) procedures conducted on the Township Stand Origin Coverage.

ANOVA [a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
ORIGIN	Main Effects	(Combined)	22282.16	3	7427.39	1.77	.150
		LTGBA	333.66	1	333.66	.08	.778
		FBA	19151.48	1	19151.48	4.58	.033
		POSLTGBA	1.37	1	1.37	.00	.986
	2-Way Interactions	(Combined)	12474.10	3	4158.03	.99	.395
		LTGBA * FBA	74.57	1	74.57	.02	.894
		LTGBA * POSLTGBA	10288.67	1	10288.67	2.46	.117
		FBA * POSLTGBA	662.03	1	662.03	.16	.691
	3-Way Interactions	LTGBA * FBA * POSLTGBA	10985.96	1	10985.96	2.63	.105
	Model		47357.36	7	6765.34	1.62	.126
	Residual		5841657.74	1396	4184.57		
	Total		5889015.10	1403	4197.44		

a. Stand Age Class by LTGBA, FBA, POSLTGBA

b. All effects entered simultaneously

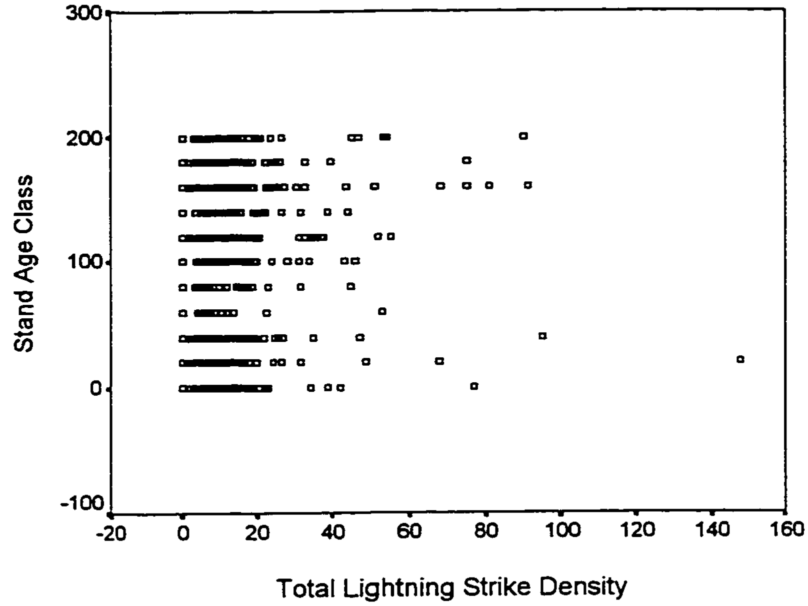

Figure E-35 Stand Age Class by Total Lightning Fire density, as measured in the number of lightning fires per square kilometer, in the Township Stand Origin Coverage.