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LINKING LANDSCAPE PATTERN AND FOREST DISTURBANCE:

FIRE HISTORY OF THE SHAKWAK TRENCH, SOUTHWEST YUKON TERRITORY

by

Shawn R. Francis

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

Plant Ecology

DEPARTMENT OF BOTANY

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled *LINKING LANDSCAPE PATTERN AND FOREST DISTURBANCE: FIRE HISTORY OF THE SHAKWAK TRENCH, SOUTHWEST YUKON TERRITORY* submitted by *SHAWN R. FRANCIS* in partial fulfillment of the requirements for the degree of *MASTER OF SCIENCE* in *PLANT ECOLOGY*.

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ABSTRACT

In an effort to maintain basic ecosystem processes, new landscape-based forest management initiatives are attempting to emulate natural disturbance patterns. Understanding and characterizing these natural disturbance patterns has therefore become a research priority. In a fire patterned landscape such as the North American boreal forest, fire history studies can aid in obtaining this information. A fire history study was performed in the Shakwak Trench, southwest Yukon Territory, with special emphasis on the spatial occurrence of individual wildfires and their relationship to landscape characteristics.

A strong spatial correspondence exists between certain landscape features and the forest disturbance history of the Shakwak Trench. Some locations within this valley have consistently escaped fire for very long periods of time while others have burned frequently. Specifically, nearly all old forests occur on steep north- and east-slope aspects while frequently burned areas are associated with south- and west-slope aspects. Therefore, simply describing an average fire cycle or frequency to characterize the disturbance regime of this area is misleading. The spatial pattern of disturbances on the landscape is of great ecological importance and can exert much control over the forest age-class distribution.

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I truly hope that this information will help us to become better stewards of our limited forest resources.

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CHAPTER ONE:

Introduction and Thesis Outline

1.1 Introduction

Fire has long been recognized as an important component of the North American boreal forest (Van Wagner 1990). Few other disturbance mechanisms control vegetation dynamics on such large-scales in this region. Directly or indirectly, fire initiates forest succession, controls forest species composition and age-structure and maintains the heterogeneous character of the boreal forest vegetation mosaic (Johnson 1992, Rowe 1983, Rowe and Scotter 1973). Highly flammable forest fuels, a coniferous forest canopy architecture conducive to high rates of fire spread, and extreme mid-summer climatic anomalies create a fire regime which is characterized by high intensity, stand replacing fire events with relatively short return intervals (fire return times for many areas of the boreal forest range from 50-200 years) (Johnson 1992, Rowe and Scotter 1973).

In the boreal forest of northwestern Canada, landscape-based sustainable forest management initiatives are attempting to emulate natural disturbance regimes (Franklin 1993, Franklin and Forman 1987). Given the important role of fire as the dominant source of disturbance in these forests, understanding the ecological role of fire at individual, stand and landscape levels, and how fire interacts with other disturbance mechanisms, has become the emphasis of recent research. A large body of knowledge exists about fire effects on individuals and stands (Johnson 1992, Wein and Maclean 1983, Kelsall et al. 1977, Rowe and Scotter 1973, Ahlgren and Ahlgren 1960) but landscape level spatial processes are poorly documented. Fire history studies, by identifying forest elements in various age-classes that have survived fire for certain periods of time across the landscape (the time-since-fire map), can help provide some of this spatial information. There is a need to provide an ecological rationale for prescribing one landscape pattern over another (Knight 1987) as the arrangement of physical and biotic components which comprise the landscape mosaic appear to have important consequences on wildlife habitat, biological diversity, nutrient and energy flow, productivity, and disturbance spread and frequency (Turner and Romme 1994, Turner et al. 1989, Forman and Godron 1986, Pickett and White 1985). Areas which have differing frequencies and spatial extents of disturbance may also display inherently different landscape patterns. However, it should be stressed that while spatial fire patterns may be emulated, forest harvesting and stand replacing fires are ecologically very different.

Heinselman (1973) pioneered the modern study of fire effects on forest age-class distributions. Building on the methods of Heinselman (1973), Van Wagner (1978) and Johnson (1979) proposed the use of a negative exponential and Weibull model (reviewed by Johnson and Gutsell 1994), respectively, to provide some unifying concept for examining the effects of fire on forest age-class distributions in the North American boreal forest. Recent studies which have used these techniques include Johnson and Larsen (1991), Clark (1990), Johnson et al. (1990) and Masters (1990). These methods are based on the assumptions that fires occur independently of one another and landscape-vegetation characteristics play minor roles in the probability of forest elements burning. The negative exponential and Weibull models can therefore be described as spatially aggregated as they do not take into account stand patterns across the forest landscape (Turner and Romme 1994). Differences in fire behaviour and frequency are believed to be primarily due to climatic conditions, both over short (hours) and long (centuries) time-scales (Johnson 1992). Also, because the analysis is performed on forest age-class distributions, it is assumed that the current forest age-class distribution is an accurate reflection of the historical fire regime, a hypothesis which has not been verified from reconstructed forest disturbance information.

The concept that a fire regime is climatically driven is widely accepted and it has been shown that extreme fire years are correlated with synoptic weather patterns which create extreme fire conditions across nearly continental scales (Johnson and Wowchuk 1993, Flannigan and Harrington 1988). However, Turner and Romme (1994) have demonstrated that there is an interaction between climate and landscape patterns in which moisture thresholds play an important role. Below some critical level of precipitation and given the proper wind conditions with associated lightning ignition sources (extreme fire weather), landscape patterns are not important and climatic conditions control fire behaviour. Above some threshold of fuel moisture content, the probability of a fire beginning and spreading across the landscape is nearly zero as fuels become incombustible. Landscape pattern appears to control the range between these two extremes.

Due to the important role of fire in the boreal forest, factors which influence individual fires can then be expected to be general predictors of fire effects. Fire history studies not based on the techniques of Van Wagner (1978) and Johnson (1979) have commonly cited various landscape characteristics being important to the frequency, behaviour and burn patterns found in an area. These include slope (Johnson 1992), elevation (Veblen et. al. 1994, Tande 1979), aspect (Rowe and Scotter 1973), terrain roughness (Heinselman 1973, Zackrisson 1977) and the position of hydrologic features (Bergeron 1991). The primary influence of physiographic features on fire behaviour is thought to be through the control of surface moisture (Rowe and Scotter 1973). While slope and aspect have been central to explaining plant distribution along environmental gradients in the field of plant ecology, the effects of these two characteristics on fire frequency have not been clearly demonstrated.

Well suited to examine the temporal nature of fire events, fire history models such as the negative exponential and Weibull incorporate very little spatial information. Temporal information, when not put in a spatial context, is of limited use for applied landscape management issues. Land managers require knowledge not only of when disturbance events have occurred and how much area they affected but also where on the landscape these processes are operating and whether any clear patterns result. It is the goal of this thesis to link landscape patterns and forest age-class distributions in an effort to provide some of this necessary spatial information.

I.2 Thesis Outline and Objectives

The form of this thesis will follow three major sections. Chapter Two will present reconstructed fire and forest disturbance history information from the Shakwak Trench, southwest Yukon Territory. In that chapter it will be illustrated that current fire frequency models, the negative exponential and the Weibull, may be deficient as underlying assumptions for their use are not met in the Shakwak Trench.

Chapter Three will link reconstructed forest disturbance history information and landscape characteristics from the Shakwak Trench to illustrate that the spatial distribution of forest elements is related to the spatial distribution of terrain characteristics. Therefore, the assumption that disturbance processes are acting independently of landscape characteristics may not be correct. Certain terrain units in the Shakwak Trench display characteristic disturbance regimes.

Chapter Four will summarize the thesis and provide a basis for future research. In some areas of the boreal forest, linking landscape patterns and forest age-class information may be an effective approach to aid in the management and classification of forest resources.

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CHAPTER TWO:

Fire and Forest Disturbance History of the Shakwak Trench, Southwest Yukon Territory

II.1 Introduction

The North American boreal forest fire regime is characterized by large, high intensity stand replacing wildfires with relatively short return intervals (Johnson 1992, Wein and MacLean 1983, Kelsall et al. 1977, Rowe and Scotter 1973). As a disturbance agent, wildfire initiates forest succession and maintains the heterogeneous character of the boreal forest vegetation mosaic. Few other natural disturbance mechanisms control vegetation dynamics on such large-scales in this region. Increasingly, however, forest harvesting is replacing wildfire as the primary source of disturbance in the southern boreal forest. On the most basic level, forest harvesting and stand replacing wildfires perform similar functions as they both create gaps in the forest canopy which results in the fragmentation of large tracts of homogeneous forest.

Recognizing these basic similarities, recent landscape-based forest management initiatives have focused much attention on fire history studies. Fire history studies form an important component of baseline data collection in an era of sustainable forest management attempting to emulate natural disturbance regimes on the boreal landscape in an effort to maintain pre-harvest levels of biodiversity (Franklin and Forman 1987). As was discussed in Section I.1, there is a large body of knowledge about fire effects on individuals and stands but landscape level spatial processes remain poorly understood. Attempting to emulate natural landscape disturbance patterns with forest harvesting techniques requires a knowledge of how the interaction between individual fires and other forest disturbance mechanisms have produced final time-since-fire age and vegetation mosaics. Fire history studies, by identifying forest elements in various age-classes that have survived fire for certain periods of time (the time-since-fire map), can assist in providing such information. However, it should be stressed that while spatial fire patterns may be emulated, forest harvesting and stand replacing wildfires are ecologically very different in the amount and type of coarse woody material and soil conditions which remain following these disturbance events.

Numerous fire history studies have been performed in many different fire regimes using various methods (Dieterich 1983, Tande 1979, Arno and Sneck 1977, Zackrisson 1977, Arno 1976). Many early fire history studies took place in the southwestern United States and were designed for low intensity, non-stand replacing fire environments. Heinselman (1973) pioneered the modern study of fire effects on forest age-class distributions in the boreal fire environment.

The negative exponential and Weibull models (reviewed by Johnson and Gutsell 1994, Johnson 1992) have been used to describe the effects of fire on forest age-class distributions in the boreal forest. Well suited to describe temporal variation of fire events, these models incorporate very little spatial information. Recent studies which have used these models include Johnson and Larsen (1991), Clark (1990), Johnson et al. (1990) and Masters (1990). Use of the negative exponential and Weibull models are based on the following assumptions: (1) fires occur independently of one another, (2) landscape-vegetation characteristics play minor roles in the probability of forest elements burning, (3) differences in fire behaviour and frequency are thought to be due primarily to climatic conditions both over short (hours) and long (centuries) time-scales (Johnson 1992), and (4) the current forest age-class distribution is considered to be an accurate reflection of the historical fire regime, an assumption which is difficult to verify from reconstructed forest disturbance information.

II.2 Objectives

Gaining a better understanding of how individual fires and other forms of forest disturbance interact on the landscape to create and maintain a natural vegetation mosaic is integral to ecologically sound methods of forest management. To this end, a descriptive fire history study of the Shakwak Trench in southwest Yukon was initiated. The primary objectives of this study were to:

(1) Reconstruct fire history in the Shakwak Trench with special emphasis on the spatial occurrence of individual fire events.

(2) Identify other mechanisms of forest disturbance that interact with fire in maintaining the heterogeneous vegetation mosaic within the Shakwak Trench study area.

(3) Examine the ability of current fire frequency models (negative exponential and Weibull models) to describe fire history within the Shakwak Trench.

The Shakwak Trench study site was chosen because of relatively anthropogenically undisturbed forest conditions, logistical support provided by the Arctic Institute of North America's Kluane Lake Research Station, and the existence of the Kluane Boreal Forest Ecosystem Project (Krebs et al. 1995). This project is examining plant and animal trophic interactions within the Yukon boreal forest and a forest disturbance will aid in the overall interpretation of final Kluane Boreal Forest Ecosystem Project results.

II.3 Study Site Description

The Shakwak Trench study site is a northwest-southeast trending montane-subalpine valley located at 61°N 138°W near Kluane Lake in southwest Yukon Territory, Canada (Figures 2.1 and 2.2). The Shakwak Trench is in Ecoregion 8 (Ruby Range) as defined by Oswald and Senyk (1977) in *Ecoregions of Yukon Territory.* The study site encompasses 480 km^2 within the three 1:50 000 NTS map sheets 115 A/13, 115 B/16 and 115 G/1. The St. Elias Mountains of Kluane National Park Reserve sit adjacent to the south study boundary and exert a strong influence on regional climate conditions (Environment Canada, Parks 1987). The Alaska Highway transportation corridor runs through the bottom lands of the Shakwak Trench.

II.3.1 Physiographic Conditions

Geology and physical geographic processes have been described extensively by Bostock (1952), Rampton (1979) and Clague (1981). Briefly, the valley is a broad, 8-14 km wide northwest-southeast trending drop-block graben nestled between the Kluane and Ruby Ranges. Numerous high gradient streams flow from these slopes to empty into either the Arctic watershed of Kluane Lake or the Pacific watershed of the Dezdeash/Alsek Rivers. Kluane Lake levels have remained relatively constant over the recent past (500 years) and extensive flooding events, like the glacial Lake Alsek

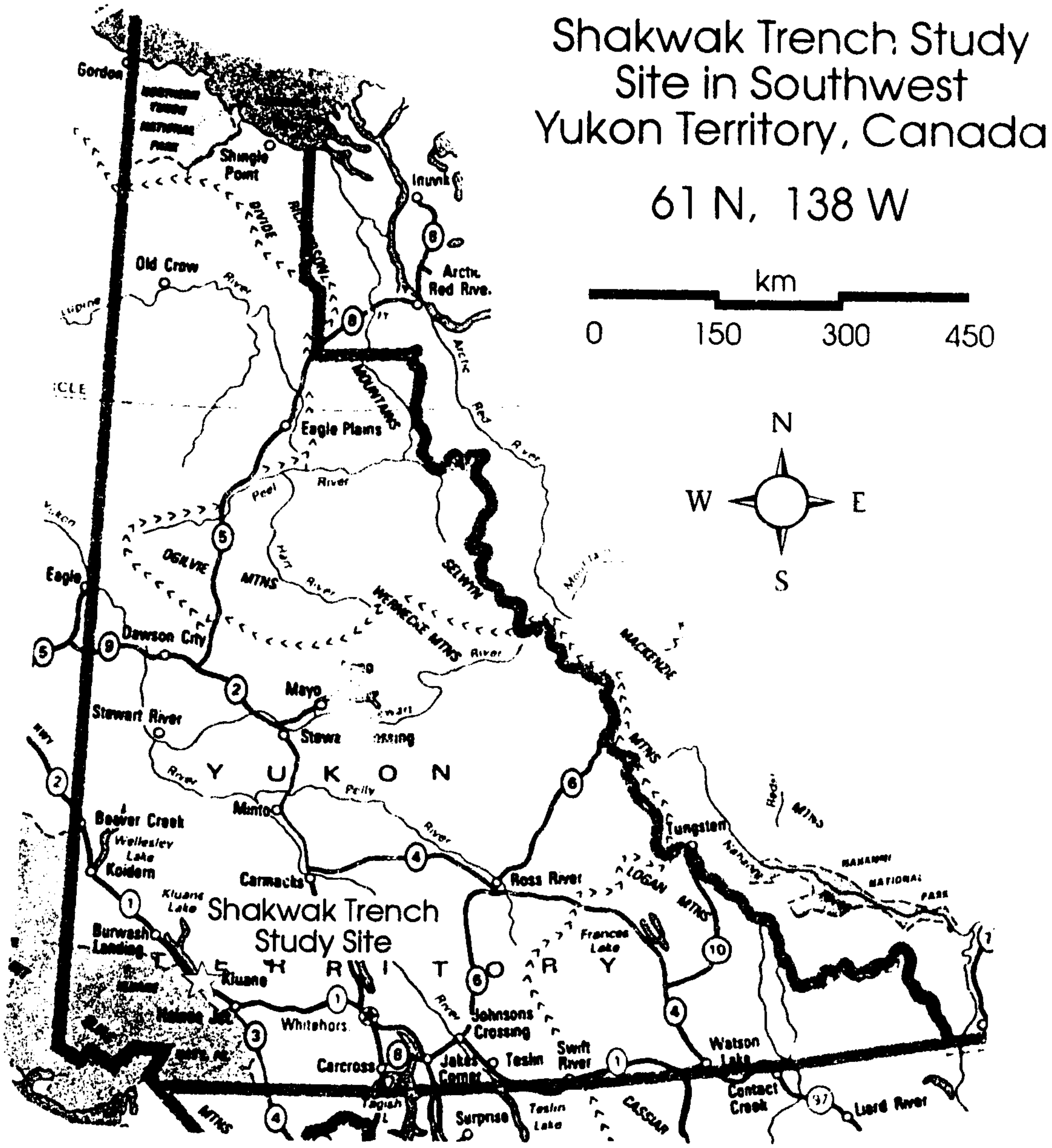


Figure 2.1. The Shakwak Trench study site is located in southwest Yukon Territory at apx. 61N, 138W on the southeast shore of Kluane Lake. Adapted from Road Atlas (1990).

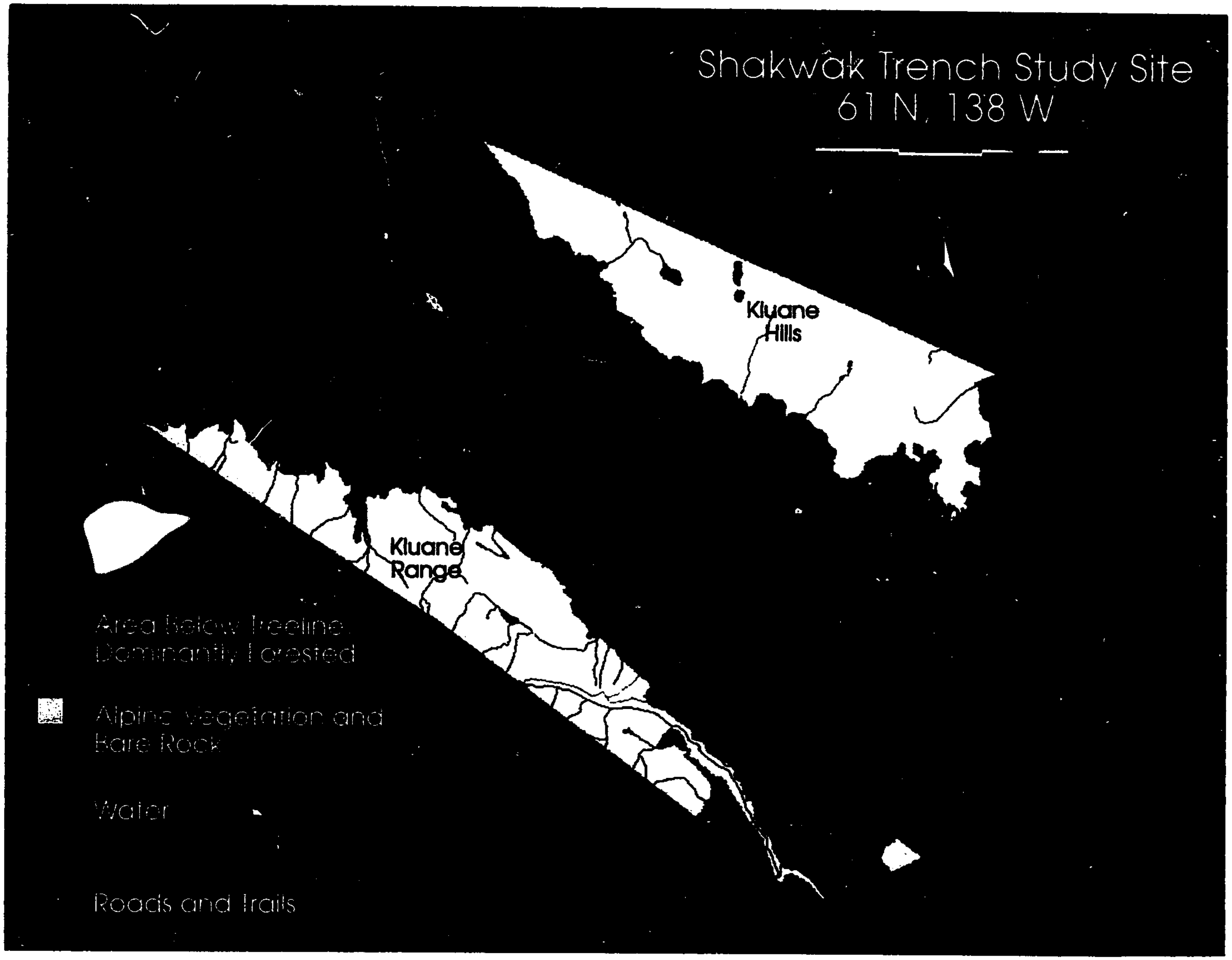


Figure 2.2. The Shakwak Trench study site: major geographic features.

inundations (Clague and Rampton 1982), have not affected this area. Gently rolling terrain dissected by steep-walled fluvial channels characterize the valley bottom and lower slopes of the Shakwak Trench: surficial material is comprised of glacial till and outwash sediments with scattered loess and eolian deposits (Rampton 1979). Bedrock and rock outcrops at high elevations are dominated by volcanic and igneous rock with small inclusions of sedimentary and clastic materials. Relief in excess of 1000 m exists between the valley floor and upper alpine slopes within the study area. Discontinuous permafrost is present on north-facing slopes and in poorly drained areas.

II.3.2 Climate

Climatic conditons and wildfire regimes are closely associated (Johnson and Wowchuk 1993, Johnson 1992). Historical climate information is available in the form of a dendroclimatic study performed adjacent to the study area by Allen (1982) (Figure 2.3). Distinct climatic phases are apparent from this chronology. Similar to most areas in northwestern North America, a warming trend since the end of the Little Ice Age (ca. 1820) has occurred. During this time, glaciers have retreated substantially from their Little Ice Age maximal positions (Borns and Goldthwait 1966, Denton and Stuiver 1966). However, it can not be stated conclusively that the post-Little Ice Age warming trend was associated with drier conditions.

Even though the Shakwak Trench is situated only ca. 150 km from the Gulf of Alaska, a cold, dry continental climate characterizes the area due to a strong rain shadow effect of the adjacent St.Elias Mountains. The study area has short, cool summers and long, cold winters with a mean annual temperature of ca. -3°C. Seasonal summer-winter

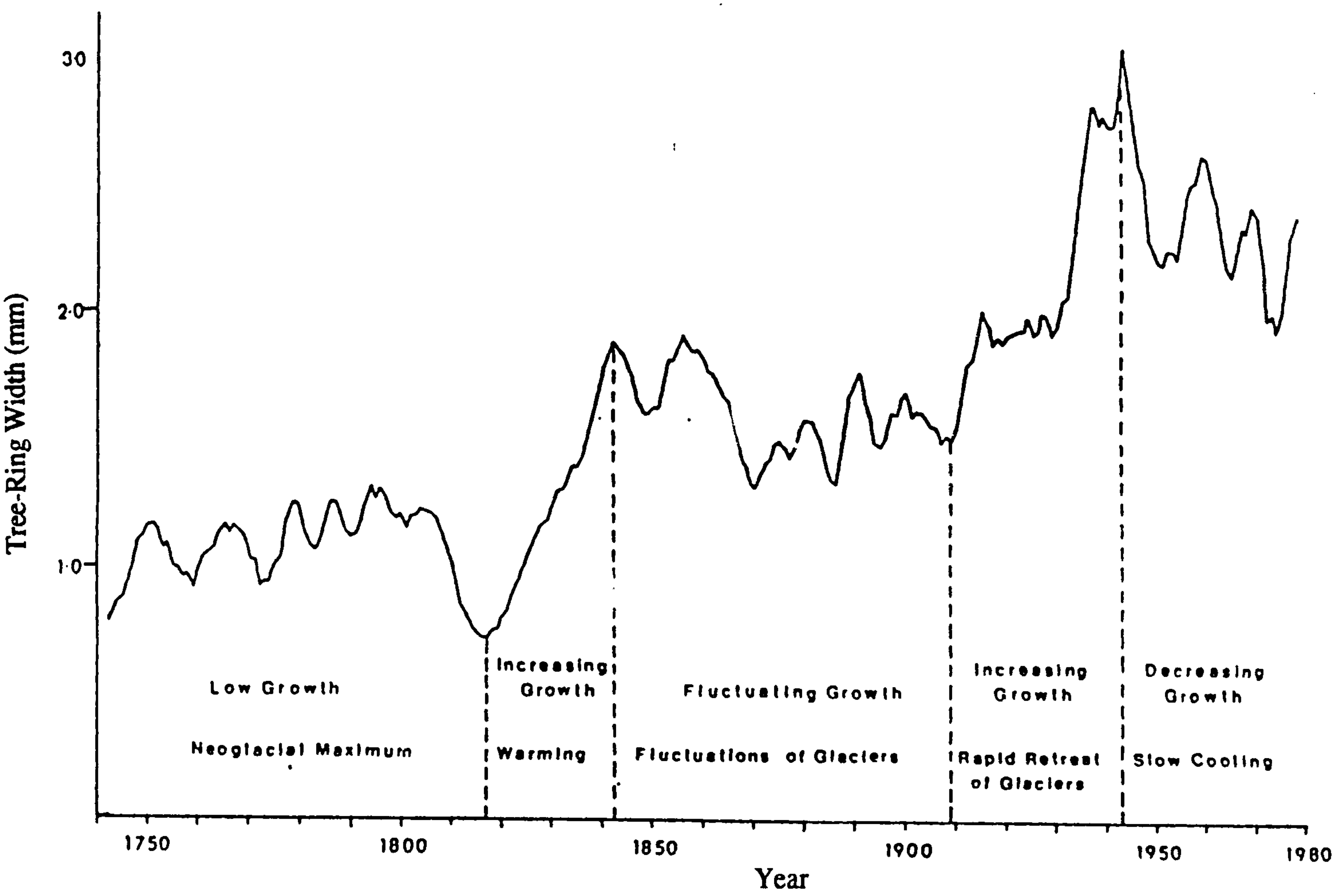
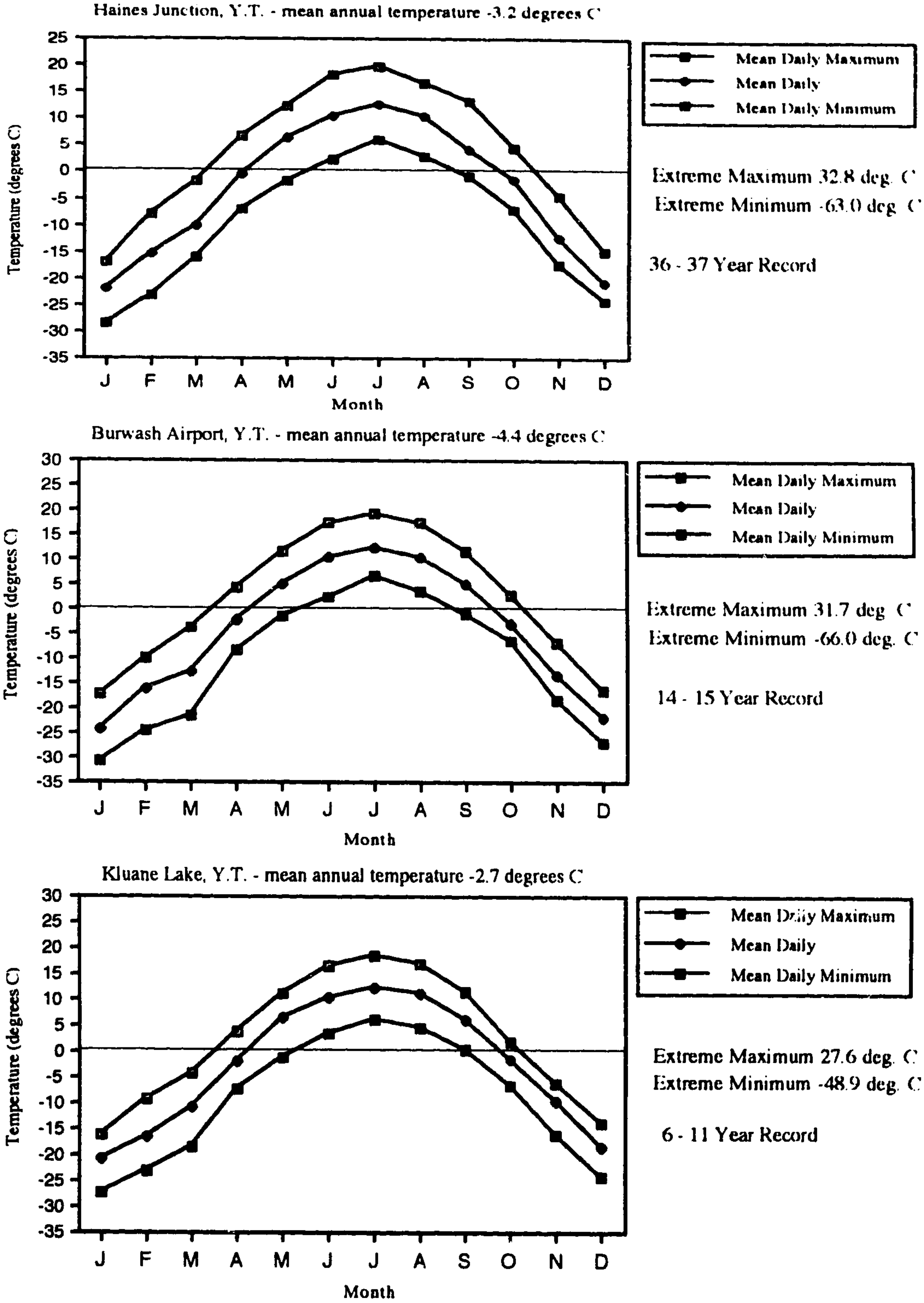


Figure 2.3. The Slims River tree-ring width chronology with interpreted climatic phases. Adapted from Allen (1982).



Extreme Maximum 32.8 deg. C
Extreme Minimum -63.0 deg. C

36 - 37 Year Record

Extreme Maximum 31.7 deg. C
Extreme Minimum -66.0 deg. C

14 - 15 Year Record

Extreme Maximum 27.6 deg. C
Extreme Minimum -48.9 deg. C

6 - 11 Year Record

Figure 2.4. Mean daily maximum, mean daily and mean daily minimum temperatures for the Kluane Region: Haines Junction, Burwash Airport and Kluane Lake climate stations. Data from Atmospheric Environment Services (1982).

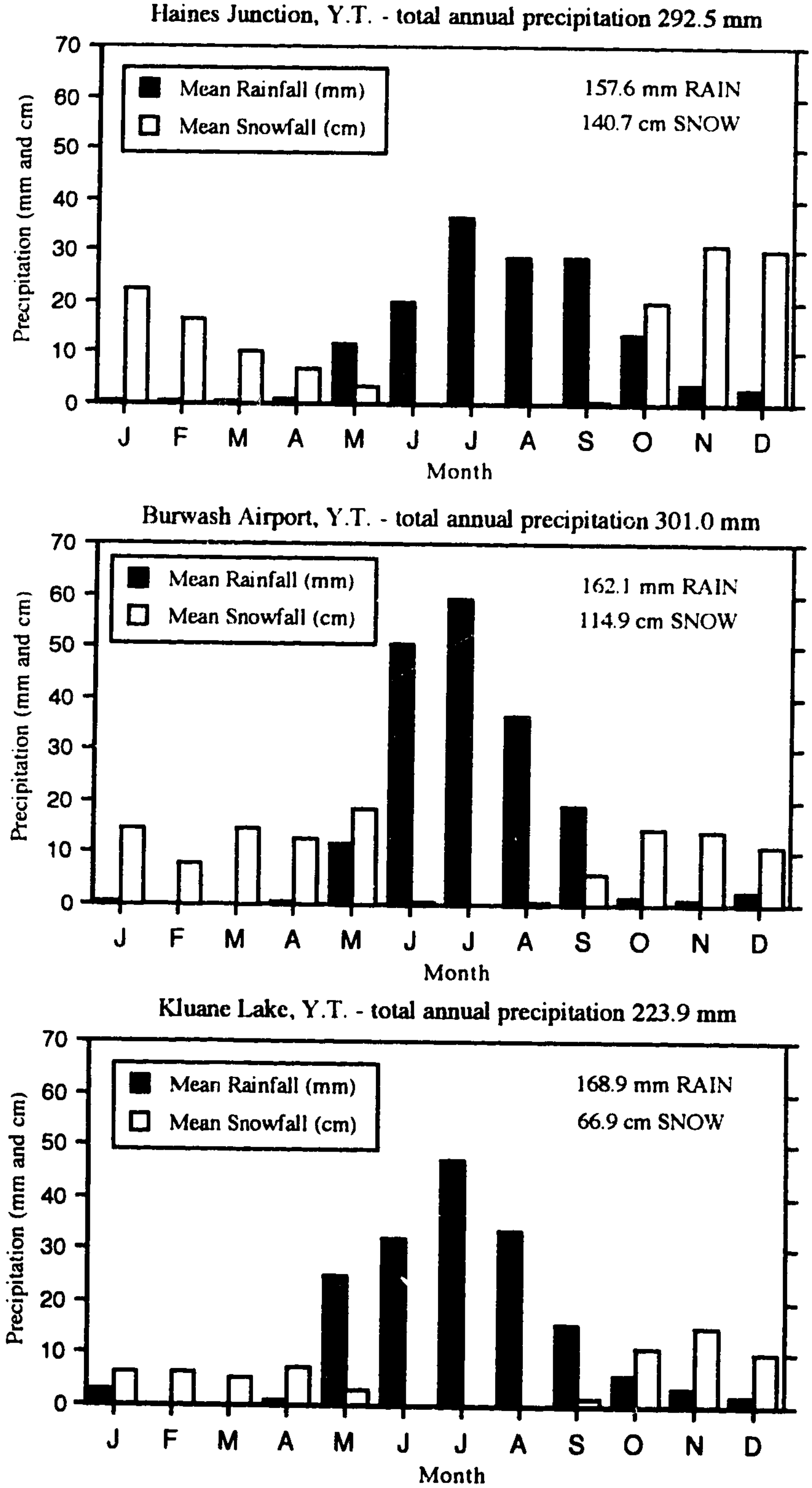


Figure 2.5. Precipitation records for the Kluane Region: Haines Junction, Burwash Airport and Kluane Lake climate stations. Data from Atmospheric Environment Services (1982).

extremes can be more than 80°C (Figure 2.4). Precipitation is low with a mean annual average of ca. 230 mm, most of this falling in the form of rain during summer months (Figure 2.5). Marginal climate information exists for Kluane Lake so the neighbouring stations of Haines Junction (65 km to southeast) and Burwash Landing (60 km to northwest) have been included for comparison (Figure 2.1)

While the predominant wind direction during summer is from the southwest, local wind patterns are heavily influenced by glacial effects, extreme topography and valley orientation (Environment Canada, Parks 1987). Atmospheric and Environment Service wind record summaries are available for Kluane Lake, Burwash Airport and Haines Junction (Table 2.1). There is great variability among these three stations. During summer months, the main Shakwak Valley is in the wind shadow of the St. Elias mountains as predominant winds are from the southwest. However, due to large side-valleys which enter perpendicular to the main trench (the Alsek, Slims and Jarvis Rivers), katabatic and glacial winds can funnel through these passes to create brief wind storms and spectacular dust clouds along dry glacial loess filled stream beds (Environment Canada, Parks 1987, Nickling 1978). These characteristics may be important during wind driven fire events.

The occurrence of lightning, a primary source of ignition for forest fires, is rare in the study area compared with neighbouring systems (Yukon Forest Service lightning data 1994). The entire Kluane region lies outside the major "lightning belt" of central Yukon Territory (Hawkes 1983). This "lightning shadow" may be an orographic effect caused by the St. Elias mountains. The distribution of lightning strikes has been shown to be non-random in other mountainous systems (Van Wagtendonk 1991); lightning frequency may

Table 2.1. Summarized monthly wind conditions for the Haines Junction, Burwash Airport and Kluane Lake climate stations. Values are given as average wind speeds (km/hr) and prevailing direction (highest percentage frequency for that month). Data from Atmospheric Environment Services (1982), figure adapted from Environment Canada, Parks (1987).

Station	**Month**												**Year**
	J	F	M	A	M	J	J	A	S	O	N	D	
Haines Junction	4.1 NE	5.5 NE	6.3 NW	7.8 NW	9.2 SW	9.3 SW	7.7 NW	6.7 NW	5.6 NW	5.2 NE	4.7 NE	4.2 NE	6.4 NW
Burwash Airport	7.1 WNW	10.5 WNW	10.3 WNW	15.5 ESE	16.2 ESE	13.7 ESE	12.6 ESE	12.5 ESE	14.4 SE	15.2 WNW	11.4 WNW	8.5 WNW	12.3 ESE
Kluane Lake	6.0 SE	7.8 SW	8.4 SW	9.6 SW	9.3 SW	8.9 SW	8.2 SW	9.4 SW	9.9 E	9.9 SE	11.0 SE	8.4 E	8.9 SW

be related to elevation and valley orientation. The frequency of lightning storms will strongly influence the frequency and spatial pattern of fires on a landscape (Johnson 1992, Harvey 1979, Chapman and Thomas 1968).

II.3.3 Vegetation

The following description uses terminology from Douglas (1980). The Shakwak Trench Study Site spans three major ecological zones based on elevational gradients: montane valley bottom forests (760-1080 m), subalpine mid- and upper-slope forests (1080-1370 m), and alpine tundra (above 1370 m). Below an elevation of ca. 1380 m, the valley supports a complex vegetation mosaic dominated by closed canopy white spruce (*Picea glauca* (Moench) Voss) forests interspersed with aspen (*Populus tremuloides* Michx.) and willow (*Salix* spp.) - dwarf birch (*Betula glandulosa* Michx.) meadows. Subalpine forests are typically open canopy white spruce - tall willow shrub communities which grade into low shrub - dwarf vascular alpine plant communities. Paleoecological investigations suggest that spruce forests have dominated the valley bottom vegetation community for the past ca. 8500 years (Stuart et al. 1989). The interpretation of this paleoecological information has important ramifications for the arrival and economic base of indigenous peoples in the region.

This disturbance study focused on montane and subalpine forest communities since obtaining accurate origin dates for alpine vegetation is extremely difficult. Also, no conspicuous fire evidence was found in alpine areas.

II.3.4 Historical Human Land-Use and Settlement

Few sources exist for historical land-use information in the study area due to native oral traditions and the very recent arrival of Europeans. Relevant sources of human cultural information include the Kluane National Park Reserve fire history study (Hawkes 1983, based on earlier investigations by Wright 1980 and Workman 1978), a report prepared for the Greater Kluane Land Use Plan (Gotthardt 1989), Royal Canadian Mounted Police (RCMP) monthly/annual reports, and Geological Survey of Canada exploration papers. Human settlement and land-use patterns can be divided into three distinct phases: pre-European native land-use (before 1900), European mining and exploration (ca. 1900-40) and Alaska Highway construction and subsequent use (1940-present).

There is archaeological evidence that Southern Tutchone, Tanana and Tlingit peoples have periodically inhabited the Kluane area for at least 8000 years (Gotthardt 1989, Workman 1978). Their impact on forest disturbance (primarily wildfire) in this region is largely unknown. The use of fire through prescribed burning has been the source of much speculation in fire history studies yet little evidence directly supports this theory. In the Kluane Region it is known that the Southern Tutchone used fire to create moose browse and thaw stream banks to aid in collection of alpine vetch roots (Workman 1978). Also, semi-permanent fishing camps were located on the shores of Kloo and Sulphur Lakes for hundreds of years (Gotthardt 1989), a frequently burned unit within the study area. Some well established native traveling trails were also known to exist in the Jarvis River and Christmas Bay area (Gotthardt 1989). In northern Alberta, Lewis (1982, 1977) reported that systematic spring and late-fall burns were set along lake, stream and meadow edges by Cree natives to enhance wildlife forage and clear travel corridors. Lewis argues that the boreal forest partially displays its current physiognomy due to anthropogenic fire.

European arrival in the Kluane Region is a relatively recent event (Gotthardt 1989, Workman 1978). The Kluane Gold Rush from 1902-04 saw over 1000 miners flood into the area. A wagon road was constructed from Whitehorse in 1903-04 (this travel corridor largely parallels the present Alaska Highway) to supply the gold fields and an RCMP post established at Silver City. Tent cities also sprang up both at Kloo Lake and Silver City. However, this small boom quickly faded. Small-scale lumbering, fishing and big-game hunting took place during the 1920s and 30s as the Kluane Region began to be known for its wilderness attributes.

The building of the Alaska Highway in 1942-43 changed the face and character of the Kluane area more than any other single event. Silver City and the current site of the Kluane Lake Research Station were used as supply depots by military engineers to ship equipment across Kluane Lake prior to the spanning of the Slims River delta. It is only since completion of the highway that relatively large, permanent settlements have been established in the nearby communities of Haines Junction, Burwash Landing and Destruction Bay. This phase of human settlement appears to have had minimal impact on the fire regime.

II.3.5 Recent Developments

The study area is currently "fire-free" and has not experienced a major wildfire for over 40 years. A spruce beetle (*Dendroctonus rufipennis* Kirby) outbreak is affecting large areas of the Shakwak Trench near Kluane Lake and southern portions of Kluane National Park Reserve (Klassen 1996). The area affected by this single insect outbreak is orders of magnitude larger than any single wildfire event in the recent past. Harvest plans for beetle-damaged timber are being considered by Yukon Forest Resources, Northern Affairs Program (Northern Affairs Program 1994).

II.4 Methods

Forest disturbance history reconstruction methods for this project can be divided into six distinct phases: 1) airphoto interpretation, 2) field reconnaissance and forest sampling, 3) dating of fire scar and tree increment core material, 4) mapping individual fires and stand boundaries, 5) construction of the time-since-fire map, and 6) archival literature search.

II.4.1 Airphoto Interpretation

A series of 1:10 000 black and white airphotos (FF92023, Lines 1-11, Photo Numbers 1-317, July, 1992) provided complete coverage of the study area. A 1:50 000 UTM grid was overlaid on acetate airphoto overlays through the use of a transfer scope. This provided the primary means of site determination and field navigation. Given the detailed nature of the airphotos, positional accuracy in the valley bottom is well within 100 m as checked against a portable Global Positioning System. Based on interpretation of canopy height differences on these airphotos, distinct stand margins were identified and sample sites subjectively chosen with a view to access and possible extrapolation of information. In some situations, fire margins could not be accurately determined from airphotos due to small canopy height differences. Whenever this condition was encountered, sample sites were chosen in a systematic manner. Sampling was not performed in a random manner as the aim of this project was to reconstruct, both spatially and temporally, individual forest disturbance events.

II.4.2 Field Reconnaissance and Forest Sampling Methods

Sampling within the study area took place during the summers of 1994 and 1995. Two hundred and sixty-five sites were sampled during this period (Figure 2.6) with many other areas visited for verification. Field reconnaissance consisted of navigating to predetermined locations based on the airphoto interpretation and sampling forest disturbance information and stand ages. Along distinct fire margins, fire scarred trees were sought and their locations recorded on the airphotos. At these locations, the following were collected: (a) fire scarred tree disks, (b) a minimum of two tree increment cores from large canopy dominants in both the post-fire regenerating stand (this provides an estimate of post-fire regeneration lag-time) and the adjacent mature, unburned stand, (c) height and DBH from all trees cored or from which fire scars were collected, (d) physical site characteristics (slope, aspect, relative moisture regime, relief), and (e) general stand information (duff thickness, presence of soil charcoal and coarse woody material, stand physiognomy, regeneration characteristics, successional status and if present, spruce

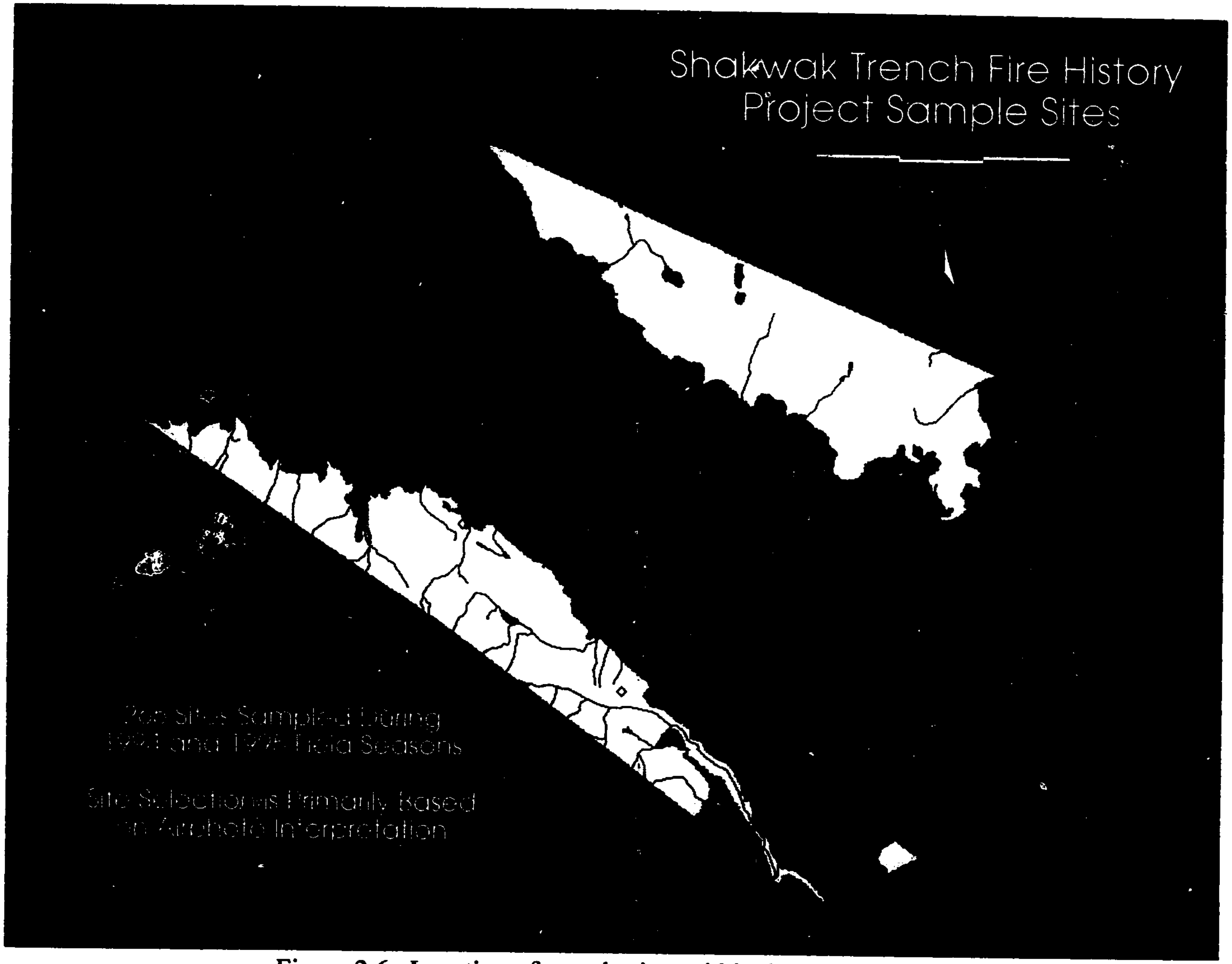
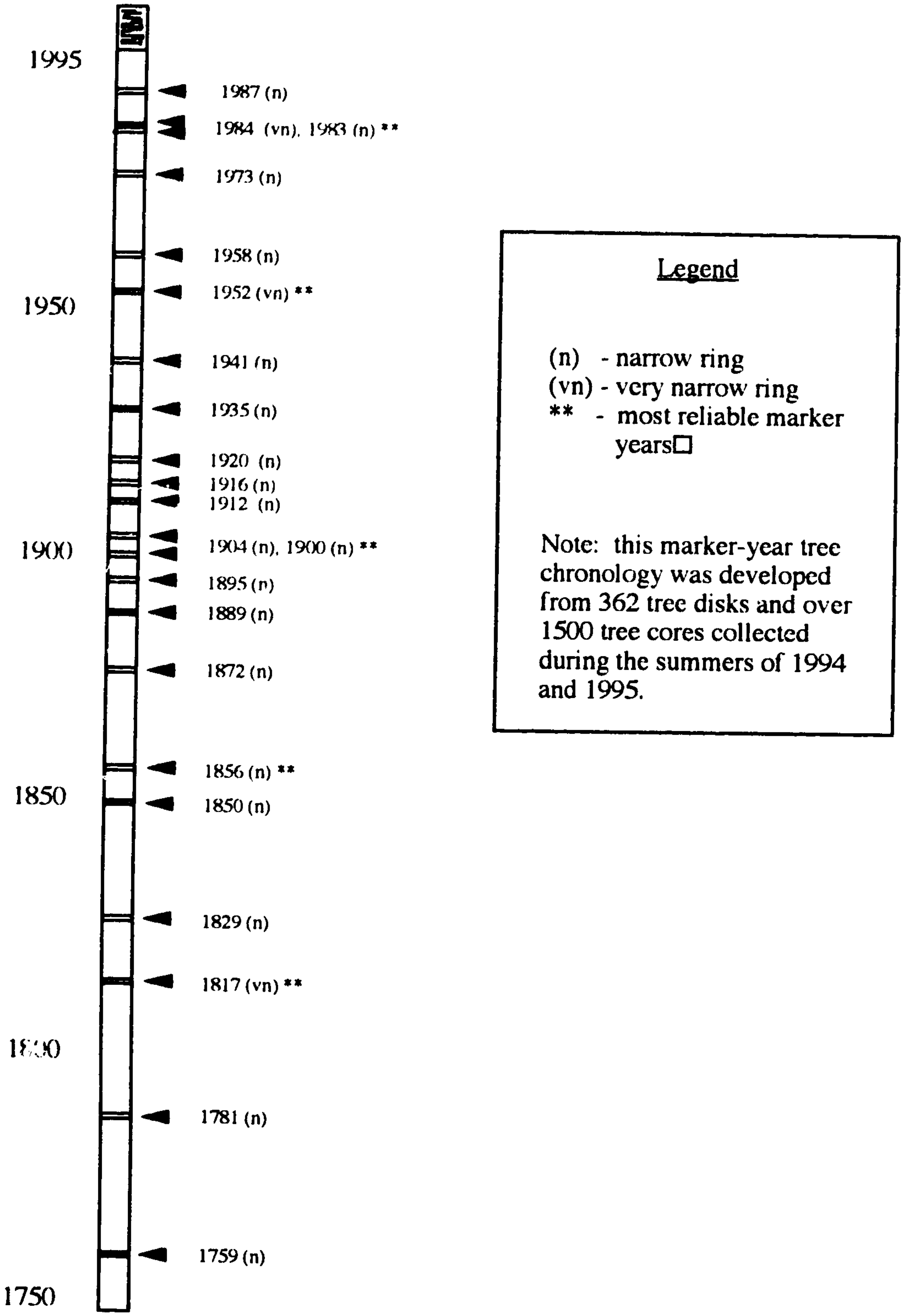


Figure 2.6. Location of sample sites within the Shakwak Trench.

beetle damage). All trees were cored at a height of 30 cm above ground in an attempt to obtain accurate tree ages as the time required for a tree to grow 30 cm can be highly variable due to site factors, microclimates, tree genetics and herbivory (Norton et al. 1987, Jozsa et al. 1984). Two disks, collected at ground level and a height of 30 cm, were collected from each of 30 young trees in post-fire origin stands to examine possible age differences between "true" tree ages and coring heights. Fire-scarred tree disks were collected as low as possible on the bole and replicated along the fire margin to verify fire dates whenever the opportunity arose. Obtaining tree cores in stands greater than 200 years old was often difficult as much heart-rot was encountered. This problem has been alluded to in nearby dendrologically intensive studies (Hawkes 1983, Allen 1982).

II.4.3 Dating of Fire Scars and Tree Increment-Cores

Using the dendrochronological techniques of Yamaguchi (1991) and McBride (1983), all fire-scarred tree disks and tree increment cores were dated. Three hundred , sixty-two fire-scarred tree disks and over 1500 tree increment cores were used to establish the disturbance history and stand ages. A 40X dissecting microscope was used to date all samples. Standard ring-width measurements were not taken as dendroclimatic information for the area currently exists (Allen 1982, Jozsa et al. 1981) and it was not the aim of this study to correlate fire and climatic events. Instead, relative ring-width patterns were noted and a tree marker-year chronology was developed to cross-date samples using the method of Yamaguchi (1991) (Figure 2.7). This method allows the detection of missing and false rings and creates a very accurate tree chronology.



Note: this marker-year tree chronology was developed from 362 tree disks and over 1500 tree cores collected during the summers of 1994 and 1995.

Figure 2.7. Marker-year tree chronology developed and used to cross-date all fire scars and tree increment cores in the Shakwak Trench.

II.4.4 Mapping Individual Fires and Determination of Time-Since-Fire Dates

Individual fire and stand disturbance events were reconstructed by transferring fire scar and tree increment core dates to acetate overlays using a 1:32 000 scale vegetation map of the study site (Hucal and Dale, 1993) as a base layer with the aid of airphotos and topographic maps. Some fire events were too small to map accurately and simply exist as a "blip" on the time-since-fire map. These events are generally 1-4 ha in size. The smallest residual or unburned patch within a contiguous fire patch preserved at the original mapping scale is approximately 10 ha. Individual fire events were reconstructed back to 1800. Prior to this date, individual fire reconstructions are extremely inaccurate due to a lack of temporal (fire scar evidence) and spatial resolution. Where distinct fire margins could not be delineated from airphotos and an age-difference was determined to exist, major topographic features were used to aid in boundary placement. Time-since-fire dates for stands originating prior to 1800 and for which no fire scar evidence existed were estimated based on the age of the oldest tree found plus 25 years. An average post-fire regeneration lag-time of approximately 25 years was empirically determined from regenerating stands of fire scar-dated events. This long post-fire regeneration delay agrees with the value reported by Hawkes (1983) for the neighbouring Kluane National Park Reserve fire history study.

II.4.5 Construction of the Time-Since-Fire and Fire Frequency Maps

Acetate fire boundary overlays were digitized in the *v.digit* module of the GRASS 4.1 (Anon. 1993) geographic information system (GIS). A separate data layer was constructed for each fire year back to 1800 and the annual area burned was calculated with the GIS. These vector maps were then converted to raster maps and combined with the *r.patch* command to produce a time-since-fire map for the period 1800-present (fire-scar dated events for which boundaries are known or approximately known). In this map, the most recent fire events form definite boundaries and are overlayed on top of earlier events. Areas of overlap can then be calculated and displayed to produce a fire frequency map for this time period. For areas originating prior to 1800 for which fire scar evidence did not exist or individual fire boundaries were unknown, a single stand origin data layer was digitized and patched with the area burned from 1800-present. Unlike the time period 1800-present, stand origin dates prior to 1800 are based primarily on tree increment core ages. This combination of stand origin dating methods provided a complete time-since-fire map for all areas below treeline within the study valley.

II.4.6 Archival Information

Archival literature sources relating to this project are limited but were examined to gain a better understanding of past forest conditions and attempt verification of fire scar-dated wildfires (archaeological and cultural history of the area has been discussed previously in Section II.3.4). Useful sources of literature included Geological Survey of Canada and RCMP monthly/annual reports. Many RCMP reports pertaining to the Kluane area have been gathered into a single resource document, "*Support Material for the Kluane Wildlife Management Database*", by Lotenberg (1995).

II.5 Results and Discussion

Results are presented in four major sections: 1) detailed fire history information from 1800-present based on individually reconstructed fire events, 2) pre-1800 fire history information (age-class distribution of forested area within the Shakwak Trench study site), 3) other forms of forest disturbance encountered, and 4) vegetation recovery from fire and forest disturbance events. Discussion of these results follows in the same section.

II.5.1 Section I: Fire History of the Shakwak Trench (1800-Present)

II.5.1.A *Fire History Summary*

Fire history statistics for the time period 1800-present are summarized in Table 2.2. As described in the methods, these fire history summary statistics are based on individually reconstructed fire events. Year of fire, sum of yearly burned area, interval between fire years, the number of spatially discrete fires for a given year, the number of fire scars used to date individual fire events, their corresponding fire map, and fire boundary accuracy are all presented. There has not been a wildfire in the study area since 1956. The last fire event to burn more than 2 km^2 (200 ha) occurred in 1929 near Kloo Lake and this was the only event found to be historically referenced. Glover (1929), while on a routine RCMP patrol from Champagne to Kluane Lake, noted "A forest fire was burning in the vicinity of Kloo Lake and considerable timber had fallen across the government road which had to be removed". Fire Map 1 displays the location of all areas burned since 1800. Fire Maps 2 to 24 show the geographic location of individual fire events during this time period. The accuracy of these fire boundaries generally decrease with the passage of time as recent fires overburn older events.

Table 2.2. Fire history summary table for the Shakwak Trench (1800-present).

Year of Fire	Sum of Yearly Burned Area (km2)	% of Forested Area (353 km2)	Interval Between Fires (Years)	# Spatially Discrete Fires for that Year	# Fire Scars Used	Geographic Location (Fire Map Reference)	Fire Boundary Accuracy
1956	0.00	0.00	39	1	1	2	K
1953	0.01	0.00	3	1	1	2	K
1951	0.01	0.00	2	1	1	2	E
1943	0.04	0.01	8	3	4	2	K
1939	0.11	0.03	4	1	2	2	K
1937	0.16	0.05	2	1	3	2	K
1936	1.22	0.35	1	3	5	2	K
1934	1.10	0.31	2	3	15	3	K
1932	0.51	0.14	2	2	2	3	K
1930	0.04	0.01	2	1	1	3	E
1929	7.38	2.09	1	2	6	4	K
1928	1.47	0.42	1	2	4	5	K
1925	0.07	0.02	3	1	2	5	K
1924	2.60	0.74	1	5	16	5	K/E
1923	0.77	0.22	1	2	6	6	E
1921	4.21	1.19	2	2	15	6	K
1920	9.03	2.56	1	7	39, **	7	K
1919	3.72	1.05	1	1	9	8	K
1918	0.23	0.07	1	1	1	8	K
1916	0.19	0.05	2	2	2	8	K
1915	1.18	0.33	1	2	2	8	K/E
1914	0.16	0.05	2	1	2	9	K
1913	1.56	0.44	1	2	10	9	K
1912	0.10	0.03	1	1	1	9	K
1908	2.66	0.75	4	1	2	9	E
1907	0.57	0.16	1	2	2	10	E
1906	8.46	2.40	1	2	6	10	K
1904	0.10	0.03	2	1	2	11	E
1903	1.80	0.51	1	2	5	11	E
1902	0.01	0.00	1	1	1	11	K
1898	0.15	0.04	4	2	2	11	E
1893	0.61	0.17	5	3	4	12	E
1892	8.64	2.45	1	2	6	12	E
1891	0.43	0.12	1	1	2	13	K
1888	10.74	3.04	3	3	8, **	13	K/E
1885	2.75	0.78	3	3	4	14	E
1883	1.06	0.30	2	1	4	14	K
1881	0.51	0.14	2	2	3	14	E
1878	32.13	9.10	3	2	14	15	K/E
1877	14.18	4.02	1	3	14	16	K

Table 2.2. Fire history summary table (continued).

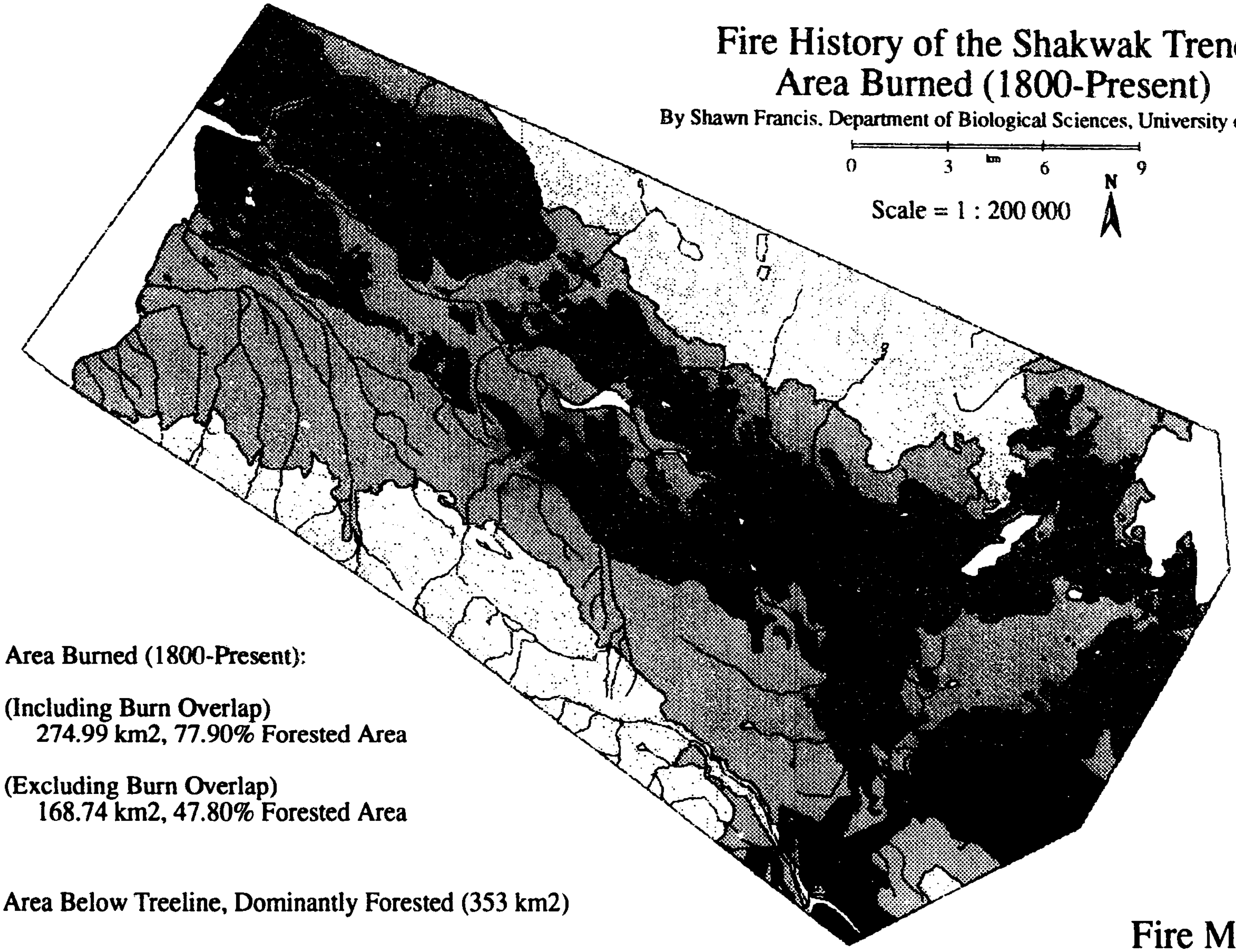
Year of Fire	Sum of Yearly Burned Area (km2)	% of Forested Area (353 km2)	Interval Between Fires (Years)	# Spatially Discrete Fires for that Year	# Fire Scars Used	Geographic Location (Fire Map Reference)	Fire Boundary Accuracy
1875	3.17	0.90	2	2	4	17	K/E
1872	9.92	2.81	3	4	27	17	K
1871	2.36	0.67	1	1	3	18	K
1865	21.09	5.97	6	1	24	18	K
1861	0.03	0.01	4	1	1	19	E
1858	2.57	0.73	3	1	2	19	E
1855	0.09	0.02	3	1	11	19	E
1853	0.04	0.01	2	1	1	19	E
1849	3.62	1.03	4	1	2	19	E
1848	0.05	0.02	1	1	1	20	K
1847	15.98	4.53	2	2	14	20	K/E
1845	43.97	12.46	1	1	28	21	K
1844	6.22	1.76	1	1	2	22	E
1836	23.10	6.55	8	2	1	22	E
1822	3.76	1.07	14	1	3	23	E
1820	2.97	0.84	2	1	**	23	E
1818	0.27	0.08	2	1	1	23	E
1815	0.55	0.16	4	1	1	24	E
1814	0.48	0.14	1	1	1	24	E
1806	14.07	3.99	8	1	**	24	E
Totals	274.99	77.92		105	356		

NOTE: All fires events are fire scar-dated unless noted by **

Notation for Fire Boundary Accuracy is as follows:
K = Fire Boundary Known
E = Fire Boundary Partially Estimated

Fire History of the Shakwak Trench
Area Burned (1800-Present)

By Shawn Francis, Department of Biological Sciences, University of Alberta



■ Area Burned (1800-Present):

(Including Burn Overlap)
274.99 km2, 77.90% Forested Area

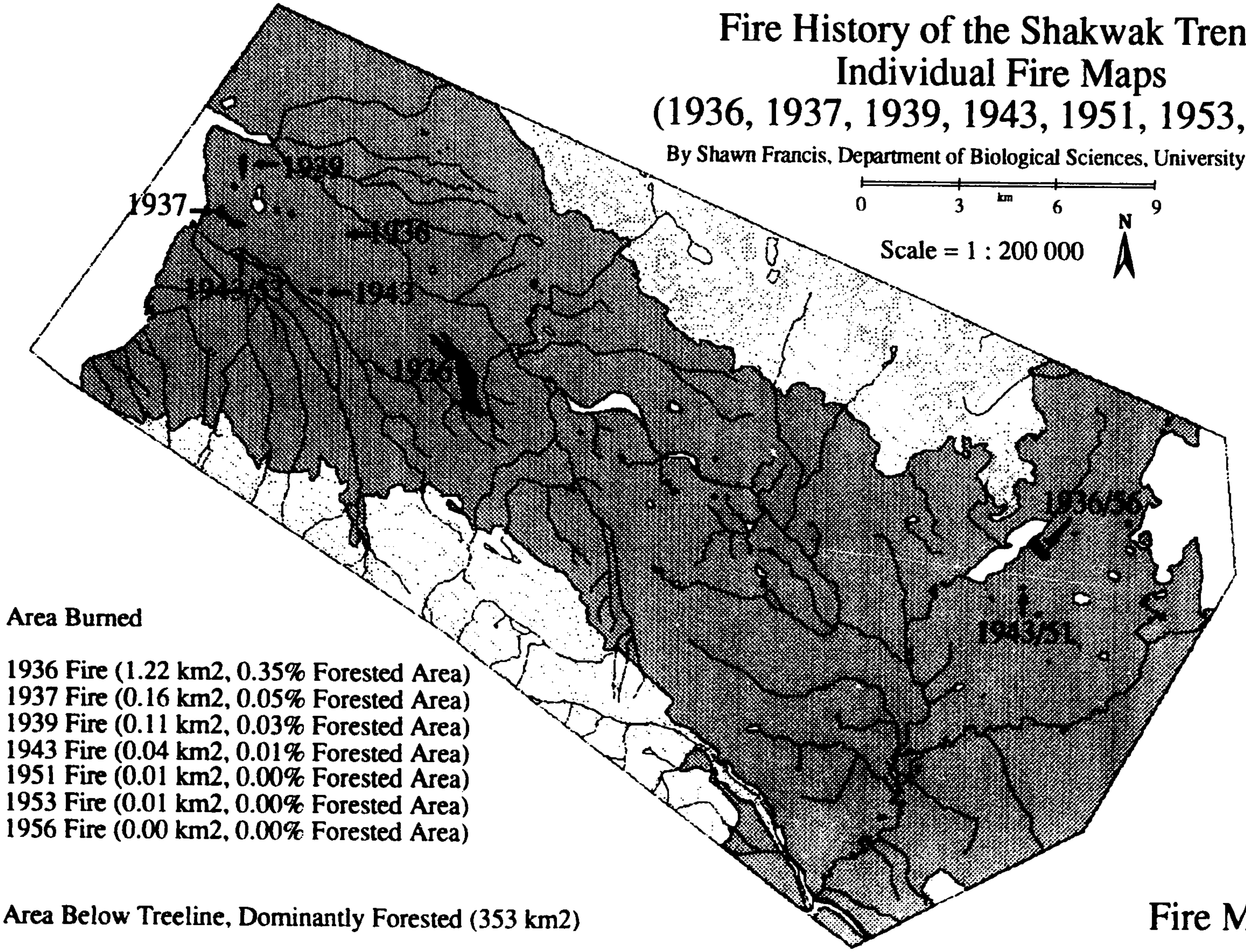
(Excluding Burn Overlap)
168.74 km2, 47.80% Forested Area

▨ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 1

Fire History of the Shakwak Trench
Individual Fire Maps
(1936, 1937, 1939, 1943, 1951, 1953, 1956)

By Shawn Francis, Department of Biological Sciences, University of Alberta



■ Area Burned

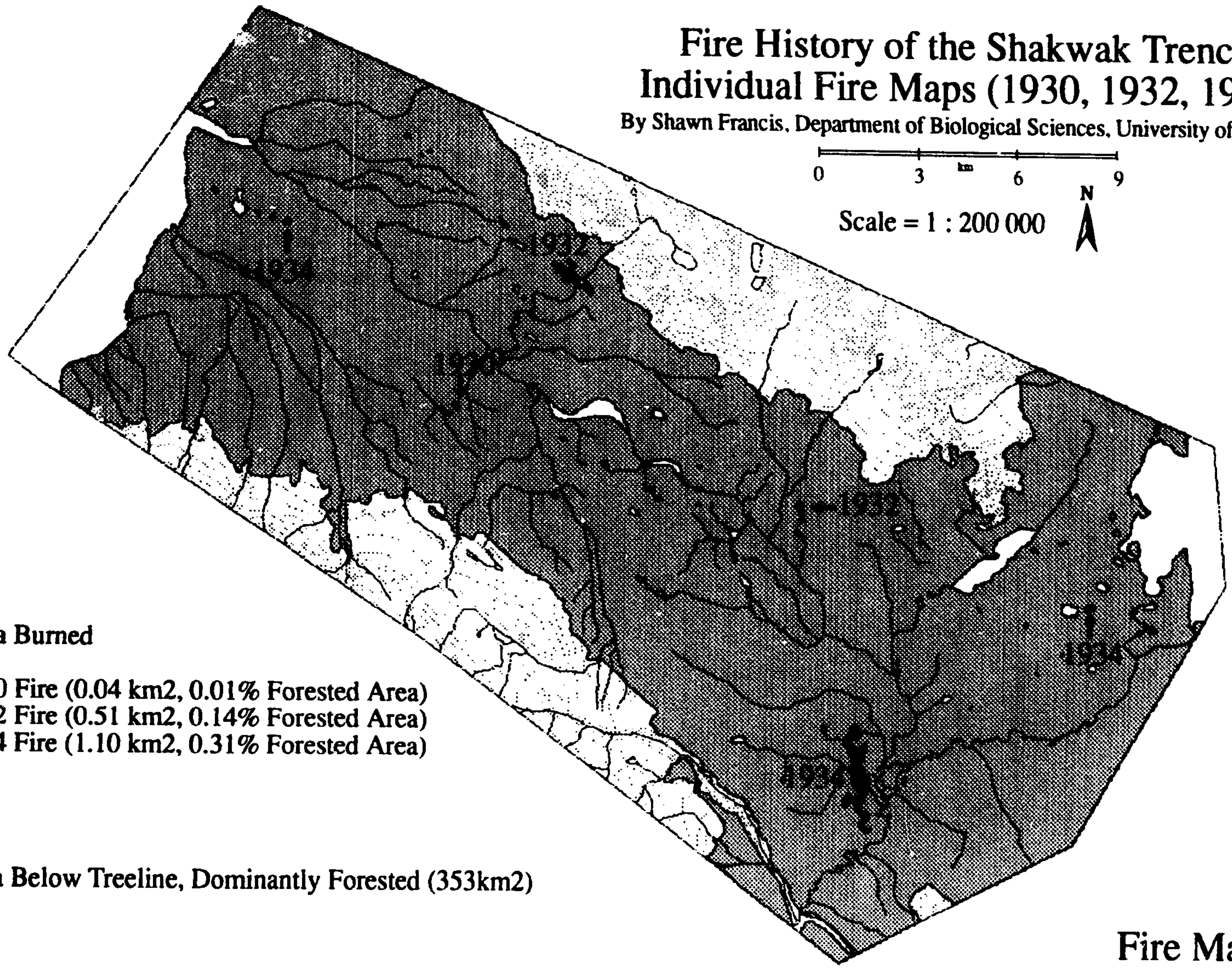
1936 Fire (1.22 km2, 0.35% Forested Area)
1937 Fire (0.16 km2, 0.05% Forested Area)
1939 Fire (0.11 km2, 0.03% Forested Area)
1943 Fire (0.04 km2, 0.01% Forested Area)
1951 Fire (0.01 km2, 0.00% Forested Area)
1953 Fire (0.01 km2, 0.00% Forested Area)
1956 Fire (0.00 km2, 0.00% Forested Area)

▨ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 2

Fire History of the Shakwak Trench
Individual Fire Maps (1930, 1932, 1934)

By Shawn Francis, Department of Biological Sciences, University of Alberta



■ Area Burned

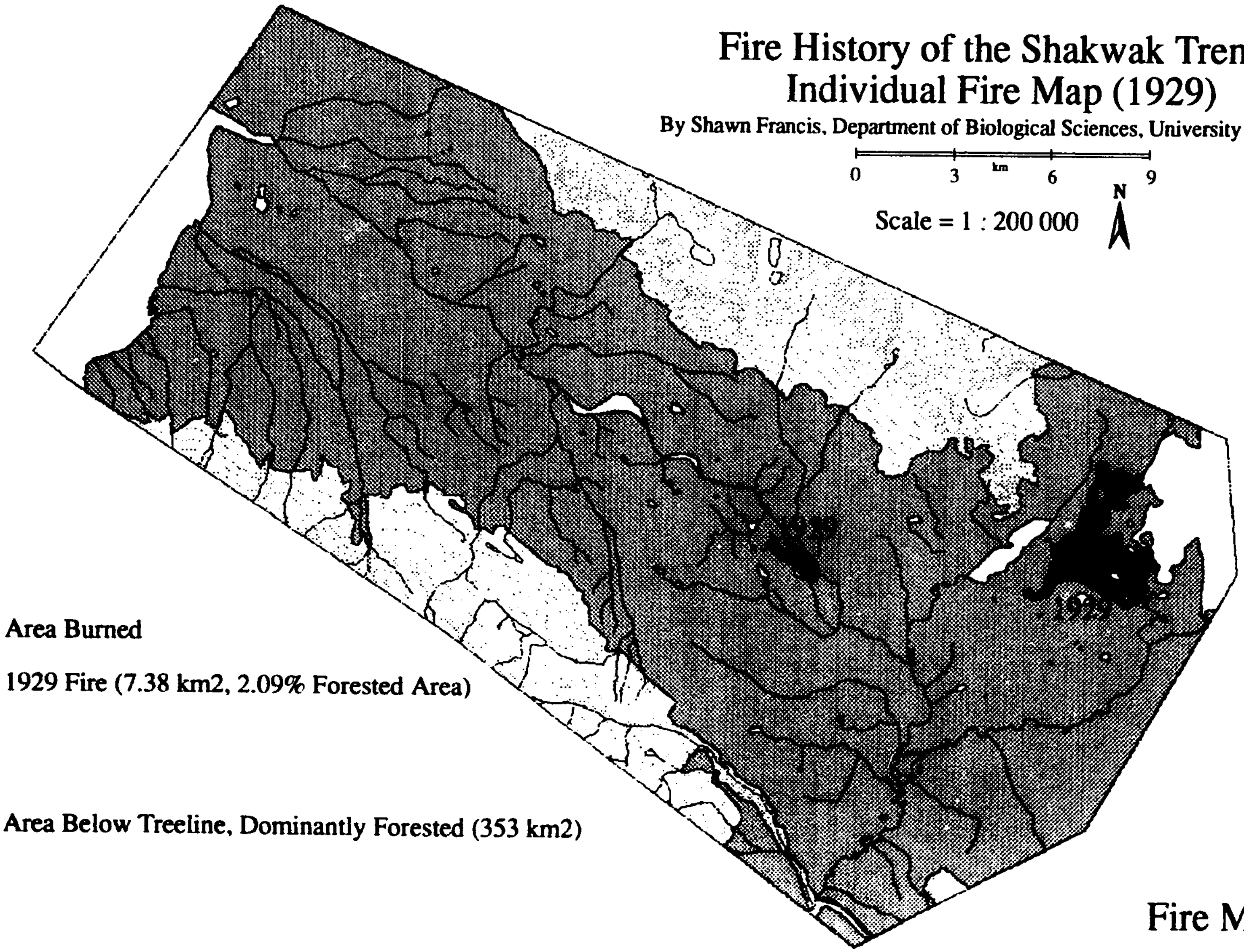
1930 Fire (0.04 km2, 0.01% Forested Area)
1932 Fire (0.51 km2, 0.14% Forested Area)
1934 Fire (1.10 km2, 0.31% Forested Area)

▨ Area Below Treeline, Dominantly Forested (353km2)

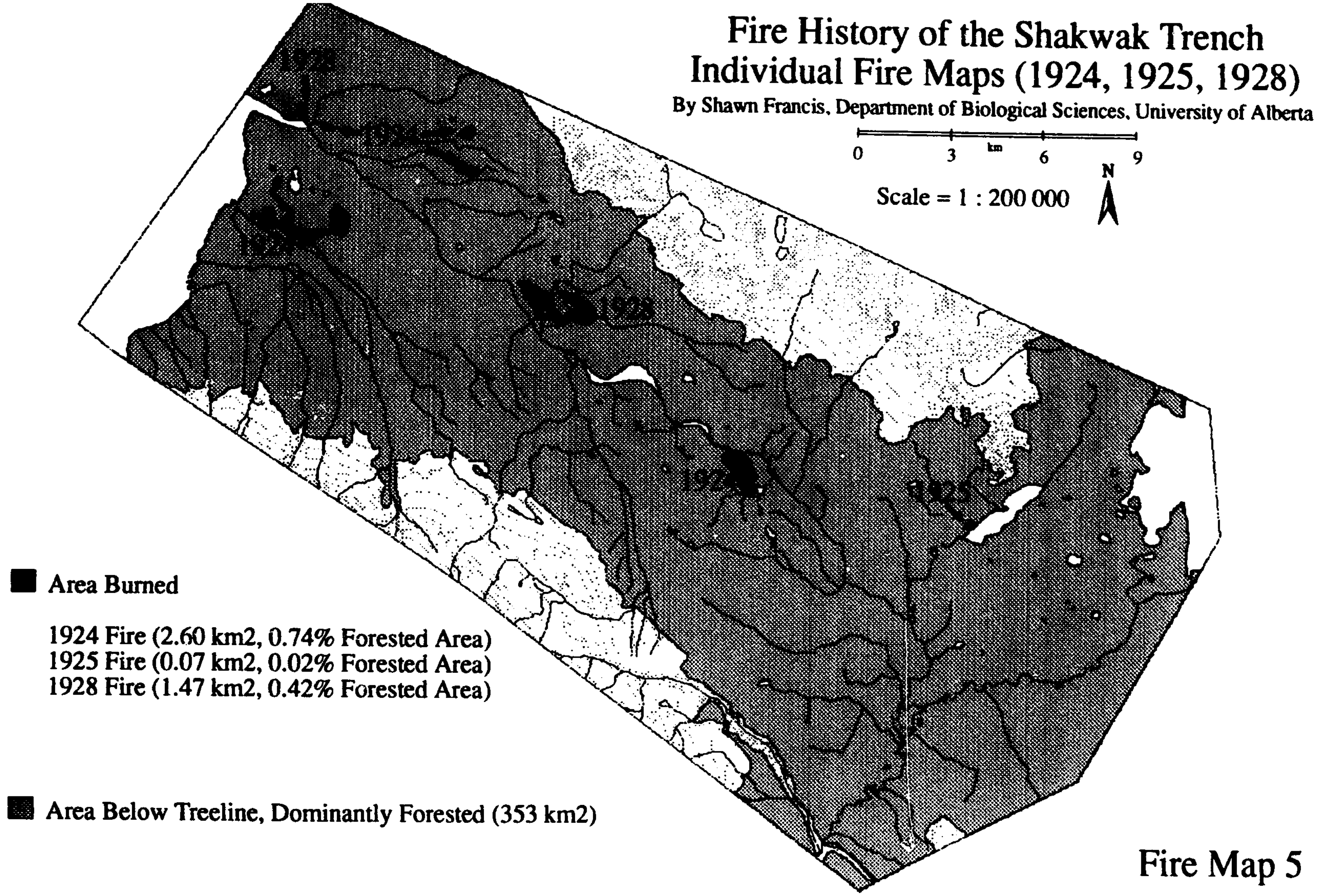
Fire Map 3

Fire History of the Shakwak Trench
Individual Fire Map (1929)

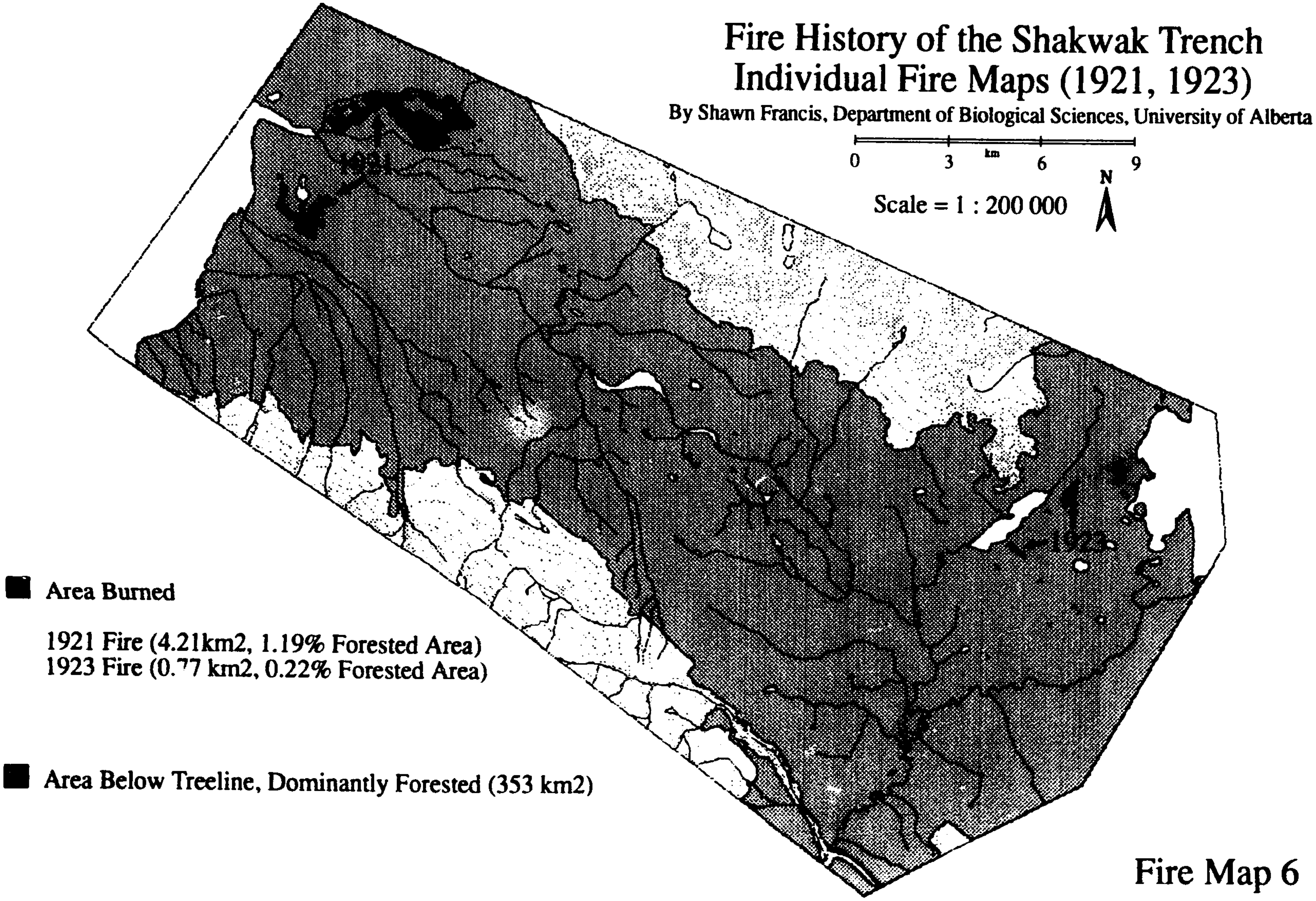
By Shawn Francis, Department of Biological Sciences, University of Alberta



Fire Map 4


Fire History of the Shakwak Trench
Individual Fire Maps (1924, 1925, 1928)
By Shawn Francis, Department of Biological Sciences, University of Alberta
0
3
km
6
9
N
Scale = 1 : 200 000
1928
1924
1925
1928
1924
1925
■ Area Burned
1924 Fire (2.60 km2, 0.74% Forested Area)
1925 Fire (0.07 km2, 0.02% Forested Area)
1928 Fire (1.47 km2, 0.42% Forested Area)
▨ Area Below Treeline, Dominantly Forested (353 km2)

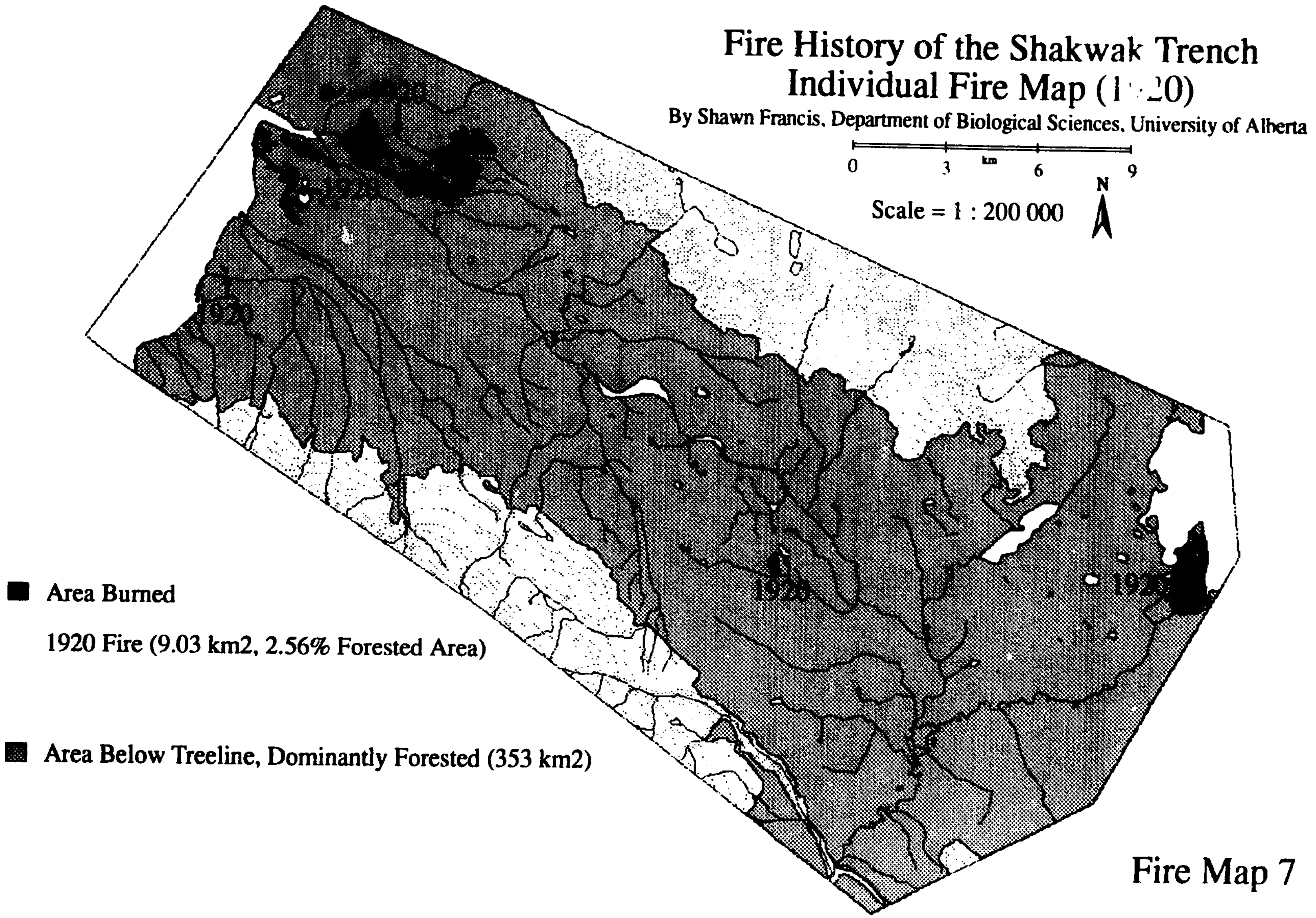
Fire Map 5


Fire History of the Shakwak Trench
Individual Fire Maps (1921, 1923)
By Shawn Francis, Department of Biological Sciences, University of Alberta
0
3
km
6
9
N
Scale = 1 : 200 000
1921
1923
Area Burned
1921 Fire (4.21km2, 1.19% Forested Area)
1923 Fire (0.77 km2, 0.22% Forested Area)
Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 6

Fire History of the Shakwak Trench
Individual Fire Map (1920)

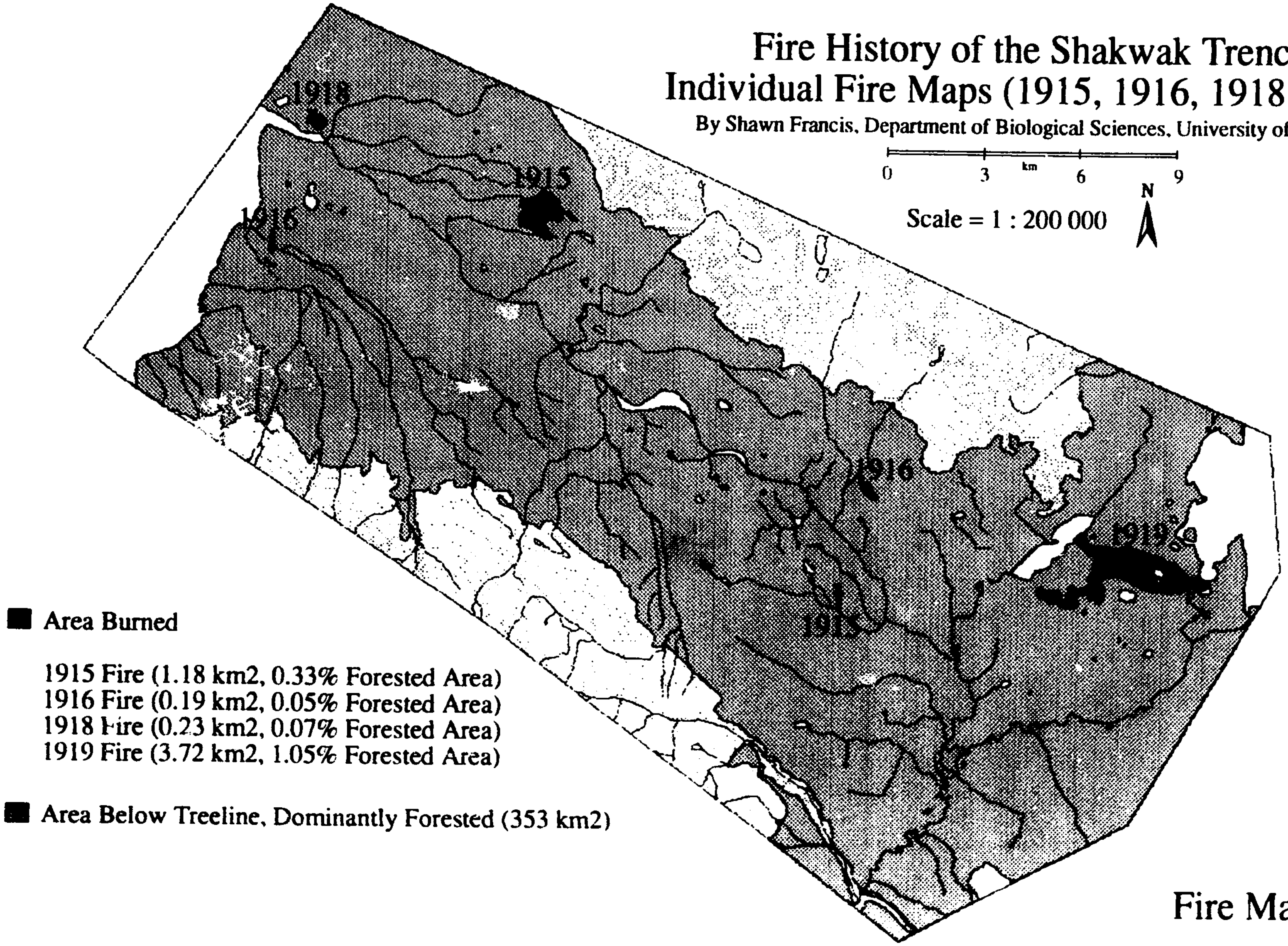
By Shawn Francis, Department of Biological Sciences, University of Alberta



Fire Map 7

Fire History of the Shakwak Trench
Individual Fire Maps (1915, 1916, 1918, 1919)

By Shawn Francis, Department of Biological Sciences, University of Alberta



Scale = 1 : 200 000

■ Area Burned

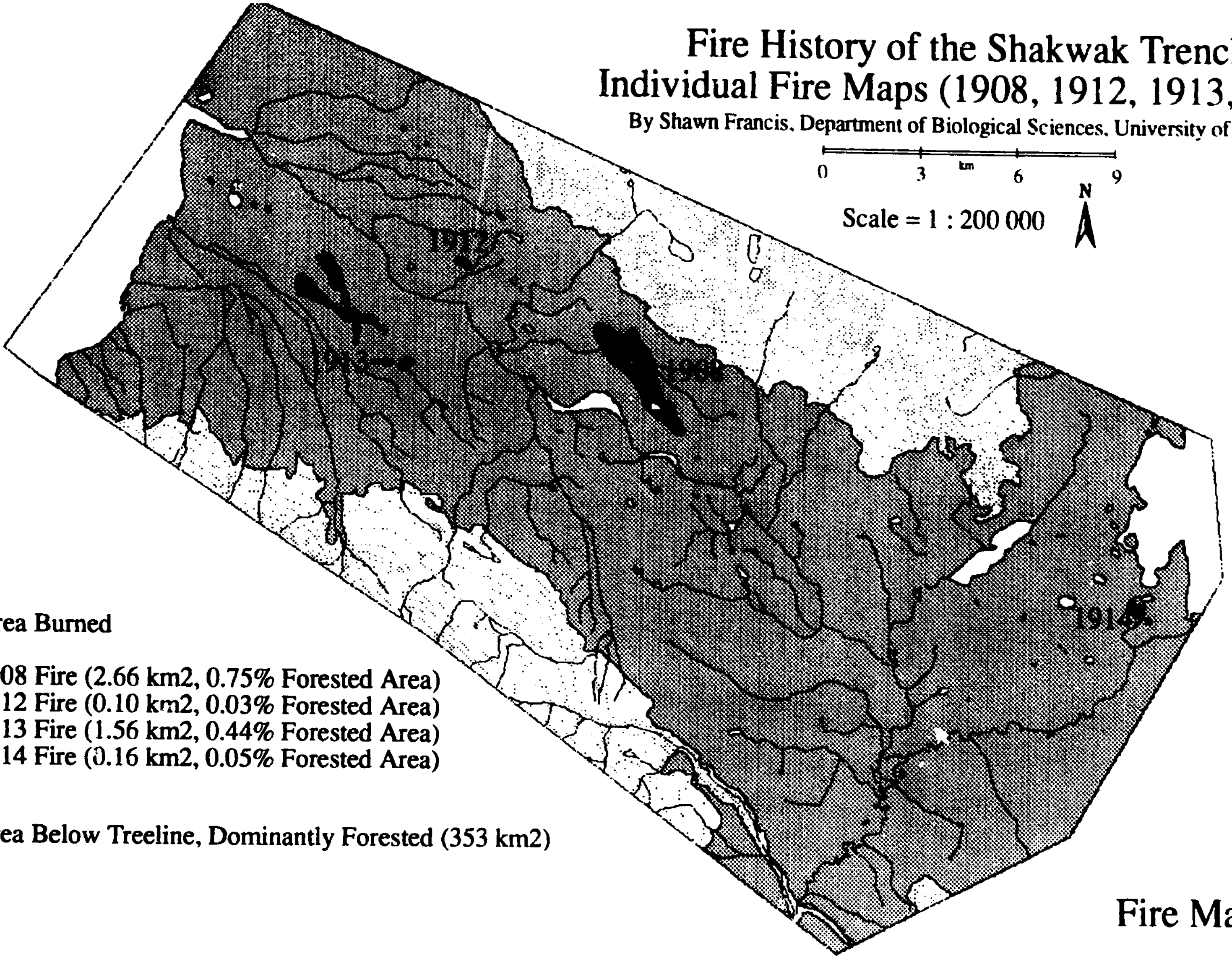
1915 Fire (1.18 km2, 0.33% Forested Area)
1916 Fire (0.19 km2, 0.05% Forested Area)
1918 Fire (0.23 km2, 0.07% Forested Area)
1919 Fire (3.72 km2, 1.05% Forested Area)

■ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 8

Fire History of the Shakwak Trench
Individual Fire Maps (1908, 1912, 1913, 1914)

By Shawn Francis, Department of Biological Sciences, University of Alberta

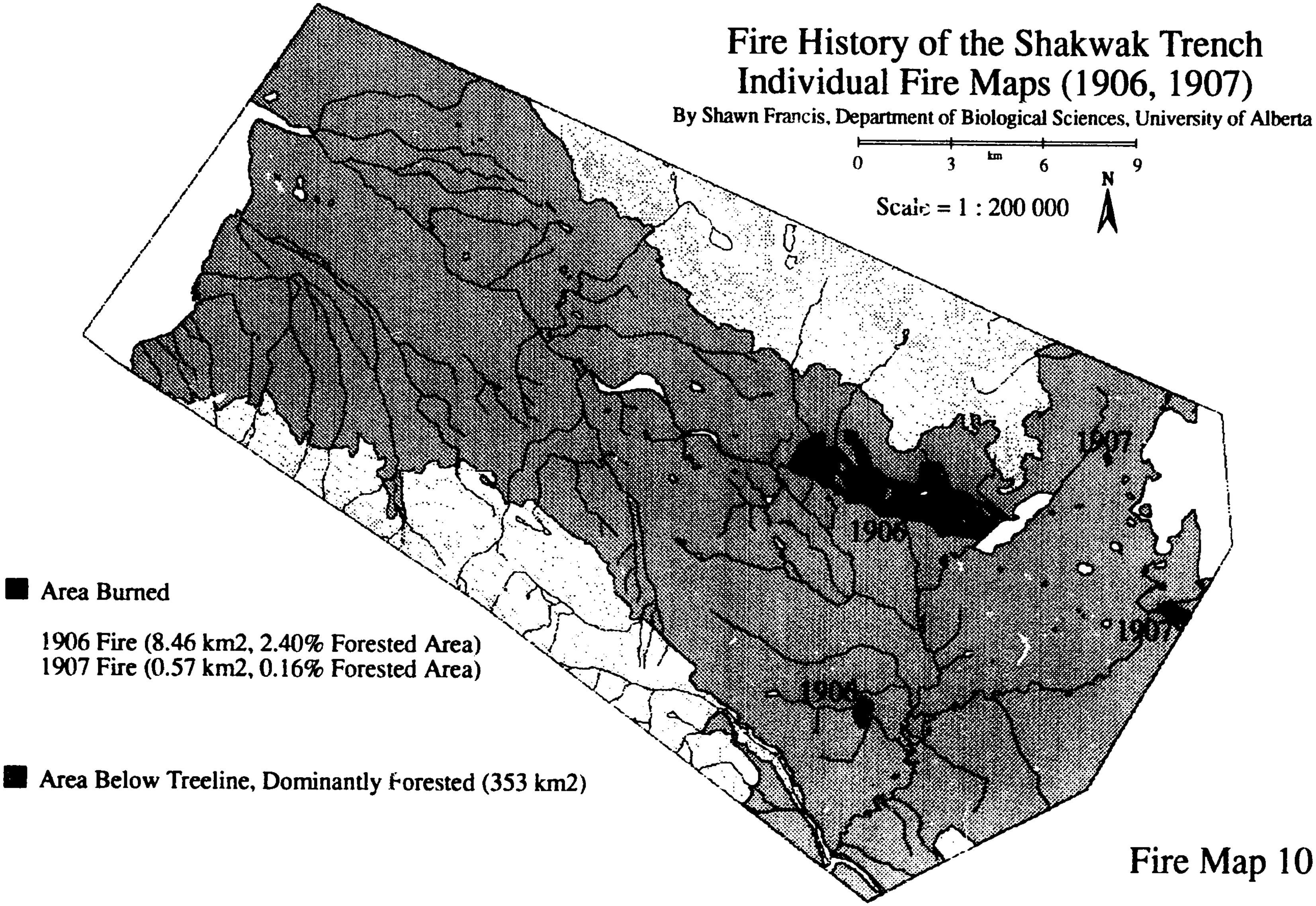


■ Area Burned

1908 Fire (2.66 km2, 0.75% Forested Area)
1912 Fire (0.10 km2, 0.03% Forested Area)
1913 Fire (1.56 km2, 0.44% Forested Area)
1914 Fire (0.16 km2, 0.05% Forested Area)

▨ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 9



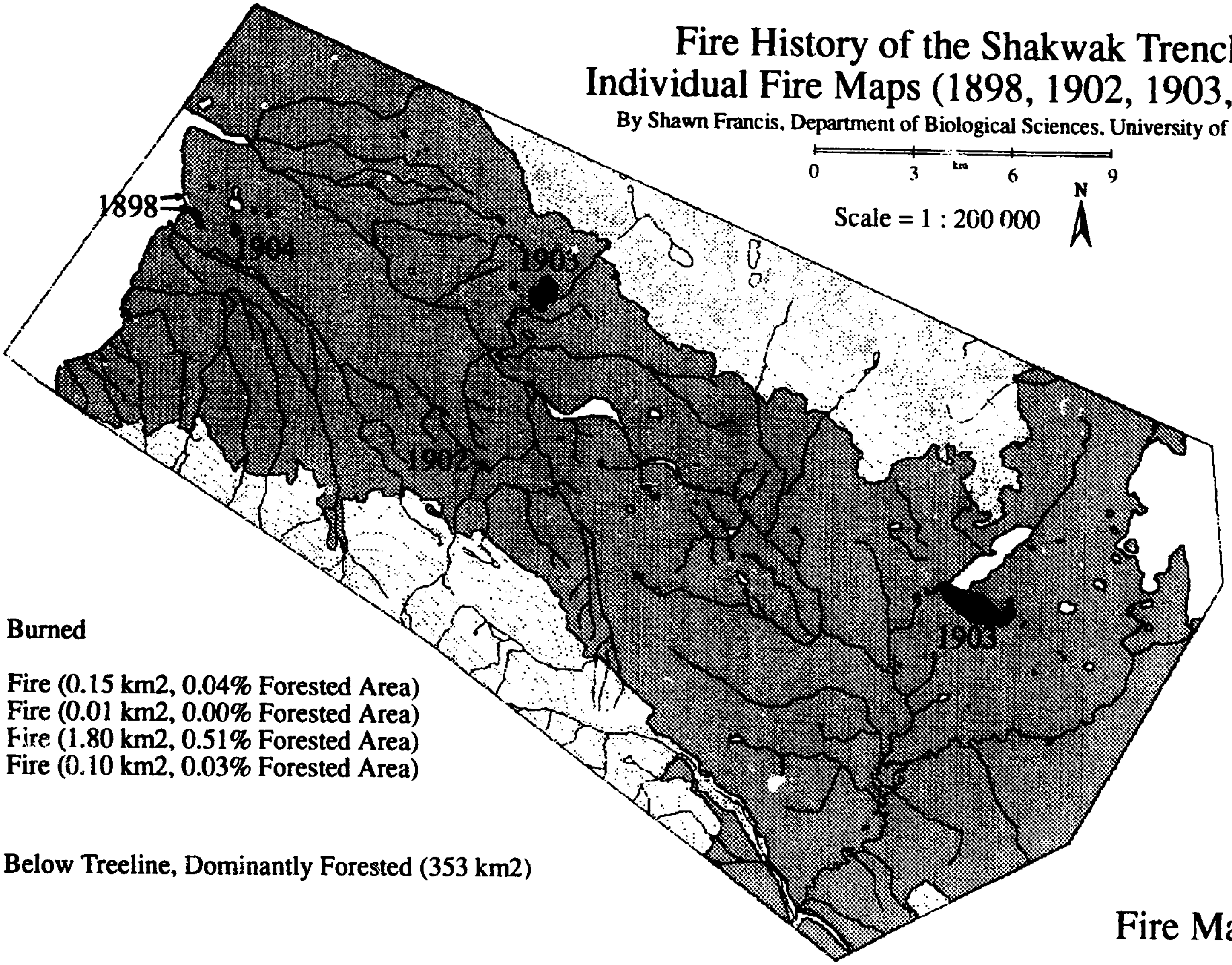
Fire History of the Shakwak Trench
Individual Fire Maps (1906, 1907)

By Shawn Francis, Department of Biological Sciences, University of Alberta

Fire Map 10

Fire History of the Shakwak Trench
Individual Fire Maps (1898, 1902, 1903, 1904)

By Shawn Francis, Department of Biological Sciences, University of Alberta

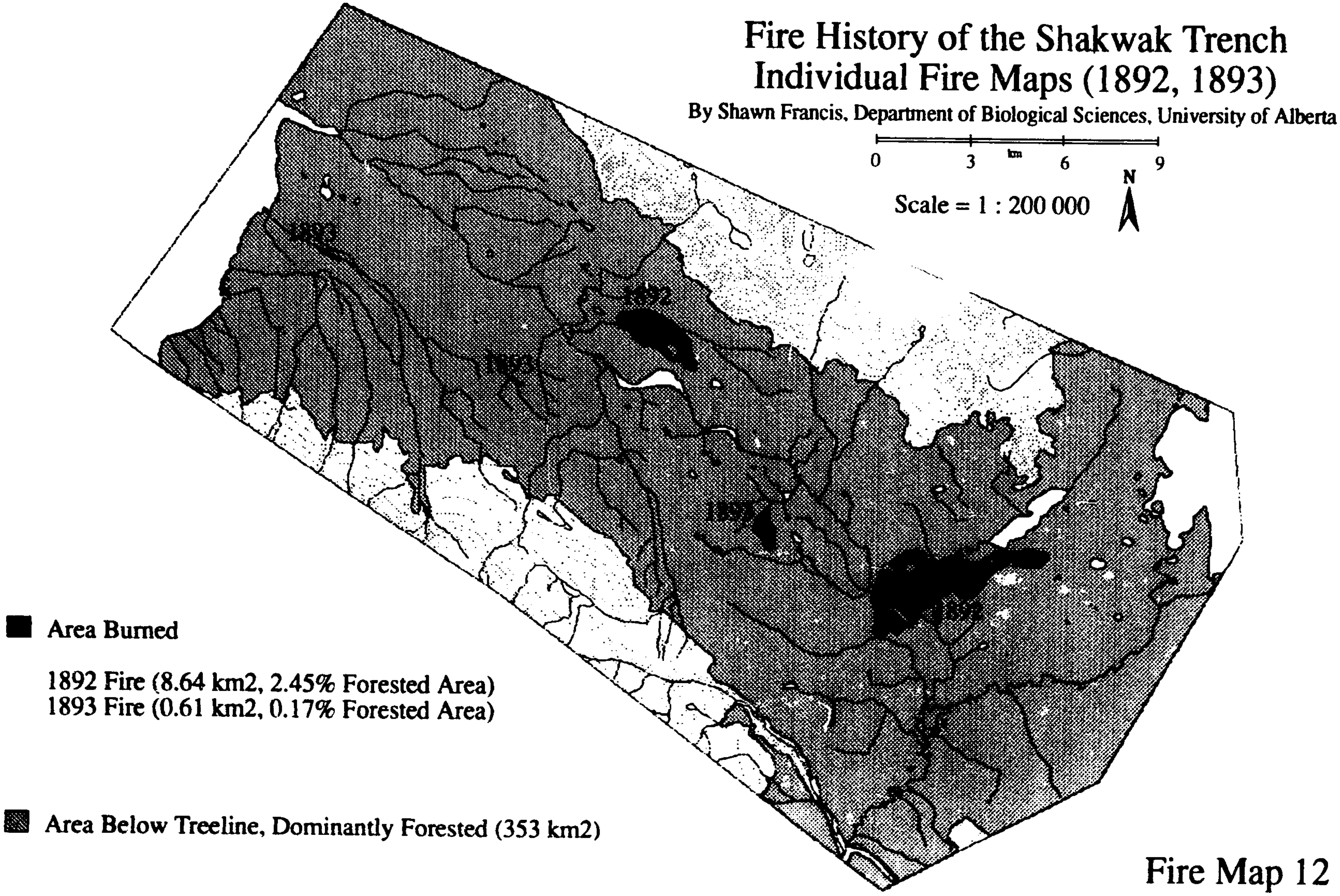


■ Area Burned

1898 Fire (0.15 km2, 0.04% Forested Area)
1902 Fire (0.01 km2, 0.00% Forested Area)
1903 Fire (1.80 km2, 0.51% Forested Area)
1904 Fire (0.10 km2, 0.03% Forested Area)

▨ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 11



Fire History of the Shakwak Trench
Individual Fire Maps (1892, 1893)

By Shawn Francis, Department of Biological Sciences, University of Alberta

Scale = 1 : 200 000

■ Area Burned

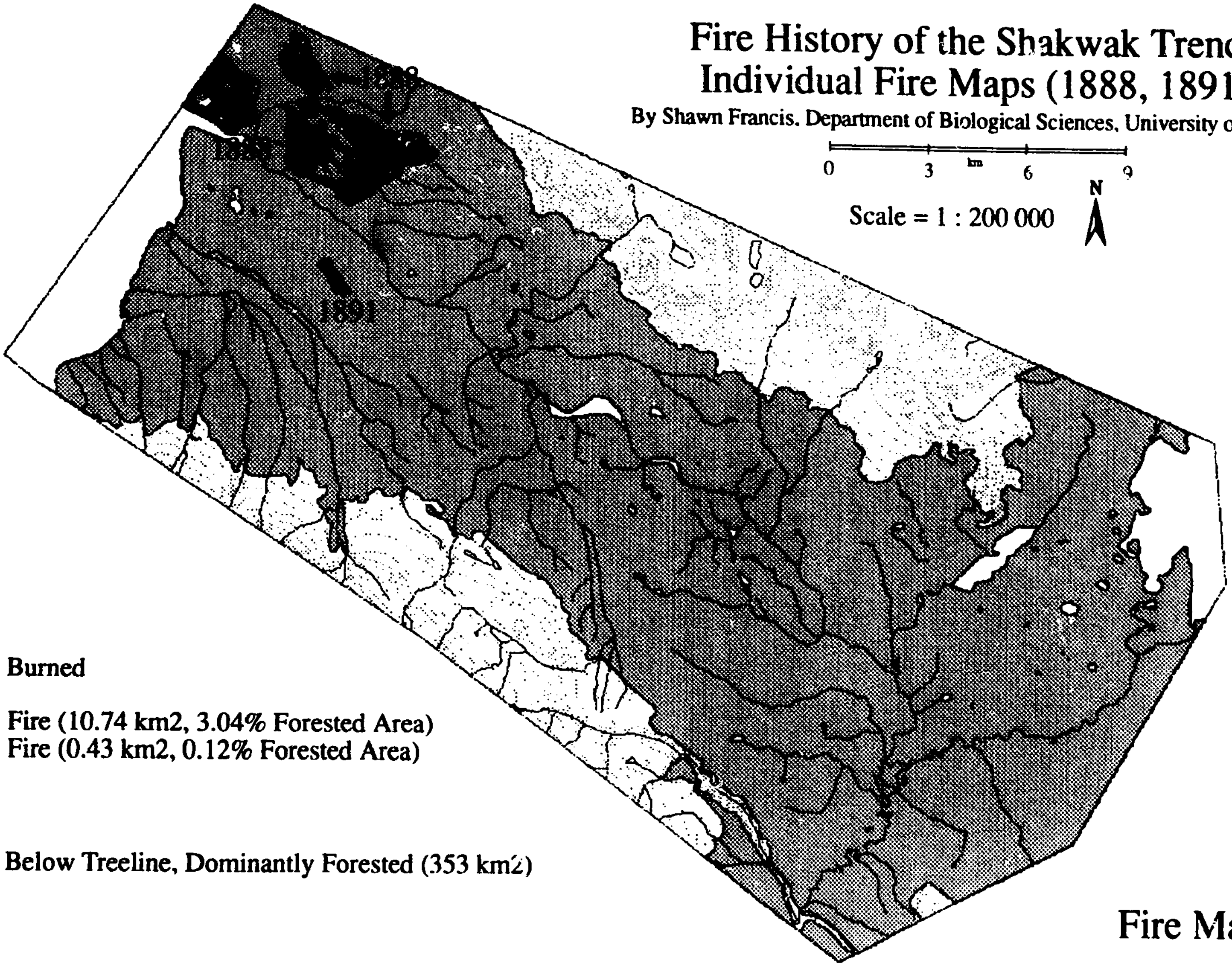
1892 Fire (8.64 km2, 2.45% Forested Area)
1893 Fire (0.61 km2, 0.17% Forested Area)

▨ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 12

Fire History of the Shakwak Trench
Individual Fire Maps (1888, 1891)

By Shawn Francis, Department of Biological Sciences, University of Alberta

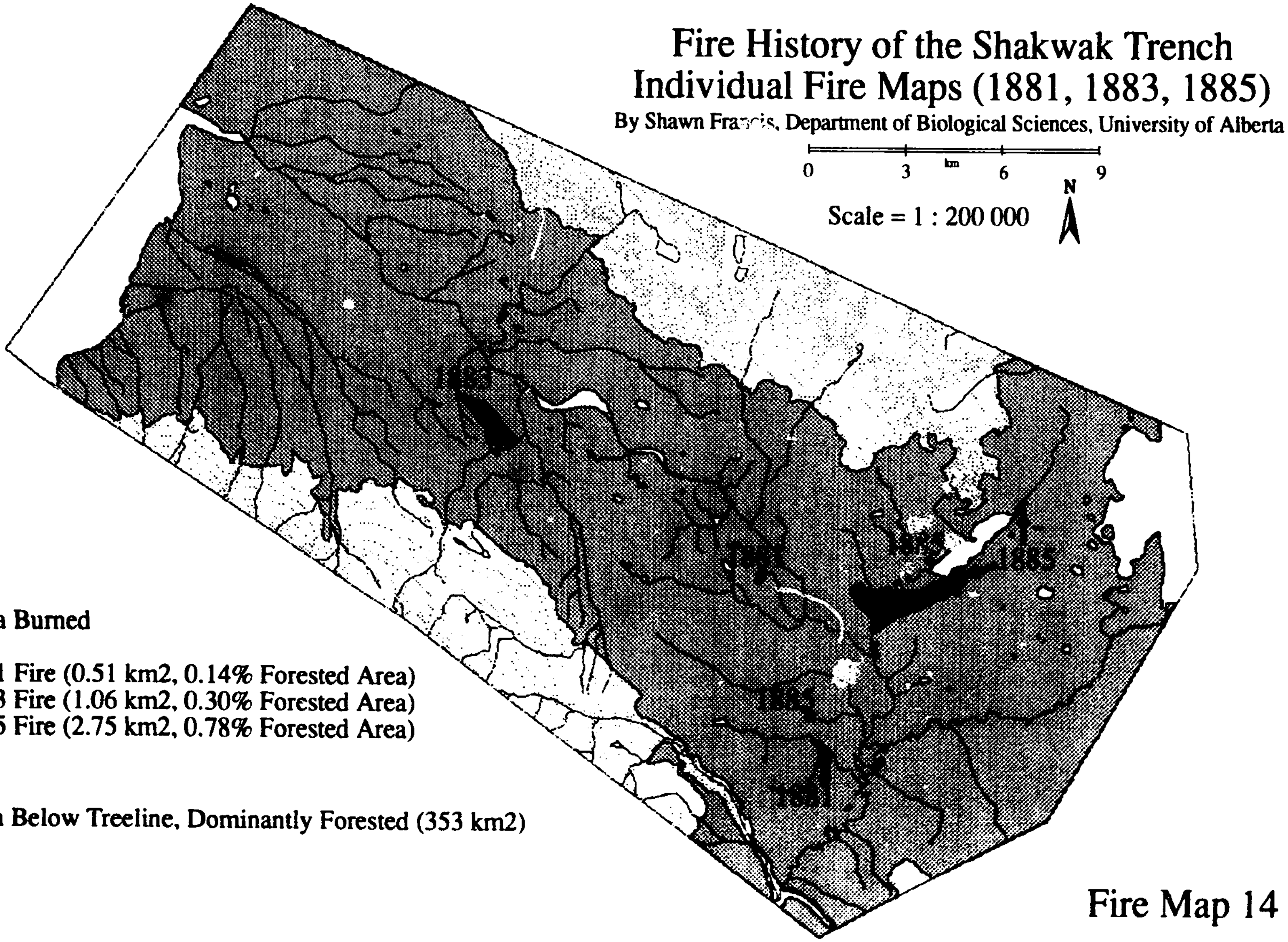


■ Area Burned

1888 Fire (10.74 km2, 3.04% Forested Area)
1891 Fire (0.43 km2, 0.12% Forested Area)

▨ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 13



Fire History of the Shakwak Trench
Individual Fire Maps (1881, 1883, 1885)
By Shawn Francis, Department of Biological Sciences, University of Alberta

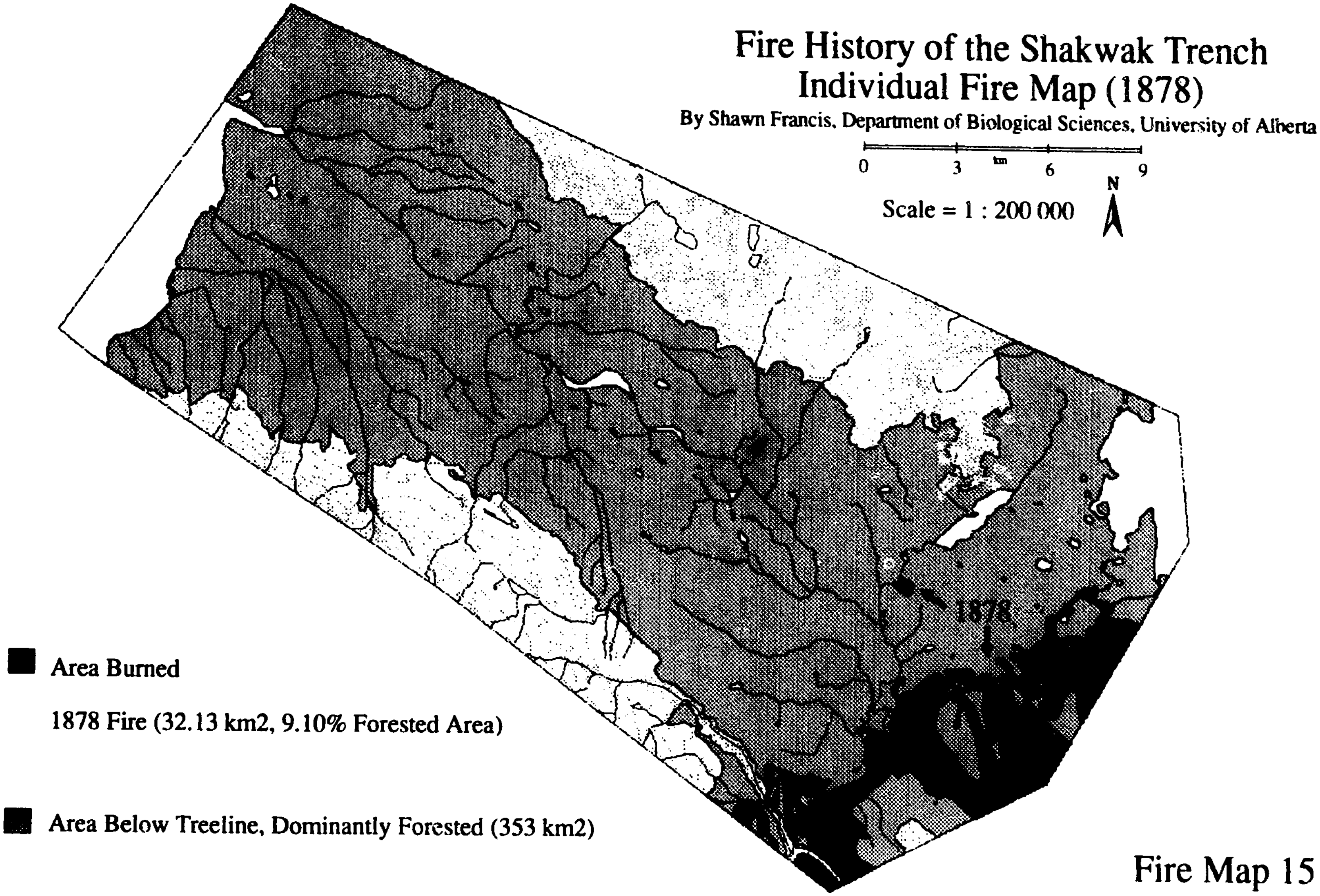
Scale = 1 : 200 000

■ Area Burned

1881 Fire (0.51 km2, 0.14% Forested Area)
1883 Fire (1.06 km2, 0.30% Forested Area)
1885 Fire (2.75 km2, 0.78% Forested Area)

▩ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 14



Fire History of the Shakwak Trench
Individual Fire Map (1878)

By Shawn Francis, Department of Biological Sciences, University of Alberta

Scale = 1 : 200 000

■ Area Burned

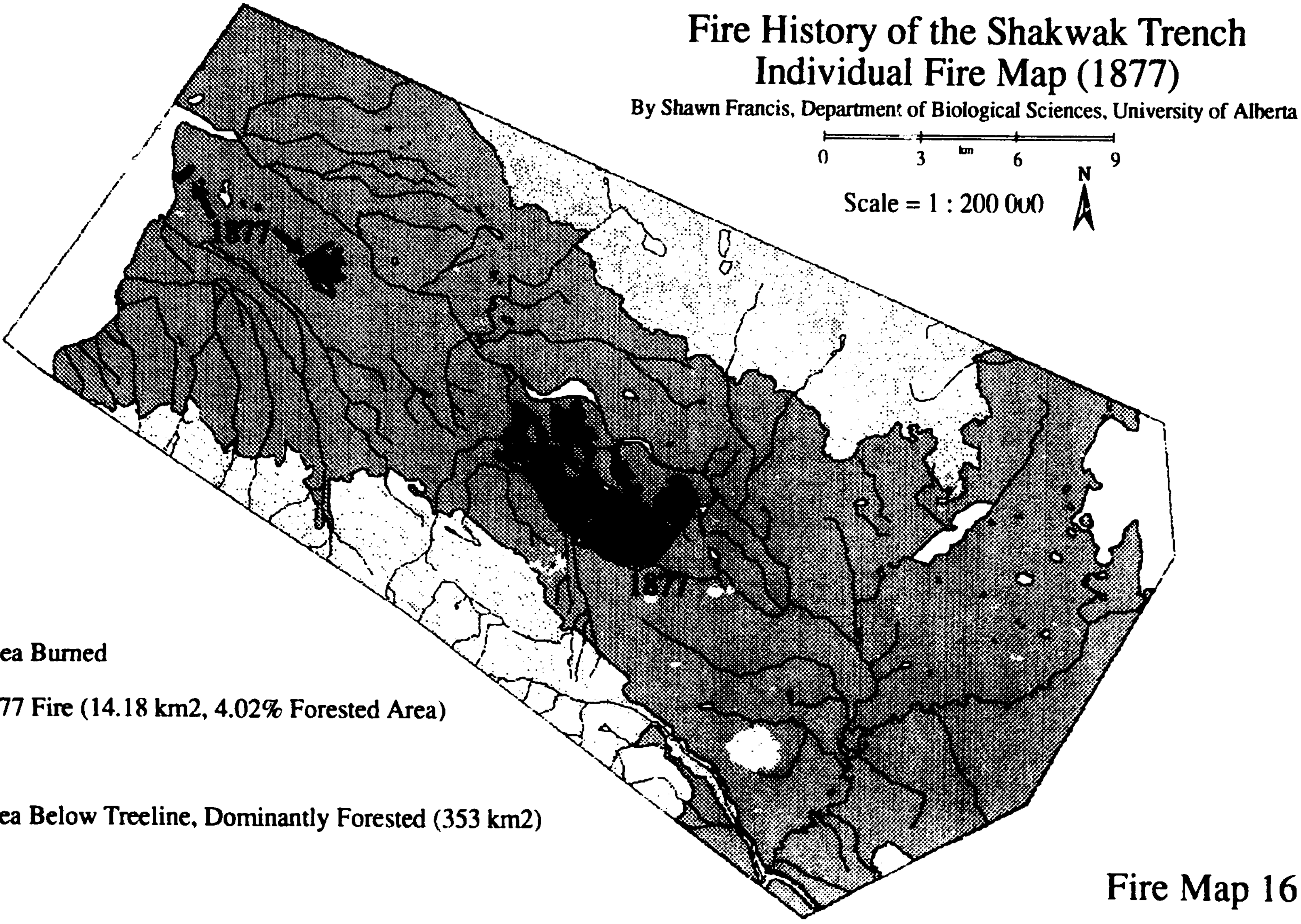
1878 Fire (32.13 km2, 9.10% Forested Area)

▨ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 15

Fire History of the Shakwak Trench
Individual Fire Map (1877)

By Shawn Francis, Department of Biological Sciences, University of Alberta



Scale = 1 : 200 000

■ Area Burned

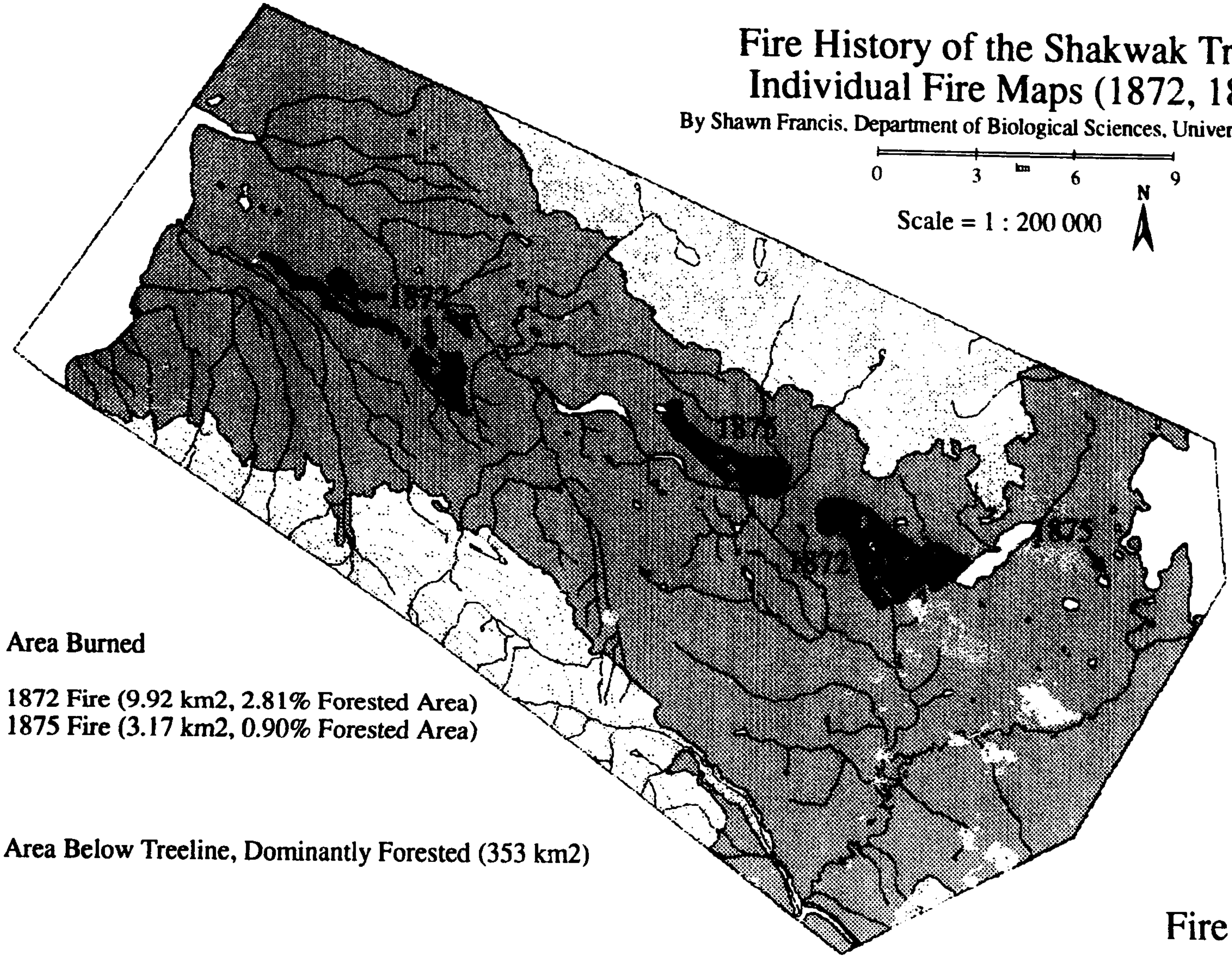
1877 Fire (14.18 km2, 4.02% Forested Area)

■ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 16

Fire History of the Shakwak Trench
Individual Fire Maps (1872, 1875)

By Shawn Francis. Department of Biological Sciences, University of Alberta



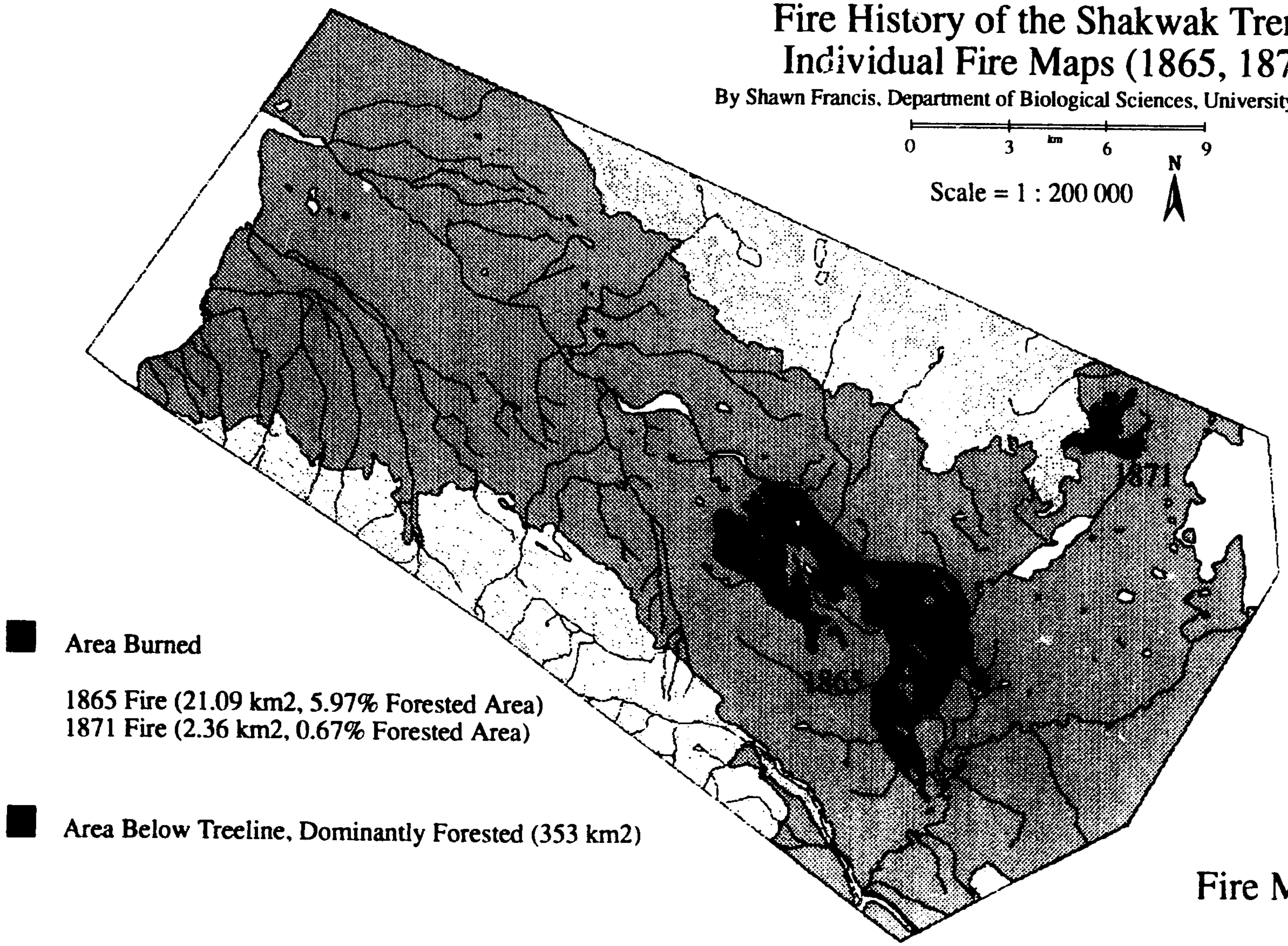
Scale = 1 : 200 000

■ Area Burned

1872 Fire (9.92 km2, 2.81% Forested Area)
1875 Fire (3.17 km2, 0.90% Forested Area)

■ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 17



Fire History of the Shakwak Trench
Individual Fire Maps (1865, 1871)
By Shawn Francis, Department of Biological Sciences, University of Alberta

■ Area Burned

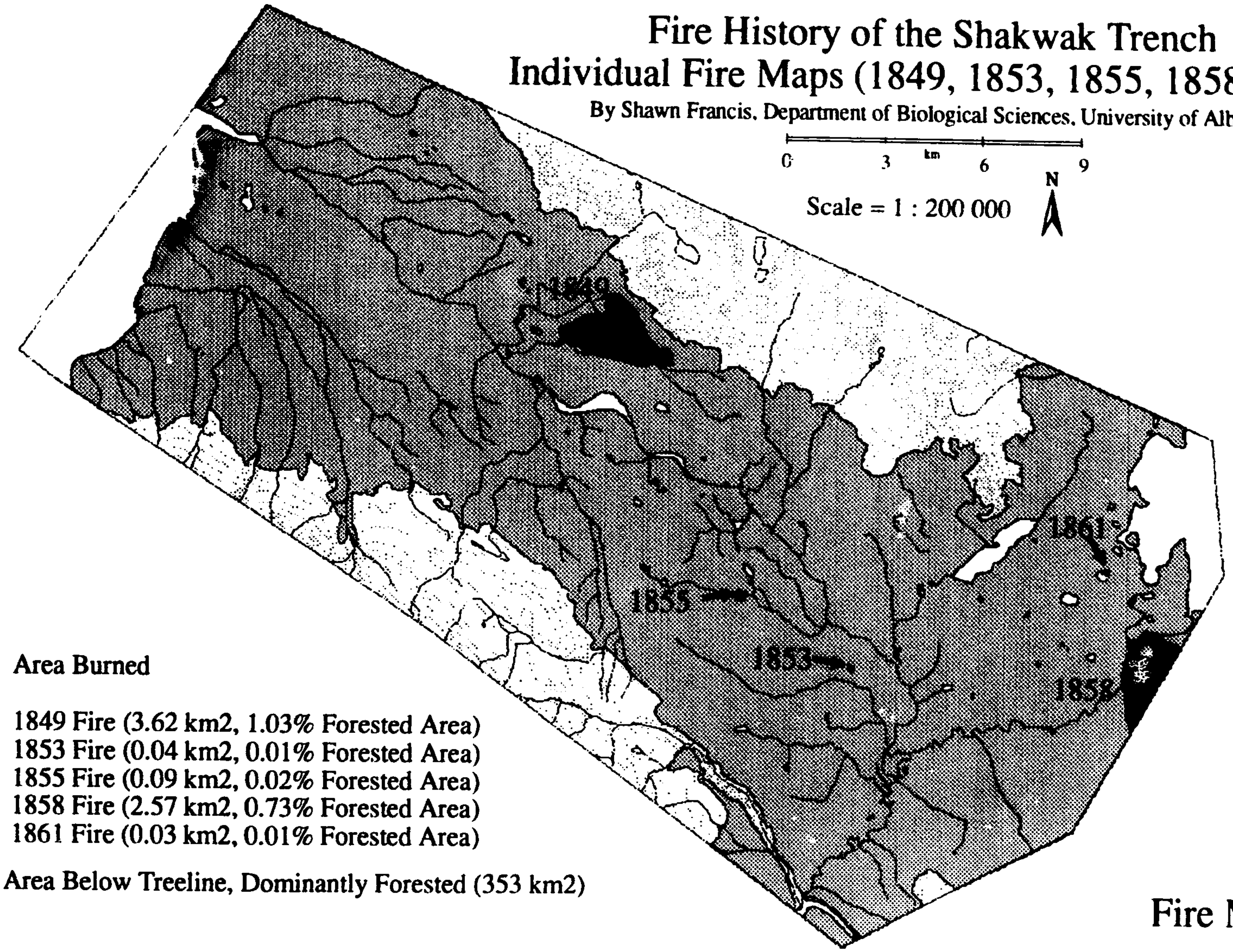
1865 Fire (21.09 km2, 5.97% Forested Area)
1871 Fire (2.36 km2, 0.67% Forested Area)

■ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 18

Fire History of the Shakwak Trench
Individual Fire Maps (1849, 1853, 1855, 1858, 1861)

By Shawn Francis, Department of Biological Sciences, University of Alberta



Scale = 1 : 200 000

■ Area Burned

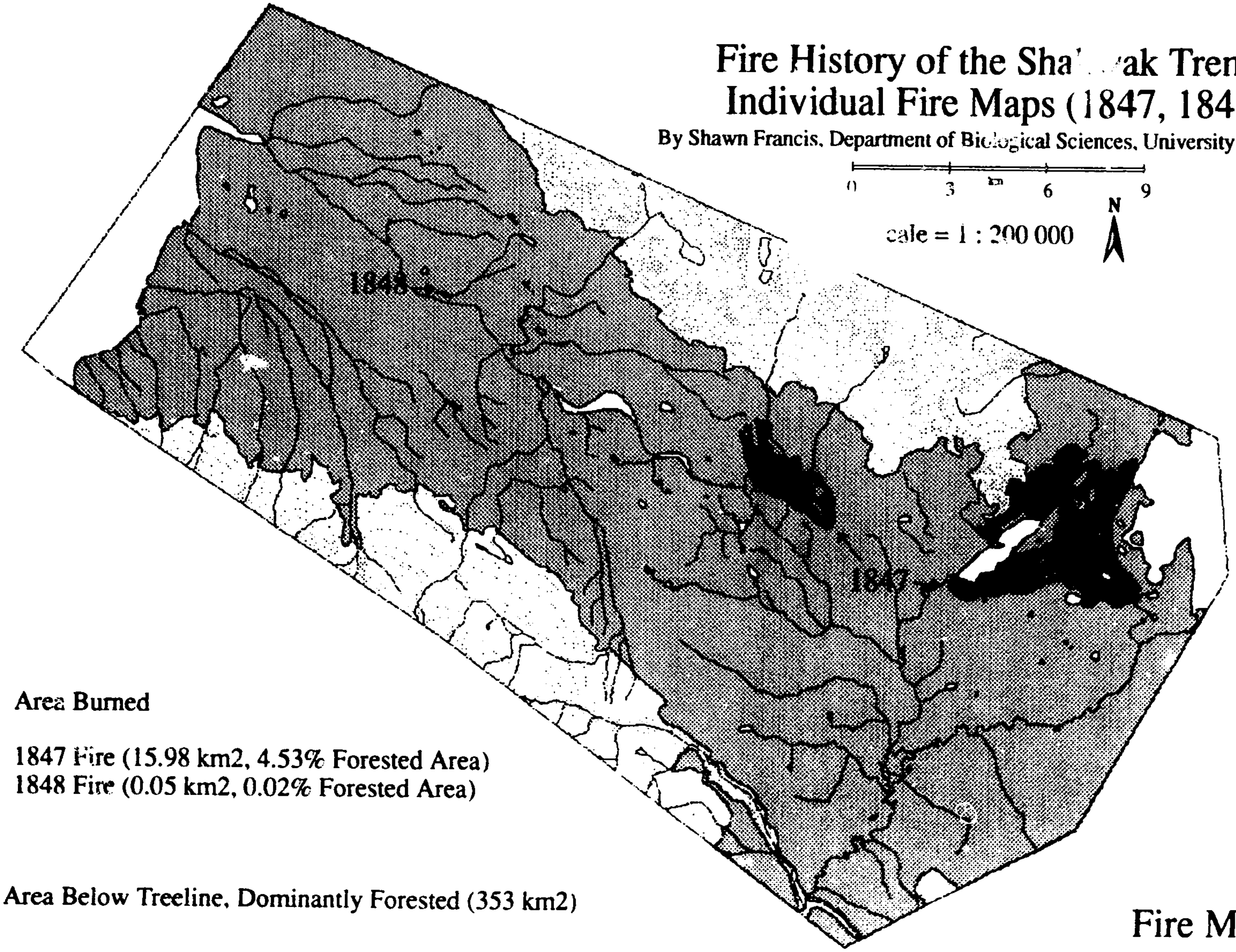
1849 Fire (3.62 km2, 1.03% Forested Area)
1853 Fire (0.04 km2, 0.01% Forested Area)
1855 Fire (0.09 km2, 0.02% Forested Area)
1858 Fire (2.57 km2, 0.73% Forested Area)
1861 Fire (0.03 km2, 0.01% Forested Area)

▨ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 19

Fire History of the Shakwak Trench
Individual Fire Maps (1847, 1848)

By Shawn Francis, Department of Biological Sciences, University of Alberta



■ Area Burned

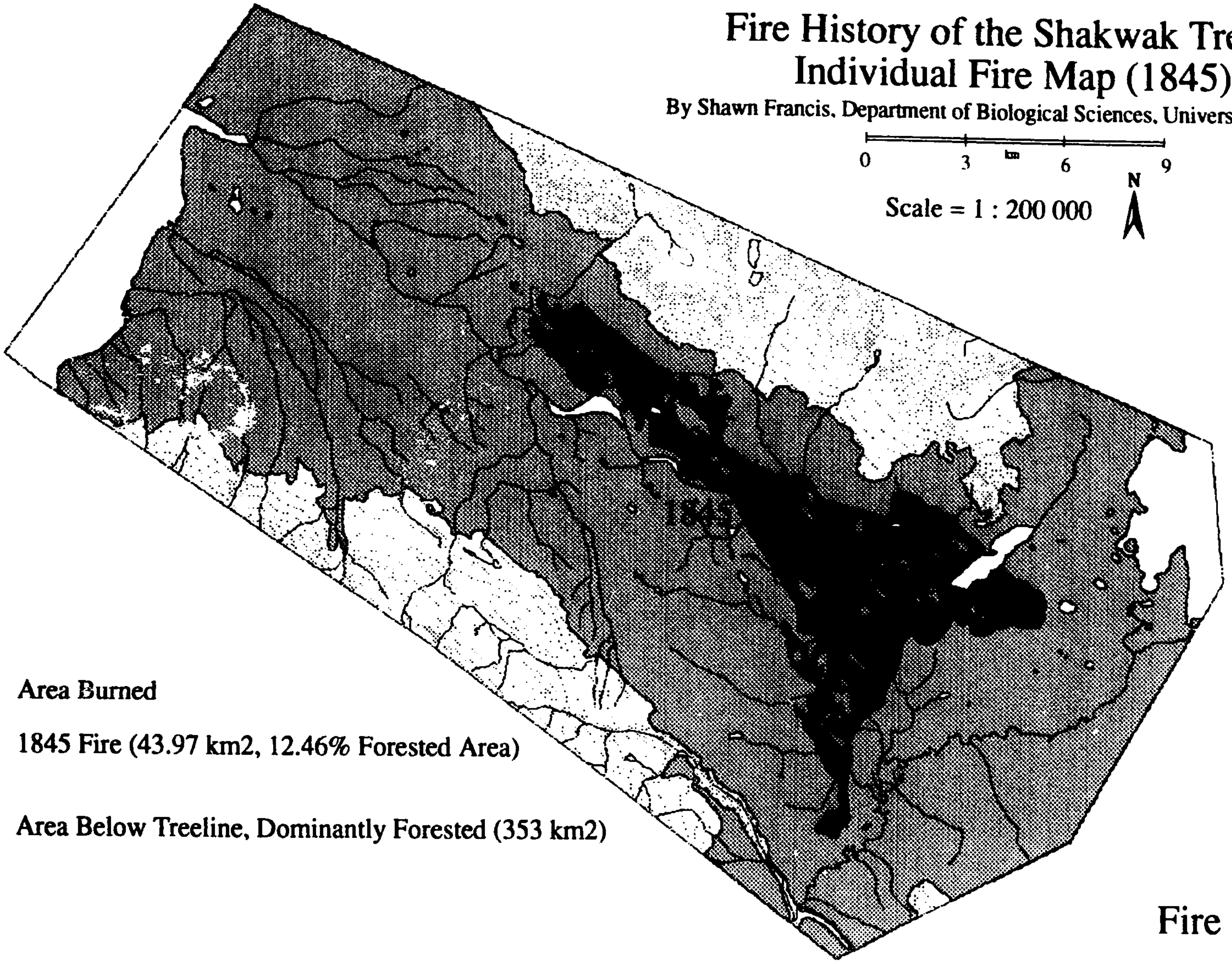
1847 Fire (15.98 km2, 4.53% Forested Area)
1848 Fire (0.05 km2, 0.02% Forested Area)

■ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 20

Fire History of the Shakwak Trench
Individual Fire Map (1845)

By Shawn Francis, Department of Biological Sciences, University of Alberta



Scale = 1 : 200 000

■ Area Burned

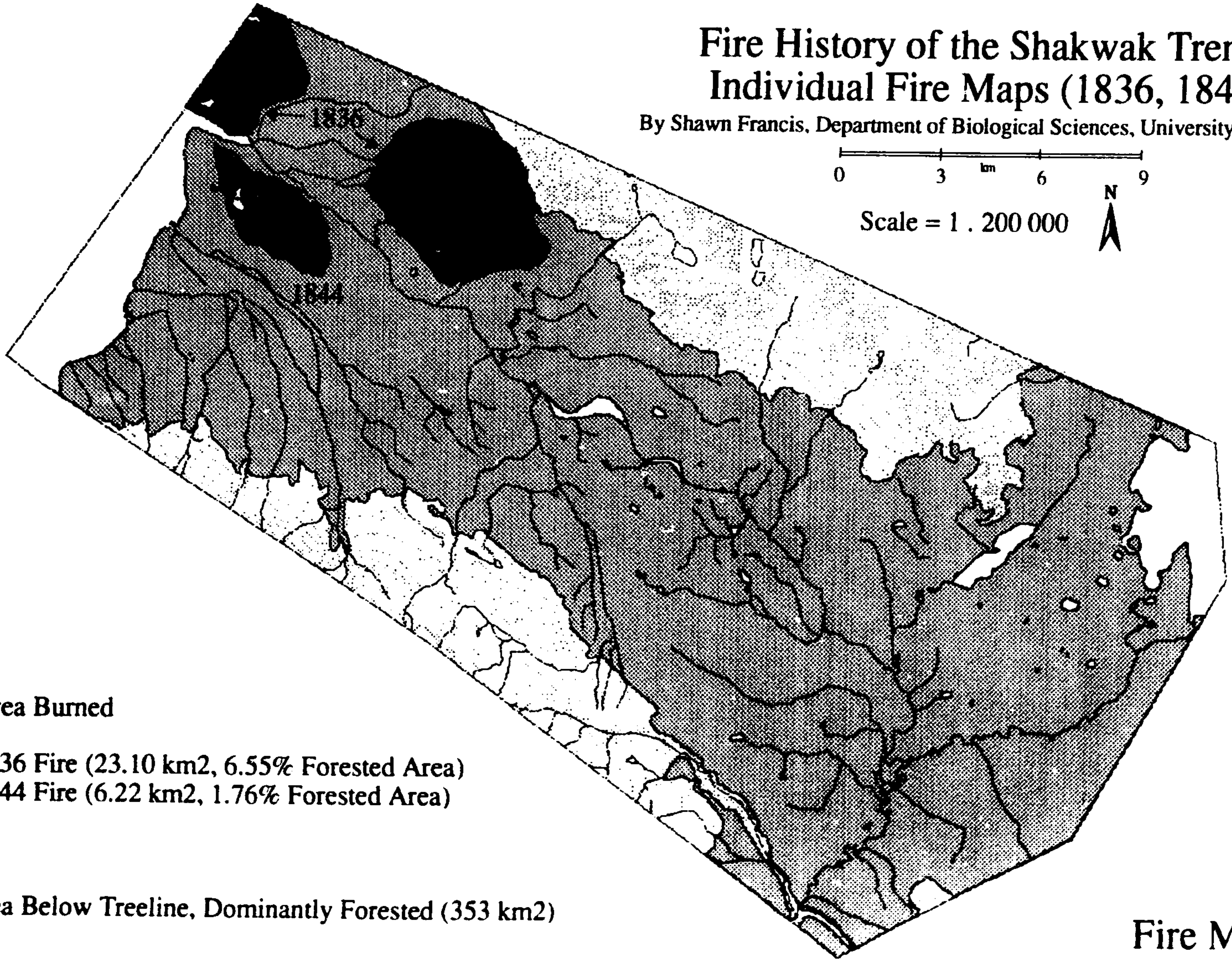
1845 Fire (43.97 km2, 12.46% Forested Area)

■ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 21

Fire History of the Shakwak Trench
Individual Fire Maps (1836, 1844)

By Shawn Francis, Department of Biological Sciences, University of Alberta



■ Area Burned

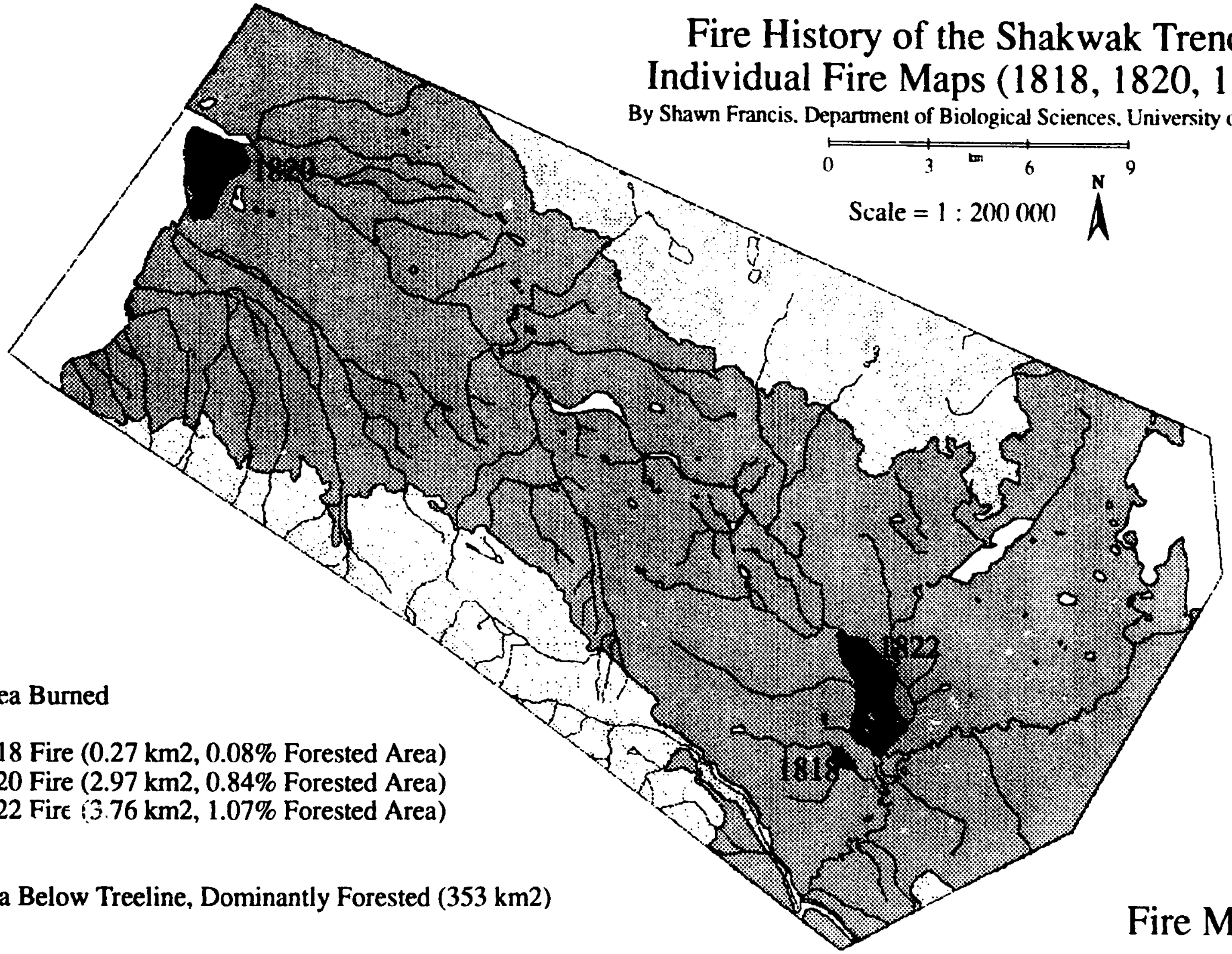
1836 Fire (23.10 km2, 6.55% Forested Area)
1844 Fire (6.22 km2, 1.76% Forested Area)

■ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 22

Fire History of the Shakwak Trench
Individual Fire Maps (1818, 1820, 1822)

By Shawn Francis. Department of Biological Sciences. University of Alberta



■ Area Burned

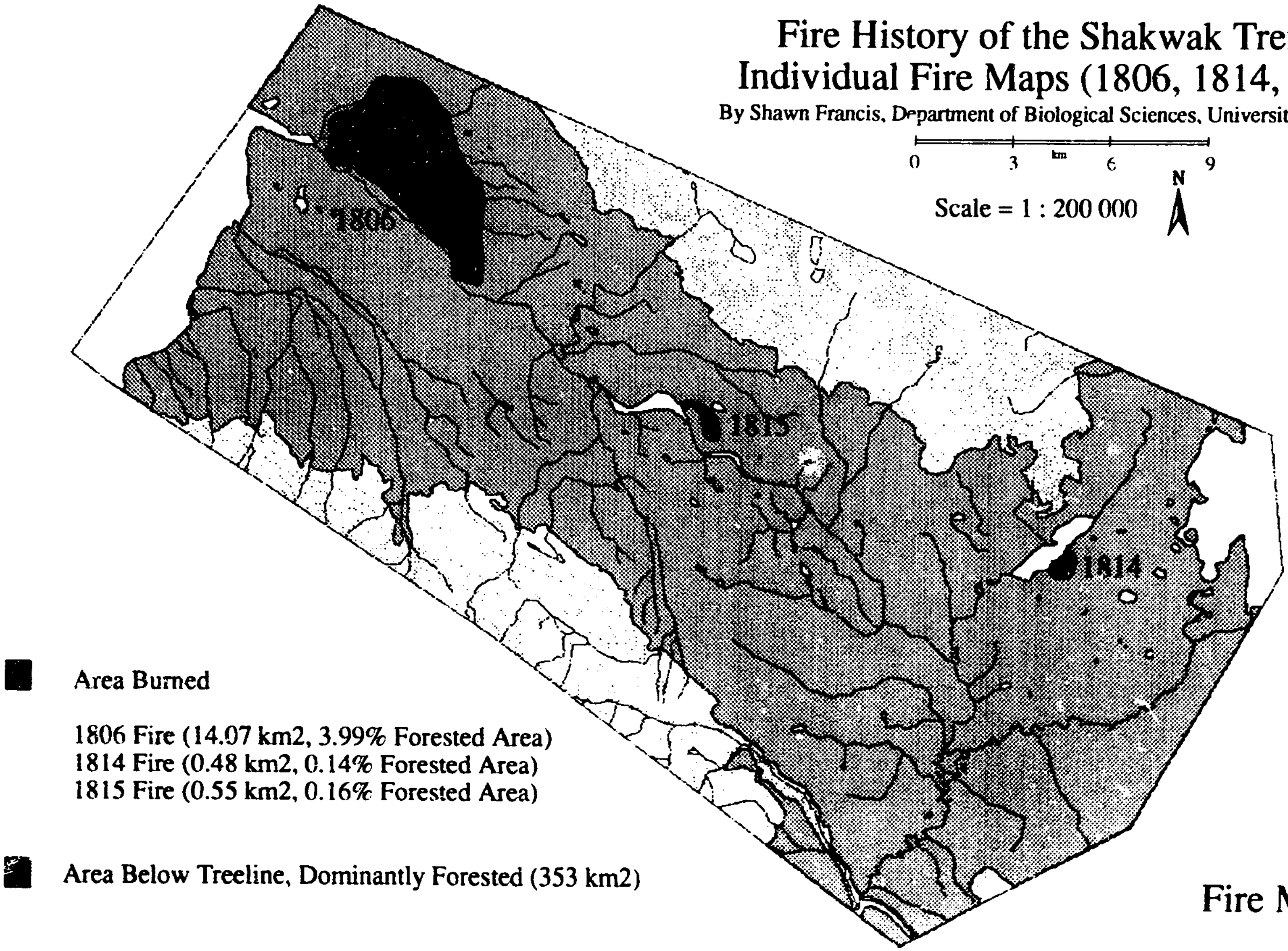
1818 Fire (0.27 km2, 0.08% Forested Area)
1820 Fire (2.97 km2, 0.84% Forested Area)
1822 Fire (3.76 km2, 1.07% Forested Area)

▨ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 23

Fire History of the Shakwak Trench
Individual Fire Maps (1806, 1814, 1815)

By Shawn Francis, Department of Biological Sciences, University of Alberta



Scale = 1 : 200 000

■ Area Burned

1806 Fire (14.07 km2, 3.99% Forested Area)
1814 Fire (0.48 km2, 0.14% Forested Area)
1815 Fire (0.55 km2, 0.16% Forested Area)

▨ Area Below Treeline, Dominantly Forested (353 km2)

Fire Map 24

Figure 2.8 graphically displays the area burned annually within the valley from 1800-present. Some large (area burned being larger than 5 km^2) fire years are temporally synchronized with large fire events (late 1840s and 1880s) across western North America as indicated by various fire history studies performed in locations such as Jasper National Park (Tande 1979), Banff National Park (Byrne 1968), the Boundary Waters Canoe Area in Minnesota (Heinselman 1973) and the Bitteroot National Forest in Montana (Arno 1976). This finding suggests a strong fire-climate linkage and supports the theory of sub-continental climatic conditions temporally coordinating extreme fire years across nearly continental scales. These climatic conditions are often associated with 50 kPa blocking pressure ridge systems or mid-tropospheric pressure anomalies (Johnson and Wowchuk 1993, Johnson 1992, Swetnam and Betancourt 1990). However, some large fire years within the Shakwak Trench are not synchronized with these continental-wide climatic extremes indicating that small-scale, localized weather systems may also be important to local fire events. Similarly, large fire years from the Kluane National Park Reserve study (Hawkes 1983) are not temporally synchronized with findings from the Shakwak Trench. Extreme topographic relief within the Kluane Region may be responsible for highly variable conditions over small lateral distances. Similar conditions probably exist in all mountainous areas.

Fire sizes are highly variable with a few, large fires being responsible for the majority of area burned (Figure 2.8). This fire regime is characteristic of conditions throughout the boreal forest of North America (Johnson 1992). The largest individual fire event during the past 200 years (1845 burn, Fire Map 21) affected 12.46% of the forested area within the study site. Larger individual burns have probably occurred in the past.

Area Burned (km2) per Fire Year in the Shakwak Trench
1800-Present

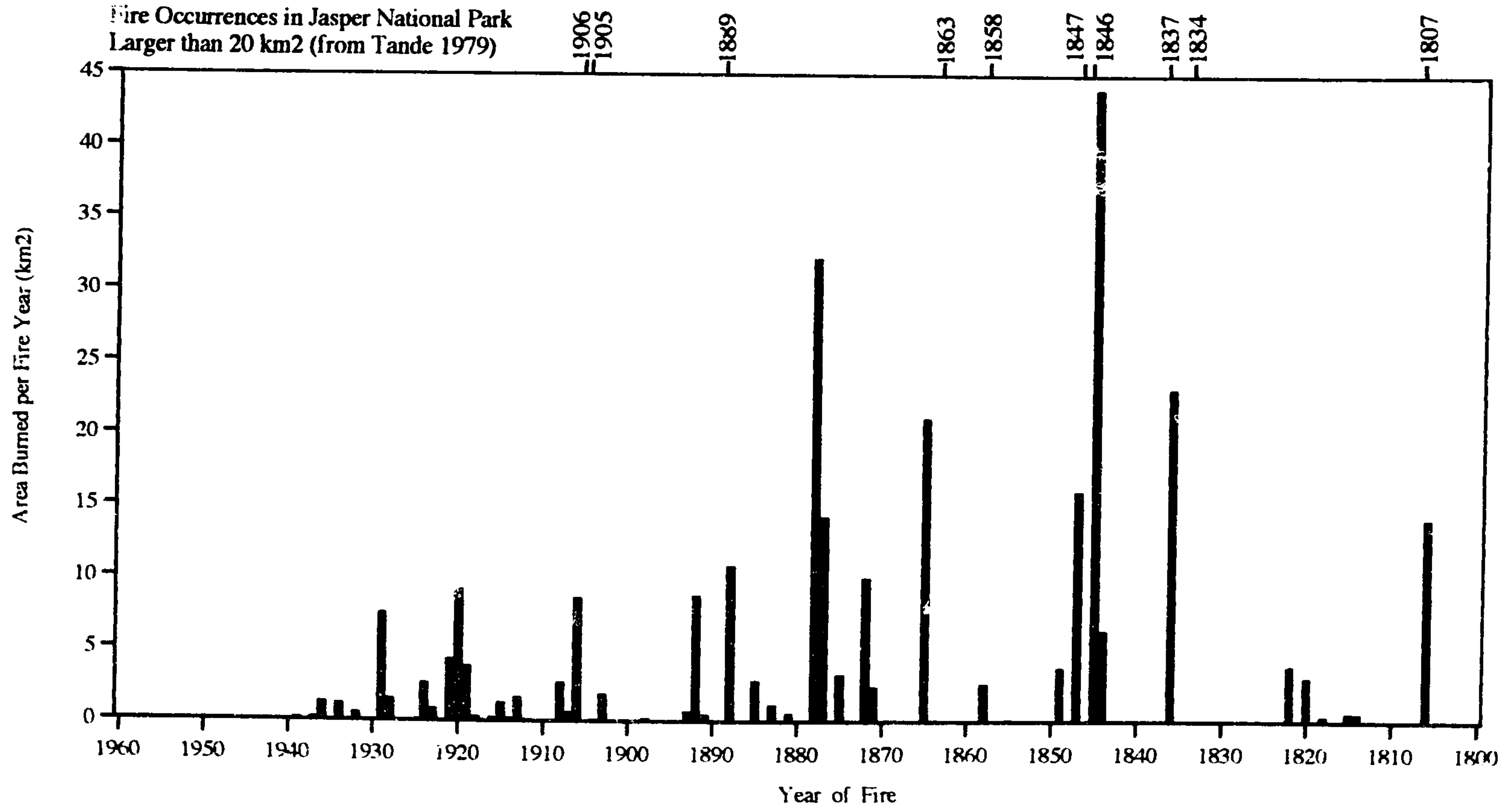


Figure 2.8. Area burned (km2) per fire year from 1800-present. There has not been a fire in the study area since 1956. Large historical fire occurrences from Jasper National Park are shown: many are temporally correlated with events in the Shakwak Trench.

Large tracts of very old, contiguous subalpine and upper-montane forest along the south study boundary may have arisen from a single fire larger than 60 km^2. Generally, individual fire sizes appear to be smaller than other areas of the boreal forest with more subdued topography. In these areas, individual fire events larger than 100 km^2 are not uncommon.

Calculating an average fire size depends on how one defines an individual fire. If the statistic is calculated using the number of years that experienced fires (59) with a total burned area of 274.99 km^2, an average fire size of 4.58 km^2 (σ = 8.24 km^2) is derived. However, if an average fire size is calculated using the number of spatially discrete fires detected (105), a value of 2.62 km^2 is found. Calculating an average fire size there becomes difficult because of these complications. Simply describing the "average" is not painting an accurate portrait of the disturbance regime when the majority of area burned results from a few, large fires.

The concept of fire cycle as the time required to burn an area equal in size to the study area has been central to fire history studies (Johnson and Gutsell 1994, Heinselman 1973). However, the relevance of this fire statistic is questionable. Johnson and Gutsell (1994) and Johnson (1992) discuss methods to estimate fire cycles from cumulative time-since-fire distributions. In these discussions, it is shown mathematically that the fire cycle equals the fire return interval or the expected fire return time per stand: this would mean that nearly all areas of the forest would burn once every fire cycle. Based on confirmed fire sizes from 1800-present and estimated fire sizes in the late 1700s, a fire cycle of 300-350 years is calculated for the Shakwak Trench. However, almost all of the area burned has occurred on the north-side of the valley with the south-side remaining fire free. In this example the fire return interval certainly does not equal the fire cycle. Simply describing the area burned without putting it in some spatial context is therefore misleading.

Individual burn patterns are complex and variable. Some recent burns with easily detectable margins display classic elliptical shapes (Alexander 1985, Anderson 1983). The 1908 and 1906 burns display this pattern (Fire Maps 9 and 10, respectively). Some burns have irregular, complex margins and do not display patterns associated with strong wind-driven fires. Many burns occurring during the 1920s (Fire Maps 5 to 7) display this behaviour. Also, irregularities in burn patterns appear to be associated with terrain complexity. The Jenny Lake area is a complex network of eskers and associated glacial features that may have dramatically influenced burn patterns in this area (Fire Maps 5 to 7). It is interesting to note the orientation of some fires in the Jarvis River area as many run perpendicular to the main valley orientation and may be associated with strong winds funneling out of the Jarvis River valley (Fire Maps 3, 12, 14, 21 and 23).

Fire behaviour in the Shakwak Trench can not be accurately reconstructed due to the long time frames involved as the last major fire occurred in 1929. However, the following observations were made. Many dry, upland areas that have burned in the past 100 years have not yet developed a notable soil duff layer perhaps indicating an intense fire behaviour. It should also be noted that organic accumulation on the soil surface is naturally very slow in this system due to the climatic conditions. Fires are generally stand replacing with the exception of meadow areas where individual trees were found to have survived multiple, low intensity events with little direct evidence of the fire on the ground. One other interesting feature was the existence of "permanent residuals" or unburned patches in the burn matrix. Many of these residuals were found in the Sulphur Lake-

Sulphur Creek area which is quite wet and meadow-like. Many residuals have survived multiple fires as indicated by differently-aged fire scars along their margins. This evidence supports the observation that many small fires nearly followed the same boundaries and were contained by similar topographic features. These small patches of unburned vegetation harboured a great deal of fire history information and became invaluable in the reconstruction of historical fire events.

II.5.1.B *A Changing Fire Regime*

The fire regime appears to have changed over the past 200 years from large, infrequent events during the 1800s to small, relatively frequent fires during the early 1900s. Figure 2.9 illustrates this change in relative fire size and frequency which occurred around the turn of the century. The possibility exists that smaller fires also occurred during the 1800s and evidence of these events has been erased by recent fires. However, fires of the magnitude experienced in the 1800s have not occurred in the 1900s. This change in fire frequency and size around 1900 cannot be directly attributed to human intervention: active fire suppression did not begin until the 1950s. There has not been a forest fire in the study area since 1956 and Yukon Forest Service documents show no recorded fire activity.

This shifting fire regime may be an interaction between climatic release from the Little Ice Age thermal minimum and the spatial occurrence of fires on the landscape. During the Little Ice Age, fire hazards may have been depressed by cool, moist conditions as proposed by Johnson and Larsen (1991). At this time, fuel accumulation could have been great. During the warming trend which followed (commencing in the 1820s based

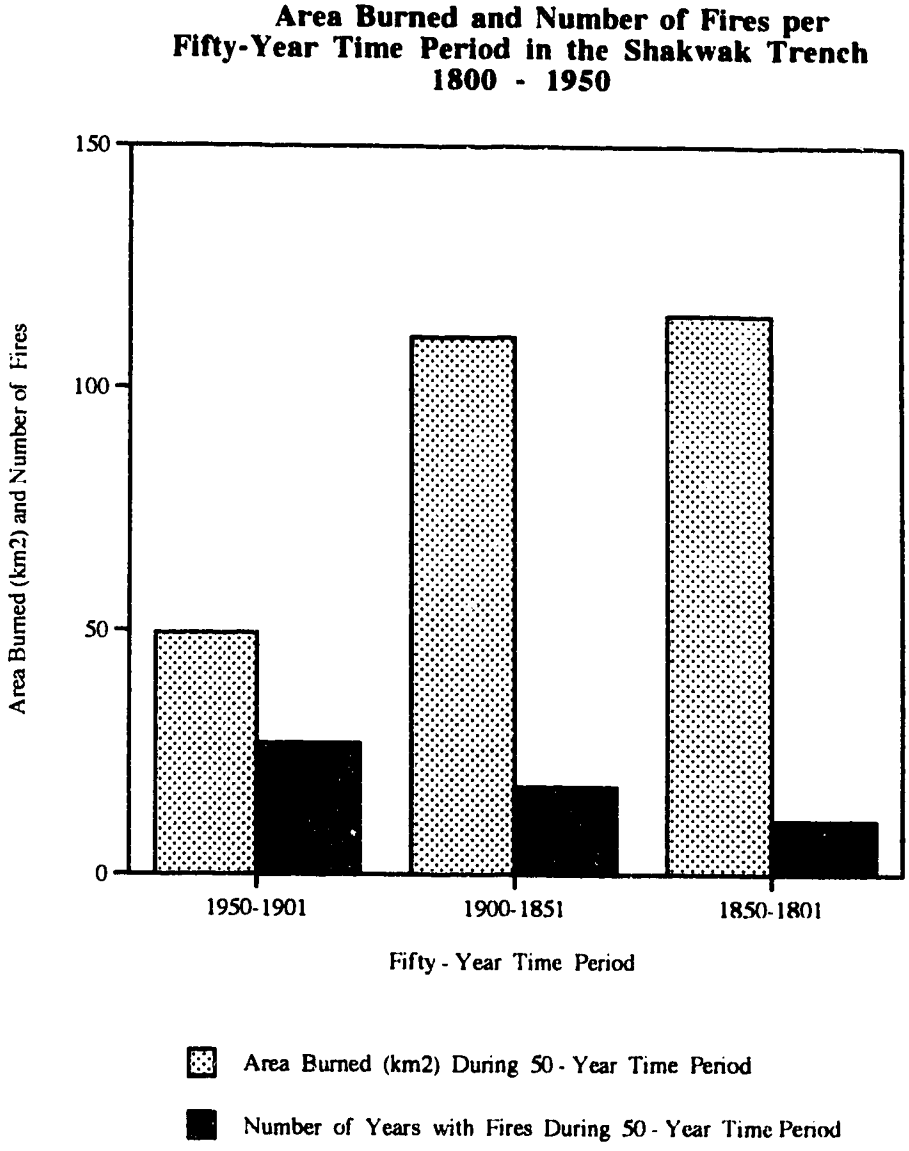
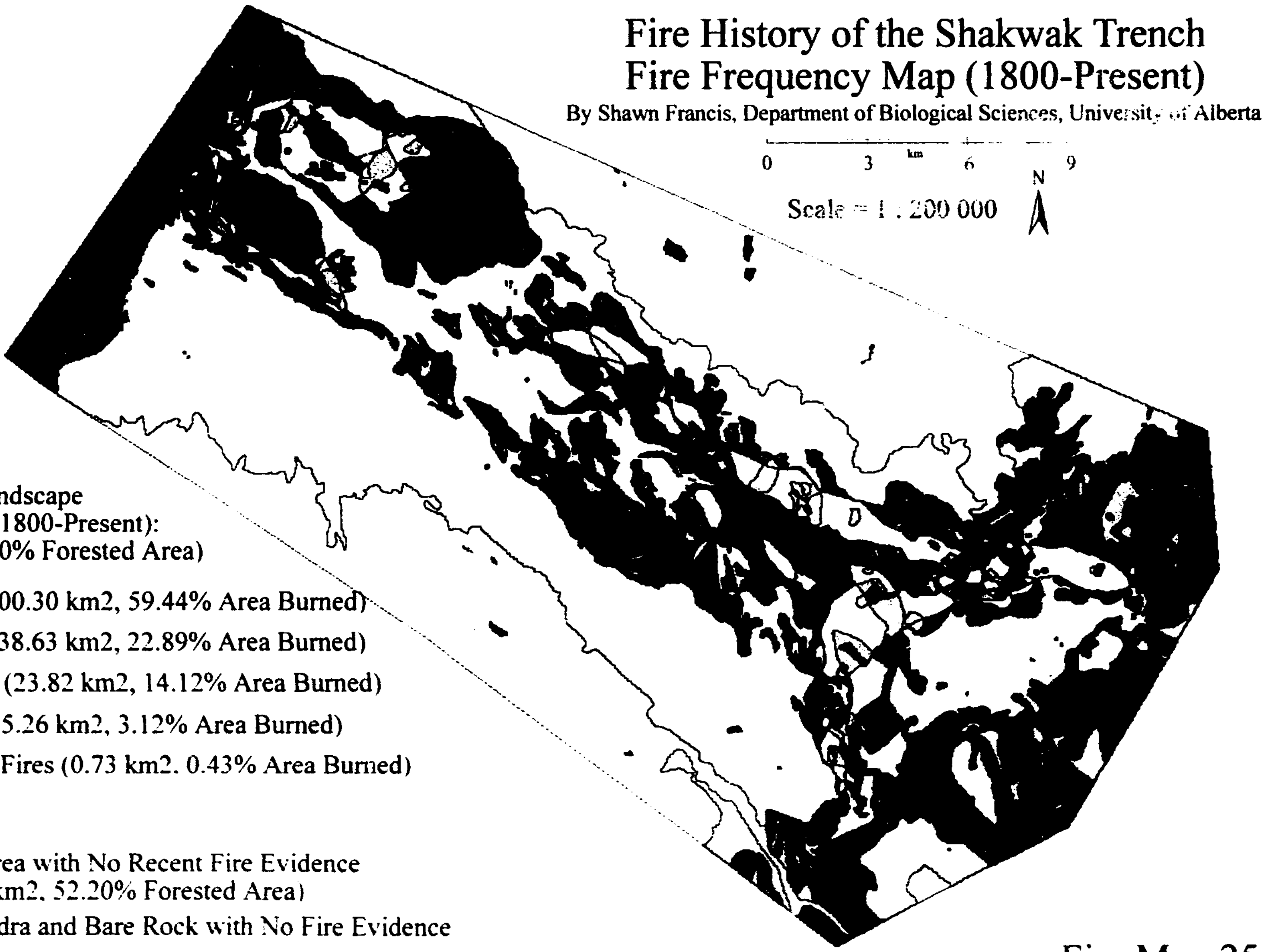


Figure 2.9. Area burned (km2) and number of fires per fifty-year time period in the Shakwak Trench from 1800-1950. The time period 1950-present is omitted as negligable areas burned during this interval.

on dendrochronological evidence of Allen (1982) and glacial geomorphological evidence of Borns and Goldthwait (1966) and Denton and Stuiver (1966)), forest fire hazard conditions could have substantially increased with the onset of warmer weather. It is difficult to state conclusively whether this period was also drier. This perhaps contributed to the large areas burned during the 1840s. Monitoring the spatial pattern of fires on the landscape (Fire Maps 2 to 24), primarily the same areas which burned in the 1840s reburned in the following 100 years, some several times. During this relatively brief period and given the slow rate of tree growth in the Kluane Region, large amounts of forest fuels would not have had time to accumulate. Therefore, even though climatic conditions were conducive to high rates of burning and fires did occur, large conflagrations were not possible due to low fuel volumes. In this sense, historical fire events may dictate the spatial occurrence of modern events and the concept of "landscape memory" may apply (Holling 1992). However, only the valley bottom and south slope of the study area burned during this period of potentially increased fire hazard. The fire regime of the study area does not appear to have been equally affected by this climatic event.

II.5.1.C *Fire Frequency and Burn Overlap*

Extensive overlap of fire events, as indicated by Fire Map 25, has occurred since 1800. This has important consequences to the current forest age-class distribution and fire history calculations. Figure 2.10 shows the relationship between the current 20-year forest age-class distribution and area burned during that time interval based on individually reconstructed fire events back to 1800. The current forest age-class distribution does not



Fire History of the Shakwak Trench
Fire Frequency Map (1800-Present)

By Shawn Francis, Department of Biological Sciences, University of Alberta

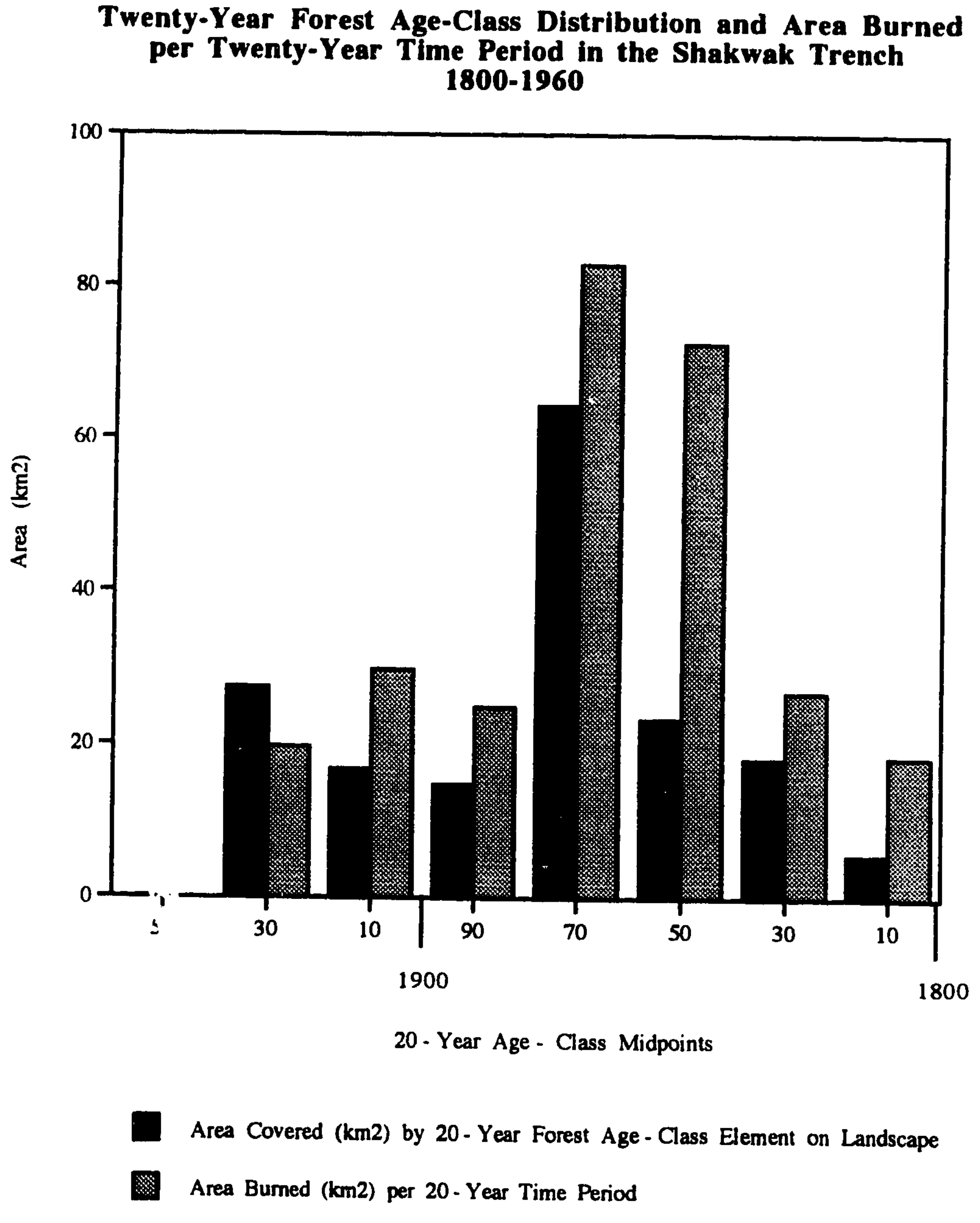
Scale = 1 : 200 000

Total Forested Landscape
Affected by Fire (1800-Present):
(168.74km2, 47.80% Forested Area)

■ One Fire (100.30 km2, 59.44% Area Burned)
■ Two Fires (38.63 km2, 22.89% Area Burned)
□ Three Fires (23.82 km2, 14.12% Area Burned)
▨ Four Fires (5.26 km2, 3.12% Area Burned)
■ Five or Six Fires (0.73 km2, 0.43% Area Burned)

□ Forested Area with No Recent Fire Evidence
(184.26 km2, 52.20% Forested Area)
Alpine Tundra and Bare Rock with No Fire Evidence
■ Water

Fire Map 25



Twenty-Year Forest Age-Class Distribution and Area Burned per Twenty-Year Time Period in the Shakwak Trench 1800-1960

Figure 2.10. Twenty-year forest age-class distribution and area burned per twenty-year time period in the Shakwak Trench from 1800-1960.

accurately reflect the disturbance history during this time period; using only the forest age-class distribution greatly under-estimates the total area burned. Rogeau (1996) was able to demonstrate this same phenomena through a simple, random fire modeling technique using forest age-class data from Banff National Park. Based on forest age-class information from the Shakwak Trench, the total area burned since 1800 is 168.74 km^2 or 47.80% of the forested area; based on individual fire reconstructions the total area burned is much greater, 274.99 km^2 or 77.90% of the forested area, as this calculation accounts for the extensive amount of burn overlap. This phenomena is primarily due to the spatial distribution of fires on the landscape: some areas burn frequently while others rarely. This has resulted in regeneration from older events being masked by more recent fires. Large fires occurred in the 1840s, 1860s and 1870s but are responsible for very little of the current forest age-class composition as these same areas have been reburned since.

II.5.1.D *Historical Land-Use and Fire: The Human Factor (1800-Present)*

There is a strong spatial relationship between humans and wildfire. Generally, wherever people live in or visit the boreal forest, fires occur (Johnson 1992, Kozlowski and Ahlgren 1978). However, these fires are usually responsible for very little of the total area burned as most events are small and easily contained as climatic conditions for fire spread may not be optimal and suppression response times minimal. Approximately 90% of the area burned in the boreal forest each year is dominated by a few, large lightning caused fires (Johnson 1992, Stocks and Street 1983, Johnson and Rowe 1975). An overview of human history within the study area has been provided previously in Section II.3.4.

Native impacts are largely unknown but there remains a possibility of some form of prescribed burning. Two multiply-fire scarred trees showing signs of recurring burns in approximately 15 year intervals were found near the Kloo Lake area, the site of a known semi-permanent summer fishing village. These fire scar dates do not correspond to other fire dates within the study area. Also, many meadow and lake margin areas have been burned repeatedly which is consistent with the findings of Lewis (1983, 1972) in northern Alberta. However, human association with this observation cannot be stated conclusively. Beyond this evidence a number of documented native traveling routes are known but their impact on the fire regime of the Shakwak Trench is unknown.

European exploration near the turn of the century and occurrence of the Kluane Gold Rush from 1902-04 does not appear to have had a major impact on the fire regime of the area. Evidence is circumstantial but small fires did occur around the wagon road, known gold mining creeks, and areas of habitation during this brief period. Many small fires around the Silver City-Jenny Lake-Christmas Bay area and Kloo-Sulphur Lake peninsula occurred in the 1920s. Small-scale lumbering, fishing and big-game hunting took place during this time. It is interesting to note that the role of the RCMP in the Yukon near turn of the century was both peace keeper and forest ranger, as indicated by "A patrol was made from Carcross to Whitehorse for the purpose of seeing that no bush fires were burning" (Snyder 1907), and "RCMP patrols keep a strict watch on campers to see they do not let fire loose, and have been very successful this season in preventing the same" (Snyder 1908). The effectiveness of these fire suppression efforts may have been minimal and should not be used solely to explain a changing fire regime near 1900.

The building of the Alaska Highway in 1942-43 changed the face and character of the Kluane area but appears to have had little effect on the fire regime. Small fires adjacent to the Old Alaska Highway (1-4 ha in size) were dated to 1943 and 1953, possibly suggesting some human association. These fire events and a small fire (1-2 ha in size) on the shore of Sulphur Lake in 1956 were the most recent fires detected.

Based on this evidence (or lack of), it cannot be stated that human land-use or settlement patterns directly caused the shift in fire regime between the 1800s and 1900s. Instead, dendroclimatic data, glacial geomorphological evidence and older burn patterns (Fire Maps 2 to 24) suggest a natural change in the fire regime. European arrival in the area simply coincides with this natural shift. However, with the current paucity of lightning ignition sources in the Shakwak Trench, it is certainly tantalizing to consider that many of these fires may be associated with human activities.

II.5.2 Section II: Pre-1800 Fire History and the Forest Age-Class Distribution

II.5.2.A *Fire History Summary*

Unlike recent fire history described in Section II.5.1 (1800-present), spatial and temporal reconstruction of very old individual fire events is nearly impossible due to the loss of evidence over time. In Section II.5.1.C it was shown that the current forest age-class distribution does not accurately represent disturbance history of the study area. Unfortunately, the only window for which to view pre-1800 fire history for the Shakwak Trench study site is through the forest age-class distribution as very little fire scar evidence exists for individual fire events. Only seven fire scars were found to date pre-1800 events accurately and of these, five date a large 1767 fire which probably burned about 40 km^2 in the valley bottom. All forest stands sampled displayed some evidence of fire and are therefore assumed to be of fire origin.

Figure 2.11 displays the current forest age-class distribution of the entire study site which is the area below treeline, dominantly forested, for which forest disturbance history information exists. The information has been grouped into twenty-year age-classes for ease of presentation and because of the variability associated with exact "stand origin dates" as will be discussed in Section II.5.4 below. Two forest age-classes, the 1870s and 1650s, dominate the distribution of forest ages and give a "bimodal" appearance to the graph. Nearly 40% of the forested area is comprised of these two age-classes possibly indicating large areas burned during these time periods (large fires were confirmed in the 1870s based on fire scar evidence). Twenty-seven percent (95.08 km^2) of the forested area has been fire-free for more than 300 years.

The included map insert (back cover) shows the geographic distribution of twenty-year forest age-class elements throughout the study area. The entire south-side of the valley is dominated by greater than 300 year old forests while the valley bottom and north boundary are dominated by younger age-classes and a more heterogeneous pattern of stand ages. For this discussion, "old forests" are classified as being 300 years old or greater and are shown in green on the twenty-year forest age-class map. The spatial difference in age-class distribution between the north and south sides of the valley gives rise to the bimodal appearance of Figure 2.11 where the south boundary is dominated by old forests while the valley bottom is dominated by younger forests. Johnson and Larsen (1991) conclude that "multi-modal" forest age-class distributions arise from historical changes in fire frequency due to climatic influences like the Little Ice Age climatic

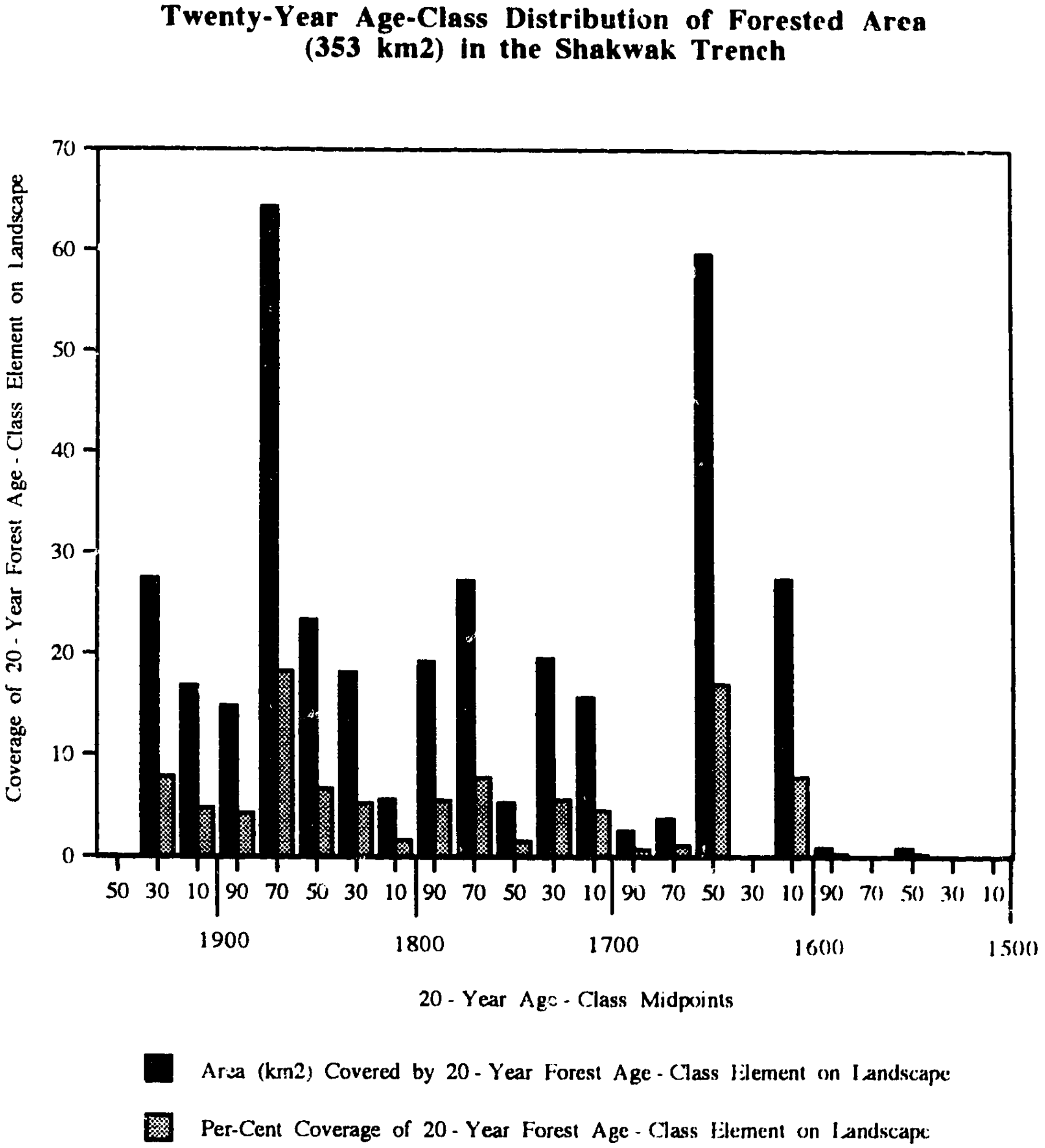


Figure 2.11. Twenty-year age-class distribution of forested area (353 km2) in the Shakwak Trench. Values are given as square kilometres and percentage of total forested area.

minimum. This theory does not explain the spatial distribution of very old forests along the south boundary of the Shakwak Trench.

This pattern of burning has existed for some time and was found worthy of notation in historical documents. Large tracts of unburned forest are historically referenced by two sources. McConnell (1904) reports, with respect to the Shakwak Trench, "...the white spruce is the most important tree. Considerable groves exist along the lower part of Slims river, on Kluane lake, on Silver creek and other places, but the district, as a whole, cannot be considered well wooded, and the supply of timber suitable for mining and building purposes is limited". At this time, large areas of the valley had been regenerating from wildfires in the 1840s and 1870s for only 30-50 years; these fire events did not affect slopes near Kluane Lake. A report from 1945 (Gibson 1945), similar to McConnells' (1904) allusion to unburned timber near Kluane Lake, reads "With the large burnt over areas adjacent to the highway both east and west of the Park Reserve the green timber at the south end of Kluane Lake is a pleasing contrast".

II.5.2.B *Fire Frequency Models and the Shakwak Trench Forest Age Class Distribution*

Fire frequency models as proposed by Van Wagner (1978), Johnson (1979) and Johnson and Van Wagner (1985) (reviewed by Johnson and Gutsell 1994, Johnson 1992) are commonly used to examine the effects of fire on forest age-class distributions. These fire frequency models are based on the assumption that fires occur independently of one another and landscape-vegetation characteristics play minor roles in the probability of a forest element burning. Also, because the analysis is performed on forest age-class distributions, it is assumed that the forest age-class distribution is an accurate reflection of the forest disturbance history. The forest landscape is viewed conceptually as a checkerboard with randomly placed, different aged forest stands occurring in each cell. Within this arrangement there are two possibilities: (1) all stands have a constant, age independent probability of burning or (2) the probability of a forest stand burning increases with its age.

If the forest age-class distribution (Figure 2.11) is plotted as a cumulative time-since-fire distribution, the function A(*t*) describes the proportion of the study area existing in age (*t*) or less since the last fire. When the probability of fire is constant and independent of stand age the function A(*t*) is a negative exponential curve where $A(t) = e^{(-t/b)}$. Conversely, if the probability of fire increases with stand age then a Weibull function results where $A(t) = e^{-(t/b)^c}$ and c assumes a value greater than 1. The negative exponential model is a special case of the Weibull model when the shape parameter $c = 1$. In both models, the parameter b is considered to be an estimate of fire recurrence on the landscape. Figures 2.12 and 2.13 show the Shakwak Trench cumulative time-since-fire distribution with corresponding best-fit negative exponential and Weibull curves, respectively. In this case the Weibull model provides a statistically significant better fit than the negative exponential model ($F_{1,95}$=6.234 p=0.05).

While the Weibull fire frequency model produces a good numerical fit for the Shakwak Trench cumulative forest age-class distribution, the value of this approach requires further consideration. In this study it was shown that the forest age-class distribution is not an accurate indicator of forest disturbance history due to the large amount of burn overlap (Section II.5.1.C). Also, it appears that fire events do not occur

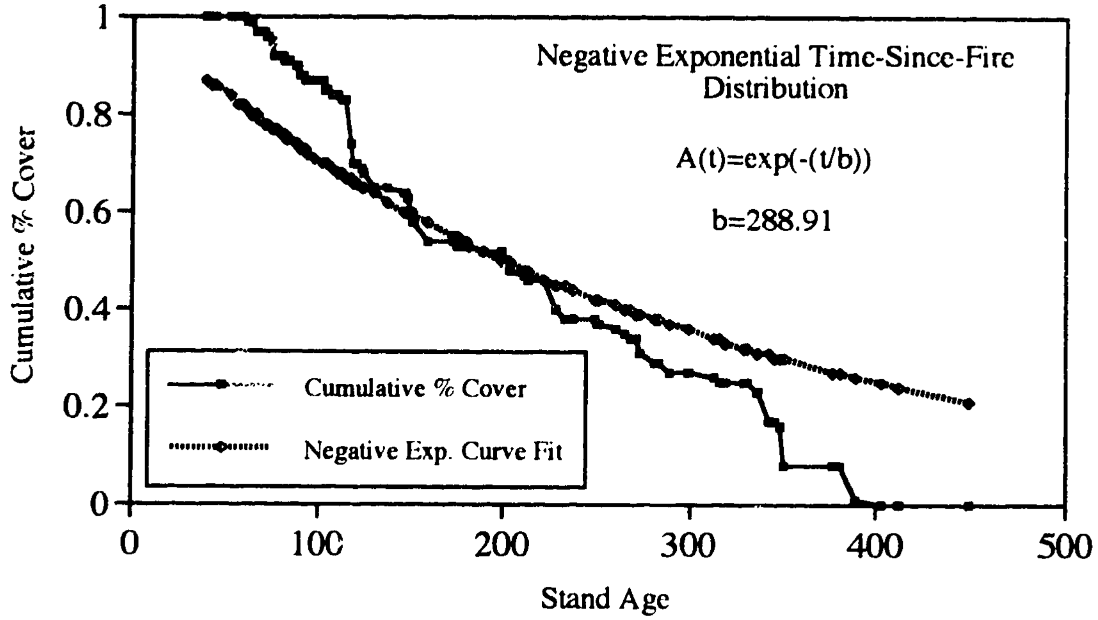


Figure 2.12. Shakwak Trench cumulative forest age-class distribution and associated best-fit negative exponential curve.

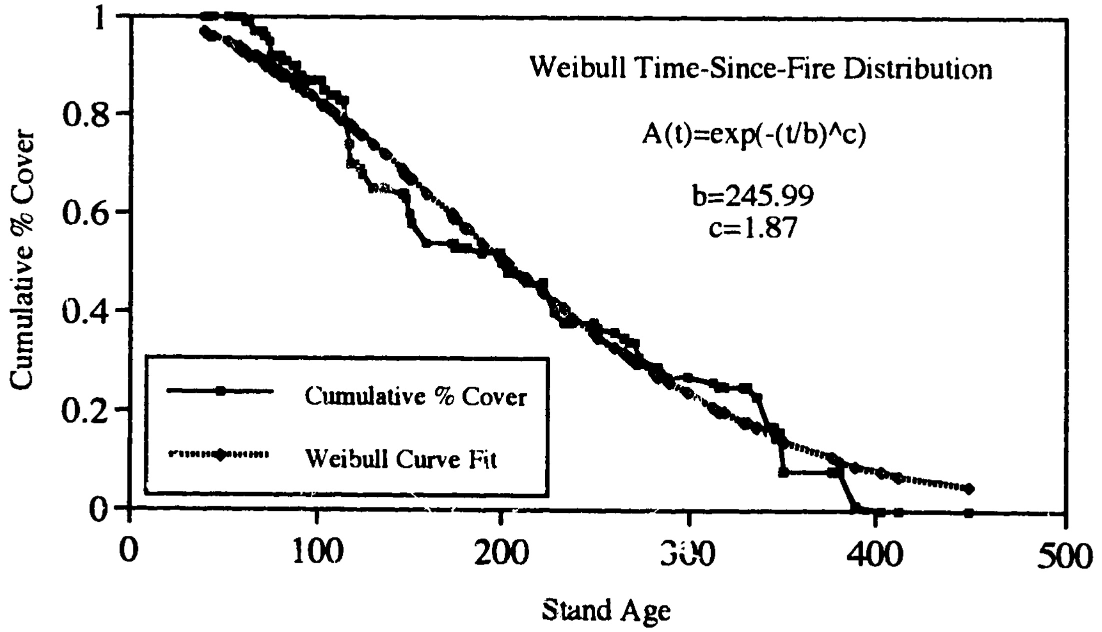


Figure 2.13. Shakwak Trench cumulative forest age-class distribution and associated best-fit Weibull curve.

randomly as some areas burn frequently while others rarely (Fire Map 25). Further, areas of high and low fire frequency within the study area appear to be associated with certain landscape units. Therefore, underlying assumptions of the Weibull and negative exponential models are not met in the Shakwak Trench and use of these methods remain in question.

II.5.3 <u>Section III: Other Forms of Forest Disturbance</u>

In addition to wildfire, flooding, landslides, wind throw, soil movements, people and forest insects are all disturbance agents in this forested landscape. Each operates at different scales and has different effects on the forest. During recent historical times, these agents appear to have played relatively minor roles in shaping the current vegetation mosaic within the study area when compared to wildfire.

II.5.3.A *Floods and Landslides*

Flooding and landslide hazards near Kluane Lake have been reviewed by Clague (1979 and 1981). High gradient streams flowing from the Kluane Ranges across alluvial fans and aprons at the edge of the Shakwak Trench can cause localized flooding. The only area of forest in the valley which has been largely affected by these events is near the southeast shore of Kluane Lake. Silver Creek and associated streams have caused wash-outs on the Alaska Highway many times in the past which disturbed surrounding forests. Also, the entire shoreline area on which the Arctic Institute and Silver City are situated is underlain by alluvial deposits and dissected by numerous abandoned river channels. This area has generally been stabilized for a long time, however, as a fire determined stand origin for this alluvial fan was dated to be approximately 1650.

II.5.3.B *Wind Throw and Soil Movements*

Large tracts of wind throw damage (the physical displacement of trees by wind) could not be found in the study area. Only localized patches along stand margins and exposed ridges displayed effects of this disturbance mechanism which in some other forested areas can be infrequent but extensive (Baker and Veblen 1990, Hemstrom and Franklin 1987). Associated with wind throw are low gradient soil movements. This was detected in many locations throughout the valley but primarily along slopes of the Kluane Hills and the Kluane Range. It appears that through some mechanism of permafrost melt or simple colluvial processes, soil cohesion is lost and downhill creep begins. Possible water logging may also be involved (Syrjanen et al. 1994). The net effect is that shallow spruce root systems become displaced and/or trees become more disposed to wind throw.

II.5.3.C *Anthropogenic Disturbance*

Physical anthropogenic impacts on the valley have historically been minimal. Besides the few transportation corridors which run through the valley bottom and some minor fuel wood harvesting-lumbering around Jenny and Kloo Lakes, the study area remains relatively unaltered by direct human impact.

II.5.3.D *Forest Insect Damage*

The detection and mapping of forest insect damage was not a direct research focus for this project but general observations were taken during two summers of field reconnaissance. Much of the valley and southern portions of neighbouring Kluane National Park Reserve are currently experiencing a major spruce beetle (*Dendroctonus rufipennis* Kirby) outbreak in which the total affected area is orders of magnitude larger than any single fire event in recent history. While an event similar to this may have occurred in the past, very little evidence for a major historical forest insect outbreak of this magnitude was detected. Large numbers of dead, unburned boles are not present as would surely remain after such a major canopy mortality event.

At this time, the historical interaction between spruce beetles and fire can only be speculated about, but large infrequent fires or large infrequent spruce beetle outbreaks will both result in rapid shifts from old to young forests. Spruce beetles and fires may therefore operate at similar spatial and temporal scales in this system. Recently burned areas of less than 100 years old are generally not susceptible to spruce beetle damage as the trees are still young and vigorous (Veblen et al. 1991, Baker and Veblen 1990). In this sense, spruce beetle damage and recently burned areas display a spatially non-overlapping distribution: this is readily visible in the study area as stands of damaged and healthy green conifers form a patchwork on the landscape. It is not known whether this spatially-non-overlapping pattern of disturbance perpetuates itself through time. However, there is no direct evidence to support the commonly held view that beetle damaged spruce forests will directly lead to large conflagrations. Extreme fire hazards are a climate mediated phenomena (Johnson and Wowchuck 1993, Johnson 1992).

II.5.4 Section IV: Vegetation Recovery from Fire and Disturbance Events

The Kluane Region is a harsh growing environment and recovery from disturbance events is a lengthy process. Post-fire regeneration lag-time can be very long and highly variable as an average post-fire regeneration lag of 25 years was empirically determined. Xeric-mesic sites are able to regenerate relatively quickly and densely while low-lying, hydric sites can take up to 50-75 years to recover sparsely from a fire event and remain shrub dominated for most of this time. Possible reasons for this are: (1) poor spruce cone crops following fire years (Hawkes 1983), (2) decreased transpiration rates due to vegetation removal which results in an elevated water table, and (3) melting permafrost caused by forest duff consumption, again resulting in periodically saturated soils.

Due to this highly variable post-fire environment, stand origin dates assigned to older forests for which no fire scars exist may not be accurate. Grouping age-class information into 20-year forest age-classes may then be a more accurate representation of the forest conditions, an approach used in this study (Twenty-Year Forest Age-Class Map Insert).

While spruce beetle outbreaks and forest fires may operate on similar temporal and spatial scales, they can have very different ecological consequences. As a forest disturbance agent, spruce beetles differ from wildfire in four major aspects: (1) spruce beetles select individual trees while wildfire is more non-selective, (2) spruce beetles create a more heterogeneous stand age-structure through its host tree selection, (3) spruce beetle mortality results in a greater abundance of large diameter coarse woody material carry-over than fire which creates structurally complex forest stands, and (4) spruce beetles can cause massive canopy mortality without removing forest floor duff, an important factor in spruce seedling germination. Forest response to the spruce beetle outbreak should be considered a research monitoring priority in the Shakwak Trench.

II.6 Summary and Conclusions

The following points can be used to summarize Chapter Two:

(1) In the Shakwak Trench, fire size is highly variable with most burned area resulting from a few large fires in the 1840s, 1870s and 1880s.

(2) Many of these large fires are temporally synchronized with large fire events from across western North America indicating the importance of large-scale, characteristic weather systems coordinating extreme fire weather on grand scales.

(3) Vegetation recovery from fire and disturbance events is a lengthy and highly variable process.

(4) The fire regime has changed over the past 200 years from large, infrequent fires to one of small, relatively frequent fires. There has not been a major fire in the Shakwak Trench since 1929. Human impact on this changing fire regime appears minimal.

(5) Fire has been the dominant disturbance mechanism during recent historical times in the Shakwak Trench. Little evidence was found for a spruce beetle outbreak of the current magnitude having occurred in the past.

(6) The current forest age-class distribution does not accurately represent forest disturbance history in this area due to the extensive amount of burn overlap which has occurred. Therefore, only using the forest age-class distribution to examine forest disturbance history is not accurate. This finding has important consequences to the

calculation and validity of fire history statistics such as fire cycle, fire frequency and fire return interval.

(7) Fire does not appear to be acting randomly in the Shakwak Trench as one side of the valley has a history of frequent, small-medium scale fires while the other side has historically experienced infrequent, large-scale fires. Therefore, the concept that the fire return interval to a certain landscape element is the same as the fire cycle is not correct for the Shakwak Trench. Describing a fire cycle without some spatial context then becomes misleading as different parts of the landscape are experiencing different fire regimes.

(8) These findings indicate that underlying assumptions of commonly used fire frequency models (Johnson and Gutsell 1994, Johnson 1992, Johnson and Van Wagner 1985) are not met in the Shakwak Trench. Therefore, the ability of these methods to accurately describe fire history in the Shakwak Trench is limited.

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CHAPTER THREE:

Linking Landscape Pattern and Forest Disturbance

III.1 Introduction

The arrangement of the landscape mosaic appears to have important consequences for wildlife habitat, biotic diversity, nutrient and energy flow, productivity, and disturbance spread and frequency in all terrestrial ecosystems (Turner and Romme 1994, Turner et al. 1989, Forman and Godron 1986, Pickett and White 1985). The study of landscape mosaics, or landscape ecology, has provided many numerical indices to describe the size, number and arrangement of landscape elements: many are simple to use but most are conceptually difficult and may not have an ecological basis. In environments that periodically experience large-scale, high intensity disturbances such as wildfire, the ultimate result will be a heterogeneous mosaic of different elements that have survived fire for certain periods of time. In these disturbance regimes, such as the North American boreal forest, the arrangement of landscape features that will influence fire behaviour can therefore be expected to influence the arrangement of the vegetation mosaic.

Landscape characteristics that may directly affect fire frequency, behaviour and burn patterns include slope magnitude (Johnson 1992), elevation (Veblen et al. 1994, Tande 1979), slope aspect (Rowe and Scotter 1973), terrain roughness (Heinselman 1973, Zackrisson 1977) and the position of hydrologic features (Bergeron 1991). Slope magnitude, slope aspect, and elevation, through their environmental control of surface moisture and temperature, may be the most important characteristics to influence landscape-level fire patterns. However, some authors hypothesize that the spatial arrangement of landscape and vegetation features is of minor importance in the probability of a forest element burning or the final burn pattern which results (Johnson 1992, Johnson and Larsen 1991, Johnson et al. 1990, Masters 1989). These authors conclude that temporal variation in climatic processes is the most important factor influencing a fire regime.

The concept that a fire regime is climatically driven is widely accepted and it has been shown that extreme fire years are correlated with synoptic weather patterns which create extreme fire conditions across nearly continental scales (Johnson and Wowchuk 1993, Flannigan and Harrington 1988). However, Turner and Romme (1994) have demonstrated that there may be an interaction between climate and landscape patterns in which moisture thresholds play an important role. Below some critical level of precipitation and given the proper wind conditions with associated lightning ignition sources (extreme fire weather), landscape patterns are not important and climatic conditions control fire behaviour. Above some threshold of moisture, the probability of a fire beginning and spreading across the landscape is very low as fuels are incombustible. Landscape patterns appear to control the range in between.

Fire and forest disturbance history of the Shakwak Trench have been discussed previously in Chapter Two. It was reported that old forests were not randomly distributed throughout the study area (for this discussion, old forests are classified as being 300 years in age or greater) (Figure 3.1). Similarly, it was found that certain areas of the Shakwak Trench have historically experienced high fire frequencies while other areas burned very rarely. It appears that spatially random fire processes are not operating in this system and therefore, methods of interpreting fire history as proposed by Van Wagner (1978) and

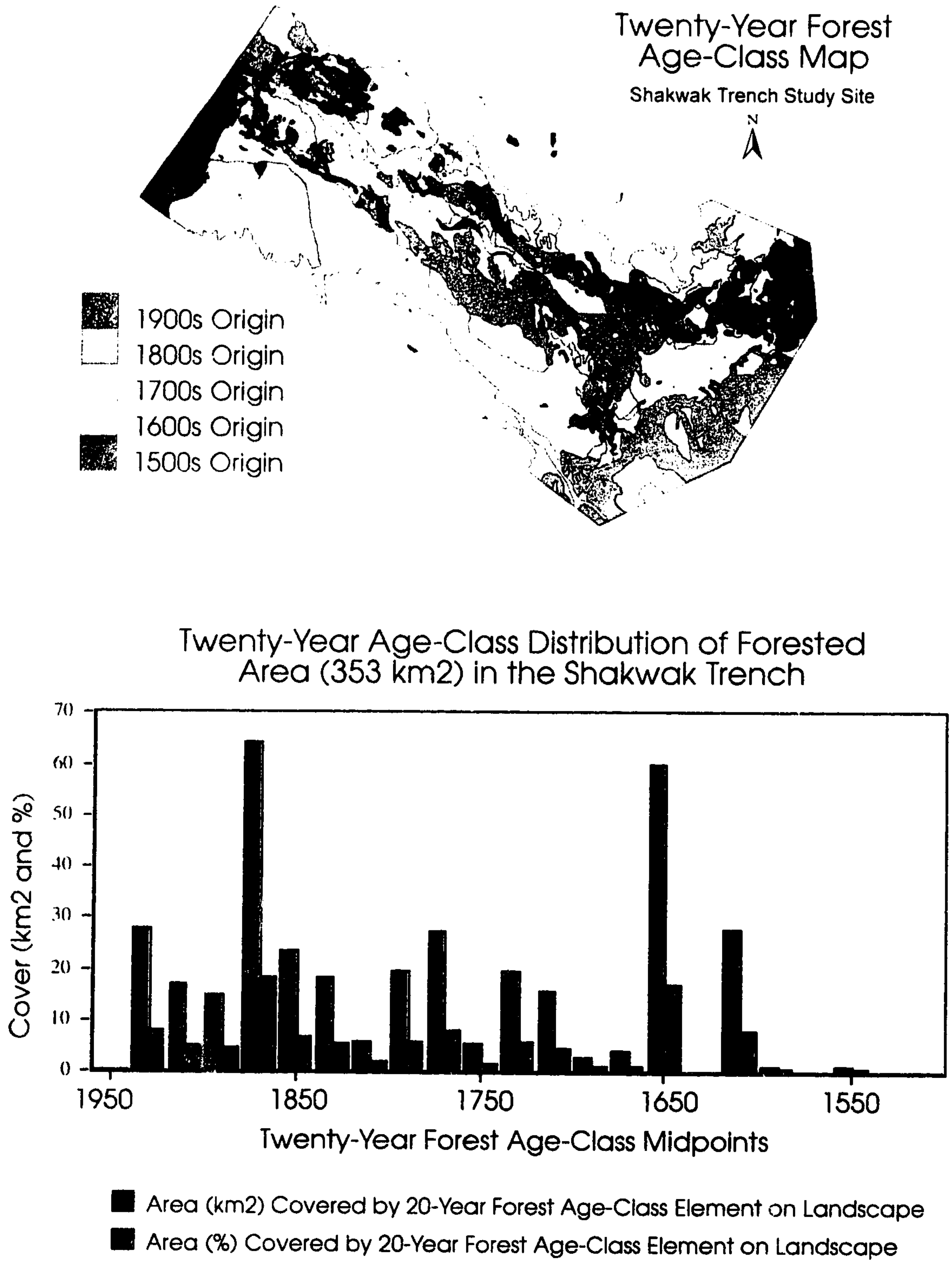


Figure 3.1. Spatial distribution of twenty-year forest age-class elements in the Shakwak Trench. Old forests are not randomly distributed throughout the valley as unburned remnants; nearly all lie in a contiguous belt along the south border of the study area.

Johnson (1979) require further consideration. Instead, the spatial arrangement of landscape characteristics, slope magnitude, slope aspect, and elevation, through their possible effects on fire occurrence, fire behaviour, and vegetation composition, influence the forest mosaic which results. In this environment, different landscape elements display different forest age-class distributions. It is not the purpose of this chapter to give reasons for the different forest age-class distributions but rather to identify important landscape characteristics and describe the forest patterns that are associated with them.

III.2 Objectives

Based on fire history and forest age-class data from the Shakwak Trench (Chapter Two), several hypotheses could be examined in a GIS environment. Few studies in the past have explicitly linked forest disturbance information with landscape characteristics in such a quantitative fashion. Specific questions include:

(1) Is the spatial distribution of the forest age-class distribution or disturbance events related to the spatial distribution of landscape characteristics? Specifically, slope magnitude, slope aspect, elevation and combinations of these landscape characteristics will be examined.

(2) Do different landscape areas within the valley experience different rates and extents of disturbance?

III.3 Methods

A desirable approach would allow an examination of differences in landscape structure without using conceptually difficult landscape indices. Such an approach would use landscape characteristics to spatially partition the valley into physiographic units and examine differences in the forest age-class distribution associated with each of these terrain classes. For this study, the following definitions will be used: (1) *Landscape characteristics*: measurable attributes of the landscape, specifically slope magnitude, slope aspect and elevation, (2) *Landscape unit*: a continuous unit within the landscape which has specific landscape characteristics and (3) *Terrain class*: similar landscape units which are classified by specific landscape characteristics.

The GRASS 4.1 (Anon. 1993) geographic information system (GIS) has been utilized to perform spatial queries between landscape characteristics and forest disturbance history information from the Shakwak Trench. Landscape information was obtained from the 1:50 000 scale NTS map sheets 115 A/13, 115 B/16 and 115 G/1. Prior to performing the spatial queries, a digital elevation model had to be created.

III.3.1 Creation of the Shakwak Trench Digital Elevation Model

The initial step in creating a digital elevation model (DEM) for the Shakwak Trench study area was to digitize 100 ft. and 40 m contour lines from the aforementioned topographic maps (Figure 3.2). The *v.surf.tps* surfacing algorithm was then applied to the digital vector map within GRASS 4.1 using a splines with tension surfacing algorithm as described by Mitasova and Mitas (1993) and Mitasova and Hofierka (1993). Parameters associated with the *v.surf.tps* surfacing algorithm were set as described in Table 3.1. This

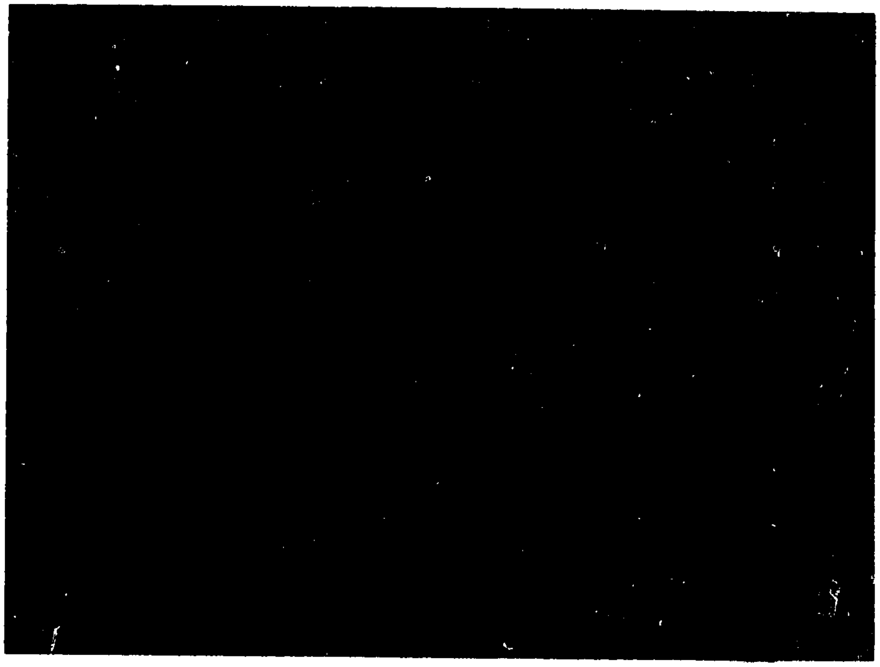


Figure 3.2. Digitized contour lines used to produce the Shakwak Trench DEM. Elevation data was obtained from 1:50 000 scale NTS topographic maps.

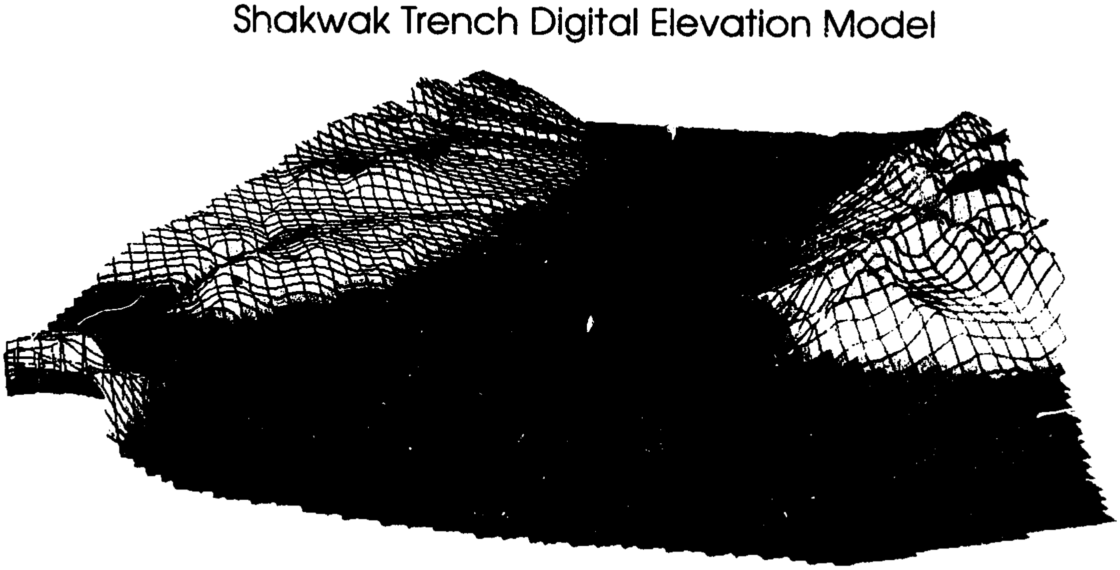


Figure 3.3. Shakwak Trench DEM as viewed from southeast at 7000 ft. a.s.l. with 1.4 x vertical exaggeration.

algorithm not only produces an elevation model but also aspect, slope, and profile, tangential, and [illegible]an curvature maps. Raster cell resolution in this elevation model is 25 m, for a total of 1 642 000 cells.

Table 3.1. Parameter values used in the GRASS 4.1 *v.surf.tps* surfacing algorithm for creation of the Shakwak Trench study area DEM.

Parameter	Description	Value
dmax	maximum distance (in meters) between points along a contour line	12.5
tension	resistance and sensitivity of the resulting surface	80
smooth	precision of the surface to follow contours	1
segmax	segmented pr[illegible]ing parameter describing the largest recta[illegible] segment in the surface	200
npmin	minimum [illegible] of points used in the interpolation of *segmax* [illegible]	400

The next step was to include hydrologic information. All water bodies, both lakes and rivers, were digitized from the topographic maps and three separate data layers created: 1) a raster hydrology layer containing only polygon features (lakes), 2) a vector layer containing only area-edge line features (lakes), and 3) a vector layer containing both lakes and rivers, which was primarily used for display purposes. In the second map layer (vector lake data), contour lines were subjectively added in *v.digit* to create lake basins within the lake polygons. This new lake data layer was patched with the original contour map and the surfacing algorithm re-applied. This step was necessary to force the surfacing algorithm to create lake basins so lake features would lie flat in their basins. The depth and shape given to subjectively created lake basins has no bearing on the final DEM as lakes were "filled" with a certain elevation value. This value then provided a mask for the entire surface area of that water feature. Known elevation values from topographic maps were attached to lake polygons while unknown values were obtained from the DEM.

The DEM and lake elevation raster layer were finally patched together using *r.patch* to produce a "true" digital elevation model with lake surfaces lying flat and assuming proper geographic positioning and elevation values within the digital landscape. The results of this effort are displayed in Figure 3.3. Spatial queries between landform characteristics and forest disturbance history could then be performed.

III.3.2 Spatial Queries Between Landscape Characteristics and Forest Disturbance History

For this study the three primary landscape characteristics examined were slope magnitude, slope aspect and elevation. To achieve this goal the Shakwak Trench study site was divided into different terrain classes. Spatial partitioning of the valley into terrain classes and the associated spatial queries have only been performed on areas below treeline for which forest disturbance history was reconstructed.

(a) Slope magnitude was examined by reclassifying the study area into areas with gentle and steep slopes. Gently sloping terrain is defined as having a gradient of 0 - 10° while steeply sloping terrain contains gradients greater than 10°.

(b) Elevation was examined by dividing the study area into "high" and "low" elevation units based on the ecological zonation of Douglas (1980). Above elevations of ca. 1060 m subalpine forests occur; this unit is termed "high-elevation forest". "Low-elevation forest" or montane forests are found in the valley bottom below elevations of 1060 m.

(c) Slope aspect was examined by reclassifying the study area into four major compass directions where north = NW - NE (46° - 135°), west = NW - SW (136° - 225°), south = SW - SE (226° - 315°), and east = SE - NE (316° - 45°).

(d) Using *r.combine*, the above landscape characteristics could be combined and their effects examined. An example of this would be partitioning the study area into steep slopes (slopes >10°) on north aspects which occur at high elevations (>1060 m) and all other areas which do not meet these conditions. This combination of landscape characteristics would then form a new terrain class.

Using the GRASS 4.1 commands *r.combine, r.reclass, r.mapcalc, r.mask* and *r.report*, multiple queries were performed to examine overlap (areal and %) and spatial correspondence of terrain classes and the forest age-class distribution. Only proportions of landscape and forest conditions were compared due to the statistical constraint of the landscape information and subjective sampling methods used (Section II.4.1). However, this allows some simple yet very powerful queries to be made:

1) Are all old forests associated with a certain terrain class?
2) Are areas which experience high fire frequencies associated with a certain terrain class?
3) Are specific disturbance regimes associated with specific terrain classes?

III.4 Results

Each of the landscape characteristics (slope magnitude, elevation, slope aspect, and combinations of those three attributes) were examined to detect differences in forest age-class structure and accordingly, disturbance regime. Results are displayed in the following manner: 1) spatial correspondence between chosen terrain classes and forest conditions and 2) the forest age-class distribution found within this terrain class as compared with the forest age-class distribution associated with separately classified terrain. Table 3.2 summarizes the average forest age found on each terrain class as calculated by weighted averaging. A separate section will examine relationships between fire frequency and landscape features.

III.4.1 Slope Magnitude

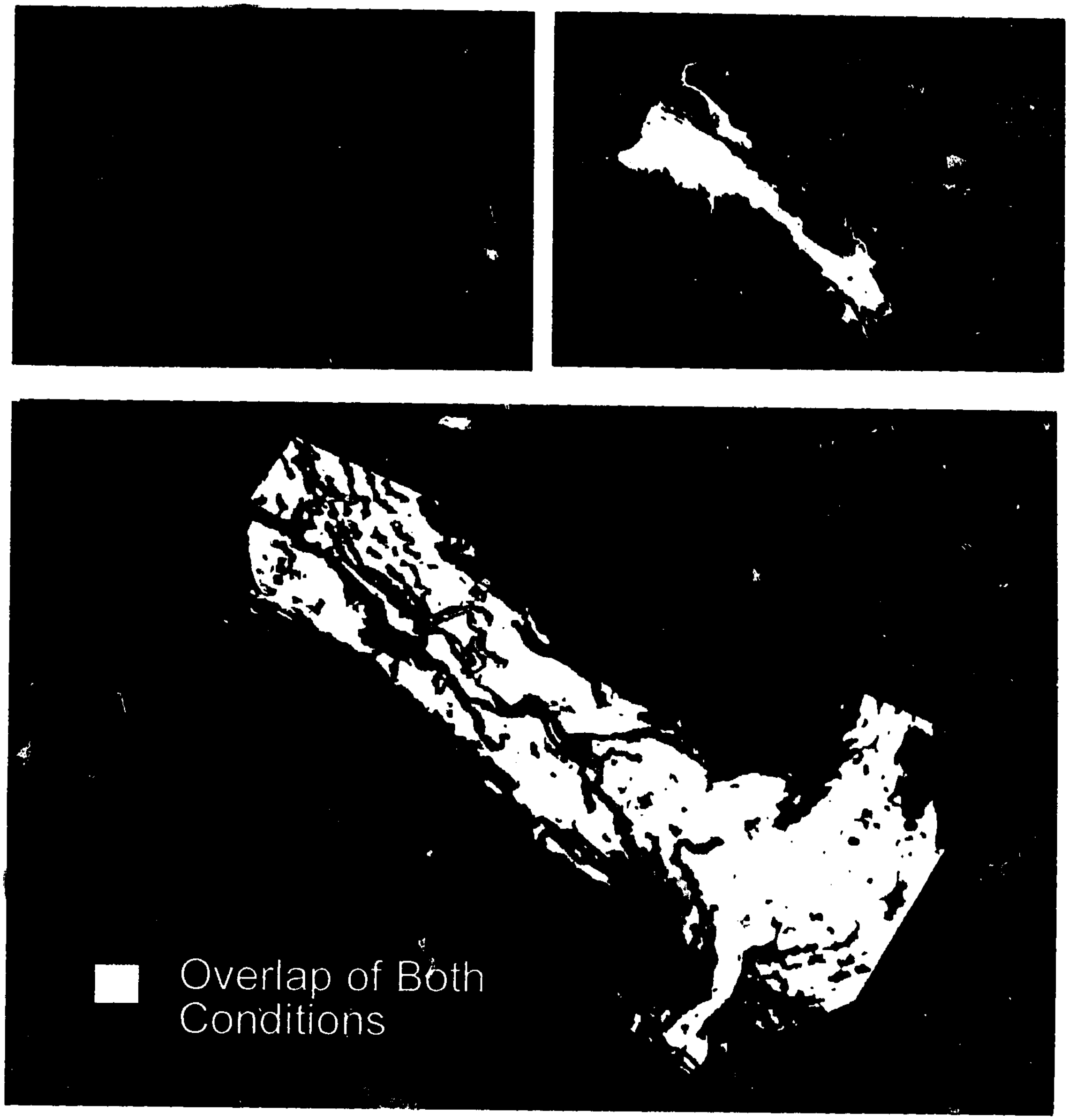
Figure 3.4 displays the spatial correspondence of gently sloping terrain and forest less than 300 years old. The entire Shakwak Trench is a broad, gently sloping valley but slopes less than 10° are generally found within the bottom lands. There is a large amount of spatial overlap between this landscape and forest condition: 83.02% of gently sloping terrain is covered by forest area that has burned within the last 300 years.

Figure 3.5 shows the forest age-class distributions found on gently and steeply sloping terrain. The forest age-class distribution of steeply sloping terrain is skewed to the right; a greater percentage of steep slopes are covered by very old forests. Average forest age on steep slopes is 254 years; gently sloping terrain is covered by forests with an average age of 184 years.

III.4.2 Elevation

Subalpine forests occur above elevations of ca. 1060 m. Figure 3.6 shows the spatial correspondence between high elevation areas within the study site and old forests. Elevations above 1060 m along the south study boundary are completely covered by forests older than 300 years old while high elevation areas at the north study boundary contain no old forests. This contributes to the poor spatial overlap of these two conditions: only 60.97% of high elevation areas are covered by forests greater than 300 years old. This may be caused primarily by valley orientation and the resulting spatial distribution of aspect elements (N,S, E, and W) throughout the valley.

While the spatial correspondence between all old forests and high elevation areas may not be high, examining the forest age-class distribution within this terrain class



Condition	Total Area (km2)	Area of Non-Overlap (km2)	Area of Overlap (km2)	% Overlap for Condition
Gently Sloping Terrain (<10 degrees)	198.44	33.70	164.74	83.02
Young Forest (<300 Years Old)	257.40	92.66	164.74	64.00

Figure 3.4. Spatial correspondence (overlap) of gently sloping terrain with forest areas less than 300 years old.

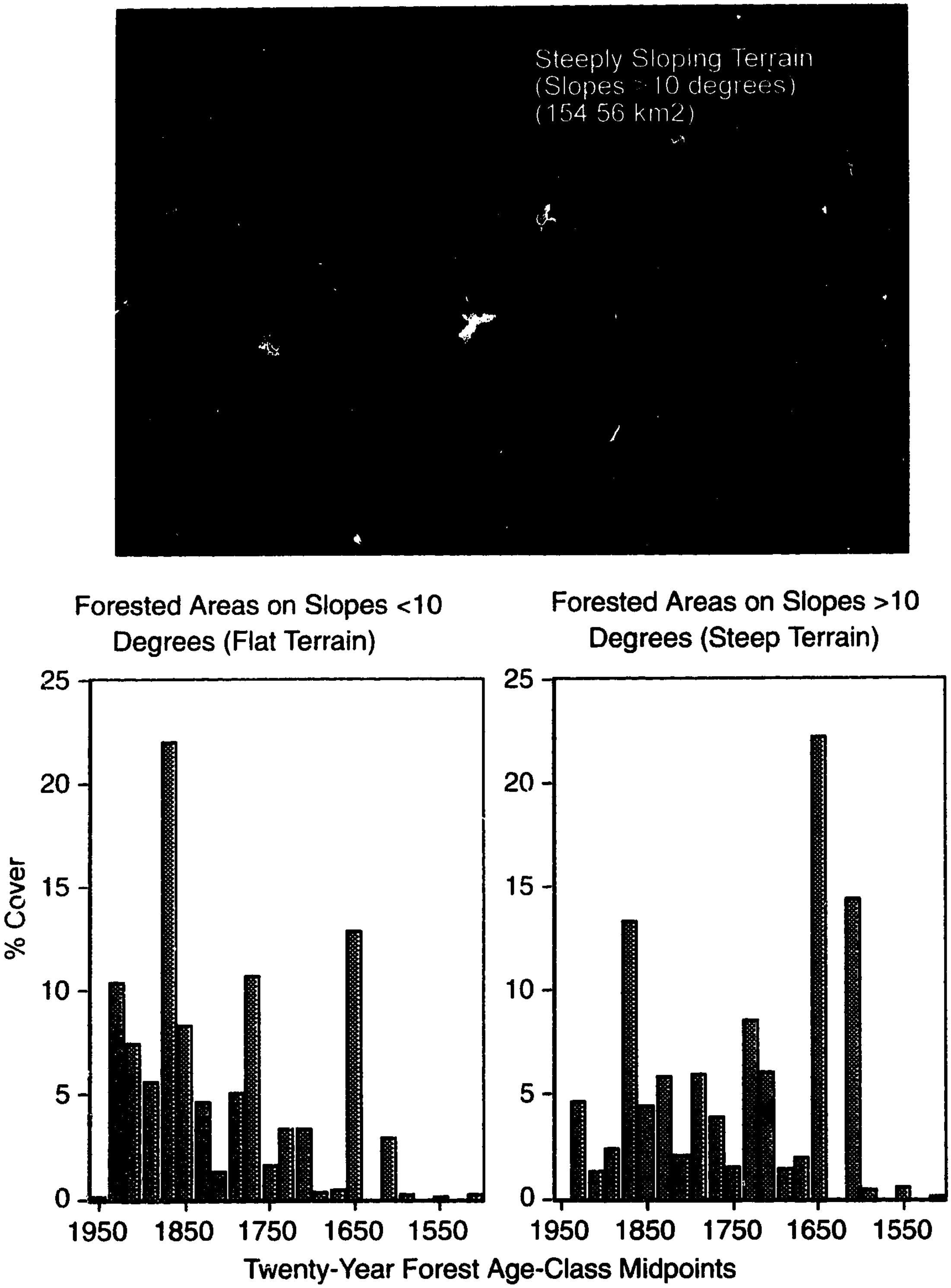
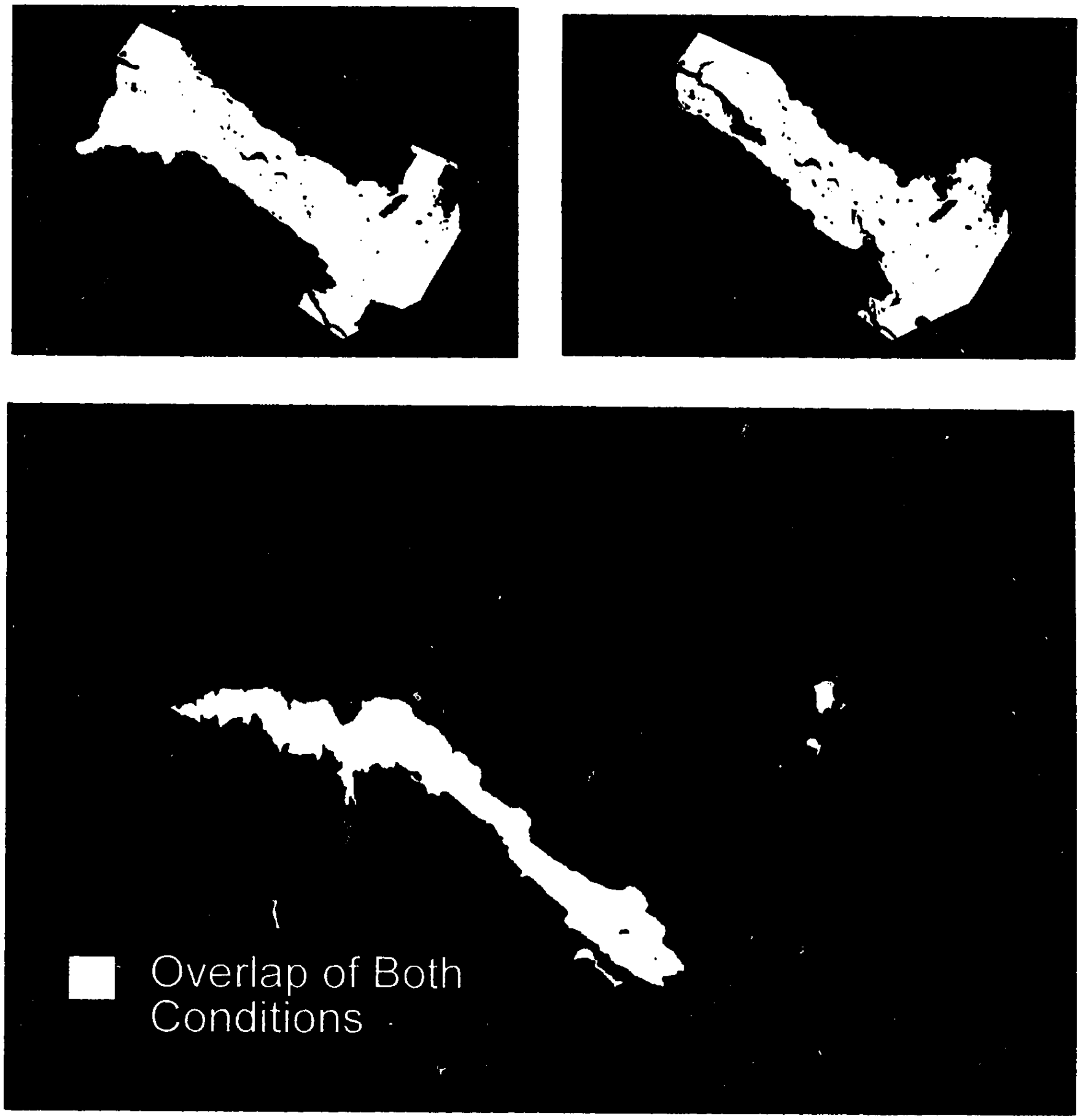


Figure 3.5. Forest age-class distributions associated with flat and steep terrain in the Shakwak Trench.



Condition	Total Area (km2)	Area of Non-Overlap (km2)	Area of Overlap (km2)	% Overlap for Condition
High Elevation Areas (>1060 m)	78.19	30.52	47.67	60.97
Old Forest (>300 Years Old)	95.08	47.41	47.67	50.14

Figure 3.6. Spatial correspondence (overlap) of high elevation terrain with forest areas greater than 300 years old.

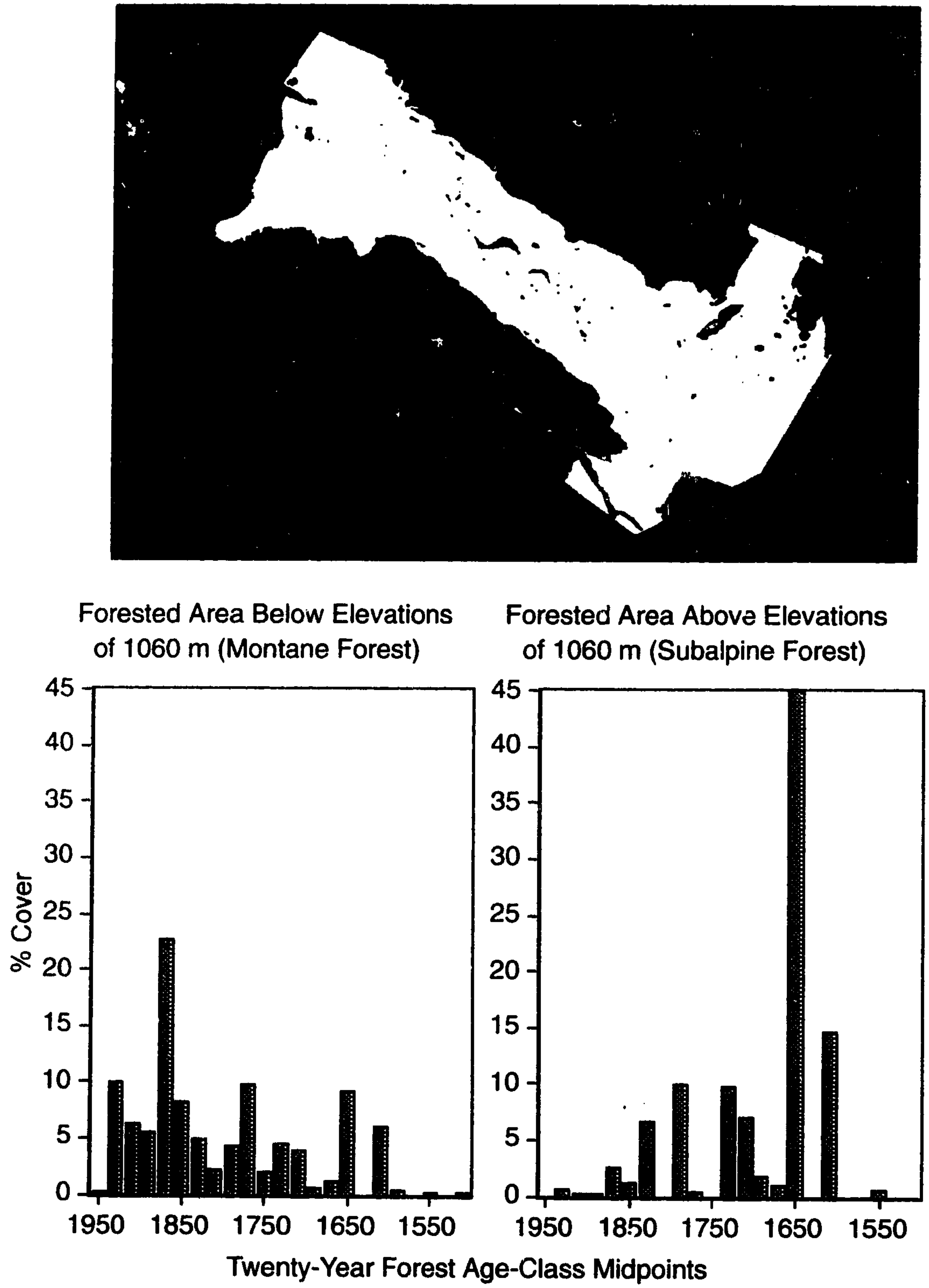


Figure 3.7. Forest age-class distributions associated with low and high elevation terrain in the Shakwak Trench.

displays a very different pattern (Figure 3.7). The subalpine forest age-class distribution is strongly skewed to the right and completely dominated by a few old age-classes, 1650 and 1610 with an average age of 304 years, while the montane forest age-classes are more evenly distributed and much younger with an average age of 189 years. These differences in age-class structure suggest that differences in disturbance regimes exist between high and low elevation forests.

III.4.3 Slope Aspect

Due to the NW-SE orientation of the Shakwak Trench study site, aspect distribution varies greatly. Figure 3.8 displays the aspect distribution of forested area within the valley. The amount of each aspect orientation contained within the study site is relatively even except for flat areas which are rare, but the spatial distribution is not: north- and east-slope aspects dominate one half of the valley while south- and west-slope aspects dominate the other.

By comparing the twenty-year forest age-class map (Figure 3.1 and map insert) to the distribution of aspect types (Figure 3.8), a striking similarity is apparent. North and east aspects are dominated by large tracts of old, contiguous forests while south and west aspects are dominated by small patches of young, fragmented forests. Conceptually this can be examined by simply dividing the valley into two landscape units based on aspect, a north-slope and a south-slope, and then examining the forest age-class distribution in each half (Figure 3.9). North-slope forests are completely dominated by a few age-classes and are heavily skewed towards older ages (average age of 254 years) while south-slope forests are on average much younger (172 years) and the age-class structure is more

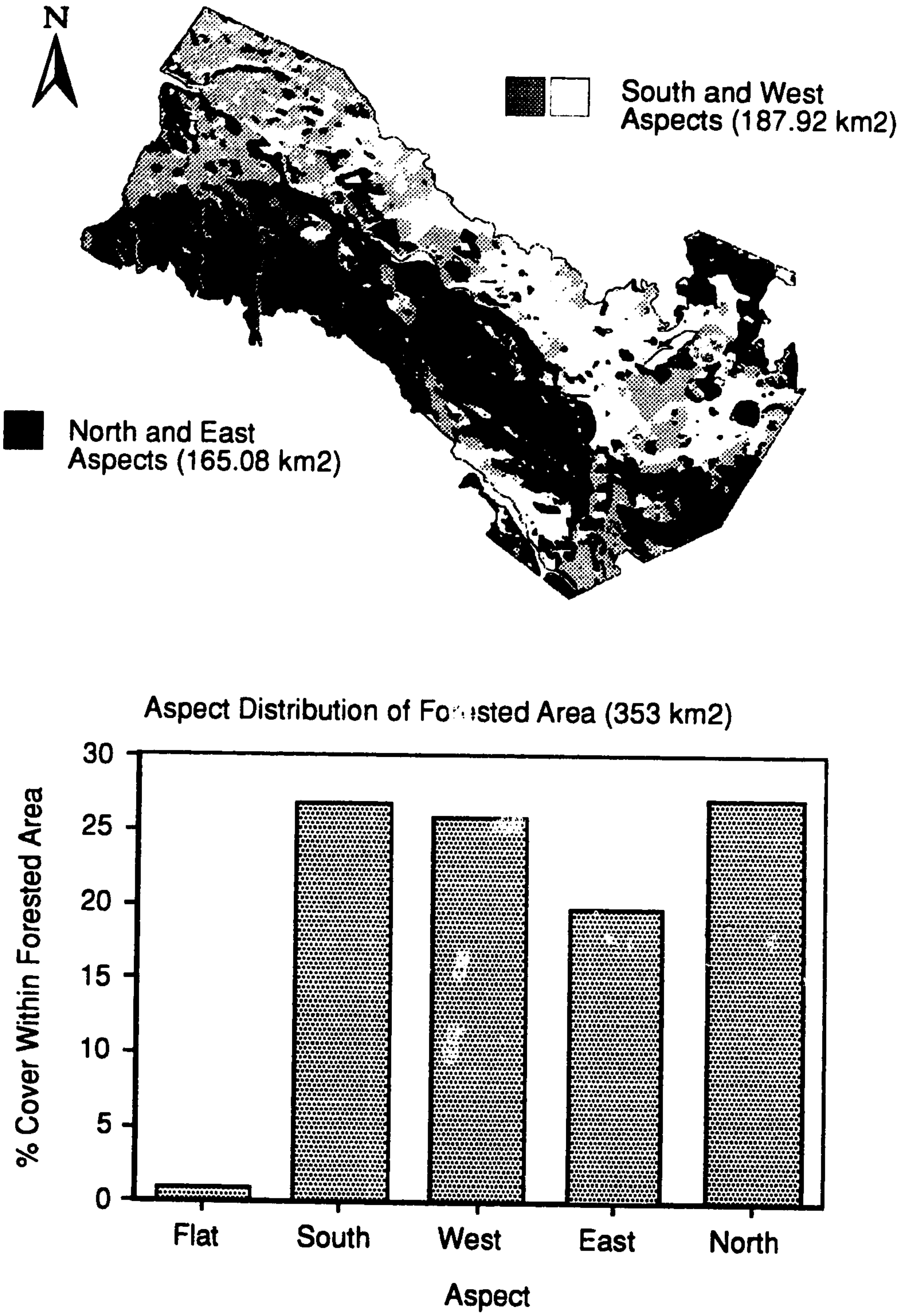


Figure 3.8. Aspect distribution of forested area within the Shakwak Trench study site.

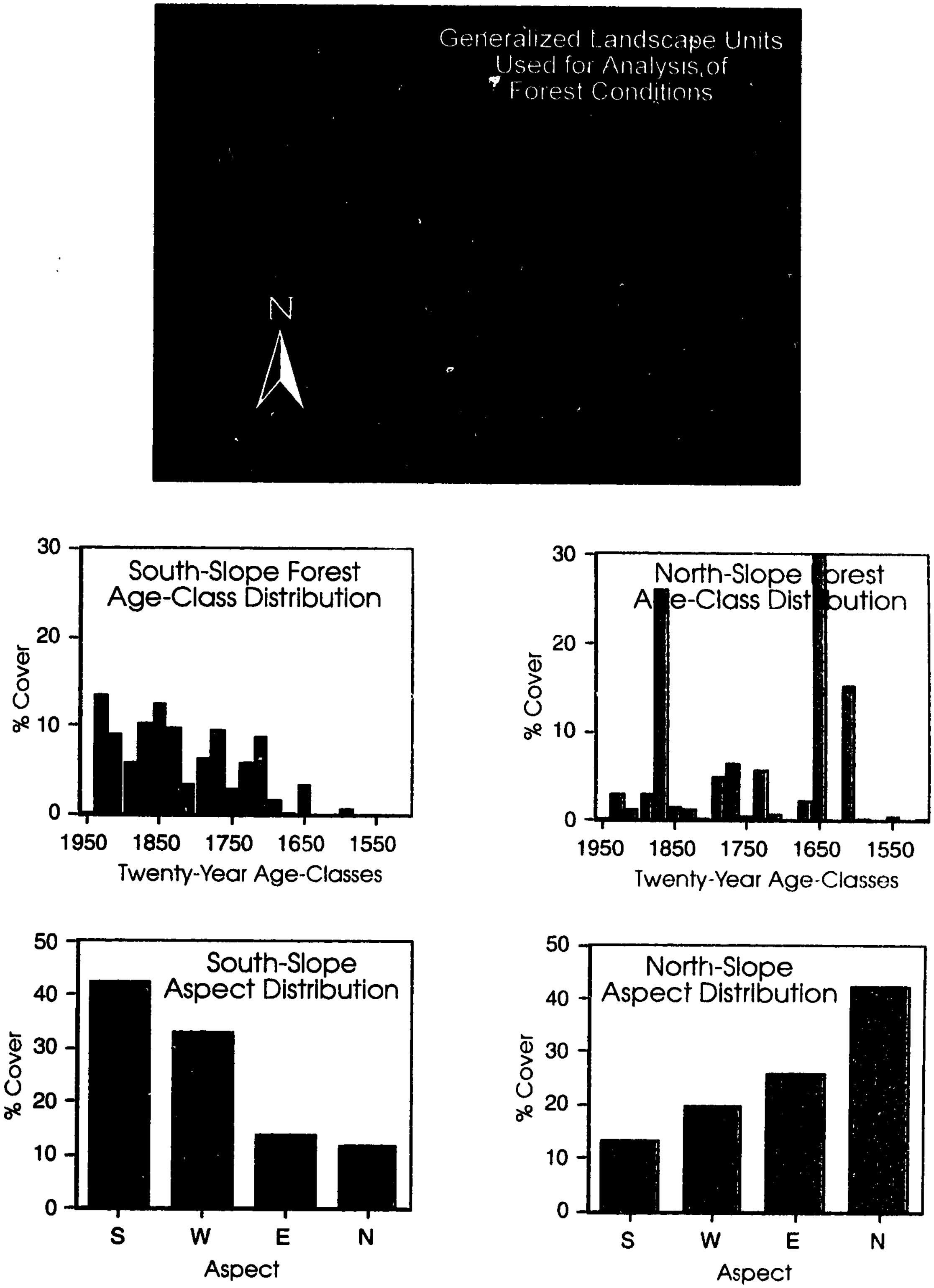


Figure 3.9. Spatially partitioning the Shakwak Trench into two dominant aspects, north and south, displays the effect of aspect distribution on forest age-class structure. Aspect distribution is primarily controlled by valley orientation.

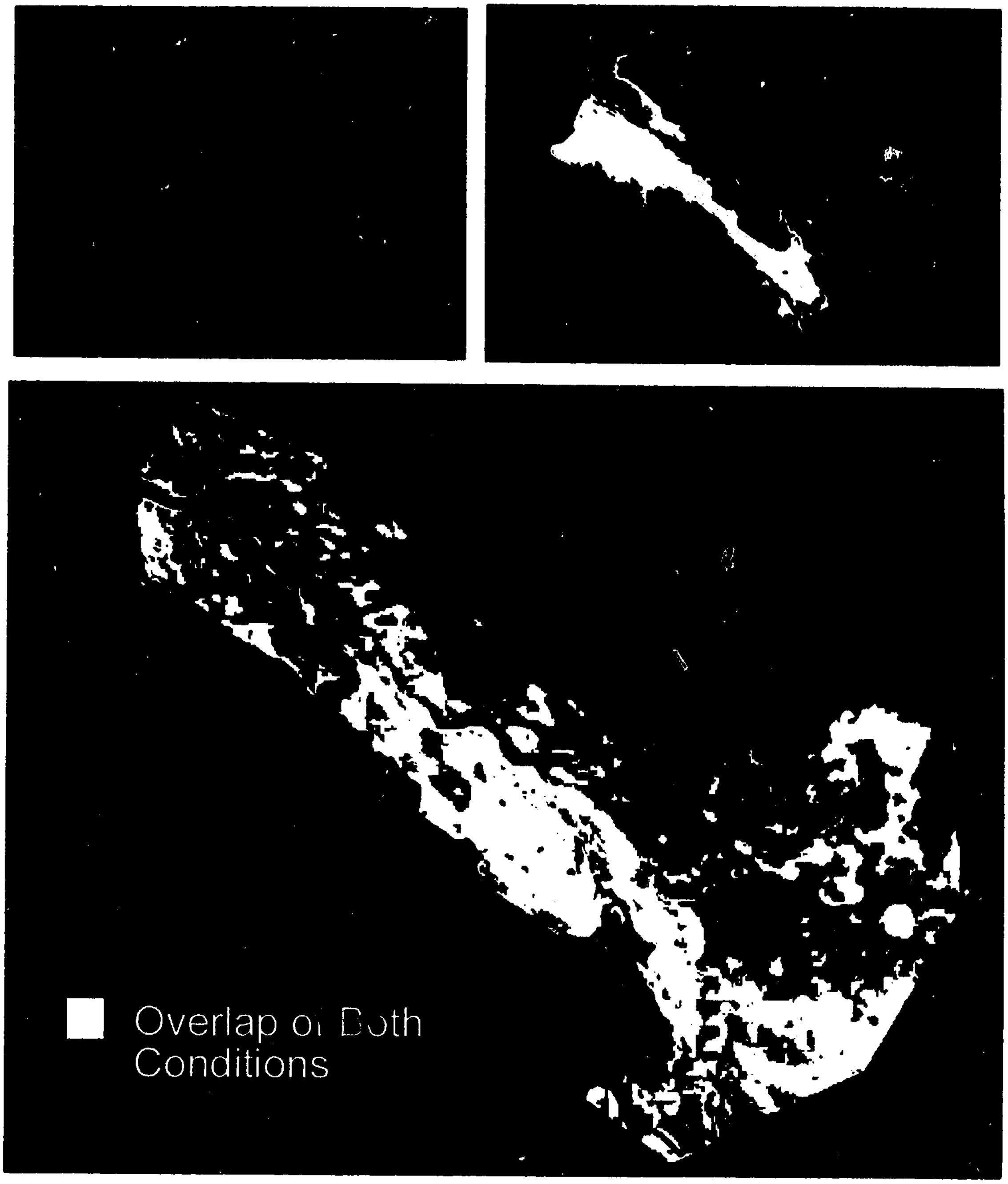
evenly distributed. Differences in disturbance regimes between these two landscape units are apparent.

Figure 3.10 shows the spatial correspondence between north- and east-slope aspects and forest areas less than 300 years old. Only 37.67% of young forests within the study area lie on north and east aspects; 62.33% of forests younger than 300 years occur on south- and west-slope aspects with the average forest age being 191 years. Once again, however, comparing the forest age-class distribution of north- and east-slope aspects with south- and west-slope aspects produces noticeable differences. Similar to a comparison of age-class distributions on north- and south-slope landscape units (Figure 3.9), north- and east-slope aspects contain a much larger proportion of greater than 300 year old forests (average age of 240 years) and these older age-classes dominate the age-class structure (Figure 3.11).

III.4.4 Combining Landscape Characteristics

It has been demonstrated that differences between individual landscape characteristics can display marked differences in forest age-class structure. However, the spatial correspondence between certain terrain classes, primarily aspect and elevation, and forest conditions was in some cases not readily apparent. For example, 37.67% of forested areas less than 300 years old occur on north- and east-slope aspects; a 40:60 relationship in this instance is not very convincing of a spatial relationship between forest age-class conditions and landscape characteristics.

By combining steep slopes with gradients greater than 10° and north- and east-slope aspects, the spatial correspondence between this terrain class and young forests



Condition	Total Area (km2)	Area of Non-Overlap (km2)	Area of Overlap (km2)	% Overlap for Condition
North and East Aspects	165.08	68.13	96.95	58.73
Young Forest (<300 Years Old)	257.40	160.45	96.95	37.67

Figure 3.10. Spatial correspondence (overlap) of north and east aspect terrain with forest areas less than 300 years old.

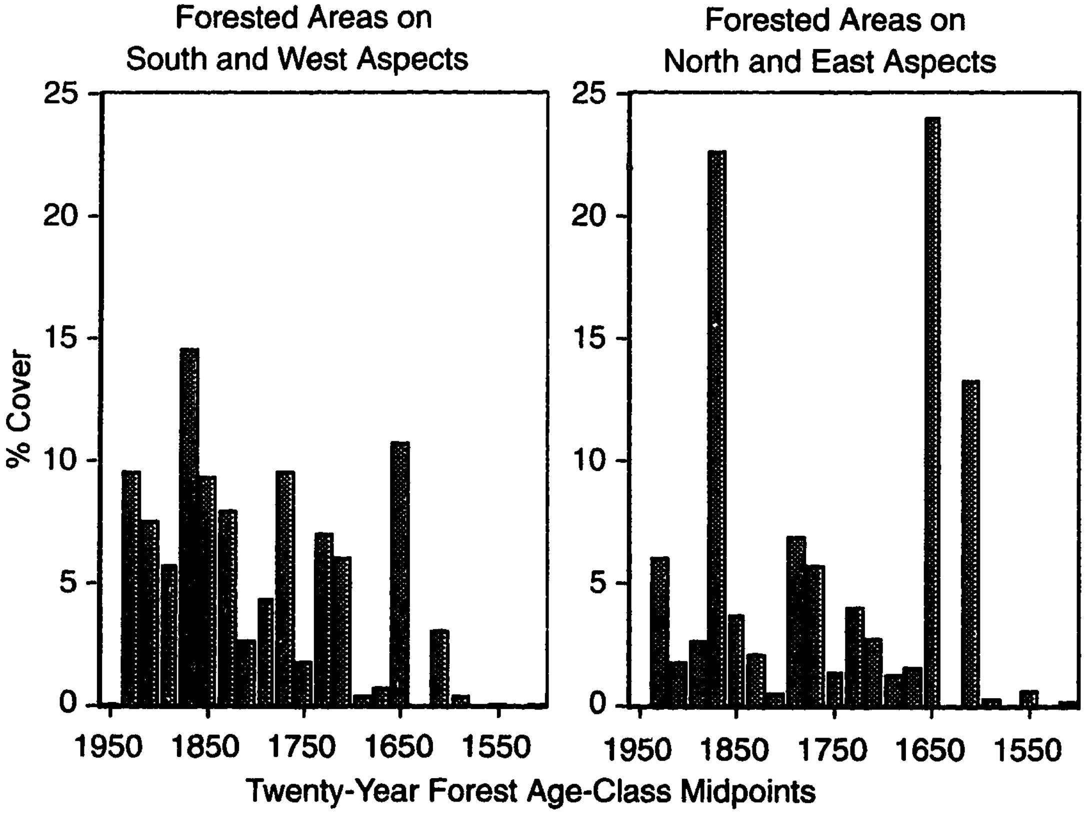


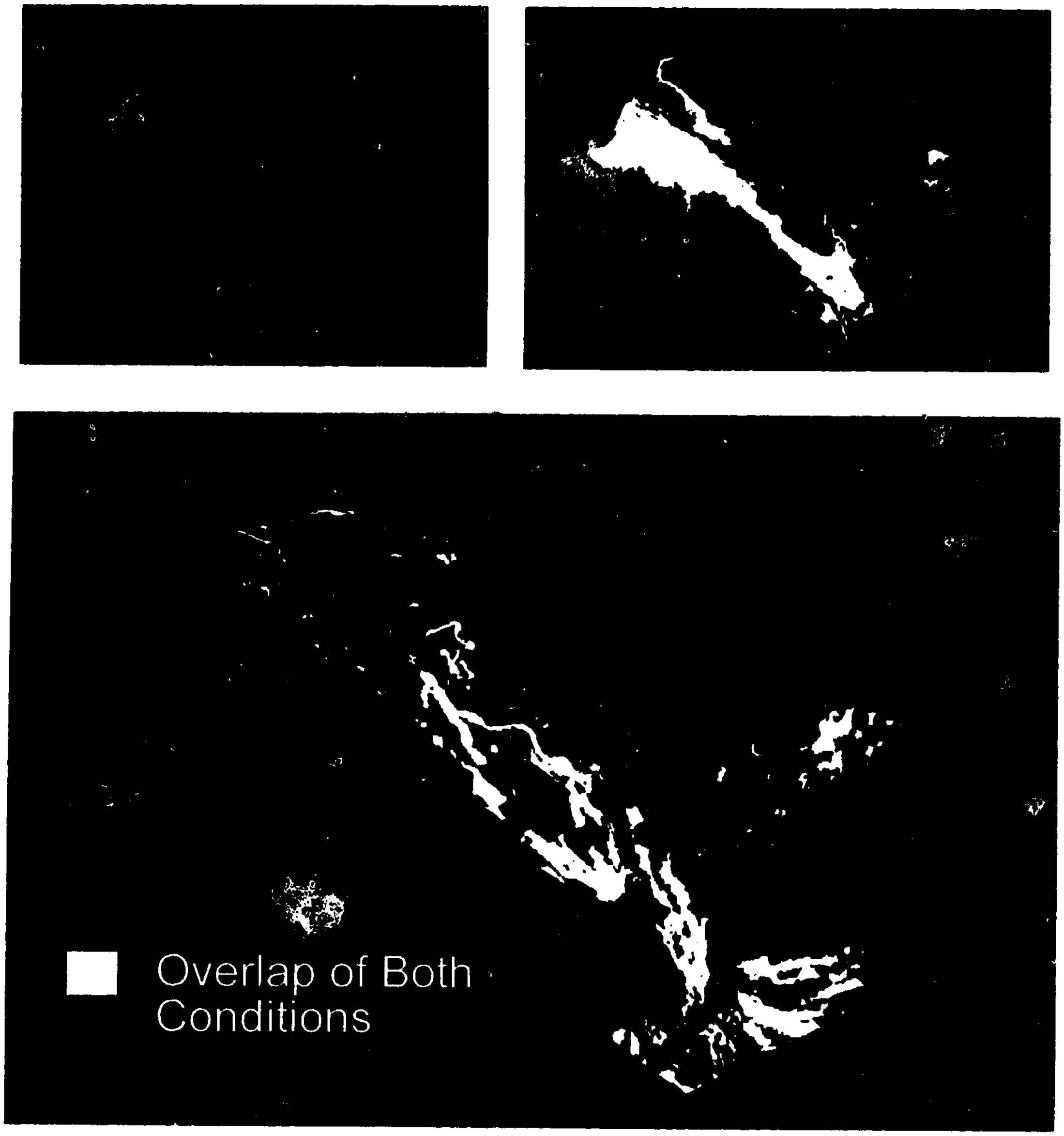
Figure 3.11. Forest age-class distributions associated with south and west aspects and north and east aspects in the Shakwak Trench.

decreases markedly (Figure 3.12). Only 14.65% of forested areas less than 300 years old overlap with steep north- and east-slope aspects. In comparison, 37.67% of young forests overlapped with the terrain class of north- and east-slope aspects alone. It should be noted that this combination of landscape characteristics forms a near perfect mask for forest areas greater than 300 years old.

Examining the forest age-class distribution associated with this terrain class (Figure 3.13) yields similar results to the north- and east-slope aspect partitioning shown in Figure 3.11. North and east aspects with steep slopes are dominated by a few, very old forest age-classes, 1650 and 1610, with an average forest age of 279 years. These age-classes form a contiguous belt of upper-montane and subalpine forest along the entire north-slope. Average forest age of areas not occurring on steep slopes of north and east aspect is 192 years.

The combination of high elevations (above 1060 m) with steep slopes and north and east aspects or "extreme terrain" produces an even more distinct pattern. The spatial correspondence of this terrain class and old forest is shown in Figure 3.14. While only 1/3 of all old forests (31.35%) are found within this terrain class, 82.26% of extreme terrain is covered by forests older than 300 years.

Extreme terrain is a relatively minor terrain class within the study site (36.24 km^2 or 10.27% of total forested area) but this small area has a marked age-class structure (Figure 3.15). Again, only two major age-classes dominate, 1650 and 1610, with most younger age-classes being completely absent. Average forest age on extreme terrain is 330 years. Accordingly, the remainder of the valley contains evenly distributed forest age-



Condition	Total Area (km2)	Area of Non-Overlap (km2)	Area of Overlap (km2)	% Overlap for Condition
North and East Aspects on Steep Slopes	90.66	52.94	37.72	41.61
Young Forest (<300 Years Old)	257.40	219.68	37.72	14.65

Figure 3.12. Spatial correspondence (overlap) of north and east aspects found on steep slopes with forest areas less than 300 years old.

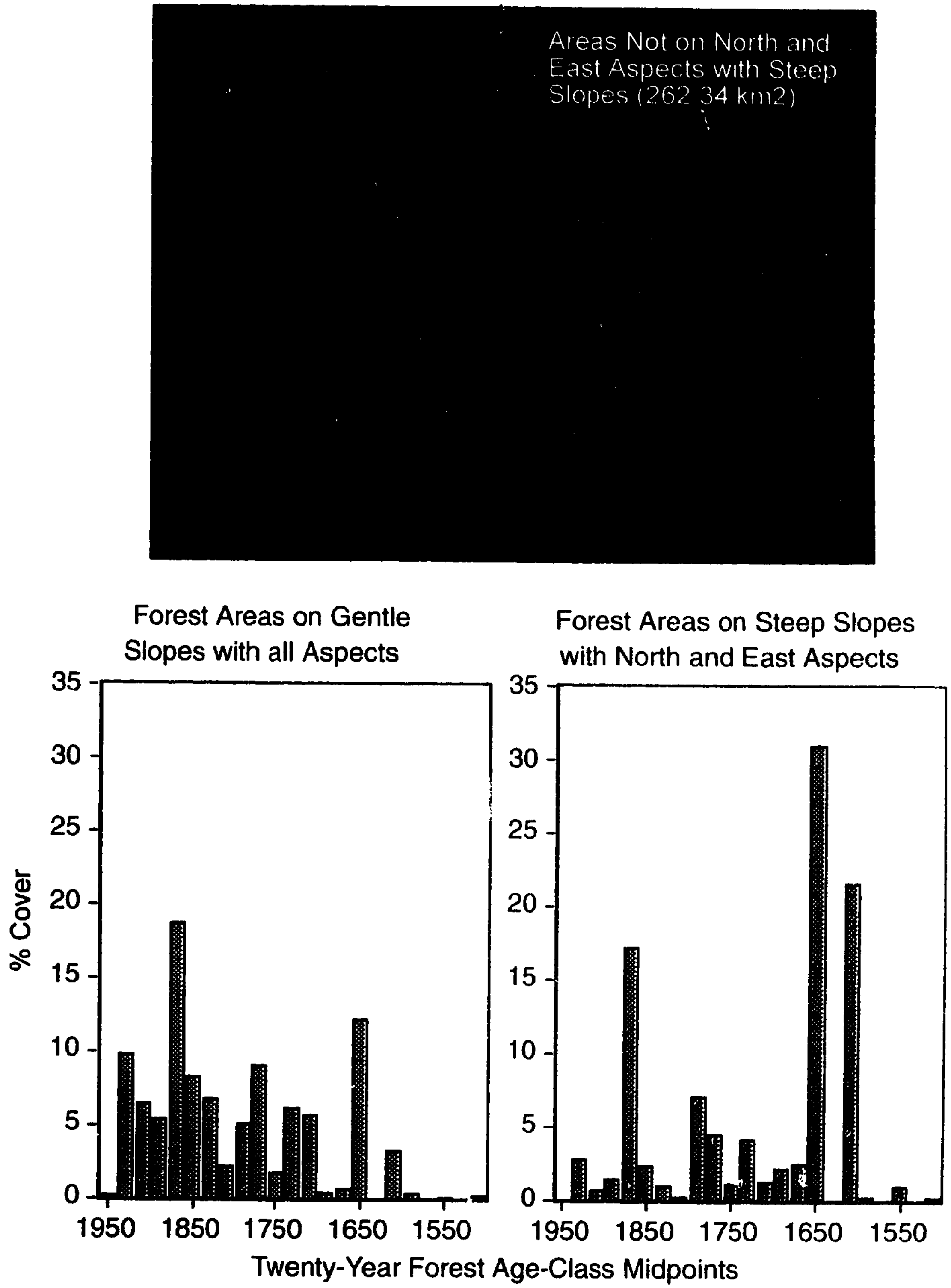
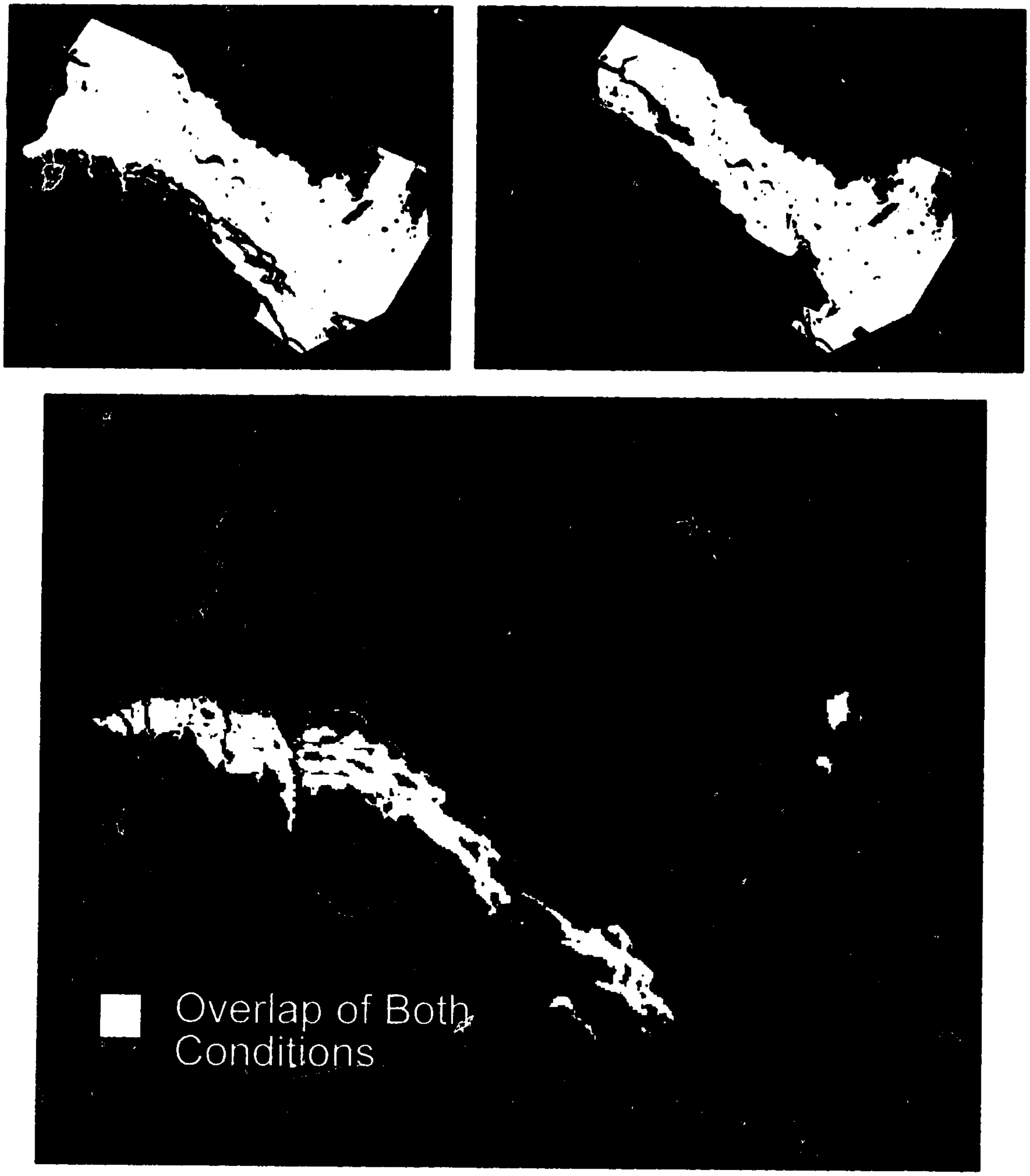


Figure 3.13. Forest age-class distributions associated with steep slopes of north and east aspects and separately classified terrain in the Shakwak Trench.



Condition	Total Area (km2)	Area of Non-Overlap (km2)	Area of Overlap (km2)	% Overlap for Condition
High Elevation Terrain on Steep Slopes with North and East Aspects	36.24	6.86	29.81	82.26
Old Forest (>300 Years Old)	95.08	65.27	9.81	31.35

Figure 3.14. Spatial correspondence (overlap) of high elevation terrain on steep slopes and north and east aspects with forest areas greater than 300 years old.

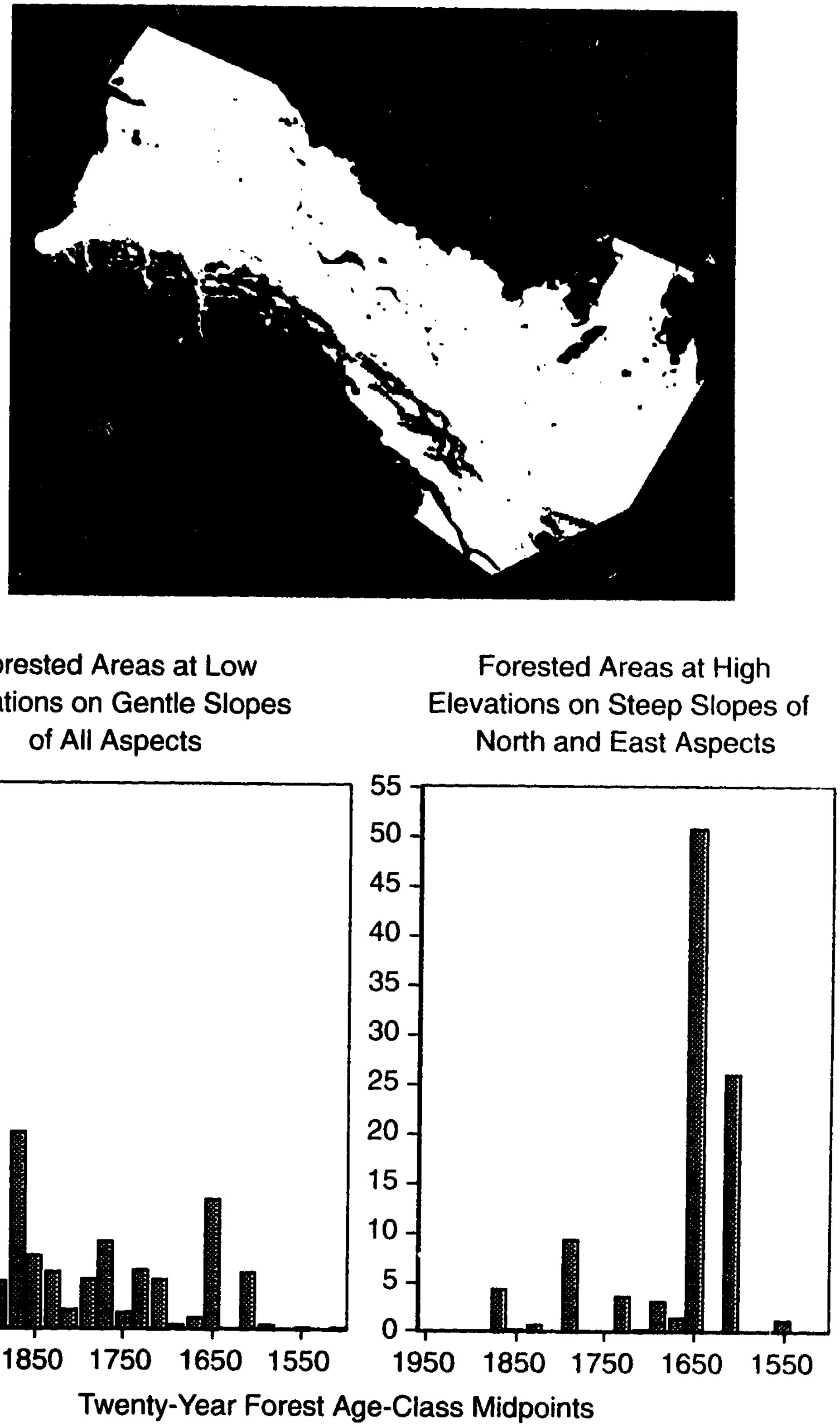


Figure 3.15. Forest age-class distributions associated with north and east aspects on steep slopes at high elevations and separately classified terrain in the Shakwak Trench.

classes with a much younger mean age of 200 years. The rate and spatial extent of disturbance appear to vary greatly between this terrain class and the rest of the study area.

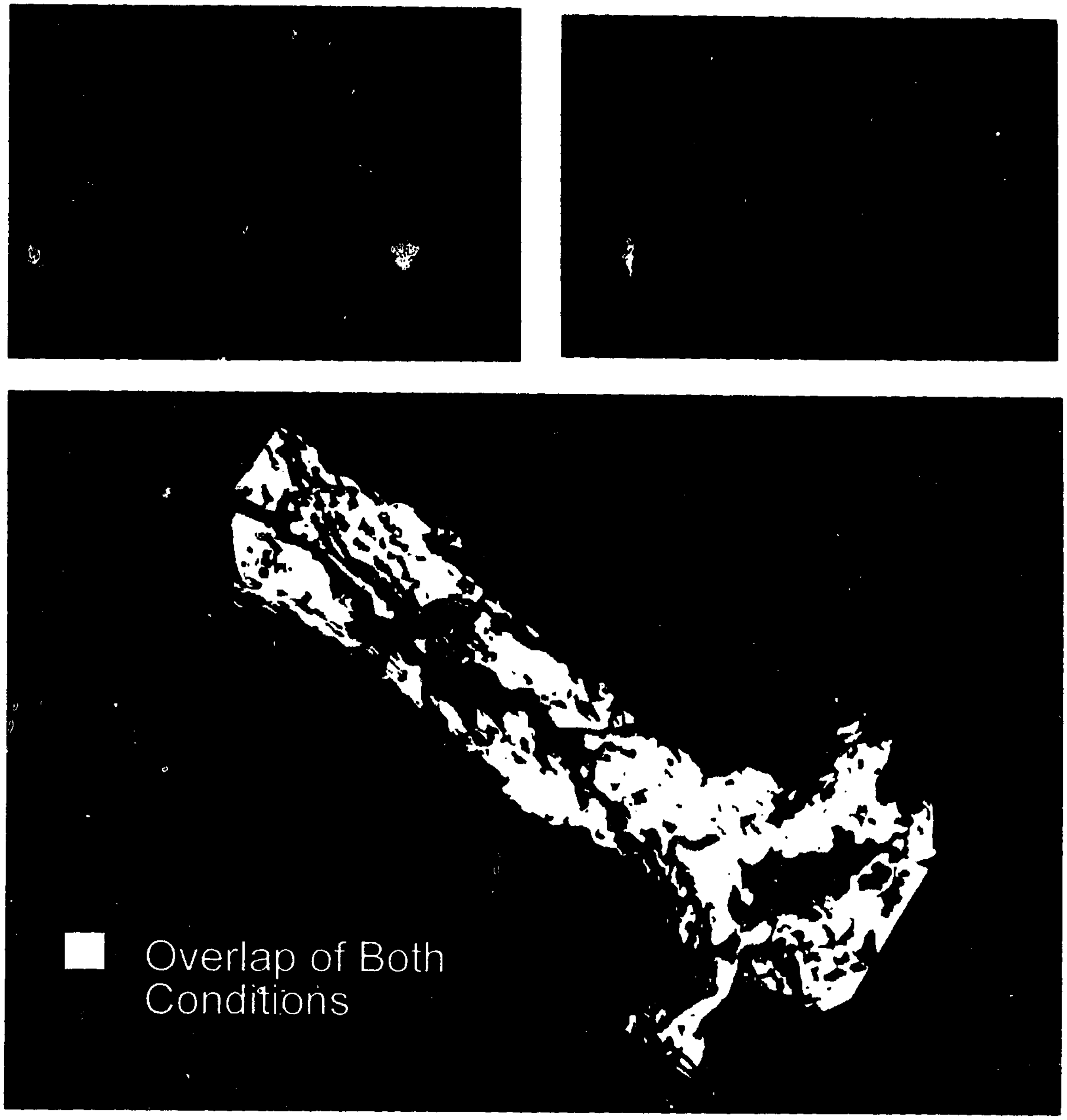
Table 3.1. Average forest ages associated with different terrain classes of the Shakwak Trench.

Landscape Characteristic	Terrain Class	Average Forest Age (Years)
Slope Magnitude	Steep Slopes (>10°) Gentle Slopes (<10°)	254 184
Elevation	High Elevation (>1060 m) Low Elevation (<1060 m)	304 189
Slope Aspect	North and East Aspects South and West Aspects	240 191
Slope and Aspect	>10° North and East Aspects All other Slope and Aspect Conditions	279 192
Slope and Aspect and Elevation	Extreme Terrain (>10°, N+E Aspects, High Elevations) All other Conditions	330 200

III.4.5 Fire Frequency and Landscape Characteristics

Based on individually reconstructed fires as displayed in Chapter Two, a fire frequency map was produced for the period 1800-present. During this time period, 168.74 km^2 of forested area was affected by fire; of this area burned, 69.79% occurred on gently-sloping terrain in the valley bottom (Figure 3.16).

Aspect distribution within the area affected by fire (168.74 km^2) from 1800-present is shown in Figure 3.17a. More area burned on south and west aspects during this time period than on north or east aspects. Relating the fire frequency map (Figure 3.17b) to



Condition	Total Area (km2)	Area of Non-Overlap (km2)	Area of Overlap (km2)	% Overlap for Condition
Gently Sloping Terrain (<10 degrees)	198.44	80.68	117.76	59.34
Recently Burned Forest (<200 Years Old)	168.74	50.98	117.76	69.79

Figure 3.16. Spatial correspondence (overlap) of gently sloping terrain and recently burned forests (less than 200 years old).

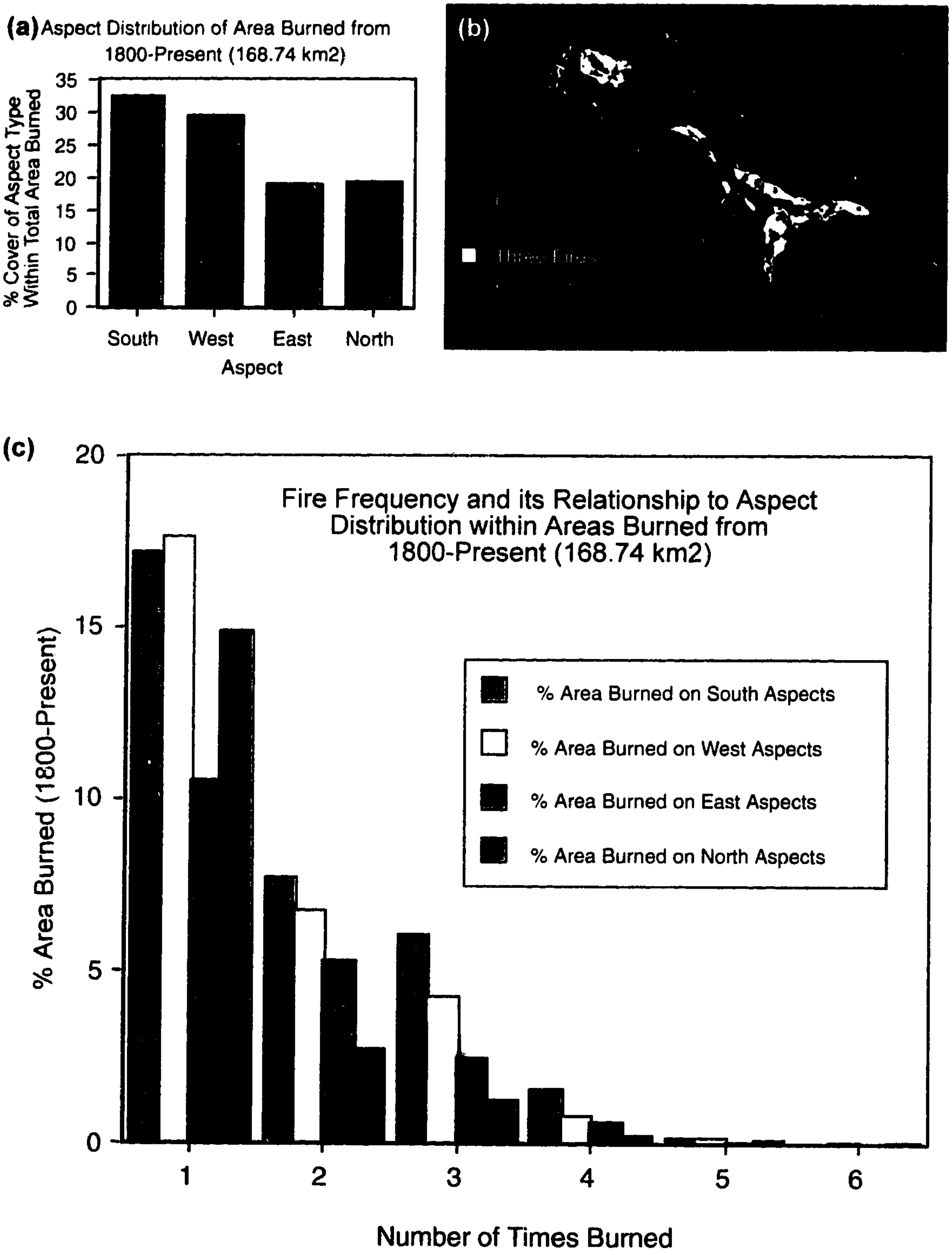


Figure 3.17. (a) Aspect distribution of the area burned from 1800-present. (b) Fire frequency map for the time period 1800-present. (c) Fire frequency and its relationship to aspect distribution within areas burned from 1800-present.

the aspect distribution is Figure 3.17c. Larger areas have burned more frequently on south and west aspects than on neighbouring north and east aspects.

III.5 Discussion

Relationships between landform characteristics and forest age-class conditions exist within the Shakwak Trench. As was shown in Section III.4, there is a high degree of spatial correspondence between certain terrain classes and forest age-class structures. Based on reconstructed forest disturbance information, these different age-class structures appear primarily to be the result of different areas of the landscape experiencing different rates and extents of disturbance.

Slope magnitude alone is not a good indicator of forest age-class structure. No major trend was observed: forests occurring on steep slopes have a similar age-class structure as those found on gentle slopes (Figure 3.5). Steep slopes are generally found at high elevations on both the north and south sides of the valley and therefore, forest age-class conditions associated with steeply sloping terrain are also heavily influenced by elevation. This appears to be the main reason for steep slopes displaying an older average age than gentle slopes (Table 3.1). As a landscape characteristic, the role of slope magnitude seems more to accentuate the effect of slope aspect as indicated by Figure 3.12. Increasing the slope magnitude of a north aspect decreases the amount of solar radiation received and this may result in higher moisture retention. An excellent example of this effect is the steep north-facing slope along Christmas Creek which forms a near mask of very old forest in a matrix of frequently burned areas.

Slope directly influences fire behaviour by increasing the effectiveness of heat transfer from the flaming front to the vegetation, similar to a strong wind-driven fire (Johnson 1992). This effect was only occasionally observed in the Shakwak Trench in the form of short fire runs up a steep slope in the valley bottom. No evidence of this behaviour was observed at high elevations. Very steep slopes such as cliffs or bare ridges may form a fuel break which will influence fire behaviour but this condition was generally not found in the Shakwak Trench. The valley is broad with only minor variation in topographic relief throughout the valley bottom.

The effect of elevation on the forest age-class distribution is marked. The average age of high elevation (subalpine) forests in the Shakwak Trench is 304 years compared with an average age of 189 years for montane forests. The fire regime in subalpine forests has been commented on by many researchers (Veblen et al. 1994, Fryer and Johnson 1988, Tande 1979, Habeck and Mutch 1973) and those authors concluded that fire is an infrequent and catastrophic event occurring only during extreme fire weather. High elevation areas are generally cooler and more moist than low elevation areas as air temperature declines with elevation gain at an average rate of 0.65°C/100 m (Environment Canada, Parks 1987). This type of disturbance regime is evident in the age-class structure (Figure 3.7) and time-since-fire age mosaic displayed by high- and low-elevation forests. Montane forests are young with a relatively even age-class structure, indicating more frequent and small-scale disturbance events. Conversely, subalpine forests are dominated by a few, very old age-classes indicating a disturbance regime driven by infrequent, large-scale events. High elevation areas on the south-slope of the Shakwak Trench are not as old as subalpine forests on the north-slope (Figure 3.6), indicating an interaction between elevation and slope aspect.

Valley orientation controls aspect distribution within the Shakwak Trench. Due to the northwest-southeast valley orientation, the study site is dominated by north- and south-slope aspects (Figures 3.8 and 3.9). North- and east-slope aspect forests were found to be, on average, older than south- and west-slope aspect forests (240 and 191 years, respectively). However, the valley bottom is generally flat with slope magnitudes less than 10° and spatial overlap between young forests and north and east aspects occurs. Minor differences in aspect, when slope gradients are less than 10°, do not appear to have a large influence on the occurrence of fire or individual burn patterns. However, increasing the slope of north and east aspects beyond a magnitude of 10° has a marked effect. Average forest age on steep north- and east-slope aspects is 279 years: this terrain class forms an almost perfect mask for forests greater than 300 years old. Only 14.65% of forests younger than 300 years occur on steep north- and east-slope aspects.

South- and west-slope aspects were found to have a higher fire frequency than north or east aspects, regardless of slope angle. In the northern hemisphere, the amount of solar radiation received by south- and west-facing slopes is greater than on north or east: drier conditions may ultimately result in easier ignition and faster rates of fire spread. Differences in fire frequency between north- and south-slope aspects of the Shakwak Trench may also be associated with an orographic wind or lightning shadow effect of the St. Elias Mountains and should be given further consideration (winds being less and lightning being more infrequent on the north-slope). However, most individual fire events display down-valley patterns indicating that winds driving the fire flaming front are blowing through the main trench. Similar to high and low elevation forests, the average age of south- and west-slope aspect forest is younger with a more even forest age-class structure than forests found on north- and east-slope aspects, which has important consequences for the time-since-fire vegetation mosaic.

There is a complex interaction between slope magnitude, elevation and slope aspect. Any single one of these landscape characteristics may not be an indicator of forest age-class conditions. However, combinations of these features produce noticeable differences in the forest age-class distribution associated with it. Because of the dominant effects of valley orientation and configuration on the spatial distribution of slope, aspect and elevation characteristics, spatially partitioning the Shakwak Trench into its dominant north- and south-facing slopes is an effective means of high-lighting differences in disturbance regimes.

Based on reconstructed fire evidence and the current forest age-class distribution, the valley appears to be operating under two distinctly different disturbance regimes. The north-slope experiences infrequent, large-scale disturbances while the south-slope experiences relatively frequent, small-to-medium scale disturbances (Figure 3.18). This pattern can be observed in the age-mosaic of the twenty-year forest age-class map (Figure 3.1 and map insert). South-slope forests display a small patch size with complex arrangement while north-slope forests are dominated by a few, very old age-classes which have originated from infrequent, large-scale disturbance events. The ultimate effect is the creation and maintenance of a spatially homogeneous age-mosaic on the north-slope of the Shakwak Trench. If the current spruce beetle outbreak is equally affecting north- and south-slopes (i.e. if beetles are not responding to a north-aspect/south-aspect

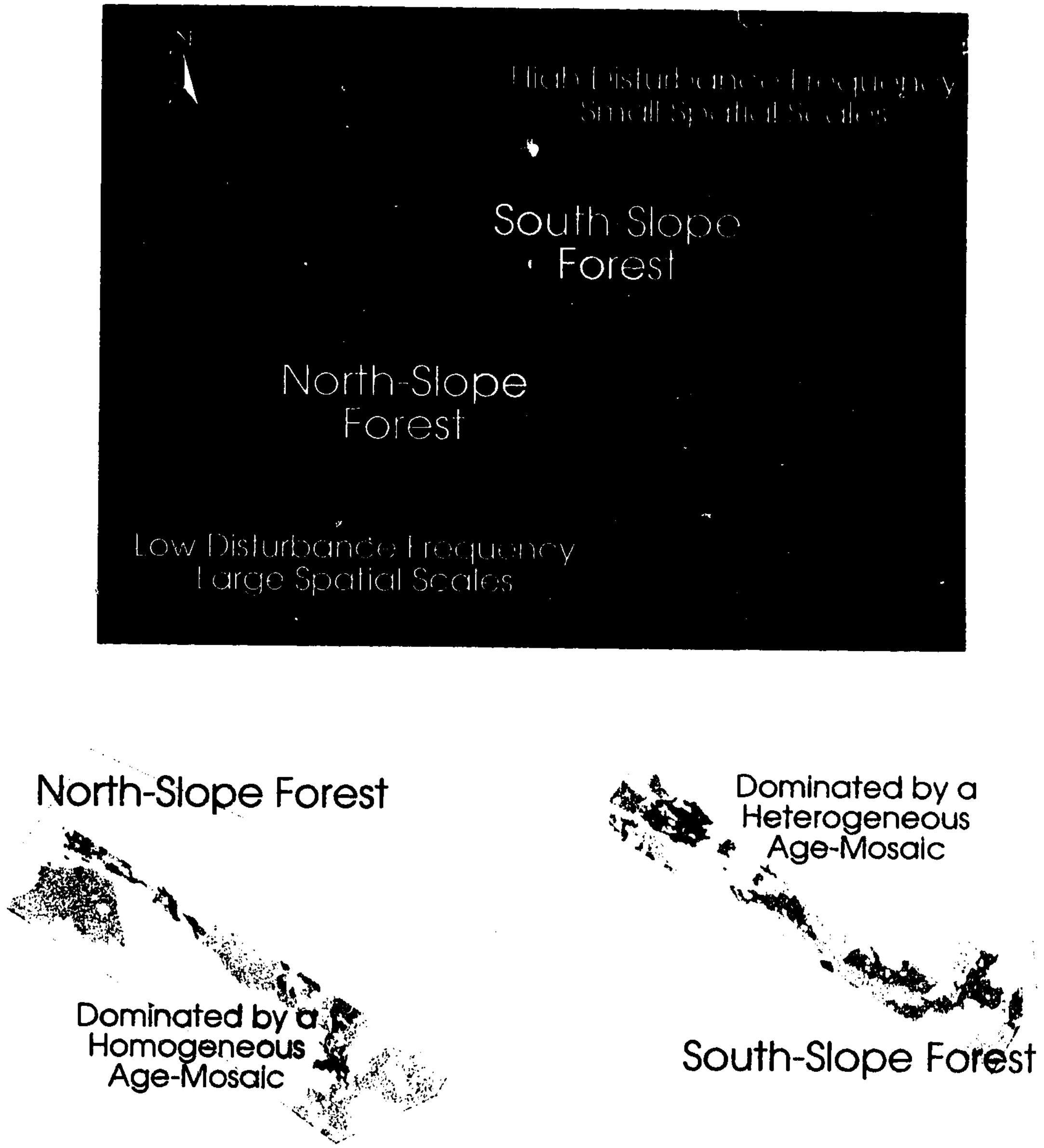


Figure 3.18. The Shakwak Trench is operating under two different disturbance regimes due primarily to valley orientation: South-slope forests experience frequent disturbance events of small spatial scales while north-slope forests are dominated by large-scale, infrequent disturbances. Small-scale, frequent disturbances will lead to a heterogeneous age-mosaic as observed in south-slope forests. A disturbance regime dominated by large-scale, infrequent events will lead to a homogeneous age-mosic as displayed by north-slope forests.

environmental gradient) within the Shakwak Trench, then this will perpetuate the same age-mosaic pattern as has developed from historical fire disturbances. The average forest age will decrease markedly but the age-mosaic will remain the same: south-slope forests will still maintain the same small patch size juxtaposition while the north-slope will remain dominated by a relatively simple age-mosaic. In this sense the spruce beetles are operating on similar temporal and spatial scales as wildfire disturbances.

Large-scale, infrequent fire events will only occur during extreme fire weather when some critical drought threshold is reached (Turner and Romme 1994). The spatial arrangement of landscape elements and forest stands may then become inconsequential as large conflagrations driven by these climatic extremes will be more directly influenced by hourly/daily weather processes (Johnson 1992). Extreme fire events which affected the entire valley may have occurred in the past but there is currently no direct evidence to support this. If the entire valley was affected by a single fire event then some long-term equilibrium may exist in the rate and extent of disturbance, punctuated by brief periods of non-equilibrium conditions resulting from catastrophic disturbance events. Non-equilibrium conditions appear to be a natural state for all disturbance prone systems dominated by large, infrequent crown fires (Turner and Romme 1994).

The effect of fire frequency on landscape pattern has been referenced by Knight (1987) and Heinselman (1973). Those authors concluded that low fire frequency may result in lowered forest heterogeneity while high fire frequencies would result in a heterogeneous vegetation pattern being maintained. Arguments such as these have provided impetus to begin prescribed burning programs in wilderness and conservation areas as fire suppression activities may have influenced natural fire frequencies. However, linkage between fire frequency and landscape pattern may not be as intuitive (Turner and Romme 1994, Baker 1992).

Turner et al. (1994) reported that infrequent, large fires resulted in more complex landscape patterns than had existed under a regime of relatively small, frequent fire events. Large fires are highly variable in behaviour, shape and intensity, leaving a fire patterned landscape with both high internal and external patch heterogeneity. Also, the number and size of unburned residual vegetation patches within a single burn event has been shown to increase with fire size (Eberhart and Woodard 1987). This complex interaction of topography, disturbance history and community and individual species interactions results in an almost infinite number of possibilities. Predicting the outcome of such a complex process may therefore not be possible. This interaction ultimately means that a heterogeneous age mosaic or time-since-fire map does not necessarily increase the heterogeneity of a vegetation mosaic, a hypothesis which requires further testing. Understanding the interaction between environmental gradients and historical events is one of the primary challenges faced by landscape ecologists (Pickett and White 1985, Watt 1947).

III.6. Summary and Conclusions

The following points summarize Chapter Three:

(1) The spatial distribution of forest age-class elements is related to the spatial distribution of landscape characteristics in the Shakwak Trench. Accordingly, in response to different rates and extents of disturbances, different terrain classes display characteristic forest age-class distributions.

(2) Complex interactions between slope, elevation and aspect characteristics within the Shakwak Trench influence the spatial distribution of forest age-classes through their possible effects on fire occurrence, behaviour and pattern.

(3) Slope magnitude appears to have no direct influence on the forest age-class distribution but serves to accentuate differences in slope aspect and elevation.

(4) High and low elevation forests experience very different disturbance regimes. Subalpine forests are old and dominated by large, contiguous patches (infrequent, large-scale disturbances) while montane forests are young and display a heterogeneous age-mosaic (frequent, small to medium-scale disturbances). Subalpine forests on north-slope aspects are older than subalpine forests on south-slope aspects.

(5) Steep north and east aspect terrain forms a near perfect mask for greater than 300 year old forests: only 14.65% of forests less than 300 years old are associated with this terrain class. Generally, the oldest forest conditions occur on steep north- and east-slope aspects at high elevations.

(6) Over the past 200 years, south- and west-slope aspects have burned more frequently than north- or east-slope aspects. This pattern of burning appears to have existed for at least the past 400 years. Accordingly, south and west aspects display younger

forest conditions than north or east aspects. Minor differences in aspect where slopes are less than 10° do not appear important in determining areas of high-low fire frequency.

(7) Due to a NE-SW valley orientation, the Shakwak Trench contains a predominant north- and south-facing slope. On the most basic level, the north-slope is characterized by large-scale, infrequent disturbances while the south-slope can be characterized by small to medium-scale, frequent disturbances. This results in the current time-since-fire mosaic where the north-slope contains a spatially homogeneous pattern versus the heterogeneous age-mosaic found on the south slope.

(8) Being able to identify landscape units with characteristic disturbance regimes and forest age-class structures will aid in the prescription of ecologically-sound forest landscape planning.

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CHAPTER FOUR:

Conclusions and Future Directions

IV.1 Conclusions of Research

Fire history studies in the Shakwak Trench of southwest Yukon Territory produced many interesting results. Some of the most important of these include:

(1) The use of current fire history models based on negative exponential and Weibull survivorship distributions, as reviewed by Johnson and Gutsell (1994) and Johnson (1992), to analyze forest fire history in this study area are questionable as their basic underlying assumptions are not met in the Shakwak Trench. First, the current forest age-class distribution is not an accurate reflection of forest disturbance history. Secondly, and associated with the first, fire does not appear to be acting randomly on the landscape: some areas have burned frequently while others rarely. Therefore, describing an average fire cycle or fire return interval for the entire study area is not useful. Temporal fire history information not put in some spatial context will lead to misleading and inaccurate conclusions regarding historical forest disturbances in the Shakwak Trench.

(2) A high degree of spatial correspondence exists between certain landscape units and forest age-class conditions in the Shakwak Trench. Identifying these units and characterizing disturbance regimes associated with them is a spatially explicit method of describing forest disturbance history.

(3) The Shakwak Trench appears to be operating under two distinctly different disturbance regimes. The north-slope is dominated by infrequent, large-scale disturbance events while the south-slope disturbance regime is characterized by relatively frequent, small-medium scale disturbances. These different disturbance regimes have dramatically influenced the time-since-fire age-mosaic associated with each terrain class. Internal forest age-class variability within these two broad landscape units are spatially related to differences in slope magnitude, slope aspect and elevation.

This study took place in a mountainous system where there are dramatic effects of slope, aspect and elevation over small distances. It should then be possible to characterize landscape-forest age-class relationships in all boreal cordillera ecosystems. At this time, it is not known whether this method will be effective for other areas of the boreal forest. The majority of the boreal shield, plains and taiga regions are characterized by subdued, rolling topography where extremely large fires can occur. As was observed in the Shakwak Trench, minor differences in slope magnitude and slope aspect appeared to have little influence on fire frequency and individual burn patterns. Subtle differences in aspect and topography may therefore have little effect on the same spatial processes in the boreal shield, plains and taiga as suggested by Johnson and Gutsell (1994) and Johnson (1992). However, subtle patterns may still be present and will provide valuable information for landscape management initiatives.

Explicitly linking landscape characteristics and forest age-class information may form the basis for sound landscape planning and provide an ecological rationale for prescribing one landscape pattern over another (Franklin 1993, Swanson et al. 1993, Franklin and Forman 1987). In the Shakwak Trench it has been demonstrated that certain terrain classes are associated with characteristic forest age-class distributions and disturbance regimes. If our goal is to use natural disturbance regimes as a guide for landscape planning, then different areas of the landscape will have to be managed, within limits, according to these disturbance regimes. Being able to isolate and quantify these areas is the initial step.

IV.2 Future Directions

Future forest disturbance studies should strive to link explicitly forest age-class conditions and landscape characteristics within a geographic information system. Detecting and quantifying the patterns observed in the Shakwak Trench would have been very difficult without the use of spatial queries between reconstructed forest disturbances and a digital elevation model. The use of very detailed digital elevation models (5 m contour data or finer) would allow the examination of small-scale topographic effects on individual burn patterns. Finer measurements of slope and aspect characteristics may yield more detailed relationships between landform conditions and forest disturbances. Also, proximity analysis between individual disturbance events and landscape characteristics/human-use patterns may also yield interesting results.

The Shakwak Trench study site is only one valley within the boreal cordillera ecoregion. Until more areas are examined in the same manner, modeling management decisions after these results would be premature. Expanding this study to surrounding areas within the Kluane Region would be a good beginning to this process.

As was observed in the Shakwak Trench, minor differences in slope magnitude and slope aspect appeared to have little influence on fire frequency and individual burn patterns. A fire history study using similar methods should be performed in the boreal shield or plains region to examine if similar patterns are detected. This could then be used to evaluate if extrapolation of this method to other boreal regions would be possible.

The questions which remain are numerous. Specifically, are most old forest stands associated with north- and east-slope aspects, however subtle, in the boreal forest? Do most unburned remnants within a burn patch occur on north- and east-slope aspects? Is the amount of aspect a good indicator of forest age-class variability given some knowledge about fire history in an area? Can the age-class mosaic be related directly to the vegetation mosaic? Linking patterns and processes which structure forest ecosystems will be crucial to the success of landscape-based forest management initiatives.

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