DENDROECOLOGICAL ANALYSIS OF SUCCESSIONAL DYNAMICS AFTER FIRE IN THE SHAKWAK TRENCH, SOUTHWEST YUKON TERRITORY.

A thesis submitted to
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Rebecca Zalatan

Department of Geography
University of Ottawa
Ottawa, Ontario
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Preface

The ecological succession of species after fire in the Shakwak Trench, southwest Yukon Territory is the focus of this study. The results were derived from data collected in June-July 2001. The organization of this thesis, divided into five chapters, reflects the focus of this work, which was to contribute to the research in the field of boreal forest postfire succession. The first chapter provides the reader with a general background of the field of succession and describes various studies focusing on postfire succession in the boreal forest. The second chapter is a description of the study site and the criteria used for their selection. The third chapter is an extensive explanation of the methodology applied. The fourth chapter has been written in the form of a paper to be submitted upon completion of the thesis for publication. It includes an abbreviated introduction, study site description, and methodology as well as a complete summary of the results and discussion. The fifth chapter is a short summary of the thesis with emphasis on the possibilities for further research.

Abstract

This study investigates the succession following fire in a relatively dry area of the boreal forest, the Shakwak Trench, southwest Yukon. The postfire successional regime is determined by an analysis of age structure and composition of tree populations in stands of different ages. The dendroecological approach used in this study is based on the sampling of one plot in each of 11 fires ranging from A.D. 1844-1998. *Picea glauca* established 0-4 years after fire and reached a period of maximum establishment after 20-40 years. *Populus tremuloides* was generally recruited immediately after fire and was no longer present after approximately 20 years, at which point, the *Picea glauca* began to dominate. *Salix* spp. were found in all stages of succession, but decreased in abundance through time. Five chronologies that were developed from ring-width measurements of the older *Picea glauca* trees depict similar growth-ring patterns, suggesting a large-scale climate influence on all sites in the region. There is a weak relation between the variability of the tree-ring chronology and the establishment of *Picea glauca* seedlings. Regeneration of tree species after fire is primarily driven by biological influences rather than climatological ones.

Résumé

Cette étude est consacrée à la succession végétale qui a lieu après feu dans une partie relativement sèche de la forêt boréale, le fossè de Shakwak, sud-ouest Yukon. Le régime de la succession après feu est déterminé par une analyse de la structure d'âge et de la composition des populations d'arbres dans des peuplements d'âges différents. L'approche dendroécologique utilisée dans cette étude implique l'échantillonage d'une parcelle de terrain dans chacune des 11 zones brûlées entre 1844 et 1998. *Picea glauca* s'est établi de 0-4 ans après le feu et a atteint une période d'établissement maximum après 20-40 ans. *Populus tremuloides* s'est généralement installé immédiatement après le feu et est plus présent après 20 ans, alors que les jeunes plants de *Picea glauca* ont commencé à mûrir et à dominer. Des espèces de Salix ont été trouvées dans toutes les étapes de la succession, mais ont diminué en abondance avec le temps. Cinq chronologies ont été développées à partir des mesures de largeur des anneaux de *Picea glauca* les plus anciens provenant des sites le long du fossè de Shakwak et dépeignent des conditions climatiques semblables. Ceci suggère une relation entre la variabilité de la chronologie et l'établissement des jeunes plants de *Picea glauca*. La régénération d'espèces d'arbres après feu est principalement le résultat d'un contrôle biologique plutôt que climatologique.

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This study would not have been possible without the completion of Shawn Francis' M.Sc. Thesis "Linking Landscape Pattern and Forest Disturbance: Fire History of the Shakwak Trench, Southwest Yukon Territory", and without the help of J. Jennings, the Resource Management Officer at DIAND, who provided the maps of the recent fire history of the region.

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Ottawa, Ontario
June, 2002
R. Z.

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CHAPTER ONE:
Introduction and thesis outline

1.0 Introduction

In the boreal forest, natural disturbances, primarily fire, have shaped the scale, texture and vegetation distribution on the landscape (Rowe and Scotter, 1973; Johnson, 1979; Tande, 1979; Dieterich, 1983; Purchase and La Roi, 1983; Morneau and Payette, 1989; Schaefer, 1993; and Stocks *et al.*, 1998). Fire plays a major role in the development of the vegetation mosaic that makes up the Canadian boreal forest; the boreal forest owes its complexity of structure and composition to the occurrence and spatial distribution of fire. As a disturbance agent, fire initiates a succession that maintains the heterogeneous character of the boreal forest vegetation mosaic (Johnson, 1992). During postfire succession, trees establish at different rates, which means that several stages of development occur before a mature stand is reached (Gutierrez and Fey, 1980).

Succession is defined as a progressive change in community structure and function over ecological time (Brown and Lomolino, 1998). Primary succession occurs when plants establish in rock or soil for the first time. If a disturbance such as a fire or storm removes most of the living organisms but leaves the soil more or less intact, secondary succession occurs. This is the most common form of succession studied in the boreal forest, and will be the focus of this study.

Although it is regarded as one of the most universal ecological concepts, succession has not been satisfactorily defined nor sufficiently explained. Clements stated as a "universal law", that "all bare places give rise to new communities except those which present the most extreme conditions of water, temperature, light, or soil"

(Clements, 1916, as cited in McIntosh, 1981: 10). The Clementsian model, which is deterministic, predictable and convergent, is based on the notion that a set of species will invade, outcompete, and replace the first group of species until a relatively stable "climax" community is established (Brown, and Lomolino, 1998). Clements' theory on succession dominated the field of Ecology for such a long period of time because it corresponded well with results found by other ecologists (Connell and Slatyer, 1977). However, many ecologists have found that this "climax" theory is flawed, and this view of succession has been widely debated (McCormick, 1968; Drury and Nisbet, 1971, 1973; Connell, 1972; Connell and Slatyer, 1977; Noble and Slatyer, 1980).

An alternate view of succession proposed by Egler (1954), hypothesises that in many situations following a disturbance event, the 'initial floristic composition' determines future shifts in species dominance. Egler (1954) emphasized the importance of site occupancy by a particular species as a factor restricting the subsequent entry of other species. With the work of many ecologists, it has become evident that the classical concepts of succession once used to describe vegetation development after a disturbance event are lacking. However, a consensus with regards to a concise theory of succession has not been clearly established. McIntosh's (1981: 12) explanation for the lack of consensus is that "some ecologists are not as alert as others to simple theoretical solutions".

1.1 Development of forest communities after fire

Fire is the most frequent and widespread form of disturbance in forested regions (Brubaker, 1986; Johnson and Miyanishi, 2001). Tree species differ in their ability to regenerate following fire and grow in a forest environment (Walker, 1999). Fire allows early successional, shade intolerant species to re-invade the landscape. This is due in part to the availability of soil moisture and mineral nutrients. However, the ability to persist in shade is a major determinant of seedling survival (Finegan, 1984). The species most intolerant of shade will regenerate first and grow faster, whereas the shade-tolerant species will persevere and dominate in later stages of succession. If fires occur frequently, early successional species (deciduous trees such as willow and aspen) may dominate the landscape. On the other hand, if fires are infrequent in nature, a region may become dominated by shade tolerant, late-successional species (coniferous trees such as spruce and fir) (Brubaker, 1986). Thus, population replacement from early to late-successional species may be regulated by the frequency of the fire cycle. Tolerance is clearly an essential component of the regeneration capacity of trees.

Determination of the successional pathway after fire is a difficult process since it is not possible to follow a site long enough to observe species replacement over time. One method used to determine the successional stages is to use a series of similar sites representing different stages of succession following fire, that is, stands of different ages (Bergeron and Dubuc, 1989; Bergeron and Charron, 1994). In general, the first stages of an ecosystem response following fire take a common form throughout the boreal forest.

> *Immediately following the fire, the forest floor and moss layers have been greatly reduced by burning, and the shading effect of the evergreen spruce canopy is removed. More sunlight reaches the forest floor, increasing soil temperatures and causing a retreat of permafrost to lower levels during the growing season. This increase in available soil volume interacts with higher temperatures to increase mineralization rate of soil organic matter, further increasing nutrient availability above that already caused by the deposition of ash. (Aber and Melillo, 1991: 285)*

A study was performed in Alaska to document the different stages of vegetative postfire succession (Van Cleve *et al.*, 1986). As in most areas of the boreal forest, fire is a common component of the Alaskan boreal forest. The dominant tree species are black spruce (*Picea mariana* [Mill.] BSP) and white spruce (*Picea glauca* (Moench) Voss) (Aber and Melillo, 1991). In Alaska, the fire rotation period, which is the number of years necessary to burn at least one time an entire area (Payette *et al.*, 1989), is approximately 100 years. *Picea mariana* seedlings are present immediately after fire due to input from serotinous cones. Deciduous species tend to increase after a fire, as the enriched soil tends to favour the growth of aspen (*Populus tremuloides* Michx.) and paper birch (*Betula papyrifera* Marsh). *Populus tremuloides* establishes quickly after fire, primarily because of its ability to reproduce by root suckering, which originates from adventitious buds on roots of the residual and cut trees (Kramer and Kozlowski, 1979; West *et al.*, 1981; Greene *et al.*, 1999), but also due to its light, well-dispersed seeds.

As a result of a fire, there is a shift in resource availability as well as species composition. Since *Picea mariana* and *P. glauca* are more shade-tolerant than *Populus tremuloides* and *Betula papyrifera*, their relative importance increases through time. This leads to a decrease in average annual soil temperatures because of the shading by the evergreen foliage. Decay rates of the soil begin to decline as the litter of *Picea mariana* and *P. glauca*, which is high in lignin content, becomes increasingly thick. Diminishing decay will eventually lead to an increase in forest-floor litter depth and organic matter content. In addition, lower soil temperatures lead to slower mineralization rates. Declining soil temperatures cause more shallow active layer depths, which restrict access to nutrients frozen in permafrost and drainage of water from the soil. As a result, the higher amount of water in the soil requires a larger amount of energy to raise its temperatures, thus further decreasing the mean soil temperature. Feathermosses and then *Sphagnum* moss tend to grow as a result of higher soil water content, further insulating the forest floor and reducing soil temperatures. These competitive species effectively reduce the relative dominance of *Picea mariana*. At this stage, the large accumulations of organic matter over the mineral soil surface make the stand susceptible to fire during dry periods (Aber and Melillo, 1991).

The above description is a general outline of the successional pathway that takes place in the boreal forest based on an extensive study peformed in Alaska. It details both the ecosystem and population level response to fire. Moreover, the particular nature of the population level succession may vary from place to place and this would depend on site-specific characteristics, relief, dominant species and climate.

Several studies have been performed in the northern boreal forest of Canada to determine the postfire recovery sequences of the vegetation (Bergerud, 1971; Shafi and Yarranton, 1973; Maikawa and Kershaw, 1976). The results have demonstrated some different trends in terms of rates of recovery and type of species involved in the successional sequence.

Two studies were performed in Alaska to establish differences in postfire succession at the landscape level (Van Cleve and Viereck, 1981; Foote, 1983). They have identified the overall postfire successional regime in this region: an initial stage with minimal establishment of moss and herbs on the newly burned soil, followed by a deciduous tree stage, and ending with a dominant spruce phase (Table 1). The main difference between the successional sequences of *Picea mariana* and *P. glauca* dominated forests is that *P. glauca* takes a longer period to dominate the stand than does *P. mariana*.

Table 1. Postfire successional stages in Alaska, USA. (Dyrness *et al.*, 1986)

Years	White spruce sites	Years	Black spruce sites
0-1	Newly burned	0-1	Newly burned
1-5	Moss-herb	1-5	Moss-herb
3-30	Tall shrub-sapling	5-30	Tall shrub-sapling
26-45	Dense tree	30-55	Dense tree
46-150	Hardwood	55-90	Hardwood-spruce mix
150-300+	Spruce	90-200+	Spruce

At treeline in northern Quebec, the dominant tree species is *Picea mariana* and the fire rotation period is estimated at 100 years (Morisset and Payette, 1983; Payette *et al.*, 1989). The stages of succession are similar to those in Alaska, even given the absence of *Picea glauca* (Morneau and Payette, 1989). *Picea mariana* regeneration begins 1-3 years after fire, and reproduction occurs for 20-25 years, with a peak establishment occurring 5 to 14 years after fire. The most important vegetational changes in species abundance occur during the first 100 years. Succession in Quebec differs from that in Alaska in that the overall postfire sequence eventually leads to the development of *Cladina stellaris* (lichen) – *Picea mariana* woodlands, rather than a feathermoss forest. Shade tolerance and longetivity of the constituent tree species, canopy closure and time-since fire are important factors driving successional processes after the initial stage of establishment (Taylor, *et al.*, 1987; Bergeron and Dubuc, 1989; Morneau and Payette, 1989).

Studies in *Picea mariana* dominated forests in the Northwest Territories and Labrador suggest a slower successional pattern. Maikawa and Kershaw (1976) estimated a 60-year period before significant *Picea mariana* seedling established in the Northwest

Territories. In southeastern Labrador, succession is slow but progressive, with tree establishment commencing immediately after fire. However, most regeneration occurring only on 20- and 30-year-old burns (Foster, 1985). One similarity of these two studies to the situation in Alaska is that as the tree canopy closes in over time (>150 years), the lichen ground cover is replaced by moss (Maikawa and Kershaw, 1976; Foster, 1985).

1.2 Species and site variability

Studies have shown similarities in the successional sequence among the various parts of the North American boreal forest (Maikawa and Kershaw, 1976; Van Cleve and Viereck, 1981; Foote, 1983; Foster, 1985; Payette *et al.*, 1989). In spite of regional differences in the environment and community composition, the general pattern of vegetation recovery after fire is relatively similar. All of these studies have been performed in areas where the dominant species are both *Picea mariana* and *P. glauca*, or *P. mariana* alone. In the southwest Yukon, *Picea glauca* is the only conifer species in this relatively dry area of the boreal forest. Several trees characteristic of the North American boreal forest, including *Picea mariana*, larch (*Larix laricina* (Du Roi) K. Koch), *Betula papyrifera* and lodgepole pine (*Pinus contorta* Dougl. Ex Loud var.) are rare or absent in the southwest Yukon. Moreover, given the similarities among boreal forest succession across large areas it would be expected that the southwest Yukon would undergo a braodly similar successional sequence, in spite of the differences in plant community composition.

In addition to species diversity, the postfire successional sequence may be affected by site-specific differences. Donnegan and Rebertus (1999) performed a study in a subalpine zone, and found that rates and patterns of succession vary dramatically depending on the site. For example, they found that rates of succession on mesic lower slopes or sites with north aspects are twice those on south-facing slopes. Sirois and Payette (1989) found differences in the age structures of the dominant species on hill and lowland sites. In addition to having a faster rate of regeneration on hill sites, the seedling population was established by the 11th year following fire, whereas on lowland sites, it required 17 years. Thus, microsite differences may affect the postfire successional sequence of a specific location. Hence, it is imperative that a study of succession utilizes sites with homogeneous physical characteristics and that they be located in a region undergoing a similar climatic regime.

1.3 Effects of fire on *Picea glauca* and *Picea mariana*

Picea glauca and *P. mariana* react differently in the presence of fire (Scotter, 1972). *Picea glauca* has thin, easily damaged bark, is shallow-rooted and has branches that often extend nearly to the ground. This species is not particularly fire resistant, and its characteristics render it highly vulnerable to surface fires. *Picea glauca* is at a disadvantage relative to *P. mariana* because it does not bear seed at an early age. The cones of *Picea glauca* open at maturity at which time the seeds are disseminated. *Picea glauca* has neither serotinous cones, which retain seeds for several years and render a species more adaptive to fire, nor can it reproduce effectively vegetatively or by root suckering (Stewart *et al.*, 1998; Greene and Johnson, 2000).

Picea mariana on the other hand, has serotinous cones, which open due to the heat of a forest fire, releasing the seeds and permitting early establishment (Johnson, 1981). On upland sites, *Picea mariana* may be as susceptible to destruction by fire as

Picea glauca. However, on lowland sites *P. mariana* trees are more likely to survive on a variable landscape containing both upland and lowland areas, ensuring a continuing source of seed to restock burned-over areas. In addition, the seed supply is located in the upper part of tree crowns, and is seldom completely consumed by fire. In contrast to *Picea glauca*, *P. mariana* seed production appears to start earlier and is more regular.

> In general, *"[Picea mariana] is better adapted to recurring fire than [Picea glauca] because it produces seed at an earlier age and retains it for several years in semi-closed cones. Certain deciduous species such as Populus tremuloides, and Betula papyrifera, tend to dominate immediately after fire, however, [Picea glauca] is more shade tolerant, which enables it to dominate the canopy over a longer period of time. These characteristics plus its ability to reproduce vegetatively by layering, make it a persistent tree over a range of sites."* (Rowe, 1970: 252, as cited in Scotter, 1972).

1.4 Seed dispersal

Seed dispersal is one of the major factors affecting the regeneration rate of species dependent on seed to reproduce (Dix and Swan, 1971; Greene and Johnson, 1989; Stewart *et al.*, 1989). Early successional species such as *Salix* and *Populus* often produce more than 100 000 small, wind dispersed seeds per tree (Fowells, 1965). On the other hand, late-successional taxa such as *Picea* have a more irregular production, producing less than 10 000 seeds in good years (Fowells, 1965). Seeds of *Picea glauca* have been observed to disperse up to 300 metres (Nienstaedt and Zasada, 2002). The length of time for establishment of *Picea glauca* is variable but it is known to recruit immediately after fire or after only a short delay (Dix and Swan, 1971; Youngblood, 1995; Lieffers *et al.*, 1996; Galipeau *et al.*, 1997). However, Galipeau *et al.* (1997) demonstrated that the soil parent material was the main factor affecting *Picea glauca* seedling density, and that distance from seed source was only second in importance. They concluded that *Picea* *glauca* was not limited by the abundance and location of seed sources for regeneration because of its smaller, lighter seeds.

To better understand the influence of seed sources on the regeneration capacity of *Picea glauca* in this study, further research would need to be performed in each site. It is not however, the purpose of this study to determine the patterns of seed dispersal and its impact on seedling establishment.

1.5 Climate and Postfire Succession

One way of establishing the relationship between postfire succession and climate is to study the variations in tree-ring widths, using methods of dendrochronology (Cook and Kairiukstis, 1990). Tree-rings may be used as a proxy record of climate or to quantify the presence of local influences on climate in a region. Trees react to changing climatic conditions by adjusting their growth and reproductive characteristics (Brubaker, 1986). Due to their longevity, trees experience a greater number and potentially greater amplitude of climatic variations than other plants (Brubaker, 1986). A study performed in the subarctic alpine treeline of northwestern Canada found that a period of low recruitment for *Picea glauca* corresponded to trends in radial growth and reconstructed climate (Szeicz and Macdonald, 1995). This study demonstrated that stand age distributions and establishment of *Picea glauca* was episodic during the past 200 years, but that these episodes were climate-driven. There was a correlation found between low rates of successful regeneration and climate for much of the period from the late 18th century to the mid-19th century. This period of low regeneration corresponded to the culmination of the Little Ice Age cooling. Increases in *Picea glauca* recruitment during the past 150 years corresponded with increases in annual and seasonal temperatures.

Payette and Gagnon (1979) have shown that tree establishment distribution of *Picea mariana* and *Larix laricina* at sites located 150 km apart in Quebec were similar, indicating that climatic variations can be influential under conditions less severe than those at treeline.

Radial growth of the tree trunk also responds to climatic variations. For example, ponderosa pine (*Pinus ponderosa* Laws.) experienced reduced radial growth in response to the droughts in the 1920s and 1940s (Brubaker, 1980). As seen in the ring-width indices, the trees were affected by the drought but managed to resume normal growth once favorable conditions returned. Sexual reproduction of trees can also be affected by changing climatic regimes (Dobbs, 1976).

1.6 Objectives

The objective of this study is to analyse postfire succession in the boreal forest of the southwest Yukon. In particular, this study will: (1) describe the successional pathway in the region by analyzing forest stands of different ages; (2) determine whether postfire tree establishment is driven primarily by climate or by biological influences; (3) define the relationship between tree radial growth, population seedling establishment and climate; and (4) determine the climatological regime of the region using a series of chronologies.

1.7 Hypotheses

Postfire successional studies have been performed in regions where the dominant species are both *Picea mariana* and *P. glauca*, or *P. mariana* alone. In addition, these studies were performed in different geographical locations situated in different environments (Maikawa and Kershaw, 1976; Payette, 1976; Foster, 1985; Van Cleve *et* *al.*, 1986). The Alaska study was performed in a high-latitude, mountainous environment with a continental climate (Van Cleve *et al.*, 1986). The study site in Labrador was located in a wet, coastal environment (average annual precipitation of 1100 mm), with many of the important boreal forest species absent or uncommon (Jack pine (*Pinus banksiana* Lamb), *Picea glauca*, *Populus tremuloides*, and *Populus balsamifera*) (Foster, 1985). The studies performed in Quebec were in low-elevation (average 225 m) sites, with a more humid (average annual precipitation of ca. 500 mm), yet cold environment (Morneau and Payette, 1989; Sirois and Payette, 1989). The study performed in the Northwest Territories was located in a dry region (average annual precipitation 300 mm), with the presence of common boreal species such as *Picea mariana* and *Betula papyrifera* (Maikawa and Kershaw, 1976).

Nevertheless, the rate and sequence of postfire vegetation recovery in these different parts of the boreal forest have shown many similarities in spite of differences in species composition and site characteristics. Thus, in the Shakwak Trench, Yukon Territory, *Picea glauca* dominated forests should follow comparable patterns of postfire succession.

These regions showing similar postfire successional regimes differ in terms of their environment but also in terms of their climate. Their postfire regime is however, quite similar, which suggests that it is not the climate that is the primary factor driving succession but rather the biological characteristics of the trees. Under the assumption that postfire succession in the Shakwak Trench will be similar to other parts of the boreal forest, the stages should not be affected by the climate of the region. Thus, biological influences of the regeneration capacity of trees after fire will govern these stages of succession.

Chronologies are often developed from trees located where climatic factors greatly affect tree-ring variability (Cook and Kairiukstis, 1990). However, trees growing under favorable climatic conditions can also carry reliable climatic information (Cook and Kairiukstis, 1990). The chronologies developed in this study were derived from low-lying sites, with optimal tree-growth conditions.

Three hypotheses will be explored in this study:

H_1: Postfire succession in the Shakwak Trench depicts similar patterns to those found in other regions of the Canadian boreal forest.

H_2: Biological influences govern the rate of postfire succession in the Shakwak Trench, southwest Yukon Territory.

H_3: Trees growing on relatively favorable sites in the boreal forest show variations in growth rates due to climate causes.

1.8 Significance of study

Francis (1996) explored the fire history of the Shakwak Trench, with special emphasis on the spatial occurrence of fire and its effect at the landscape level. The study determined that certain locations in the Shakwak Trench have escaped fire for long periods of time while others have burned frequently. This spatial pattern of disturbance greatly affects the forest age-class distribution (Francis, 1996). However, the recovery of vegetation after fire was not explored in this study. In fact, plant succession after fire in the boreal forest has received much less attention than studies of tree growth. A dendroecological study of the regeneration of species after fire has yet to be performed in Yukon Territory. Given the importance of fire as a dominant disturbance factor in this region, it is essential to ascertain its impact at the landscape level. This is the purpose of this study.

Dendrochronological techniques have been used as a method of climate reconstructions in several regions of the subarctic and at different landscape levels (Jacoby and Cook, 1981; Jacoby *et al.*, 1985; Briffa *et al.*, 1992; Szeicz and MacDonald, 1995). However, reconstructions have not yet been published from several sites in the Shakwak Trench, southwest Yukon Territory. The results of this study could be used in comparison with other dendrochronological studies performed in the Yukon, Alaska and Northwest Territories (Oswalt, 1958; Jacoby and Cook, 1981; Allen, 1982; Cropper, 1984). More specifically, chronologies developed from the Shakwak Trench may provide insight into the relation between tree growth and climate, and may explain patterns found in the establishment of *Picea glauca* individuals. Further, the chronologies developed here are obtained from interior forest sites, not specifically selected for paleoclimate sensitivity. This study will contribute to our understanding of climate change impacts on tree growth and establishment in "typical" boreal forest environments.

This region has been the focus of a collaborative study that has attempted to determine the dynamics of a forest ecosystem on a short-term, experimental level (Krebs *et al.*, 2001). The present study can contribute to our understanding of this complex ecosystem by providing researchers with a more quantitative analysis of the successional dynamics of the vegetation in the Shakwak Trench, thus extending the spatio-temporal side of the Kluane Lake study (Krebs *et al.*, 2001).

On a more general level, ecological managers require a general understanding of the patterns of vegetation recovery after a large-scale disturbance event. Thus, an awareness of stand dynamics and successional differences between different regions will better enable forest managers to choose the most appropriate silvicultural options and forest regeneration strategies, to meet management objectives throughout the boreal forest.

CHAPTER TWO:
Study site description

2.0 Site Selection

A total of 11 sites in the Shakwak Trench were selected to obtain a temporal sequence of the postfire succession (Figure 1). The fire history of a portion of the Shakwak Trench has been studied by Francis (1996) and formed the basis for the selection of sites 1-7. These sites are all located in the valley bottom within an area of approximately 480 km^2, within the three 1:50 000 NTS map sheets 115 A/13, 115 B/16 and 115 G/1. In addition to their relative accessibility, these fire sites were chosen according to the date they burned, so as to obtain stands in several stages of succession. The largest fires were also selected to ensure that the plot was properly located within the limits of the fire and to avoid the edge. The most recent fire in the Shakwak Trench is dated as 1930.

Table 2 contains the date when the study plots last burned. It was evident as a result of this study that four of the areas obtained from Francis (1996) were not correctly dated or properly situated. For these sites, the age of the fire was approximated, based on the year of the first tree established in the plot. To obtain sites in earlier stages of succession, recently burned regions were identified by J. Jennings, Resource Management Officer (personal communication, DIAND, Haines Junction, 2002). Fire sites 8-11 are all located further south along the Alaska Highway on the 1:250 000 NTS map sheet 115A. The presence of charcoal in the soil and fire scarred stumps in each fire site confirmed that a fire had occurred. Figures 2-17 are photos taken of each site in this study.

Figure 1. Location map of the 11 sites in the Shakwak Trench, Yukon Territory.

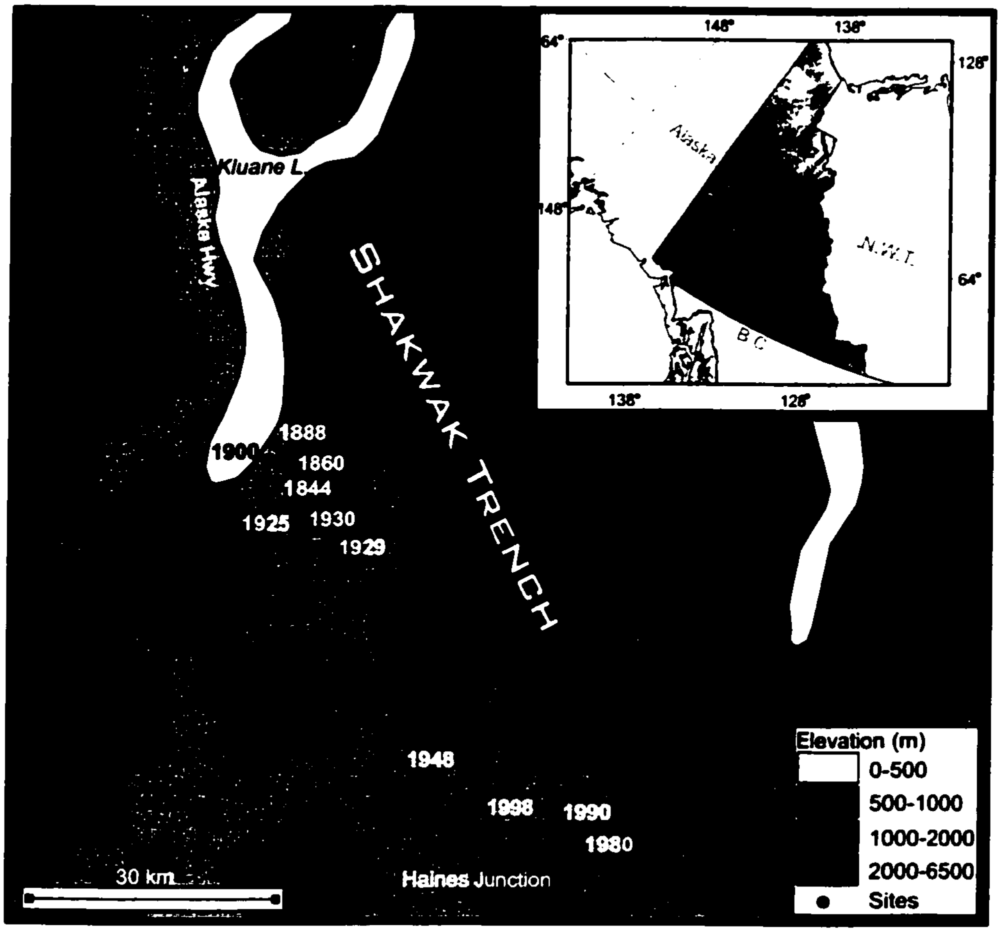


Table 2. Age of fires in the study site.

Fire	Estimated age of fire	Real age of fire
1	1806	1860*
2	1820	1900*
3	1844	1844
4	1888	1888
5	1906	1925*
6	1929	1929
7	1948	1948
8	1956	1930*
9	1980	1980
10	1990	1990
11	1998	1998

*Estimated age based on age structure analysis

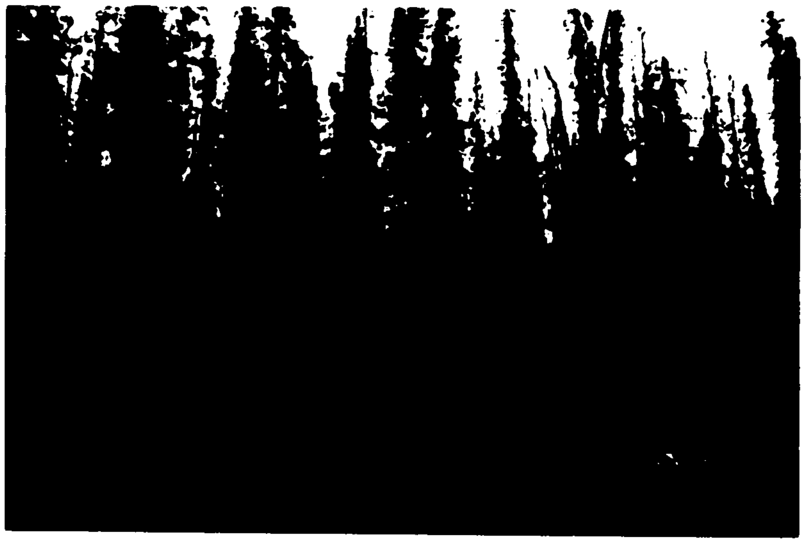


Figure 2. View of 1844 fire from Jenny Lake

Figure 3. Plot 1 of 1844 fire on Jenny Lake

Figure 4. Plot 2 of 1844 fire on Jenny Lake

Figure 5. Plot 3 of 1844 fire on Jenny Lake

Figure 6. 1860 fire near Christmas Creek

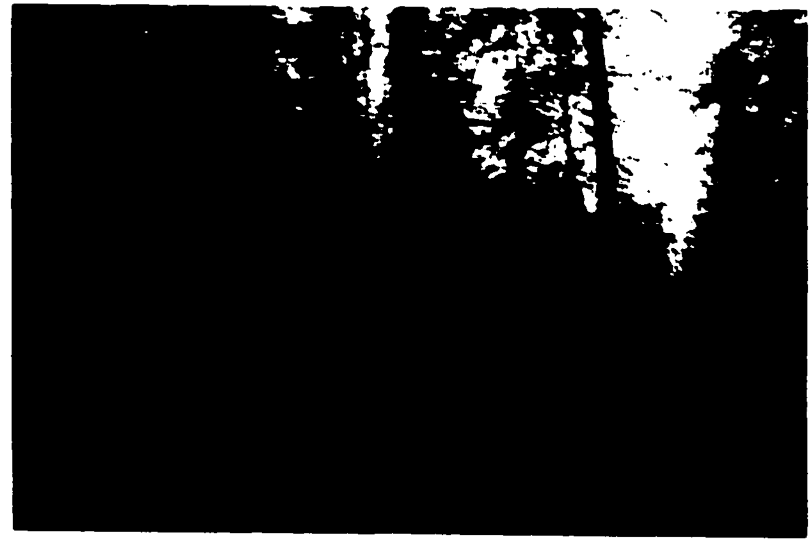


Figure 7. 1888 fire on Emerald Lake

Figure 8. 1900 fire on the Cultus Rd.

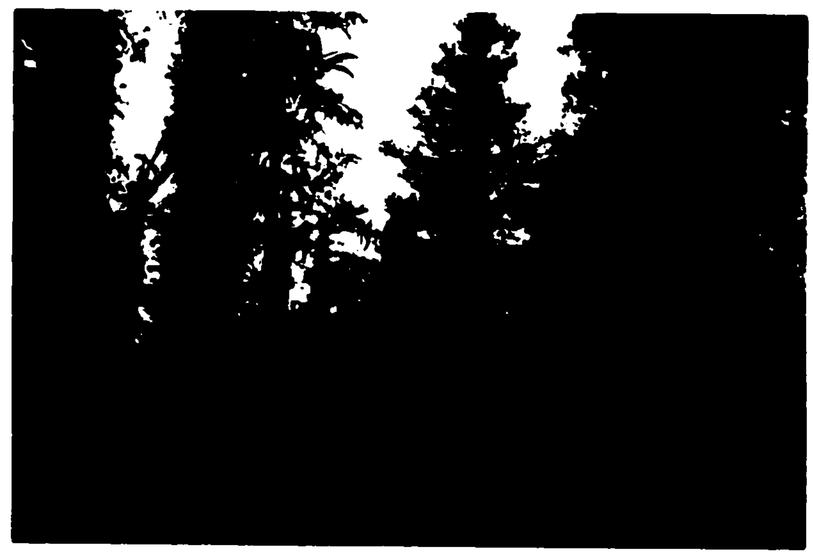


Figure 9. 1925 fire on Sulphur Lake

Figure 10. 1929 fire near Kloo Lake

Figure 11. 1930 fire on Sulphur Lake

Figure 12. 1948 fire near Haines Jct.

Figure 13. 1998 fire off the Alaska Hwy.

Figure 14. Plot 1 of the 1980 fire on the Aishihik rd.

Figure 15. Plot 2 of the 1980 fire on the Aishihik rd.

Figure 16. Plot 1 of the 1990 fire on the Aishihik rd.

Figure 17. Plot 2 of the 1990 fire on the Aishihik rd.

2.1 Site characteristics

The study sites are located within the Shakwak Trench (Figure 1), a northwest-southeast trending valley near Kluane Lake. The Shakwak Trench is adjacent to the St. Elias Mountains of the Kluane National Park and Park Reserve.

The site characteristics do not differ greatly between the study plots, with the exception of the 1888 site, which has a higher slope (Table 3) and the numbers and type of species of trees vary (Table 4). Grain size analysis of one soil sample and loss-on-ignition of the litter layer were measured in each plot to characterize the soil environment of the study region. These results were grouped by region: Cultus region (1844, 1860, 1888, and 1900 fires), Sulphur/Kloo Lake region (1925, 1929, 1930 and 1948 fires), and Haines Junction region (1980, 1990, and 1998 fires) (Figures 18, 19, and 20).

The organic layer is relatively uniform across the region, with the exception of the 1888 fire, where a steep slope prevents the accumulation of a thick organic layer (Figure 20). As expected, there was an accumulation of organic matter through time (Foster, 1985), with the exception of the 1998 fire. The high amount of litter and understory still remaining on the forest floor of the 1998 fire, suggests that it was most likely a light fire (Zasada, 1986), and as a result, the organic layer present before the fire was not entirely consumed.

The soils are dominated by sands and fines for all plots in the study site (Figure 18). Replicate samples were analysed in each of three plots (1844P1, 1860, 1900) to quantify the within-plot variability (Figure 19 and 21). The results show that the between-site variability of these three sites is not significant, suggesting that the soil environment is similar, at least within any one region.

Table 3. Site characteristics for plots located in the Shakwak Trench, Yukon Territory.

Fire	Location	Plot size (m)	# of Plots	Fire scars	Slope (°)	Sum of burned area (km^2)	Interval Between Fires (Years)*
1844P1	61°03'N, 138°21W	10x20	1	0	2	6	1
1844P2	61°03'N, 138°21'W	10x20	1	0	2	6	1
1844P3	61°03'N, 138°21'W	10x20	1	0	3	6	1
1860	61°03'N, 138°20'W	10x10	1	0	0	14	8
1888	61°04'N, 138°22'W	10x10	1	0	14	11	3
1900	61°04'N, 138°23'W	10x20	1	0	6	3	2
1925	60°57'N, 137°59W	10x20	1	0	0	8	1
1929	60°56'N, 137°54'W	10x20	1	0	0	7	1
1930	60°57'N, 137°57'W	10x20	1	0	5	<4ha	1
1948	60°49'N, 137°42'W	10x20	1	0	0	2	n/a
1980P1	60°52'N, 137°02'W	10x10	1	0	2	13	n/a
1980P2	60°52'N, 137°02'W	10x10	1	0	1	13	n/a
1990P1	60°52'N, 137°02'W	10x10	1	2	0	3	n/a
1990P2	60°52'N, 137°02'W	10x10	1	1	0	3	n/a
1998	60°50'N, 137°20'W	10x20	1	5	0	37	n/a

Fire	Orientation	Height of canopy (m)	Elevation (m)	Canopy type
1844P1	E-W	10	2700	closed
1844P2	E-W	10	2700	closed
1844P3	E-W	10	2700	closed
1860	N-S	12	2800	closed
1888	N-S	10	2700	closed
1900	E-W	12	2700	closed
1925	E-W	6	2800	closed
1929	N-S	6	2800	open
1930	N-S	6	2800	open
1948	E-W	4	2500	open
1980P1	E-W	2	2500	open
1980P2	E-W	1	2500	open
1990P1	E-W	2	2500	open
1990P2	N-S	2	2500	open
1998	E-W	2	2500	open

The location of the plots was determined using a Global Positioning System.
The elevation of the plots was determined using topographical maps.
Note: * interval between fires was obtained from Francis (1996).

Table 4. Number of trees in plots located in the Shakwak Trench, Yukon Territory.

Fire	Number of trees			
	Picea glauca	***Populus tremuloides***	***Salix* spp.**	***Populus tremuloides***
1844P1	*89	0	+	0
1844P2	167	0	+	0
1844P3	*50	0	+	0
1855	72	0	1	0
1888	68	0	1	0
1895	56	0	0	0
1920	20	0	20	0
1929	56	0	100	0
1935	343	0	84	0
1948	190	0	120	1
1980P1	7	85	0	0
1980P2	51	28	0	0
1990P1	125	62	0	0
1990P2	10	47	0	0
1998	27	0	48	0

Note: * *P. glauca* seedlings were present but were not analyzed; + were present but were analyzed.

Figure 18. Grain size analysis of sites in the Shakwak Trench, Yukon Territory.

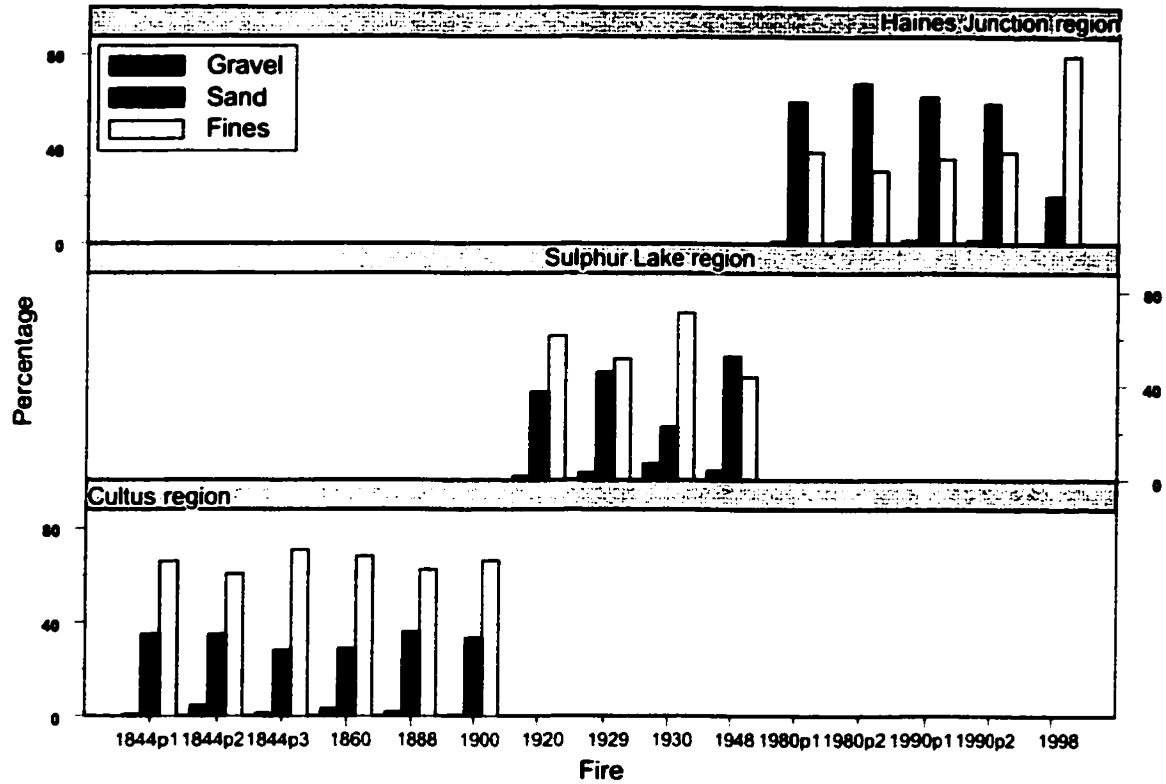


Figure 19. Grain size analysis of replicate samples in the Cultus region, Yukon Territory.

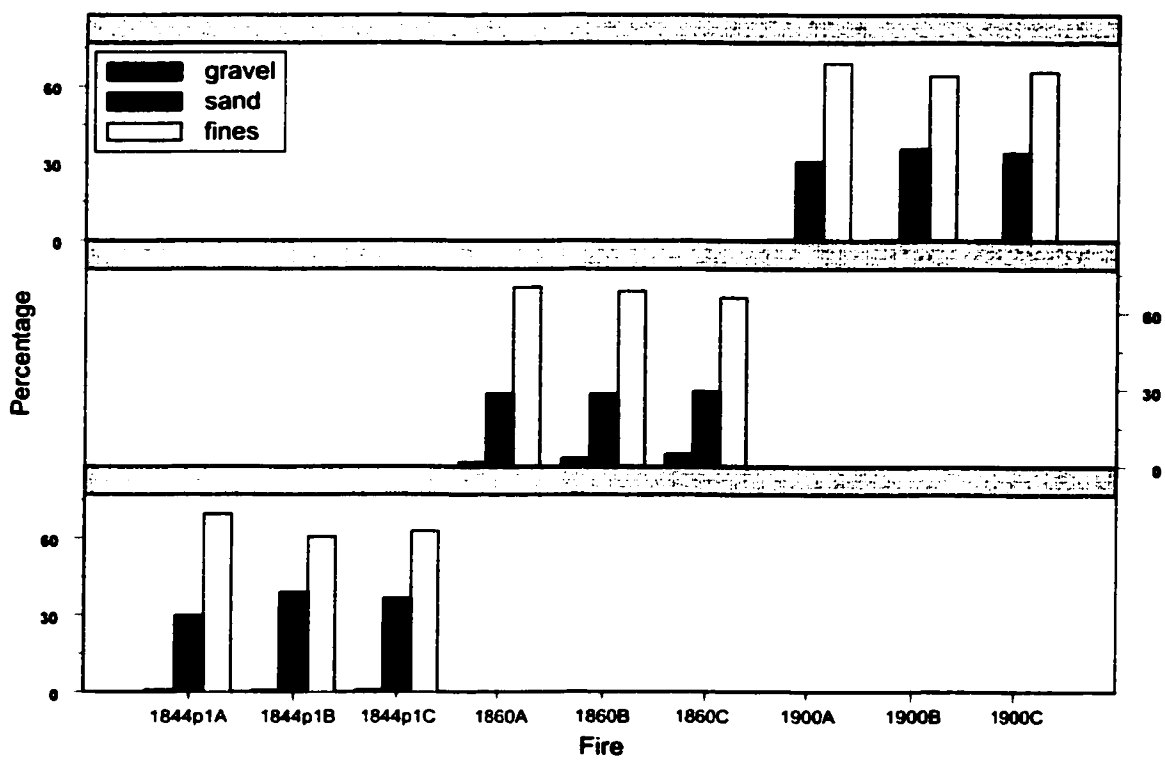


Figure 20. Percentage of organic material (Loss-on-ignition) on fires of increasing age plotted by region in the Shakwak Trench, Yukon Territory.

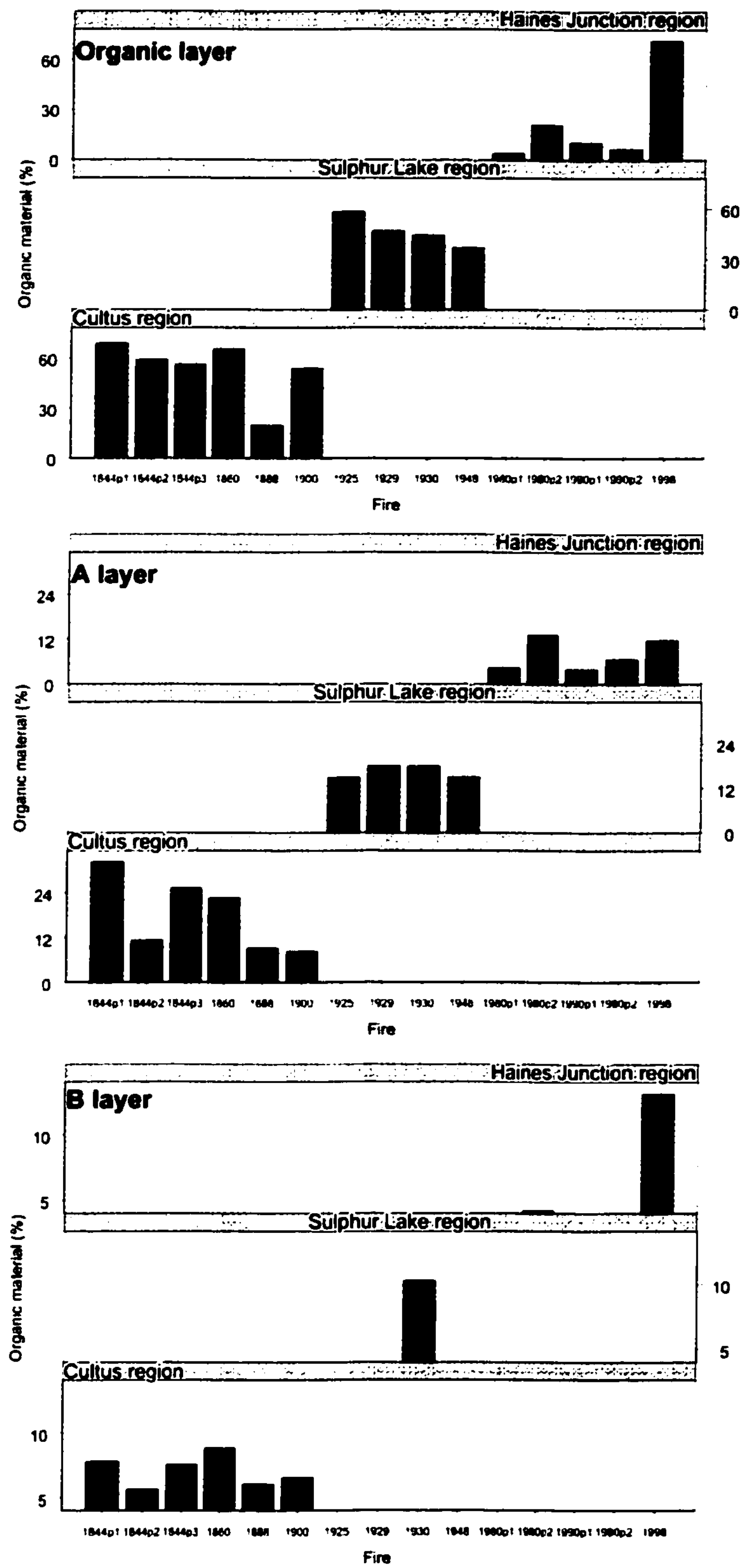
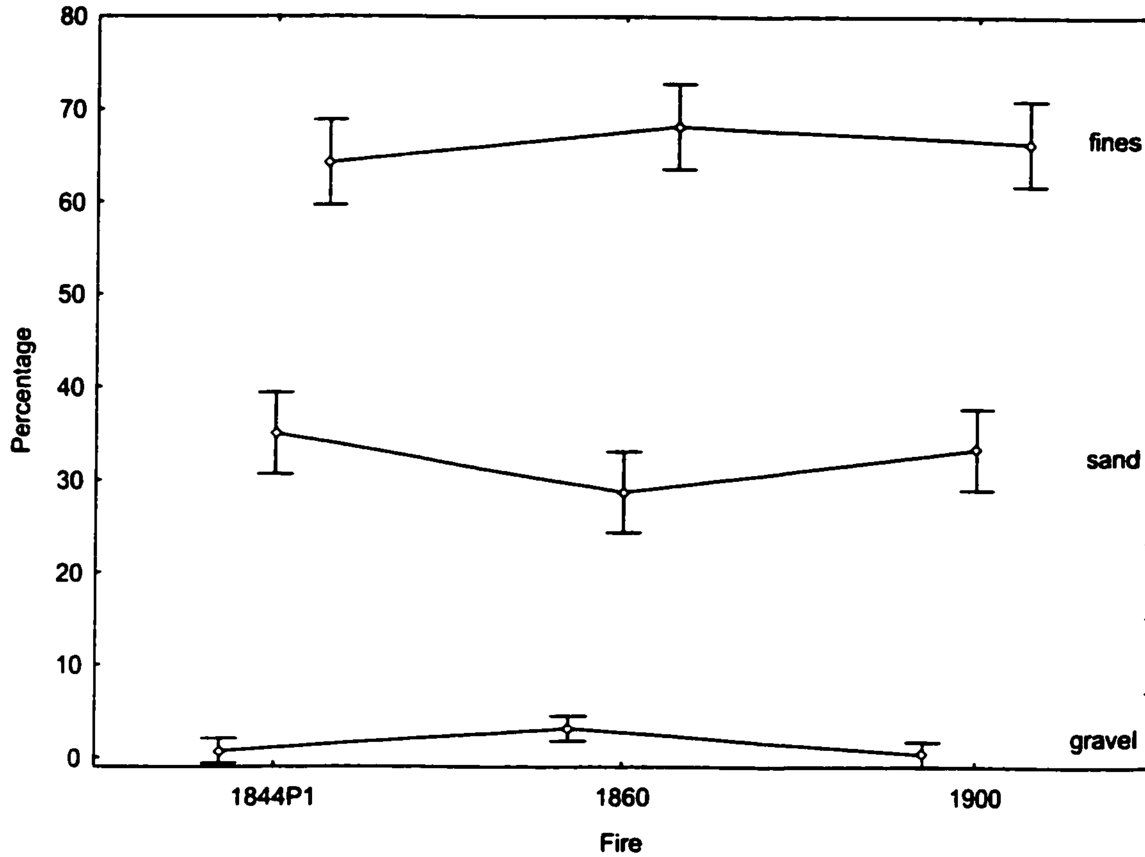


Figure 21. Between site variability of replicate soil analysis from three fires in the Shakwak Trench, Yukon Territory.



Understory vegetation was sampled at each plot to determine the changes in vegetation in each stage of postfire succession. The most significant change in the understory occurs after approximately 100 years, at which time the species richness begins to decline and feathermosses begin to dominate (Table A1-A5, Appendix A). See section 3.1 for the methodology associated with understory sampling.

2.2 Climate

As a result of the proximity of high elevation mountain ranges and alpine glaciers, the climatic conditions in the Kluane Lake region are diverse (Krebs and Boonstra, 2001). The region is in the rain shadow of the St. Elias Mountains. It is located at the transition of the cold, dry Arctic and the warm Pacific air mass, and displays strong seasonal cycles.

The region experiences short, cool summers and long, cold winters with mean January and July temperatures of ca. -20°C and ca. 12°C, respectively (Haines Junction weather station, Figure 22). Total annual precipitation is low, with an average of 315 mm, (Haines Junction), consisting mostly of rain during the summer months (Figure 23). Three climate stations, Burwash Landing, Haines Junction and Whitehorse Airport show similar trends in seasonal temperature and precipitation since the 1940's. Precipitation data is more dissimilar between the three stations, which is not surprising since it is an intermittent phenomenon and is more influenced by topographic factors. In general, Whitehorse tends to be warmer, nevertheless the stations are all highly correlated. In spite of higher interannual variability, the stations tend to be highly correlated for precipitation as well.

Figure 22. Seasonal temperatures derived from mean monthly data for Haines Junction, Whitehorse Airport and Burwash Landing. Source: Meteorological Service of Canada (MSC website).

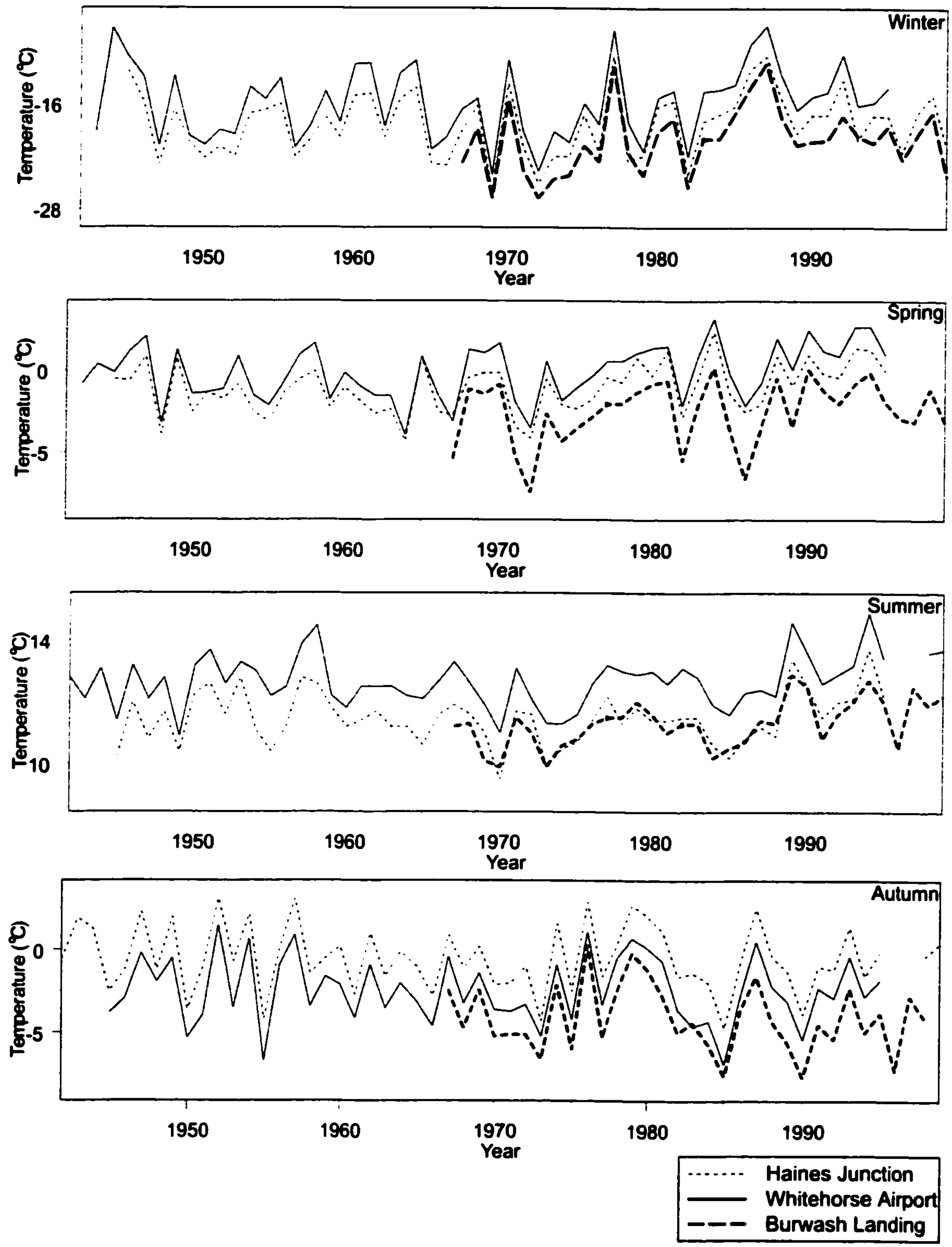
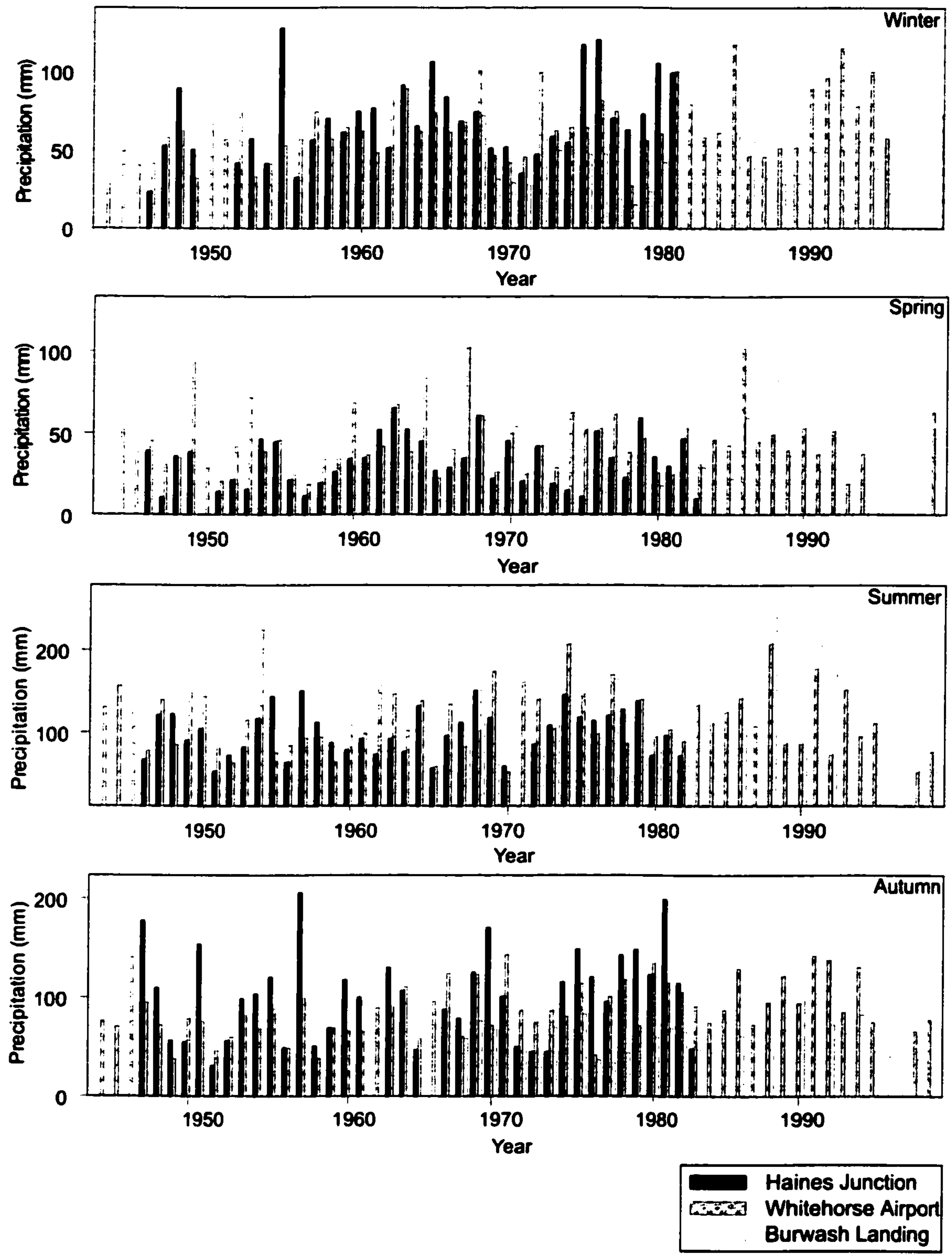


Figure 23. Seasonal precipitation derived from monthly totals for Haines Junction, Whitehorse Airport, and Burwash Landing. Source: Meteorological Service of Canada (MSC website).



2.3 Vegetation

The vegetation of the study area has been described by Rowe (1972) as dominated by *Picea glauca*, *Populus tremuloides* and balsam poplar (*Populus balsamifera* L.), with shrub-dominated areas of willow (*Salix* spp.) and dwarf birch (*Betula glandulosa* Michx.). Typical species of the boreal forest such as *Larix laricina*, *Pinus contorta*, *Picea mariana*, and *Betula papyrifera* are absent from the study area but occur approximately 200 km northwest and southeast of the Kluane region (Krebs and Boonstra, 2001). The *Picea glauca* dominated forests that occupy the landscape today established about 8000 years B.P. (Stuart *et al.*, 1989; Lacourse and Gajewski, 2000; Krebs and Boonstra, 2001).

The vegetation can be divided into three ecological zones based on elevation (Douglas, 1974): montane valley-bottom forests (760-1080 m), subalpine forests (1080-1370 m), and alpine tundra (above 1370 m). This study focused on montane and subalpine forest communities. The Shakwak Trench is dominated by young stands in various stages of succession. Fire is the main cause of the spatial heterogeneous character of the vegetation.

CHAPTER THREE:
Methodology

3.0 Methodology

To study the postfire succession in the boreal forest of the southwest Yukon, 11 fires were sampled, ranging in age from 4 years to 156 years. Knowing the date of the fire is necessary to determine the time that has elapsed since the last major disturbance (fire), which destroyed the stand and initiated succession (Romme, 1977).

3.1 Forest composition

For each fire, a plot was established and a detailed dendroecological analysis performed. Plot location was selected to be representative of the area. The size of the plots was either 10 by 20 m or 10 by 10 m depending on the density of the trees.

In each plot, all living trees >2 m in height were tagged and mapped. Distance to the nearest neighbor was measured, and the diameter at breast height (d.b.h.) recorded. All trees with a d.b.h. <30 cm, as well as all saplings and seedlings were cut at the base. The remaining trees were cored (see section 3.21).

Three replicate plots of 10 by 20 m were taken from the 1844 fire to determine whether one plot is representative of a site. The first two plots were located side by side on the edge of the fire and the third plot was located further from the edge of the fire. Two 10 by 10 m plots were taken of the 1980 and 1990 fires; one was taken near a seed source and the other was further away to quantify the effects of proximity to seed source.

Seven physical site characteristics were recorded for each fire site: geographical location, slope, aspect, height of canopy, type of canopy (open/closed), and presence of spruce beetle killed trees and dead willow trees. Understory vegetation was sampled in three 1 by 1 m quadrats for each fire site, randomly located to be representative of the vegetation. In addition, plants were collected in the region of each site. The soil was characterized by measuring the depth of the organic layer and subsequent layers, noting the presence and depth of soil charcoal. In the lab, loss-on-ignition (LOI) and grain-size were analysed. The LOI was performed on each layer to determine the percentage of organic content (Gale and Hoare, 1991). The grain-size analysis on the lowest soil layer was used to determine the dominant soil type (gravel, sands, fines) for each fire site (Gale and Hoare, 1991). To ensure reproducibility, replicate samples were analysed and demonstrated that the between-site variability of the grain-size analysis does not vary significantly in any one region. Three replicates of three fire soil pits (1844P1, 1860, and 1900) were used.

3.2 Dendrochronological analysis

3.21 Coring

Two increment cores (90° to each other) were extracted from the base of each tree with a d.b.h. >30 cm (approximately 30 cm above the ground), to obtain the most accurate age. Since growth of the tree begins at the root system, a core taken above the base may have a much younger estimated age than one taken directly at ground level (McCarthy *et al.*, 1991).

The Swedish increment borers that were used are 5 mm in diameter, and consist of a double-helix screwthread to penetrate the tree and an extractor spoon to extract the core (Stokes and Smiley, 1968; Fritts, 1976; Schweingruber, 1988). The borer is designed to remove a small core from a living tree or stump without harming it. Only under extreme conditions can parasites or other fungi enter the bore hole to cause damage (Stokes and Smiley, 1968).

The cores were left to dry for a few days, after which they were glued vertically into a groove in a wooden block using a water-soluble glue (carpenter glue). Cores were secured to the wooden block with string, as they tend to curve up during the drying process. The cores were left overnight to dry, at which time they were ready to be sanded (Stokes and Smiley, 1968). The cores and cross-sections were sanded using three progressively finer grades of sandpaper.

3.22 Dating the cores using crossdating

Dendroecological techniques are used to determine the age structure of the fire sites (Abrams *et al.*, 1995). The estimated year of establishment for each tree was determined for each stem based on the time of sampling (July-August 2001) (Szeicz and Macdonald, 1995).

The first step is to use skeleton plots of the tree-ring sequences to identify rings with unusual (very large or small) growth. These plots are used to relate a group of cores to each other by pattern matching (Stokes and Smiley, 1968). Narrow rings are recorded as they occur on strips of graph paper with 2 mm divisions. The width of each ring is compared to that of the rings on either side of it; a long vertical line is drawn where a ring is considerably narrower than its neighbor, and a shorter line when it is only slightly narrower. The oldest cores are crossdated to all other cores in order to formulate a master chronology (Stokes and Smiley, 1968).

Problems may arise when missing, locally absent or false rings are present. A ring is normally formed every growing season, but in some years of unfavorable climatic conditions, a tree may not develop an annual ring (missing ring; Stokes and Smiley, 1968). In other circumstances, a ring may be absent at some point on the tree, and therefore is only seen when a cross-section of the tree is taken (locally absent). False rings may also occur during a favorable growing season, whereby two rings are formed. For example, a tree will develop an annual ring in a normal growing season, but then favorable climatic conditions allow the tree to grow again and as a result, form a new ring. This second annual ring is considered the false ring. These missing, locally absent, and false rings can be detected by crossdating several trees from the same plot or region.

3.23 Age structure analysis

Once the age of each tree in all sites is determined, the age-class distribution of each species was computed for each fire site. Age structures are records of both establishment and subsequent survival to the time of sampling (Szeicz and Macdonald, 1995). Thus, a lack of trees in a certain age-class may be the result of a lack of establishment at that time, high mortality rates, or a combination of these factors (Whipple and Dix, 1979). Cores that did not reach the pith were excluded from the age structure analysis.

If the *Picea glauca* trees in a stand are even-aged, they probably reinvaded shortly after the disturbance, which means that their average age is the age of the fire (Bergeron *et al.*, 1998). In contrast, an area subject to forest fires that burn smaller individual stands will have a completely different age class distribution (Bergeron *et al.*, 1998). Assuming that the probability of burning is independent of stand age, the age class distribution of the burned area will follow a negative exponential distribution, with nearly 37% of the stands older than the fire cycle (Van Wagner, 1978).

3.24 Radial growth analysis

To compute a chronology based on tree rings (see section 3.3), the width of each ring must be measured. Annual growth rings were measured using a Mini-scale and Mate System Encoder connected to an AcuRite III digital counter with a precision of 0.001 mm. The accuracy of crossdating is verified using the computer program COFECHA (Grissino-Mayer *et al.*, 1992).

3.3 Chronology development using Principal Components Analysis

Standard methods of chronology development, as outlined by Fritts (1976), have been used in many studies to determine the climate signal expressed in tree-rings. Principal Components Analysis (PCA) has been used as an alternate method of chronology-building (Jacoby and Cook, 1981; Peters *et al.*, 1981; Enright, 1984). Using PCA for chronology development has both advantages and disadvantages. The main advantage of performing a PCA before computing a standard chronology is that the PCA extracts the dominant covariation in the ring-width series. That is, there may be a few trees that are not highly correlated with the first few components, which are presumed to contain the climate signal. The trees not loading on the first few components are presumed to be dominated by some local factor such as competition, and the difference in the ring-width series may cause it to be more highly correlated with a subsequent component. Several studies have computed chronologies using PCA and have noted a more accurate ring-width climate relation (Peters *et al.*, 1981, Cropper, 1982). A disadvantage associated with a PCA is that the number of components to be retained for subsequent analysis is subjectively chosen, and a clear criterion determining significant components is difficult to define. In addition, the analysis is restricted to a common period of time for all trees, which may result in a shorter chronology than if it was derived using the standard methodology. In contrast, the standard chronology approach utilizes the entire record length, with both old and young trees, thus maximizing the climate information derived from all trees. For this reason, the chronologies produced in this study will be developed using standard methods. However, a PCA will be applied as a starting point for the analysis, to decide on the most appropriate method of standardizing ring-width series and to aid in identifying any outliers.

A PCA provides: (1) eigenvalues, describing the variance explained by the component; (2) component loadings, describing the correlation between the component and the original variables (tree cores in this analysis); (3) component scores, which in this case are time-series depicting the relative strength of the component through time; and, (4) the communalities, telling the proportion of variance of the original series explained by the retained components. The series most highly loaded on the first component are the most highly correlated among themselves and thus carry the common signal. Any series not found to be loaded on the first few components are removed from the chronology, as they are not contributing to the overall climate signal.

3.3.1 Principal Components Analysis for the Jenny Lake chronology

The following is an example of the application of the PCA on a tree-ring series. Similar analyses were performed on all chronologies but only the statistical results are presented in Appendix C. The Jenny Lake chronology is among the longest of the five chronologies developed in this study. Since PCA requires a common period of analysis, 37 series beginning in 1910 or earlier were used to produce a 111-year time series (1879-2000). A PCA was performed on the entire dataset (49 series) to ensure that the series with a longer record did not deviate from the common climate signal. Eight components were extracted using the criteria of retaining all components with eigenvalues ≥1 (Daultrey, 1976).

The first component of the PCA accounted for 52% of the total variance of all the ring-width series and therefore indicates that many trees at this site are highly correlated (Table 5).

Table 5. Eigenvalues derived from results of the Jenny Lake PCA.

Value	Eigenvalue	% Total Variance	Cumulative Eigenvalue	Cumulative %
1	19.26	52.04	19.26	52.04
2	7.70	20.80	26.95	72.84
3	2.20	5.95	29.15	78.79
4	1.42	3.83	30.57	82.62
5	1.13	3.07	31.70	85.68

Table 6 presents the factor loadings and communalities of the 37 series used in this analysis. The higher the value of the loading (up to 1), the more indicative is a series of the climate signal (Nachmias and Nachmias, 1987). This statement is made under the assumption that the climate signal is largescale and affects all trees in the plot in a similar manner. Almost all trees are loaded negatively on the first component, suggesting a strong climate signal in the dataset. Some of the ring-width series are loaded highly on component two, but in both negative and positive ways, suggesting that these are growth related trends and indicate variations in growth. To interpret this, the scores can be investigated below. One series (18443511) was highly loaded on factor three but not on factor one or two. The time-series plot of this tree indicates that its growth pattern was significantly different from the other trees, and as a result was removed from the chronology, although retained in the age-structure analysis.

Table 6. Communalities and factor loadings from PCA results of the ring-width series for the 1844 plot.

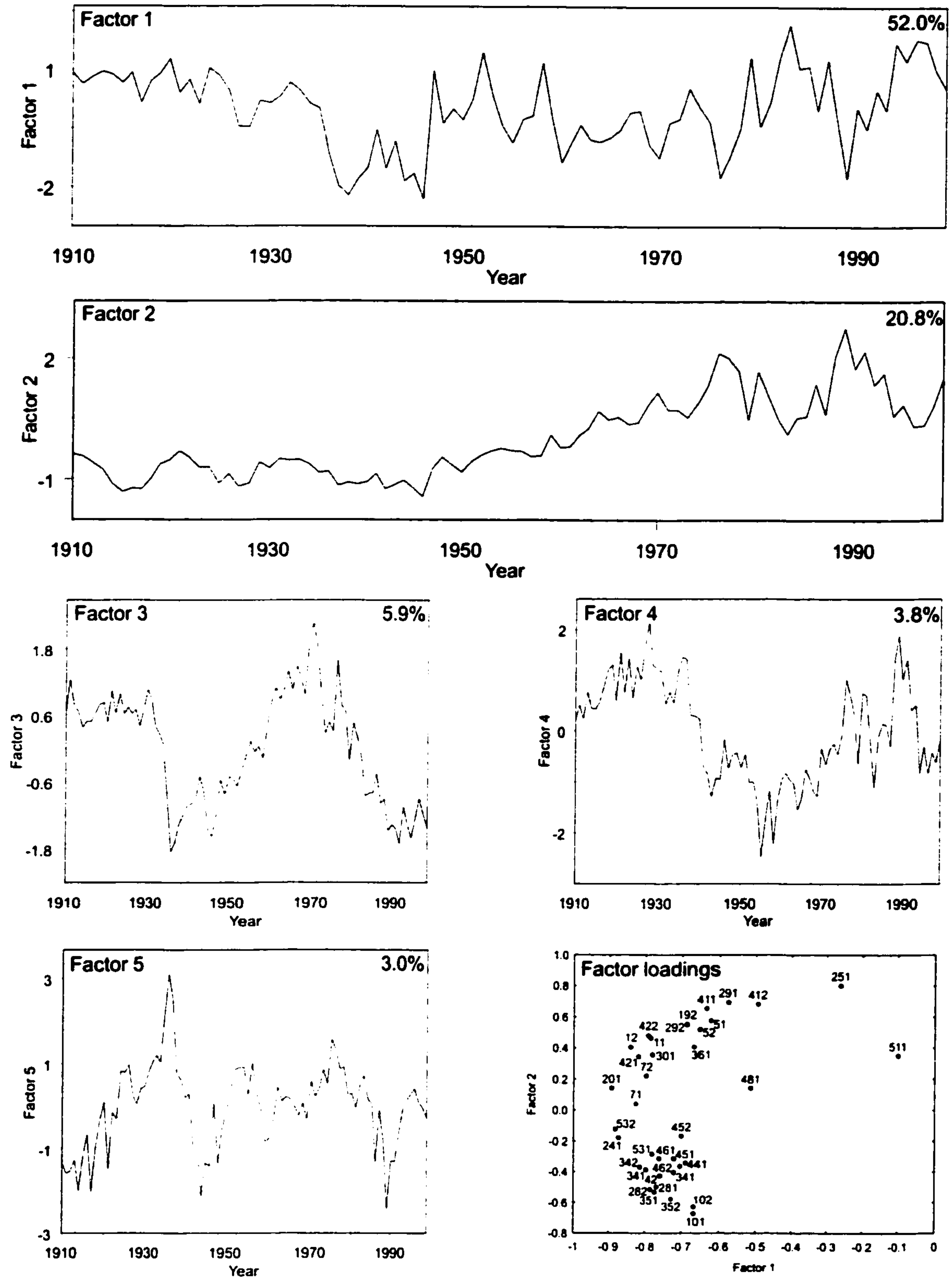
Communalities							Factor loadings				
Series	From 1 Factor	From 2 Factors	From 3 Factors	From 4 Factors	From 5 Factors	Multiple R^2	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
T18443101	0.45	0.89	0.89	0.93	0.93	0.96	-0.67	-0.67	0.01	0.18	0.03
T18443102	0.45	0.84	0.85	0.94	0.94	0.96	-0.67	-0.63	0.08	0.31	-0.03
T1844311	0.62	0.84	0.84	0.85	0.85	0.95	-0.79	0.47	0.04	-0.09	0.03
T1844312	0.71	0.88	0.88	0.89	0.91	0.96	-0.84	0.41	0.03	-0.12	0.12
T18443192	0.47	0.78	0.82	0.83	0.90	1.00	-0.69	0.56	-0.18	0.11	0.27
T18443201	0.80	0.82	0.83	0.90	0.90	0.93	-0.89	0.15	0.07	-0.27	-0.04
T1844241	0.77	0.80	0.80	0.85	0.90	0.95	-0.87	-0.18	0.09	-0.21	0.23
T18443251	0.07	0.72	0.76	0.83	0.86	0.87	-0.26	0.81	0.20	0.26	-0.17
T18443281	0.62	0.88	0.88	0.88	0.89	0.96	-0.79	-0.51	-0.06	0.00	-0.08
T18443282	0.60	0.88	0.88	0.89	0.89	0.96	-0.77	-0.53	-0.03	0.11	0.03
T18443291	0.33	0.82	0.89	0.90	0.90	0.92	-0.58	0.70	-0.26	0.09	0.08
T18443292	0.47	0.78	0.82	0.83	0.90	1.00	-0.69	0.55	-0.19	0.11	0.28
T18443301	0.61	0.74	0.75	0.80	0.90	0.93	-0.78	0.36	-0.12	-0.21	0.31
T18443341	0.64	0.78	0.79	0.82	0.82	0.97	-0.80	-0.38	0.08	-0.16	-0.02
T18443342	0.66	0.80	0.82	0.84	0.84	0.98	-0.81	-0.37	0.16	-0.11	-0.09
T18443351	0.59	0.84	0.85	0.94	0.95	0.97	-0.77	-0.49	0.12	-0.29	-0.12
T18443352	0.53	0.86	0.92	0.93	0.93	0.96	-0.73	-0.57	0.25	-0.08	-0.07
T18443361	0.45	0.62	0.62	0.86	0.86	0.92	-0.67	0.41	0.07	-0.49	-0.02
T1844341	0.52	0.68	0.69	0.75	0.75	0.86	-0.72	-0.40	-0.11	0.23	0.07
T18443411	0.40	0.84	0.84	0.84	0.86	0.95	-0.64	0.66	0.04	-0.03	-0.15
T18443412	0.25	0.72	0.80	0.80	0.85	0.95	-0.50	0.68	0.28	-0.08	-0.22
T1844342	0.58	0.76	0.79	0.83	0.83	0.90	-0.76	-0.42	-0.19	-0.19	0.00
T18443421	0.67	0.80	0.82	0.82	0.84	0.95	-0.82	0.35	-0.14	-0.05	-0.13
T18443422	0.63	0.86	0.87	0.89	0.90	0.96	-0.79	0.48	-0.08	-0.14	-0.08
T18443441	0.48	0.59	0.64	0.68	0.76	0.87	-0.69	-0.34	-0.21	0.21	-0.28
T18443451	0.52	0.62	0.86	0.86	0.87	0.92	-0.72	-0.31	0.49	-0.03	-0.09
T18443452	0.49	0.52	0.76	0.76	0.82	0.89	-0.70	-0.16	0.49	-0.03	0.24
T18443461	0.58	0.68	0.72	0.72	0.74	0.89	-0.76	-0.31	-0.19	-0.06	-0.15
T18443462	0.50	0.63	0.63	0.65	0.66	0.88	-0.70	-0.36	-0.09	-0.13	-0.10
T18443481	0.27	0.29	0.64	0.78	0.78	0.81	-0.52	0.14	0.59	0.38	0.08
T1844351	0.39	0.73	0.75	0.76	0.90	0.95	-0.62	0.58	-0.14	0.11	-0.38
T18443511	0.01	0.13	0.75	0.79	0.80	0.81	-0.10	0.35	0.79	0.19	0.09
T1844352	0.43	0.70	0.70	0.73	0.89	0.92	-0.65	0.52	-0.03	0.17	-0.40
T18443531	0.61	0.69	0.75	0.86	0.86	0.97	-0.78	-0.28	-0.25	0.33	-0.06
T18443532	0.78	0.80	0.83	0.87	0.87	0.98	-0.88	-0.12	-0.18	0.19	0.04
T1844371	0.68	0.69	0.72	0.74	0.82	0.94	-0.83	0.04	-0.18	0.14	0.29
T1844372	0.64	0.69	0.71	0.77	0.83	0.94	-0.80	0.22	-0.16	0.24	0.24

The communalities represent the proportion of variance for each series that is explained by the component. The proportion of variance of every series, except

18443511, that can be explained in the first or second factor is high. This confirms a strong climate signal in both the first and second factors.

Factor one shows decreasing values from 1910 to the mid 1930s, and high negative values for the late 1930s and early 1940s (Figure 24). Factor 2 shows negative values for the first part of the series; followed by increasing values in the 1950s to the 1990s. This suggests that nearly all series from the plot had high growth in the 1940s, shown by the negative values of the scores. Recall that the loadings on nearly all ring-width series are negative and the product of scores and loadings indicate the value of the original series. Factor scores are added (after multiplying by the relative importance of the factor; given by the score coefficients) and therefore, factor 2 is summed with factor 1 to indicate the climate signal. Since some loadings are negative and some are positive, this means that the period of time after the 1940's can show a positive or negative trend, depending on the particular tree (Appendix B).

Figure 24. Factors and factor loadings derived from Principal Components Analysis of the 1844 ring-width series. The percentage of explained variance by each factor has been provided.



3.3.2 Standardization

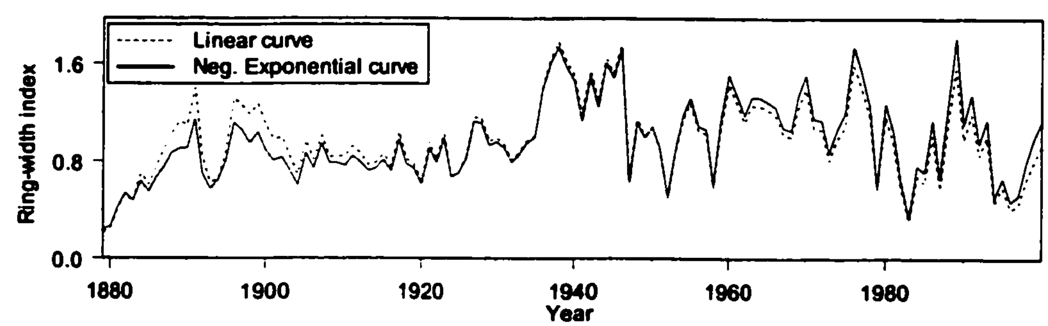
Ring widths are not only affected by climate but also change with tree age, height within the stem, site-specific characteristics and site productivity (Fritts, 1976). For the purpose of climate reconstructions, it is essential to determine the changes in ring widths associated with age or other factors and to remove them from the measurements. This correction is known as standardization, and the transformed values are referred to as ring-width indices (Fritts, 1976). The purpose of standardization is to remove an overall growth trend in tree-ring measurement series, and to remove part of the variance at very low frequencies approaching the length of the series (Grissino-Mayer *et al.*, 1992). There exists a large array of techniques that can be used for standardizing ring widths and creating a mean chronology of tree-ring indices. Each set of tree ring measurements must be standardized differently depending on the statistical properties of the data series. Once the growth signal has been defined, it is then possible to assign the most appropriate method of standardization to each series (Cook and Kairiukstis, 1990).

The time-series curves derived from the PCA scores were used to help determine the appropriate method of standardization. It became apparent from the results of the PCA that either a linear transformation, a negative exponential curve, or horizontal line would be most appropriate to standardize the ring-width series (Table 7). Once the growth curve has been selected, the ring-width of each series is divided by the corresponding value of the curve. Program Arstan is used to create the chronology and decide upon the most appropriate method of standardizing the ring-widths (Cook, 1985; Grissino-Mayer *et al.*, 1992).

The simplest approach to standardization is to use linear regression, which computes a least squares regression line through the data (Grissino-Mayer *et al.*, 1992). It is often used on series that are relatively short or have unusual growth patterns that the negative exponential curve cannot accommodate. Jacoby and Cook (1981) applied this method to a chronology developed on *P. glauca* species in the Yukon Territory. They also applied a negative exponential to a few cores to remove juvenile growth effects. An iterative procedure is applied and continues to be used until the improvement of the fit is very small (Grissino-Mayer *et al.*, 1992). In the case where the fitted curve has a negative constant or a positive slope, the negative exponential curve is rejected and a linear regression is fit to the data (Fritts, 1976).

In addition to the linear regression and negative exponential curves, a horizontal line through the mean may be applied, that is, a linear regression with the slope 0. Based on the nature of the raw ring-width series (Figures B1a-d, Appendix B) and the results of the PCA, a horizontal line was chosen for this chronology. As depicted in Figure 25, standardizing the ring widths using the linear curve or negative exponential/horizontal line made little difference to the final chronology.

Figure 25. Two methods of standardizing the Jenny Lake chronology using a linear transformation and negative exponential curve/horizontal line.



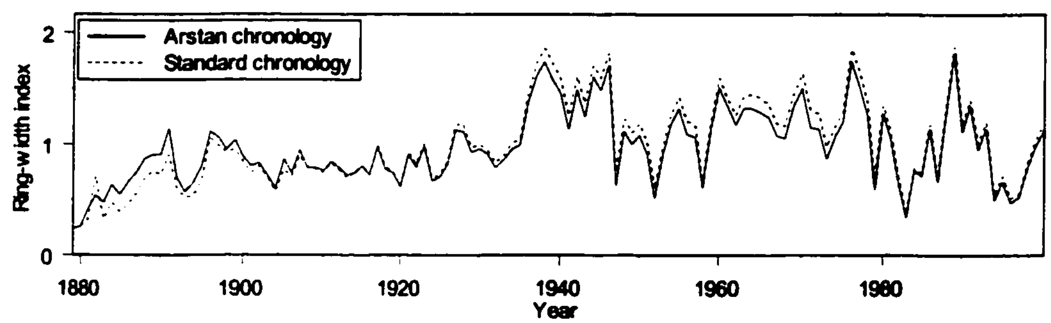
Arstan provides three versions of the chronology with different time-series characteristics. The standard chronology is computed from series of tree-ring data that have been detrended by curve-fitting to remove a large part of the variance due to causes other than climate, that is, the growth curve. The residual version of the chronology is produced in a similar manner as the standard chronology with the exception that the averaged series are residuals from autoregressive modeling. The arstan chronology is computed using the pooled model of autoregression, which is added to the residual chronology. This chronology is intended to contain the strongest climatic signal possible (Grissino-Mayer *et al.*, 1992). This is particularly useful if there are small differences in the chronologies due to competition or local factors. The output file in Arstan provides summary statistics that include the error variance for each chronology.

Table 7. Justification of the method of standardization and for the selection of the appropriate version of the chronology.

	Error Variance	
	Standard	**Arstan**
1844		
Neg.exp/Horizontal Line	0.0049	0.0033
Result	**Horizontal Line; Arstan chronology**	
1860		
Linear regression	0.0069	0.0059
Result	**Linear; Arstan chronology**	
1925		
Linear regression	0.0109	0.0124
Result	**Linear; Standard chronology**	
1929		
Linear regression	0.0033	0.0035
Result	**Linear; Standard chronology**	
1948		
Linear regression	0.0133	0.0066
Result	**Linear; Arstan chronology**	

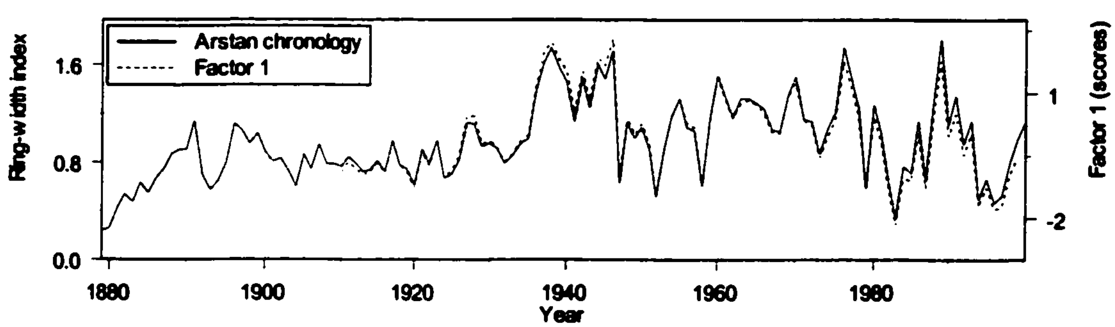
Table 7 provides the error variance for each chronology and the final method of standardization that was chosen. For the Jenny Lake chronology, the error variance was lower for the Arstan chronology, and therefore was the curve that was chosen for the final chronology. Again, the final chronology did not differ greatly between the two curves since they depicted almost identical trends (Figure 26).

Figure 26. Comparison of the standard and arstan versions of the Jenny Lake chronology.



Jacoby and Cook (1981) noted that the time-series approach using PCA to create a chronology contained more climatic information than the traditional approach. The similarities between the first factor and the chronology can be seen in Figure 27.

Figure 27. Comparison of the arstan chronology and the first factor of the PCA derived from the Jenny Lake chronology.



The results suggest that the chronology development here is robust to variations in the method used. The chronology demonstrates that in fact the first factor derived from the PCA is essentially the same as the derived chronology. The results of this chronology will be discussed in a further section.

3.4 Correlation of chronologies to climate

The relationship between climate and radial growth of five chronology sites was investigated using a correlation analysis. Correlations can be used to relate the mean monthly temperatures and the total monthly precipitation to the growth of trees in the study area. The results of the analysis will indicate whether a ring width is correlated to temperature, precipitation or to both variables, and to which month.

Climatic data were taken from the Meteorological Service of Canada website for three stations: Whitehorse Airport (Temperature: 1943-1999; Precipitation: 1942-1999), Haines Junction (Temperature: 1945-1999; Precipitation: 1945-1983, and Burwash Landing (Temperature: 1967-1999; Precipitation: 1967-1999). The analysis was performed using eight months of the present year's growth (May-December) and eight months of the previous year's growth (January-August).

3.5 Nearest Neighbor Analysis

Fires can have a varying effect on the spatial distribution of seedling establishment in a forest stand (Zasada *et al.*, 1983; Zasada, 1986). Physical properties of the postfire surface condition can vary depending on the severity of the fire. This in turn, can have an effect on the spatial distribution of seedlings. The distribution of *Picea glauca* seedlings tends to be aggregated; often it is the result of microtopographical conditions associated with the distribution of rotted wood, windthrow mounds, rocks, and pits (Zasada, 1986).

Zasada *et al.* (1983) performed an experimental study on the regeneration of trees and tall shrubs in burned upland *Picea mariana*/feather moss stands in Alaska. The variation in burn severity and surface conditions altered the spatial distribution of seed dispersal as well as the role of seed and vegetative reproduction (Zasada *et al.*, 1983). Thus, it can be inferred that fires of different burn severity will yield different patterns of seedling establishment. One way of quantifying this spatial pattern is to perform a nearest neighbor analysis on the trees in a plot. This was first performed by Clark and Evans (1954), who used it to analyse patterns in spatial maps. This statistical approach is useful when the emphasis of the analysis is on the location of stationary individuals (ie. trees) within a sampling region (Young and Young, 1998).

The nearest neighbor analysis was used to determine if the distribution of trees in a plot are clustered (close together), randomly distributed (no order), or in a uniform pattern (organized distribution). Waite (2000) has defined these spatial terms as follows: a clustered distribution is when the number of trees recorded in each plot varies considerably from the overall mean (the area outside of a cluster will contain none or very few, whereas the area within a cluster will contain many); a uniform distribution occurs when the number of trees recorded in each plot varies relatively little from the overall mean; and a random distribution is when the number of trees recorded varies equally above and below the mean.

The Nearest Neighbor Analyst Extension was used in ArcView 3.2 to quantify the R-value (index of aggregation), which is an indicator of how clustered or dispersed points are within a region. The nearest neighbor statistic (R-value) is based on the concept that the average distance between points will be large for an organized pattern, small for a clustered pattern, and average for a random pattern. Krebs (1999) provides the following equation for calculating the R-value:

$$R = \frac{\bar{r}_A}{\bar{r}_E}$$

where

R = index of aggregation
$\bar{r}_A$= mean distance to the nearest neighbor
$\bar{r}_E$= expected distance to nearest neighbor

The mean distance to the nearest neighbor is defined as:

$\bar{r}_A = \frac{\Sigma r_i}{n}$ and

and the expected distance to nearest neighbor is defined as:

$$\bar{r}_E = \frac{1}{2\sqrt{p}}$$

where

r_i=distance to nearest neighbor for individual i
n=number of individuals in study area
p=density of organisms = $\frac{\text{number in study area}}{\text{size of study area}}$

If a "boundary strip" is not applied in this analysis, the individuals located near the edge of the plot will have a larger nearest-neighbor distance than those inside, rendering the test biased (Clark and Evans, 1954). The extension allows for a "boundary strip" so that the nearest neighbor test comes out unbiased. The test is unbiased if n>7 and the study area is either a square, rectangle or a circle (Krebs, 1999).

Table 8 indicates the criteria used for the nearest neighbor analysis:

Table 8. Criteria used to perform a nearest neighbour analysis (Krebs, 1999).

R-Value	**Cluster Pattern Tendency**
R<1	Clustered Pattern
R=1	Random Distribution Pattern
R>1	Organized (uniform) Pattern

CHAPTER FOUR:
Postfire successional sequences and climate reconstructions in the Shakwak Trench, Yukon Territory.

Abstract

This study investigates the succession following fire in a relatively dry area of the boreal forest, the Shakwak Trench, southwest Yukon. The postfire successional regime is determined by an analysis of age structure and composition of tree populations in stands of different ages. The dendroecological approach used in this study is based on the sampling of one plot in each of 11 fires ranging from A.D. 1844-1998. White spruce (*Picea glauca* (Moench) Voss) established 0-4 years after fire and reached a period of maximum establishment after 20-40 years. Trembling aspen (*Populus tremuloides* Michx.) was generally recruited immediately after fire and was no longer present after approximately 20 years, at which point, the *Picea glauca* began to dominate. Willow species (*Salix* spp.) were found in all stages of succession, but decreased in abundance through time. Five chronologies that were developed from ring-width measurements of the older *Picea glauca* trees depict similar growth-ring patterns, suggesting a large-scale climate influence on all sites in the region. There is a weak relation between the variability of the tree-ring chronology and the establishment of *Picea glauca* seedlings. Regeneration of tree species after fire is primarily driven by biological influences rather than climatological ones.

4.0 Introduction

In the boreal forest, natural disturbances, primarily fire, have shaped the scale, texture and vegetation distribution of the landscape (Rowe and Scotter, 1973; Johnson, 1979; Tande, 1979; Dieterich, 1983; Purchase and La Roi, 1983; Morneau and Payette, 1989; Schaefer, 1993; Stocks *et al.*, 1998). As a disturbance agent, fire initiates forest succession that maintains the heterogeneous character of the boreal forest vegetation mosaic (Johnson, 1992). During postfire succession, trees grow at different rates, leading to several stages of development occurring before a mature stand is reached (Gutierrez and Fey, 1980).

Many studies have shown similarities in the successional sequence in the various parts of the North American boreal forest (Maikawa and Kershaw, 1976; Van Cleve and Viereck, 1981; Foote, 1983; Foster, 1985; Payette *et al.*, 1989). Despite any regional differences in the environment, the general pattern of vegetation recovery after fire has shown to be similar. However, there are several characteristics that render the southwest Yukon unique from other regions of the boreal forest. All of the previous studies have been performed in areas where the dominant species are both black spruce (*Picea mariana* [Mill.] BSP) and white spruce (*Picea glauca* (Moench) Voss), or *P. mariana* alone. *Picea glauca* is the only conifer species in this relatively dry area of the boreal forest. The absence of *Picea mariana*, which is a common species to other parts of the boreal forest, is remarkable since it is found to the north and east of this region (Dale *et al.*, 2001). In addition, several other species characteristic of the North American boreal forest, including larch (*Larix laricina* (Du Roi) K. Koch), *Betula papyrifera* and lodgepole pine (*Pinus contorta* Dougl. Ex Loud var.) are rare or absent in the southwest Yukon (Krebs Boonstra, 2001). Another feature of this region is the presence of grasslands, which are widely distributed in many areas of the boreal forest (Vetter, 2000).

The regions where postfire succession has already been explored, demonstrated different landscape characteristics, yet still yielded similar results. Thus, it would be expected that the southwest Yukon, located in the boreal forest, would undergo a similar successional sequence in spite of differences in species composition and environment. If it can be shown that the successional sequences are similar across the entire boreal forest, then the southwest Yukon Territory should not demonstrate anomalous trends to this sequence. In effect, it can be said that there exists a general trend with respect to the overall successional sequence in the boreal forest.

Dendroclimatogical reconstructions have been performed in different regions of the subarctic and at different landscape levels to provide data of past climates (Jacoby and Cook, 1981; Jacoby *et al.*, 1985; Briffa *et al.*, 1992; Szeicz and MacDonald, 1995). However, reconstructions have not yet been published from several sites in the Shakwak Trench, southwest Yukon Territory. Chronologies developed from the Shakwak Trench may help provide insight into the relation between tree growth and climate, and may explain patterns found in the establishment of *Picea glauca* individuals. Further, the chronologies developed here are obtained from interior forest sites, not specifically selected for paleoclimate sensitivity. This study will contribute to our understanding of climate change impacts on tree growth and establishment in "typical" boreal forest environments.

The objective of this study is to analyse postfire succession in the boreal forest of the southwest Yukon. In particular, the study will: (1) describe the successional pathway in the region by the analysis of forest stands of different ages; (2) determine whether postfire tree establishment is driven primarily by climate or by biological influences; (3) define the relationship between tree radial growth, population seedling establishment and climate; and (4) demonstrate that trees growing in climatologically favorable parts of the landscape can nevertheless be used for paleoclimate reconstructions.

This region has been the focus of a collaborative study that has attempted to determine the dynamics of a forest ecosystem on a short-term, experimental level (Krebs *et al.*, 2001). The present study can contribute to our understanding of this complex ecosystem by providing researchers with a more quantitative analysis of the successional dynamics of the vegetation in the Shakwak Trench, thus extending the spatio-temporal side of the Kluane Lake study (Krebs *et al.*, 2001).

4.1 Study Site

The study sites are located within the Shakwak Trench, a northwest-southeast trending valley near Kluane Lake (Figure 1). The Shakwak Trench is adjacent to the St. Elias Mountains of the Kluane National Park Reserve (Krebs and Boonstra, 2001).

The region is under the influence of a rain shadow because of its proximity to the St. Elias Mountains. The Kluane region experiences short, cool summers and long, cold winters with a mean January and July temperature of ca. -20°C and ca. 12°C, respectively (Haines Junction weather station). Precipitation is low with an average total of 315 mm annually, consisting mostly of rain during the summer months.

The vegetation of the study area is dominated by *Picea glauca*, trembling aspen (*Populus tremuloides* Michx.) and balsam poplar (*Populus balsamifera* L.), with shrub-dominated areas of willow (*Salix* spp.) and dwarf birch (*Betula glandulosa* Michx.) (Krebs and Boonstra, 2001). The *Picea glauca* dominated forests that occupy the landscape today established about 8000 years B.P. (Stuart *et al.*, 1989; Lacourse and Gajewski, 2000).

The vegetation can be divided into three ecological zones based on elevation (Douglas, 1974): montane valley bottom forests (760-1080 m), subalpine forests (1080-1370 m), and alpine tundra (above 1370 m). This study focused on montane and subalpine forest communities.

A total of 11 sites were selected to obtain a temporal sequence of postfire succession (Figure 1; Table 2). The fire history of a portion of the Shakwak Trench has been studied by Francis (1996) and has formed the basis for the selection of sites 1-7. These sites are all located in the valley bottom of the Shakwak Trench within an area of approximately 480 km^2. In addition to their relative accessibility, these fire sites were chosen according to the date they burned, so as to obtain stands in several stages of succession. The most recent fire identified by Francis is dated as 1930. To obtain sites in earlier stages of succession, recently burned regions were identified by J. Jennings, Resource Management Officer (personal consultation, DIAND, Haines Junction, 2002). Fire sites 8-11 are all located further south along the Alaska Highway.

The site characteristics do not differ greatly between all the sites, with the exception of the 1888 site, which has a higher slope (Table 3). The soils of all plots are dominated by sands and fines (Section 2.1).

Understory vegetation was sampled to determine the changes in vegetation in each stage of postfire succession. The most significant change in the understory occurs after approximately 100 years, at which time the species richness begins to decline and feathermosses begin to dominate (Appendix A).

4.2 Methodology

11 fires were sampled, ranging in age from 4 years to 156 years since the last fire. For each fire, a plot was selected for detailed dendroecological analysis. Plot location was chosen to be representative of the area. The size of the plots was either 10 by 20 m or 10 by 10 m depending on the density of the trees (Table 3). Three replicate plots of 10 by 20 m were taken from the 1844 fire to determine whether one plot is representative of a site. The first two plots were located side by side near the edge of the fire and the third plot was located further from the edge of the fire. Two 10 by 10 m plots were taken in the 1980 and 1990 fires; one was taken near a seed source and the other was further away, to quantify the effects of proximity to seed source.

In each plot, all living trees >2 m in height were tagged and mapped. Distance to the nearest neighbor was measured, and the diameter at breast height (d.b.h.) recorded. Understory vegetation was sampled in three 1 by 1 meter quadrats for each fire site, randomly located in the plot. A loss-on-ignition was performed on identifiable soil layers and grain-size analysis was performed to determine the dominant soil type (gravel, sands, fines). Results are reported in Chapter three.

Two increment cores (90° to each other) were extracted from the base of each tree with a d.b.h. >30 cm (approximately 30 cm above the ground), and trees with d.b.h <30 cm were cut low on the bole, to obtain the most accurate age. Cores and cross-sections were prepared for laboratory analysis according to methods described in Stokes and Smiley (1968). Cores were cross-dated using standard dendrochronological methods (Fritts, 1976).

Once the age of each tree was determined, the age-class distribution of each species was computed for each fire site. Age structures are records of both establishment and subsequent survival to the time of sampling (Szeicz and Macdonald, 1995). Thus, a lack of trees in a certain age-class may be the result of a lack of establishment at that time, high mortality rates, or a combination of these factors (Whipple and Dix, 1979). Cores that did not reach the pith were excluded from the age structure analysis.

Annual growth rings of selected trees were measured using a Mini-scale and Mate System Encoder connected to an AcuRite III digital counter with a precision of 0.001 mm. The accuracy of crossdating was verified using the computer program COFECHA (Grissino-Mayer *et al.*, 1992). Standard methods of chronology development, as outlined by Fritts (1976) were used.

For the purpose of chronology development, it is essential to determine the variations in ring widths associated with age or other factors (example, competition) and to remove them from the measurements. This correction is known as standardization, and the transformed values are referred to as ring-width indices (Fritts, 1976). Principal Components Analysis was used to select the most appropriate method of standardizing ring-width series and to aid in identifying trees to include in the chronology. The series most highly loaded on the first component are the most highly correlated among themselves and thus carry the common signal. Any series not found to be loaded on the first few components were removed from the chronology (as they are not contributing to the overall climate signal).

The relation between climate and radial growth of five chronologies was investigated using correlations between mean ring-width and monthly temperatures and precipitation. The results of the analysis will indicate whether ring-width is correlated to temperature, precipitation or to both variables, and to which month. The analysis was performed using eight months of the present year's growth (May-December) and eight months of the previous year's growth (January-August).

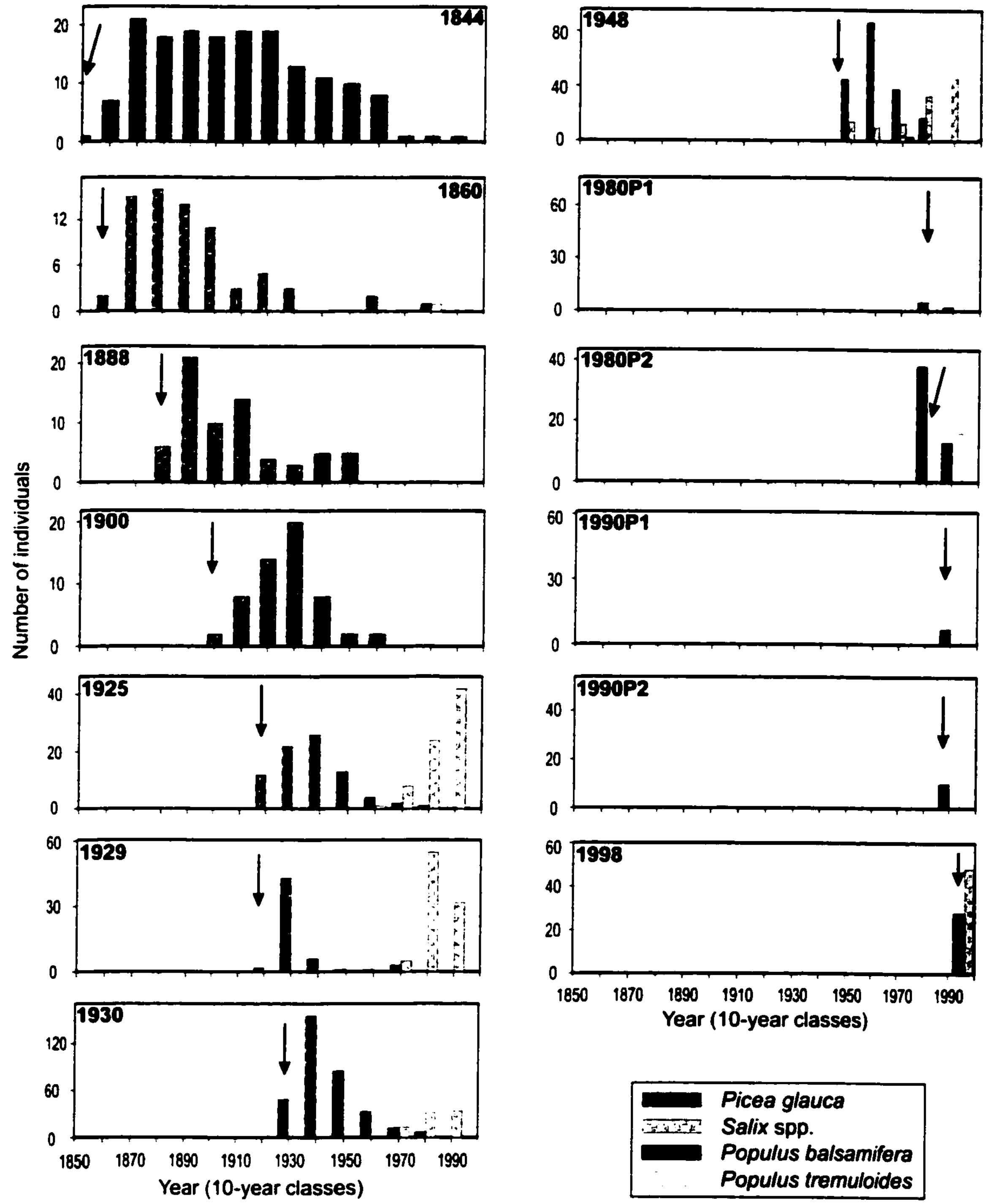
4.3 Results

4.3.1 Age-structure analysis

The age-structure analyses (Figure 28) were plotted in 10-year age classes and include all tree species found in the site. In all stands, the canopy was dominated by *Picea glauca*, with the exception of the younger fires (1980, 1990, and 1998), which were dominated by *Populus tremuloides*. The uneven-aged distribution of all species in the plots is typical of closed canopy forests (Abrams *et al.*, 1995). *Picea glauca* is recruited sporadically for a number of years, which results in discontinuous age structures separated by periods when no species become established (Nienstaedt and Zasada, 2002). Although it was not quantified in this study, it is possible that mortality occurred in these plots, which could modify the age structures.

Picea glauca typically established 0-4 years after fire and reached a period of maximum establishment after 20-40 years. However, lag-time of 12-25 years was found for the three plots on the 1844 fire site. This was the only site that demonstrated a lag-time greater than 4 years, which indicates that some other factor may have been affecting the regeneration of *Picea glauca*.

Figure 28. Age structure histograms for sites in the Shakwak Trench, plotted in 10-year age-classes, and arranged in order of increasing age of fires. The arrow represents the year of the fire.



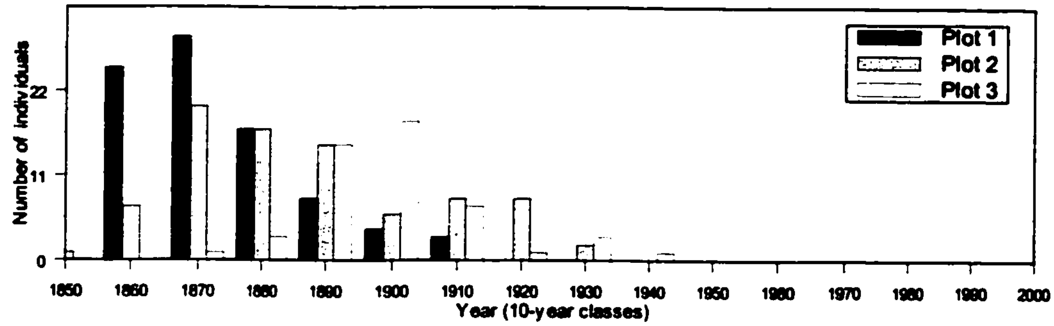
For all sites, the rate of regeneration of *Picea glauca* typically decreased following this 20-40 year peak of establishment, however at the time of sampling there were still some seedlings present in some of the oldest fires. The sites closest in age (1925, 1929 and 1930) show broadly similar age-structures, however the 1929 site experienced very little regeneration.

Populus tremuloides was generally recruited immediately after fire (1980, 1990, and 1998 fires), and is present for at least 20 years. Between 20 and 50 years (when no fires were sampled), *Populus tremuloides* disappeared, at which point *Picea glauca* gained dominance. The only *Populus balsamifera* was recorded approximately 20 years after fire in the 1948 site.

Salix spp. were found in most plots except the 1990 and 1980 fires. It is quite probable that *Salix* were outcompeted by *Populus tremuloides*, which densely populated these two plots. There were *Salix* spp. found in the 1844, 1888, and 1900 fires, however they were outside of the sampling plot. The presence of *Salix* spp. in the oldest fires shows that this species is able to continue to reproduce throughout most stages of succession, with maximum abundance between 50-80 years after fire. Although *Salix* spp. are still present in the oldest sampled forests, their abundance tends to decrease rapidly as the stand ages and *Picea glauca* trees age to maturity.

In the older fires, the saplings and seedlings were dominated by *Picea glauca*, while among the younger fires *Populus tremuloides* seedlings were most often dominant. In the older fires (1844, 1860, 1888, and 1900), the regeneration rate of *Picea glauca* decreased after approximately 40 years.

Figure 29. Age structure analysis of *Picea glauca* for three plots taken from the 1844 fire near Jenny Lake, Yukon Territory.



Three plots were taken of the 1844 fire to determine how representative one plot is of the postfire successional sequence (Figure 29). Plots one and two are located side by side, whereas plot three is located approximately 50 m away, closer to the interior of the fire. All three plots depict an age frequency distribution that is similar to the other fires. In plots one and two, the *Picea glauca* seedlings established within 12 to 15 years after fire (respectively), however there was a lag of approximately 35 years in plot three. The lag of all of these plots was greater than that found in the other sites, especially that of plot three. This site is also the oldest fire and the age of the fire or age structure may simply be associated with greater error. The longer lag effect in plot three is possibly due to some localized site difference. As it is located further from the edge of the fire, it is possible that it was also further from a seed source, which would result in a delayed regeneration (Stewart *et al.*, 1998; Greene and Johnson, 2000). Alternatively, the particular climate at the time subsequent to the fire may have caused this delay; regeneration lag for *Picea mariana* has been attributed to a particularly high seedling mortality during the first 3-4 years following fire (Sirois and Payette, 1989). Thus, it is possible that a higher mortality rate in plot three accounted for the slower regeneration of *Picea glauca*.

4.3.2 Diameter at breast height and year of establishment

There is little relation between size and age of the trees in these plots. Older *Picea glauca* trees have both a large and small diameter at breast height (d.b.h.), whereas the younger trees have a smaller d.b.h. (Figure 30a-c). There is a high variability in the pattern of growth for trees in such a closed-canopy environment. Other studies have also shown poor correlations between tree age and size. For example, a study performed in central Oregon showed that a two-metre tall red fir tree (*Abies magnifica* A. Murr.) can be either 25 or 80 years old (Agee, 1983).

4.3.3 Chronology characteristics

Five chronologies, ranging in age from 45 to 130 years, were derived using *Picea glauca* individuals to obtain an assessment of climate variations in the region (Figure 31, Table 9). The longest chronology only dates back to 1870. However, the purpose of this study was not to develop long paleoclimate proxy records, but to see if closed canopy forests similarly record climate variations in the boreal forest, on sites not selected for optimal sensitivity of ring-width characteristics (Fritts, 1976).

The mean sensitivity is relatively low for all chronologies, which is expected since they were not derived from climatologically sensitive regions (Table 9). However, a low sensitivity value does not indicate that a climate signal is not present in the tree-rings (Watson *et al.*, 2000). Mean ring-width values are considerably larger than those found by Watson *et al.* (2000) at higher altitude sites in the southwest Yukon. The wider ring-widths indicate that environmental constraints on tree growth were less severe at the

Figure 30a. Scatterplots of diameter at breast height (d.b.h.) as a function of year of establishment.

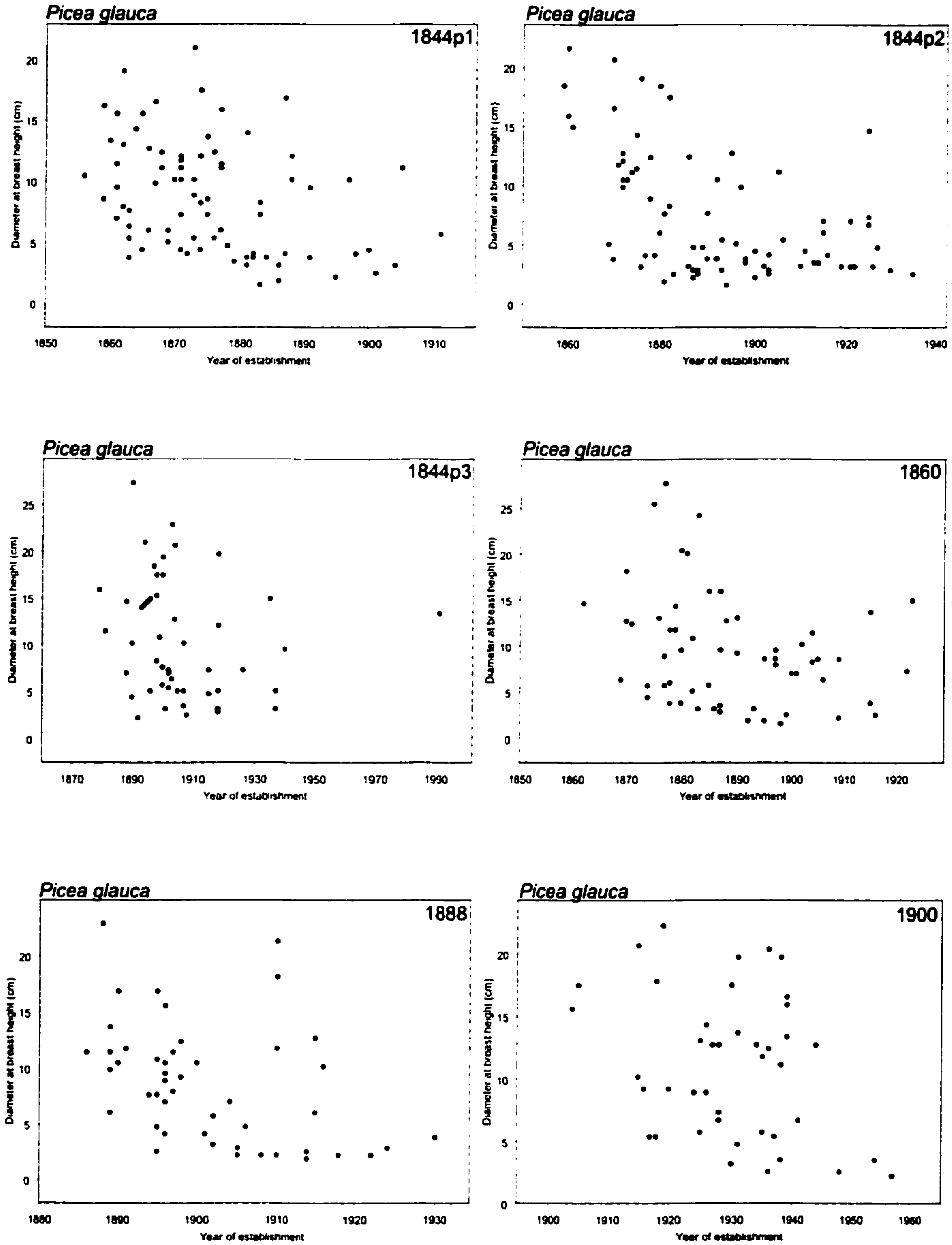


Figure 30b. Scatterplots of d.b.h. as a function of year of establishment.

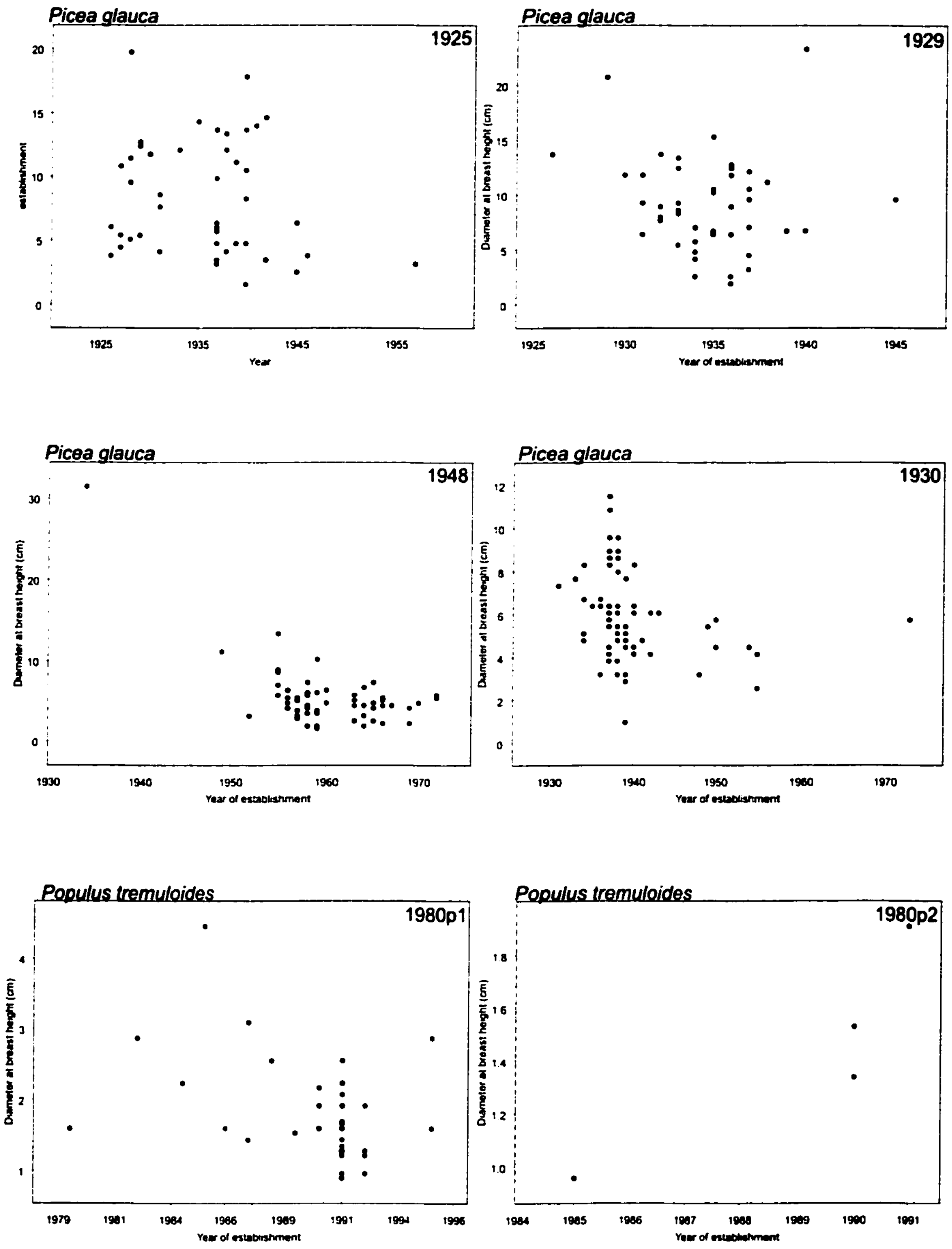


Figure 30c. Scatterplots of d.b.h. as a function of year of establishment.

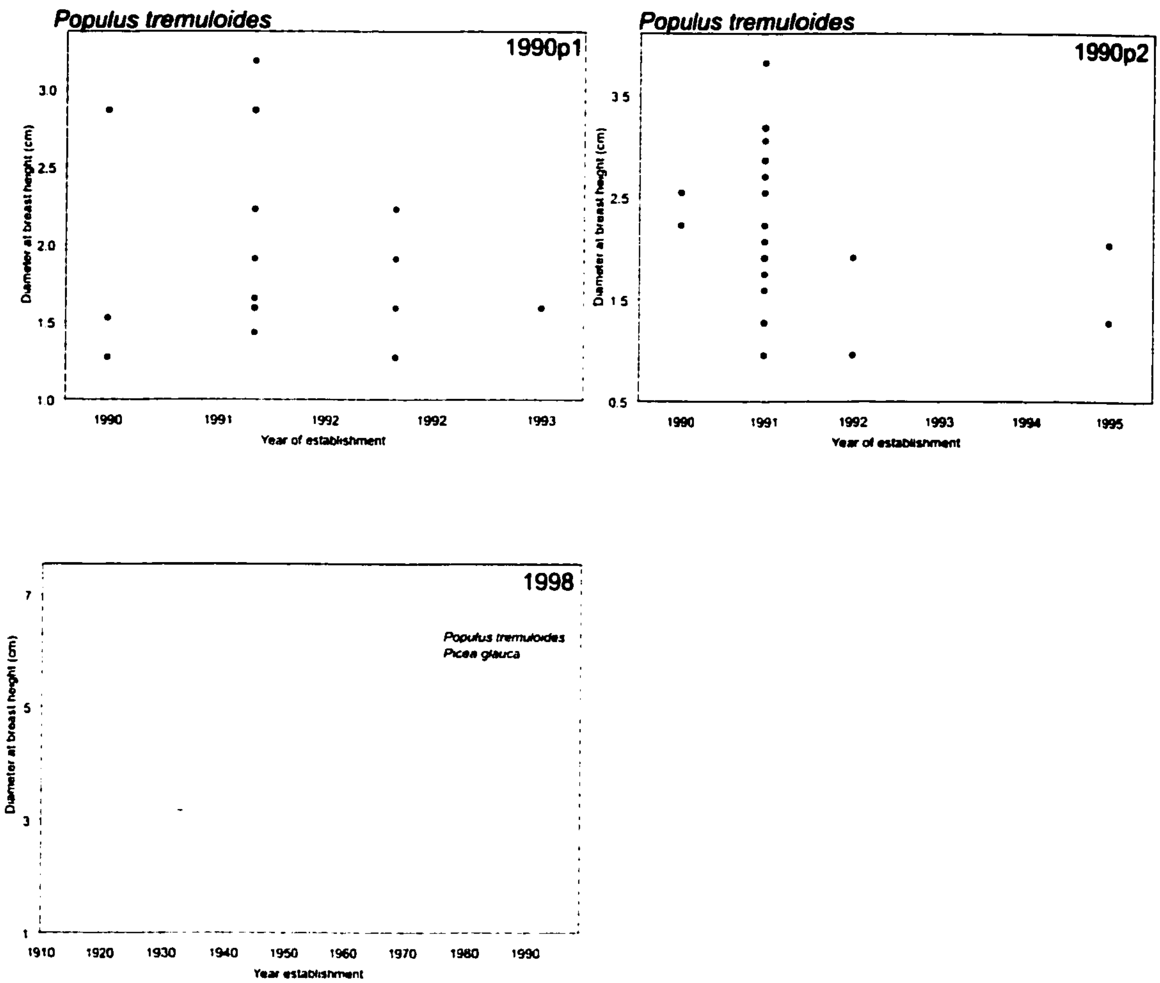


Figure 31. Ring-width chronologies of *Picea glauca* for five sites located in the Shakwak Trench, Yukon Territory. These chronologies represent the entire geographical range of the study region and are plotted in chronosequence against a common time interval (1870-2000).

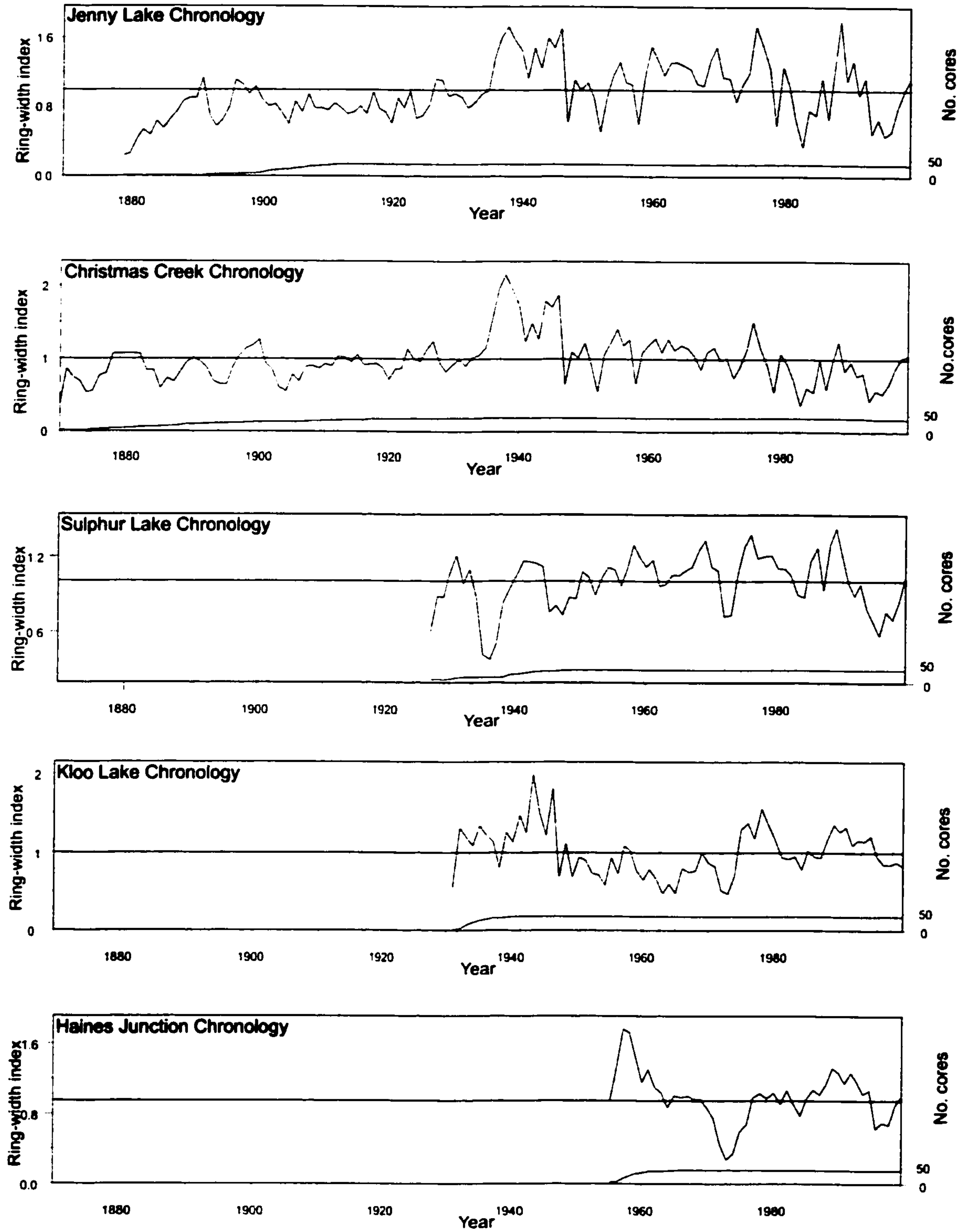


Table 9. Summary characteristics of the *Picea glauca* chronologies in the Shakwak Trench, Yukon Territory.

Chronology	Chronology Length	No. Trees	No. Radii	Oldest Tree Age	Species	Standard deviation
Jenny Lake	1879-2000	22	35	122	*P. glauca*	0.33
Christmas Cr.	1870-2000	21	40	131	*P. glauca*	0.32
Sulphur Lake	1926-2000	20	38	75	*P. glauca*	0.22
Kloo Lake	1931-2000	21	41	70	*P. glauca*	0.31
Haines Jct.	1955-2000	31	41	46	*P. glauca*	0.30

Chronology	Mean sensitivity	1st order autocorrelation	Mean Measurement (mm)	Coefficient of variation
Jenny Lake	0.23	0.63	0.94	0.33
Christmas Cr.	0.20	0.68	0.79	0.32
Sulphur Lake	0.14	0.68	0.87	0.24
Kloo Lake	0.22	0.53	0.91	0.31
Haines Jct.	0.16	0.82	0.73	0.30

sites in this study. The coefficient of variation (cv) ranged from 0.24-0.33, which is significantly lower than the values computed for the Yukon chronologies by Luckman *et al.* (2002). This indicates that the chronologies of the Shakwak Trench have a much lower variability in ring-width than those of higher altitudes. The first order autocorrelation is relatively high and reasonably close to the values obtained from Watson *et al.* (2000). A high first-order autocorrelation implies that the ring-width in a given year is highly dependent on ring width, and therefore presumably the climate, of the previous year.

Time-series plots of the chronologies show reasonable coherence (Figure 31). The Jenny Lake chronology derived from plot 3 of the 1844 fire site demonstrates a rising growth from the 1880s to the 1930s, followed by a strong release between 1935-1945, which was also evident in a Yukon chronology from Jacoby and Cook (1981).

Since about the 1950s, the chronology tends to vary about the mean, with some tendency toward a decreasing trend. This had also been noted in other studies in the northwest of Canada (Kukla *et al*, 1977; Bradley and England, 1978). The Christmas Creek chronology, derived from the 1860 fire site, shows similar trends to those found in the Jenny Lake chronology with a more pronounced decrease since the 1950s. The Sulphur Lake and Kloo Lake chronologies were derived from the sites of the 1925 and 1929 fires, respectively, and are broadly similar to the former two chronologies. The release in the mid-1930s was not as pronounced in the Sulphur Lake chronology most likely because of the low period of growth which preceded it. The chronology from Haines Junction was derived from the 1948 fire plot, and is further away from the other chronologies. All chronologies show decreased growth in the early 1970s however this period is especially pronounced in the Haines Junction chronology.

4.3.4 Chronology comparisons

Correlation matrix plots and correlation coefficients for the five chronologies in the Shakwak Trench vary between –0.13 to 0.89 (Figure 32, Table 10). The Jenny Lake and Christmas Creek chronologies are highly correlated (0.89), which is not surprising considering their close proximity. The lowest correlations are between the Christmas Creek and Kloo Lake chronologies (-0.13), and between the Jenny Lake and Haines Junction chronologies (0.10), which show little relation among the series. This is in part due to the fact that the correlations measure the relation between individual ring-widths. The lower frequency changes are more coherent, as seen by the time series plots (Figure 31).

Figure 32. Correlation matrices of the five chronologies in the Shakwak Trench, Yukon Territory.

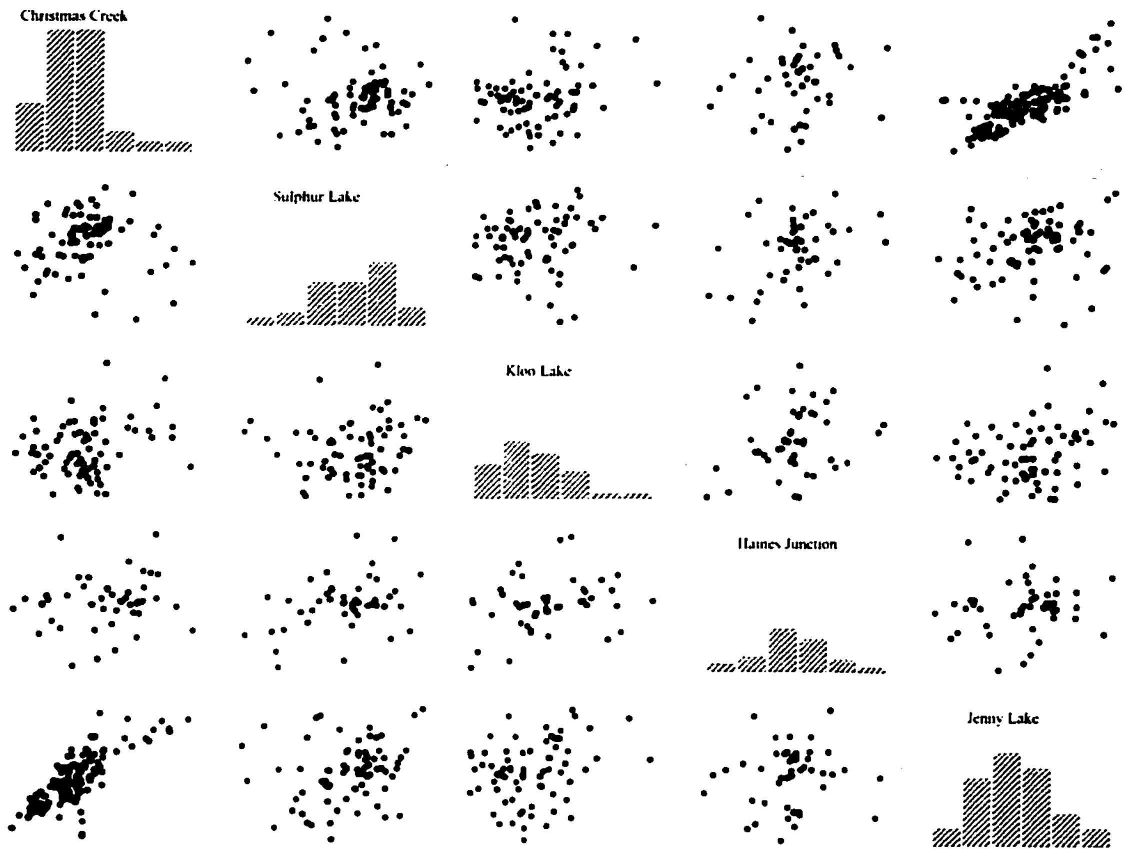


Table 10. Correlation matrix of the five chronologies in the Shakwak Trench, Yukon Territory.

Chronology	Christmas Cr.	Sulphur Lake	Kloo Lake	Haines Jct.	Jenny Lake
Christmas Cr.		**0.48**	-0.13	0.14	**0.89**
Sulphur Lake	**0.48**		**0.37**	**0.39**	**0.58**
Kloo Lake	-0.13	**0.37**		0.26	0.05
Haines Jct.	0.14	**0.39**	0.26		0.10
Jenny Lake	**0.89**	**0.58**	0.05	0.10	

Note: Correlations in bold are significant at p<0.05, n=46.

4.3.5 Climate and tree species establishment

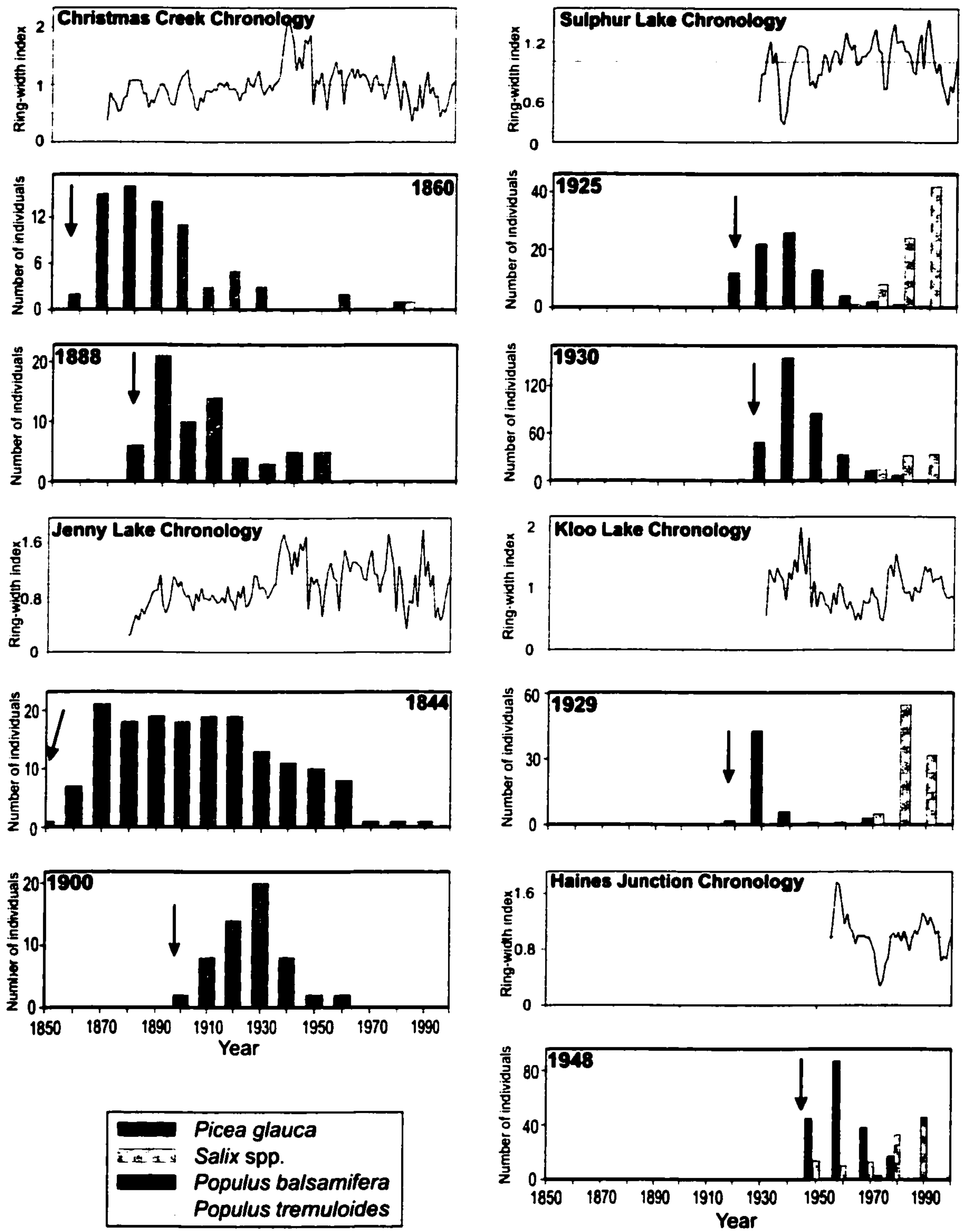
In the two longest chronologies there is a visual relation between the tree-ring chronology and the establishment of *Picea glauca* seedlings (Figure 33). During periods of low variability in the chronology (1870-1935), the establishment of *Picea glauca* was high. In the decade following this period is a release in the chronology, and from the 1940s to the end of the chronology (2000) the variability is much higher. In the age structure graphs, this period of high variability is coupled with a decrease in establishment of *Picea glauca*. This relation is not as clear for the younger fires.

Although the results suggest that the variability in climate is a driving factor for *Picea glauca* seedling establishment, further research must be performed to strengthen the validity of these results. In fact, the period of low variability in the chronologies is also a period of below normal growth. Decreases in establishment after the 1940s may also be due to the fact that as time progresses, the stand becomes too dense for further seedlings to successfully establish themselves. Other abiotic factors such as nutrient availability, soil moisture and shading could also influence seedling establishment at this stage.

4.3.6 Principal Components Analysis (PCA)

The first and second components of all chronologies accounted for between 58.4% and 79.9% of the variance (Table 5, C1a-b, C2a-b, C3a-b, and C4a-b; Appendix C). All series were highly loaded on factor one and two for the Jenny Lake and Christmas Creek chronologies (Figures 24, C1a-b, C2a-b, C3a-b, C4; Appendix C). Most of the series are highly loaded on the first and second factors for the Sulphur Lake chronology.

Figure 33. Age structure histograms and chronologies for the oldest fires in the study region. The age structures are plotted by 10-year classes and placed below the chronology located nearest each site. The arrow represents the year of the fire.



However, there are a number of the series that are loaded on the third factor, which indicates that this component carries some of the climatic signal found in these tree rings. Most of the series were highly loaded on the first and second components for the Kloo Lake and Haines Junction chronologies. There was one series in each chronology that was highly loaded on the third component, which indicates its growth differs significantly from the other trees.

4.3.7 Correlation of chronologies to climate

All chronologies, except the Haines Junction chronology, are negatively related to the previous summer's temperatures (Figure 34). In contrast, the Haines Junction chronology responded positively to the previous year's summer temperatures. The Christmas Creek, Jenny Lake and Sulphur Lake chronologies all responded positively to winter temperatures and similarly to the summer temperatures of the growth year. The Kloo Lake and Haines Junction chronologies were positively related to the summer temperatures of the growth year. In general, the chronologies of closest geographical proximity exhibit similar responses to the climate data.

All chronologies exhibit a positive correlation to precipitation of the autumn months of the previous growth year (Figure 35). The Sulphur and Kloo Lake chronologies were also positively correlated with precipitation during the previous year's growing season. There is little significant correlation between ring-width and precipitation of the current year. In general, precipitation is not as well correlated in comparison to temperature for all chronologies.

Figure 34. Correlations of mean annual temperature to the five chronologies in the Shakwak Trench, Yukon Territory. *Significant at $p<0.05$.

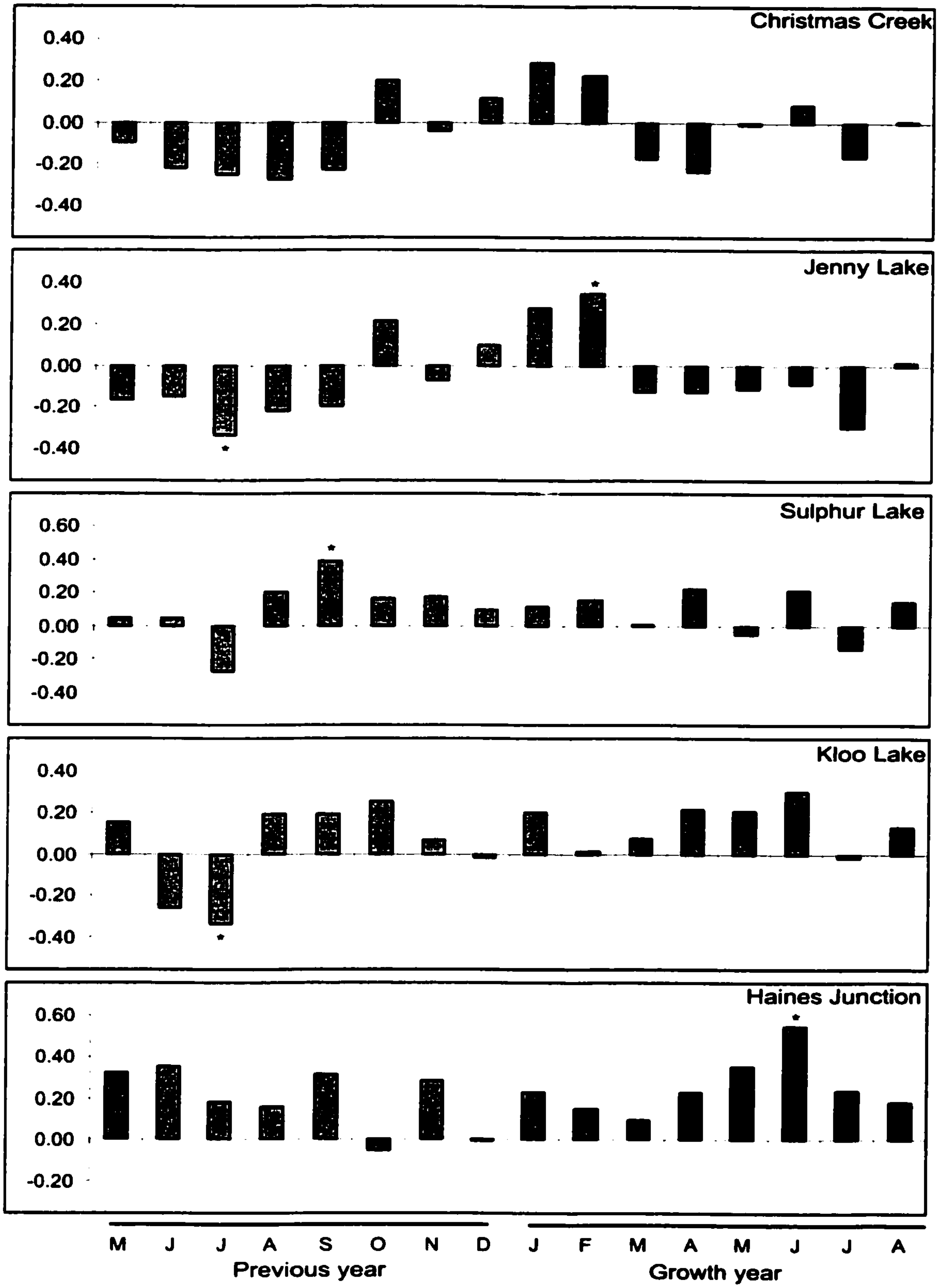
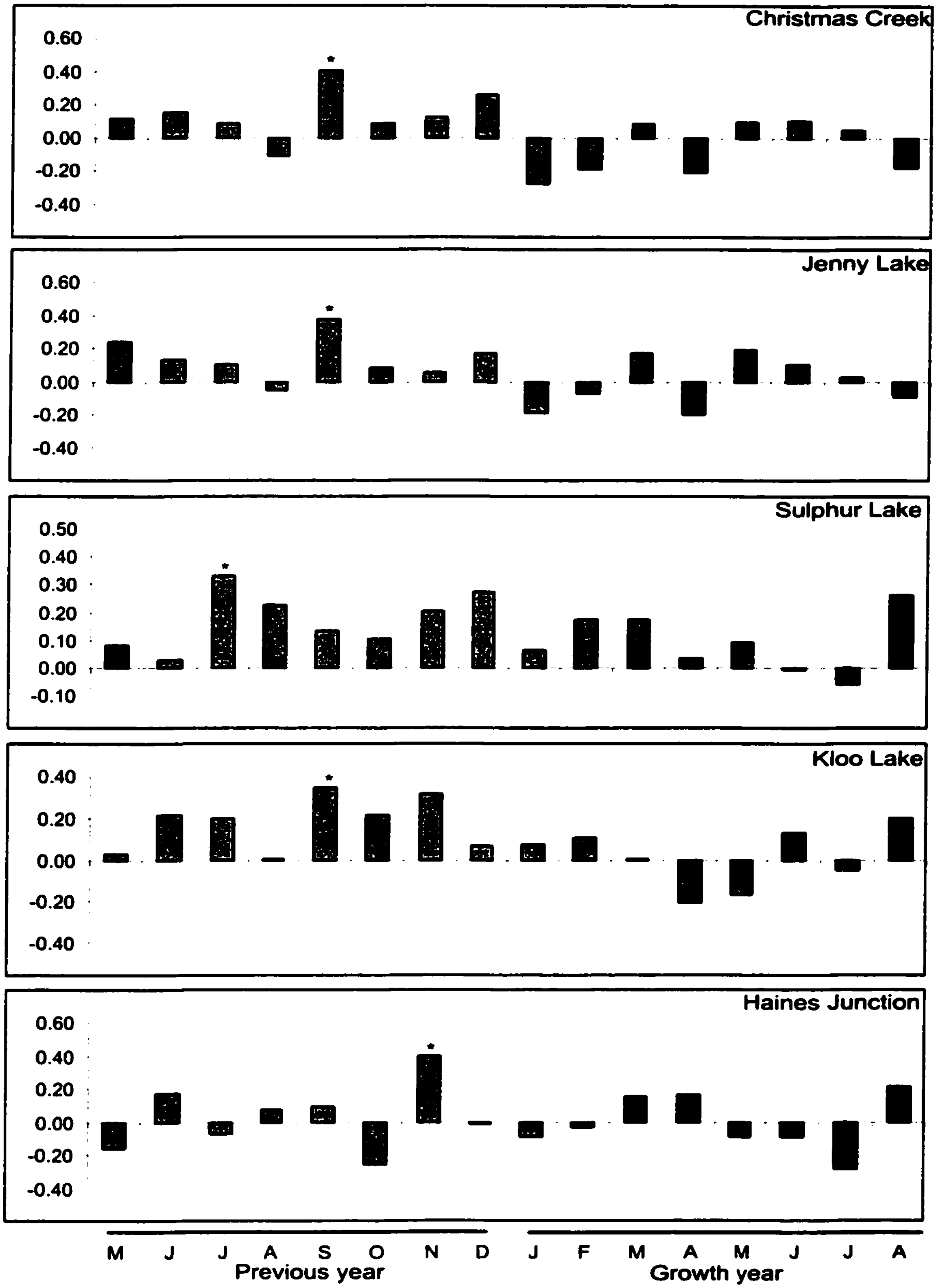


Figure 35. Correlations of total annual precipitation to the five chronologies in the Shakwak Trench, Yukon Territory. *Significant at $p<0.05$.



4.3.8 Spatial analysis

A nearest neighbor analysis was performed on each fire site to determine the cluster pattern tendency (Table 11).

Table 11. Results of the nearest neighbor test.

Fire	R-value	n	Species
1844p1	8.80E-06	78	*Picea glauca*
1844p2	8.10E-06	81	*Picea glauca*
1844p3	9.37E-06	50	*Picea glauca*
1860	9.31E-06	58	*Picea glauca*
1888	7.79E-06	48	*Picea glauca*
1900	4.81E-06	44	*Picea glauca*
1925	4.91E-06	46	*Picea glauca*
1929	5.92E-06	46	*Picea glauca*
1930	6.76E-06	67	*Picea glauca*
1948	6.30E-06	138	*Picea glauca*
1980p1	8.69E-06	46	*Populus tremuloides*
1980p2a	1.38E-05	7	*Populus tremuloides*
1980p2b	1.69E-05	8	*Picea glauca*
1990p1	8.40E-06	21	*Populus tremuloides*
1990p2	8.04E-06	29	*Populus tremuloides*
1998a	5.09E-06	7	*Populus tremuloides*
1998b	7.92E-06	22	*Picea glauca*
1998c	4.68E-06	7	*Salix* spp.

All values of the index of aggregation, R (Krebs, 1999: 193) are near zero for every site (Table 11). Thus, all sites demonstrate a random distribution pattern with a tendency toward clumping. It should be noted that the sample size of some plots is relatively small which reduces the strength of this statistical test. Nevertheless, the similarity in distribution of species within each site demonstrates the homogeneous characteristics of these study sites.

4.4 Discussion

The distribution of the tree species across the region's landscape is intrinsically linked to the spatial distribution of fire. Francis (1996) concluded that fire is the dominant disturbance mechanism in the *Picea glauca* dominated forests of the Shakwak Trench. The spruce beetle outbreak presently affecting the region does not have a similar long-term impact. Spruce beetles selectively choose trees to attack whereas fire is non-selective. As a result, the landscape is more heterogeneous after a spruce beetle outbreak. In addition, a fire will remove forest floor litter aiding in regeneration, while spruce beetles will kill a tree without affecting its surroundings.

Under the similar abiotic site conditions present in all of the study sites, there is one path of succession following a fire event. The similarity of the species composition in the stands in comparable stages of vegetation recovery (1844, and 1860; 1925, 1929, and 1930), suggests that postfire succession takes a similar form for the entire study region. These findings are contrary to the summary results obtained by Francis (1996) who concluded that the recovery of vegetation from fire was a highly variable and lengthy process. He noted a postfire lag-time for *Picea glauca* of 25 years on certain hydric sites, which resulted in shrub dominated communities for up to 50-75 years. But the more detailed results presented here suggest the long lags are exceptional rather than usual, as *Picea* arrived almost immediately in nearly all of the sites.

The results of this study suggest the following postfire successional pathway in the Shakwak Trench:

1. newly burned, *Populus tremuloides* and *Salix* spp. establish immediately
2. 0-4 years – *Picea glauca* establish
3. 20-50 years – disappearance of *Populus tremuloides*
4. 50-150+ years – dominance of *Picea glauca* in canopy

The general pathway of succession is illustrated in Figure 36. The fires used in this study were sampled in chronosequence, however, due to the lack of fires in the region from 1950-80, the stages of succession from 20-50 years were not represented. The Alaskan successional model, which reveals similar results to this study, illustrates that the period from 20-50 years after fire is dominated by deciduous trees and shrubs (West *et al.*, 1981). This dense tree/shrub stage is followed by a hardwood stage that persists for up to 150 years. In the Shakwak Trench, however, sampling of the 1948 fire demonstrated that between 20-50 years, *Populus tremuloides* no longer reproduced. This allowed *Picea glauca* to dominate the forest stand more rapidly, which represents the most pronounced difference between postfire succession in Alaska and the southwest Yukon Territory. Nevertheless, the stages of postfire succession in the southwest Yukon bear many similarities to the successional regime described in Alaska and northern Quebec (Van Cleve and Viereck, 1981; Foote, 1983; Morneau and Payette, 1989; Payette *et al.*, 1989). Immediately following fire, light-seeded species such as *Populus tremuloides* and *Salix* spp., along with various herbaceous plants, become quickly established. *Populus tremuloides* also becomes quickly established primarily because of its ability to root sucker but also because of its light, well-dispersed seeds. *Picea glauca* seedlings become quickly established but do not dominate the canopy until approximately 50-70 years after fire. During the deciduous tree stage (first 50 years), *Populus tremuloides*, *Salix* spp., and *Populus balsamifera* dominate the successional pattern.

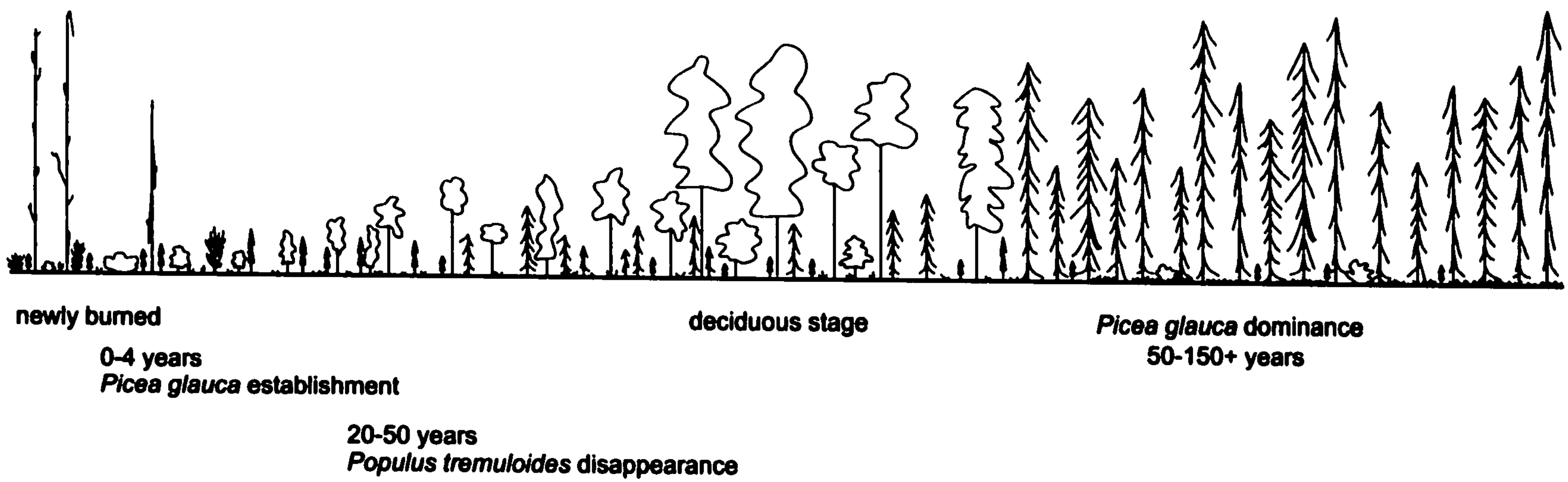


Figure 36. Postfire successional pathway in the Shakwak Trench, Yukon Territory.

As seen in this and other studies of the postfire recovery sequence in the boreal forest, the overall pattern of succession is the immediate establishment of the dominant species, eventually leading to a moss-spruce forest (Maikawa and Kershaw, 1976; Dyrness *et al.*, 1986). In southeastern Labrador however, a lag time of approximately 20-30 years was seen before the establishment of spruce seedlings (Foster, 1985). In Quebec, seedlings established immediately after fire, however the final recovery stage is dominated by lichen and not moss as seen in Alaska (Dyrness *et al.*, 1986), in Labrador (Foster, 1985) and in the Northwest Territories. (Maikawa and Kershaw, 1976).

Van Cleve and Viereck (1981) noted that in Alaska, few *Picea glauca* stands of over 200 years of age have been located, none of which have been studied. Francis' (1996) fire history study of the Shakwak Trench also demonstrated that the oldest fire recorded was in 1806. The rotation period is therefore similar in both regions, although the successional sequence is faster in the Yukon than in Alaska.

Results presented here are consistent with Egler's (1954) concept of initial floristic composition. The successional stages occur as a result of the successive disappearance of early successional species, unable to reproduce under a closed canopy. As time progresses, intolerant species begin to disappear and the dominance of shade-tolerant species increases (Connell and Slatyer, 1977). This study seems to indicate that the stages of succession are reasonably predictable and occur independently of the climatological regime of the region. There is a suggestion that climate variability affects the establishment of *Picea glauca* seedlings, and this may affect the rate of succession, but not the general pathway. The rate does not seem to have been significantly altered during the past 150 years, however, in nearly all fires, the *Picea glauca* established almost immediately. Further, the length of the stages is related to the life history of the dominant taxa. Thus, the primary constraints on the succession are biological. However, to separate potential climate effects, more plots would be needed to accurately quantify the spatial and temporal variability.

The five chronologies derived from sites along the Shakwak Trench depict similar trends in tree-ring width, suggesting a significant climatic influence on tree growth. The trend toward less favorable climatic conditions beginning in the 1950s, also found in other regions of northwestern Canada (Kukla *et al.*, 1977; Jacoby and Cook, 1981), demonstrates the strength of this climate signal over such a large area. It has been suggested that this period represents a reversal in the regional temperature increase, which occurred following the mid-1800s (Jacoby and Cook, 1981). Climate variations therefore have similar impacts on ring-width and presumably primary production over large areas of the boreal forest, and not just at ecotonal or sensitive sites.

Generally, the closer two sites are located, the higher the correlation of the chronologies. There is some variability in the correlations among the chronologies, which indicates that although they depict similar climate signals, there is some local or site-specific difference being expressed in the tree rings. Coupled with the climatic reconstructions derived from the chronologies, the PCA results demonstrate that the Shakwak Trench is experiencing similar trends in climate. This affects most trees in the forest in a similar way, irrespective of stand age or even the relative influence of competition. Results of this analysis showed that it is the radial growth of the trees and not tree establishment that is mostly correlated to the climate.

Further analysis is needed with regards to the within-site variability of tree establishment, as seen in the plots of the 1844 fire. Although this study does demonstrate that a short lag occurs for all other sites, it is possible there are either some exceptions or that some sites are simply anomalous. In addition, the older the age of the fire, the higher the probability for error in both aging and sampling. A detailed analysis of either one large fire or several fires of similar ages could be used to quantify this problem.

This study has shown the similarities of postfire successional stages to those found in other regions of the boreal forest. A dendroclimatological analysis has been used to illustrate that there is an overall climatological signal in the region. These results suggest that any site can be used for paleoclimate reconstruction and that future climate change may have large-scale impacts on fire frequency, forest growth, and subsequent tree establishment.

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CHAPTER FIVE:
Summary and Conclusions

This study investigates the reproduction and growth of trees after fire in relation to the climatic regime of the Shakwak Trench. The dendroecological analysis demonstrated that succession in the Shakwak Trench is similar to that of other regions of the boreal forest. The forests of the Shakwak Trench demonstrate a short lag in *Picea glauca* establishment, followed by a dominant deciduous stage, and ending in a closed-canopy *Picea glauca* forest underlain by mosses. Comparisons of the chronologies to the age structures of the sites demonstrated that the successional pathway of species in this region is primarily driven by biological influences.

The chronologies developed from five sites in the Shakwak Trench demonstrated similar climatic patterns with minor year-to-year variability. The correlations of the meteorological data to the chronologies suggests that it is the radial growth of trees and not an increase in establishment that is most affected by the region's climate.

5.1 Further research

Analyzing the age structures of a series of sites in different stages of succession is a useful method for extracting this successional pattern. One aspect of this study that could be further explored is the within-site differences in the postfire vegetative succession of a particular stand. Using one stand in an advanced stage of succession, several transects could be used to determine any differences in the age structures and species composition throughout the fire. This would provide useful information with respect to the differences in the regeneration capacity of the dominant tree species and factors influencing establishment of the tree species.

The results of this study are suggestive of the potential importance of biological influences on tree growth, but are by no means definitive. It would be beneficial to perform a study using several widely separated stands in the same stage of succession (burned at the same time) to determine whether the climate of the region has influenced the regeneration of trees.

A detailed analysis of the understory in each stage of succession was not performed in this study and has not yet been explored in the southwest Yukon Territory. Such an analysis would contribute to our understanding of impacts on biodiversity of the boreal forest and could be used comparatively to other understory studies performed in the boreal forest.

In short, this study has explored many fundamental concepts with respect to postfire succession in the boreal forest. The next step would be to explore each aspect of this study in detail and to perform similar analyses in other parts of the Yukon for comparative purposes.

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Appendix A:
Understory vegetation of 11 sites in the Shakwak Trench, Yukon Territory.

Figure A1. General vegetation description for sites in the study region. These species were found in the plot but not specifically quantified in the quadrats.

	Cultus region						Sulphur Lake region				Haines Jct region				
	1844P1	1844P2	1844P3	1855	1888	1895	1920	1929	1948	1956	1980P1	1980P2	1990P1	1990P2	1998
Populus balsamifera						+			+					+	
Salix arbuscubides									+						
Salix bebbiana				+	+				+						
Salix arctica					+										+
Salix glauca							+								
Shepherdia canadensis					+				+					+	+
Geocaulon luridum	+	+	+												
Solidago simplex						+	+								
Potentilla fructicosa															+
Senecio lugens							+								
Mertensia paniculata	+	+	+												
Orthilia secunda									+						
Arnica angustafolia									+						
Solidago multiflora									+					+	
Linnea borealis				+	+				+						+
Lupinus arcticus						+		+	+						
Equisletum scirpoides									+						
Arctostaphylos rubra									+						
Arctostaphylos uva-ursi					+			+						+	
Moneses unaflora									+						
Oxytropis campestris														+	
Galium boreale														+	
Epilobium angustifolium														+	+
Pulsatilla patens														+	
Pyrola choranthe							+								
Parnassia palustris							+								+
Lichen					+		+	+							

+, indicates presence of species in the plot.

Among the lichens, *Peltigera rufescens, Cladonia coniocraea, Cladonia fimbriata, Cladonia pyxidata* and *Caloplaca sinapisperma* were present

Table A2. Vegetation inventory of sites in the Jenny Lake region taken from quadrats in each plot.

	Jenny Lake region										
	1844P1-1	1844P1-2	1844P1-3	1844P2-1	1844P2-2	1844P2-3	1844P3-1	1844P3-2	1844P3-3	1855-1	1855-2
Populus tremuloides											
Picea glauca											
Salix glauca											
Salix bebbiana											
Salix arctica											
Shepherdia canadensis								2			
Rosa acicularis											
Geocaulon luridum			4								
Arctostaphylos alpina											
Arctostaphylos uva-ursi								1			
Linnea borealis		1		7	1		1				
Equisitum scirpoides											
Astragalus robbinsii											
Solidago simplex											
Potentilla fructicosa											
Polemonium pulcherrimum											
Achillea millefolium											
Anemone multifida											
Oxytropis campestris											
Achillea millefolium											
Poaceae spp.									+	+	
Moss	10	9	6	3	9	10	9	8	9	8	9
Lichen							+		1	2+	
Fungi											
dead log										1	1

The number indicates average plant cover (+, <1%; 1, 1-10%; 2, 11-19%...).

The ID number given to each fire indicates the fire and the quadrat. Eg. 1998-1 is the first quadrat of the 1998 fire.

Among the mosses, Bryum pseudotriquetrum, *Pleurozium schreberi* and *Pohlia nutans* were present.

Among the lichens, *Peltigera rufescens*, *Cladonia coniocraea*, *Cladonia fimbriata*, *Cladonia pyxidata* and *Caloplaca sinapisperma* were present

Table A3. Vegetation inventory of sites in the Jenny Lake and Sulphur Lake regions taken from quadrats in each plot.

	Jenny Lake region							Sulphur Lake region						
	1855-3	1888-1	1888-2	1888-3	1895-1	1895-2	1895-3	1920-1	1920-2	1920-3	1929-1	1929-2	1929-3	1948-1
Picea glauca											+			
Salix glauca													1	1
Salix bebbiana											5	8		
Salix arctica										4				
Shepherdia canadensis	1		+					1		1				6
Geocaulon luridum										+				
Arctostaphylos uva-ursi					8		7		4	1				
Linnea borealis	1													2
Equisitum scirpoides									1	1				
Solidago simplex	1						1						1	
Potentilla fructicosa					1		1					1		
Pulsatilla patens						1	1							
Galium boreale							1							
Epilobium angustafolium									2	1				
Hedysarum alpinum								2	4	1	2	1		
Vaccinium uliginosum										4				
Polemonium pulcherrimum					1		1							
Mertensia paniculata					1	1								
Achillea millefolium							1					1		
Anemone multifida														
Achillea millefolium													+	
Poaceae spp.	+	+	+		+	+			+	+		+	2	
Moss	6	4	7	3		8					+			
Lichen	+	4	2			1						1		
Fungi														
dead log	2	2	2	3			1				3			1

The number indicates average plant cover (+, <1%; 1, 1-10%; 2, 11-19%...).

The ID number given to each fire indicates the fire and the quadrat. Eg. 1998-1 is the first quadrat of the 1998 fire.

Among the mosses, Bryum pseudotriquetrum, *Pleurozium schreberi* and *Pohlia nutans* were present.

Among the lichens, *Peltigera rufescens*, *Cladonia coniocraea*, *Cladonia fimbriata*, *Cladonia pyxidata* and *Caloplaca sinapisperma* were present

Table A4. Vegetation inventory of sites in the Sulphur Lake and Haines Junction regions taken from quadrats in each plot.

	Sulphur Lake region					Haines Junction region						
	1948-2	1948-3	1956-1	1956-2	1956-3	1980P1-1	1980P1-2	1980P1-3	1980P2-1	1980P2-2	1980P2-3	1990P1-1
Populus tremuloides					+	+						
Picea glauca												
Salix glauca				+								
Salix bebbiana			2								+	
Salix arctica												
Shepherdia canadensis	5	5	3	5								
Rosa acicularis											+	
Geocaulon luridum												
Arctostaphylos alpina				1								
Arctostaphylos uva-ursi								1		3	9	
Linnea borealis												
Equisitum scirpoides	+											
Astragalus robbinsii			2									
Solidago simplex							1+		1			
Potentilla fructicosa												
Senecio lugens					4							
Pulsatilla patens							1				+	
Galium boreale							+					
Epilobium angustafolium											+	
Oxytropis campestris												
Achillea millefolium												
Poaceae spp.						3	1	4	2	1+		
Moss	3	2	3	4	5				3			4
Lichen					1				3+			
Fungi			+									
dead log	2	3		1					1	1		4

The number indicates average plant cover (+, <1%; 1, 1-10%; 2, 11-19%...).

The ID number given to each fire indicates the fire and the quadrat. Eg. 1998-1 is the first quadrat of the 1998 fire.

Among the mosses, Bryum pseudotriquetrum, *Pleurozium schreberi* and *Pohlia nutans* were present.

Among the lichens, *Peltigera rufescens*, *Cladonia coniocraea*, *Cladonia fimbriata*, *Cladonia pyxidata* and *Caloplaca sinapisperma* were present

Table A5. Vegetation inventory of sites in the Haines Junction region taken from quadrats in each plot.

	Haines Junction region								
	1990P1-2	**1990P1-3**	**1990P2-1**	**1990P2-2**	**1990P2-3**	**1998-1**	**1998-2**	**1998-3**	
Populus tremuloides	+		1						
Salix glauca							1	1	
Salix bebbiana									
Salix arctica							3		6
Shepherdia canadensis									
Rosa acicularis			+	+					
Arctostaphylos uva-ursi				+					
Linnea borealis			9			+			
Equisitum scirpoides						+		1	
Astragalus robbinsii									
Solidago simplex				+	+				
Senecio lugens								+	
Pulsatilla patens				+					
Galium boreale			+	+					
Epilobium angustafolium						+		4	1
Hedysarum alpinum									
Erigeron acris							+		
Polemonium pulcherrimum								+	
Anemone multifida				+	+				
Oxytropis campestris						1			
Achillea millefolium									
Poaceae spp.		+		3	2	3	+	+	
Moss				4	4	4	4	3	1
Lichen							1		1
Fungi									
dead log		1	1		1	3	1	1	1

The number indicates average plant cover (+, <1%; 1, 1-10%; 2, 11-19%...).

The ID number given to each fire indicates the fire and the quadrat. Eg. 1998-1 is the first quadrat of the 1998 fire.

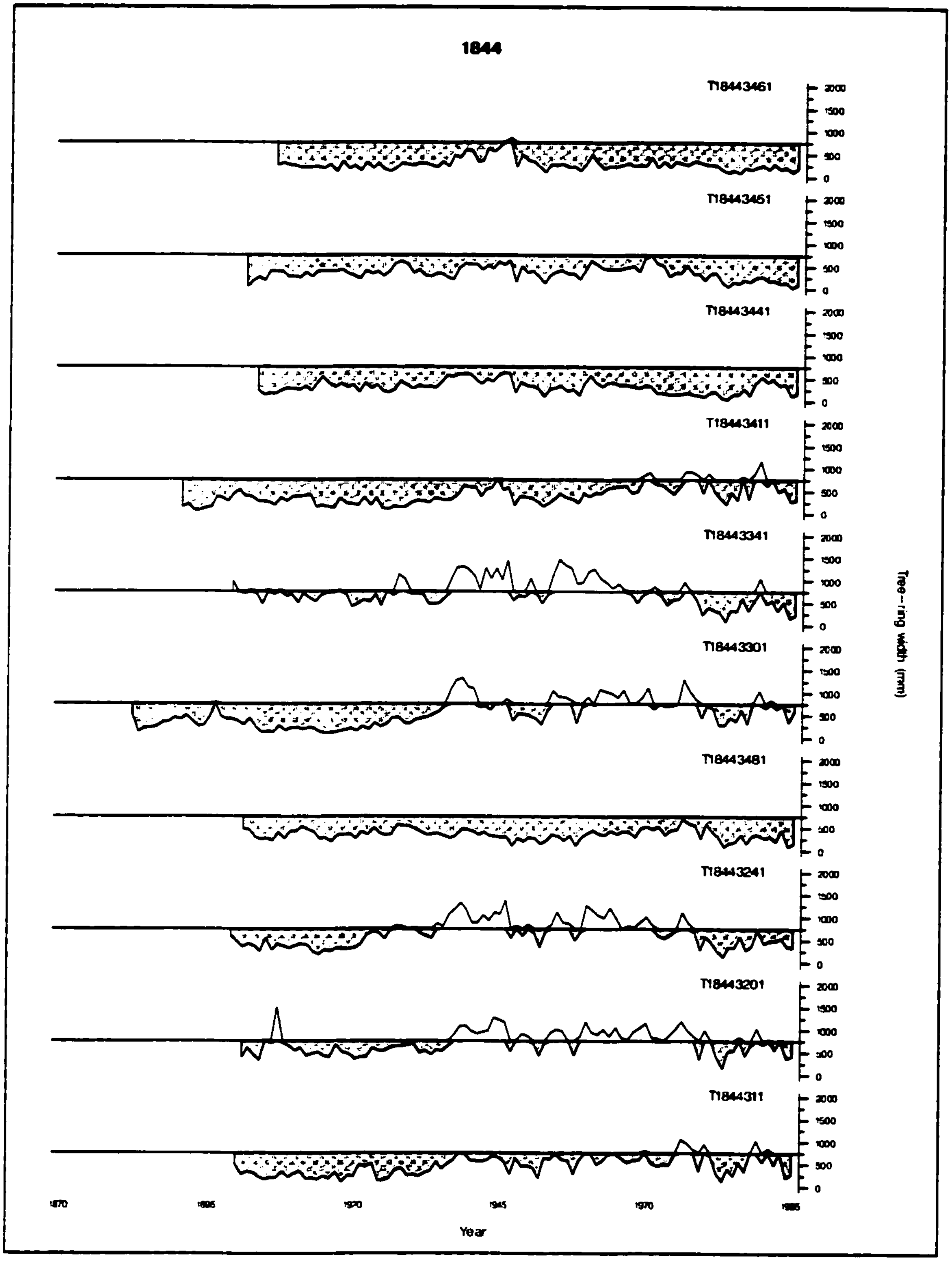
Among the mosses, Bryum pseudotriquetrum, *Pleurozium schreberi* and *Pohlia nutans* were present.

Among the lichens, *Peltigera rufescens*, *Cladonia coniocraea*, *Cladonia fimbriata*, *Cladonia pyxidata* and *Caloplaca sinapisperma* were present

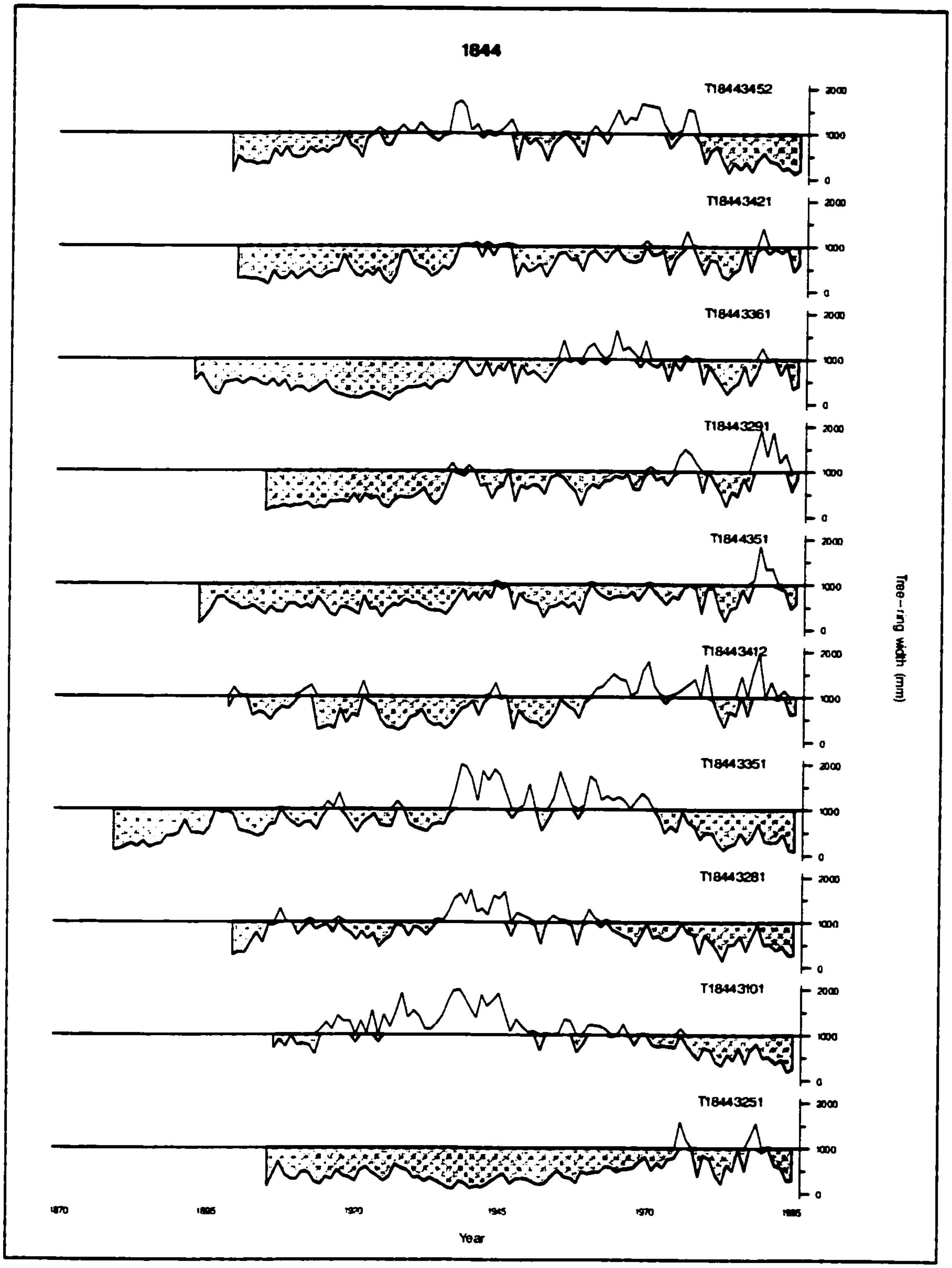
Appendix B:

Ring-widths of the individual trees comprising the five chronologies in the Shakwak Trench, Yukon Territory.

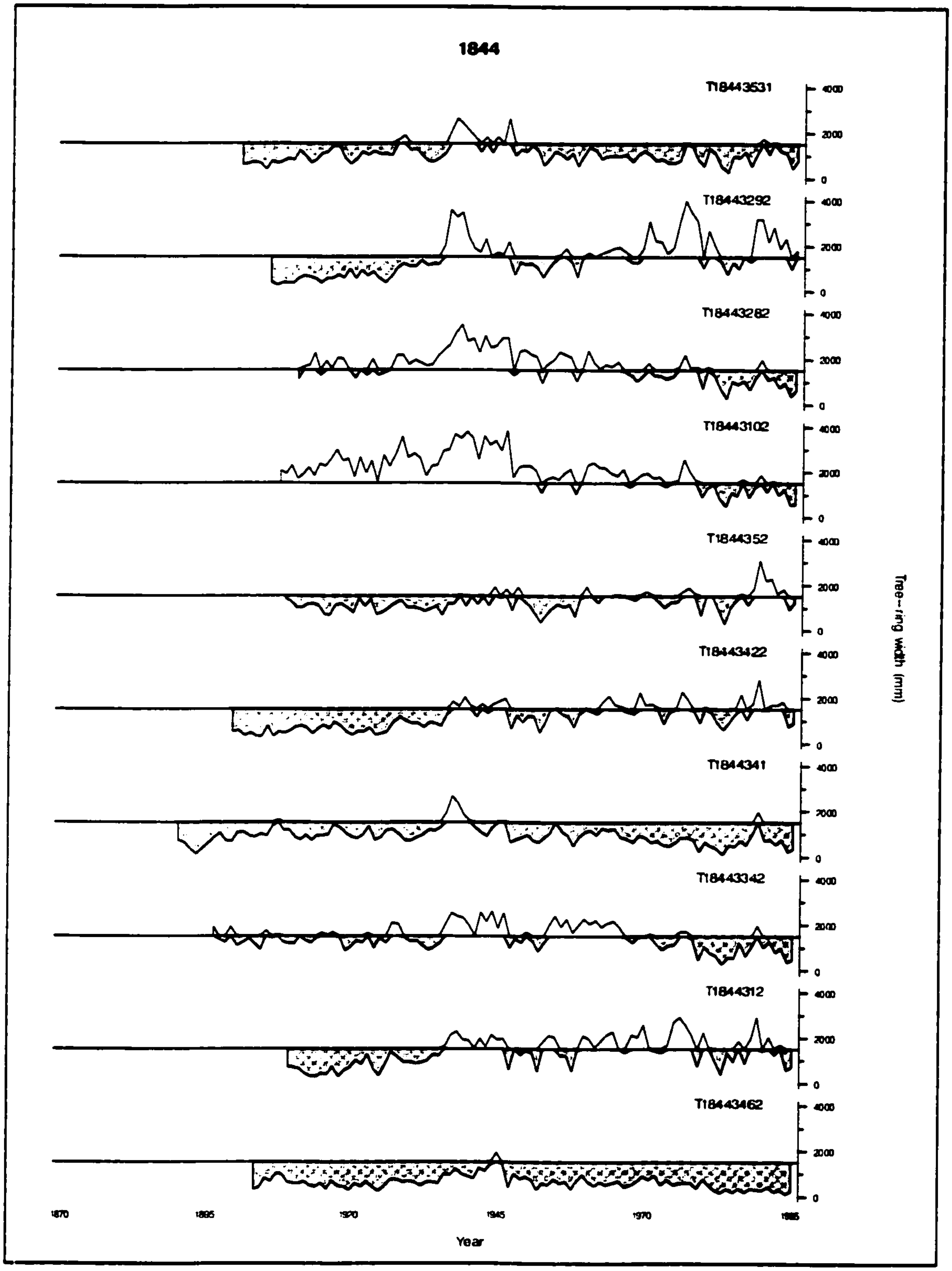
B1a. Ring widths of individual trees in the 1844 plot.



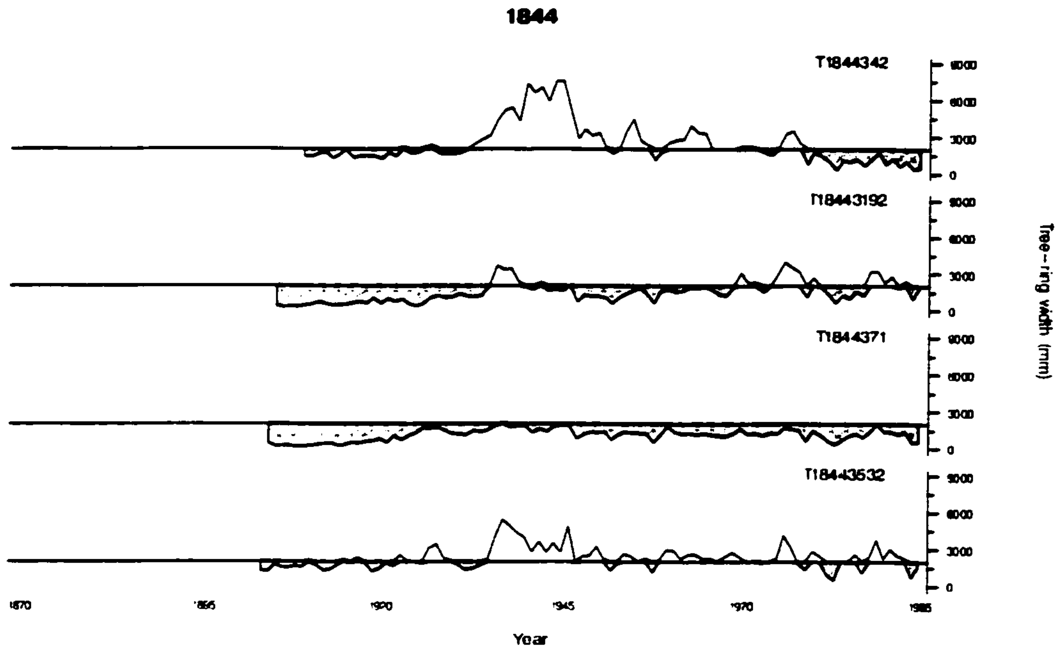
B1b. Ring widths of individual trees in the 1844 plot.



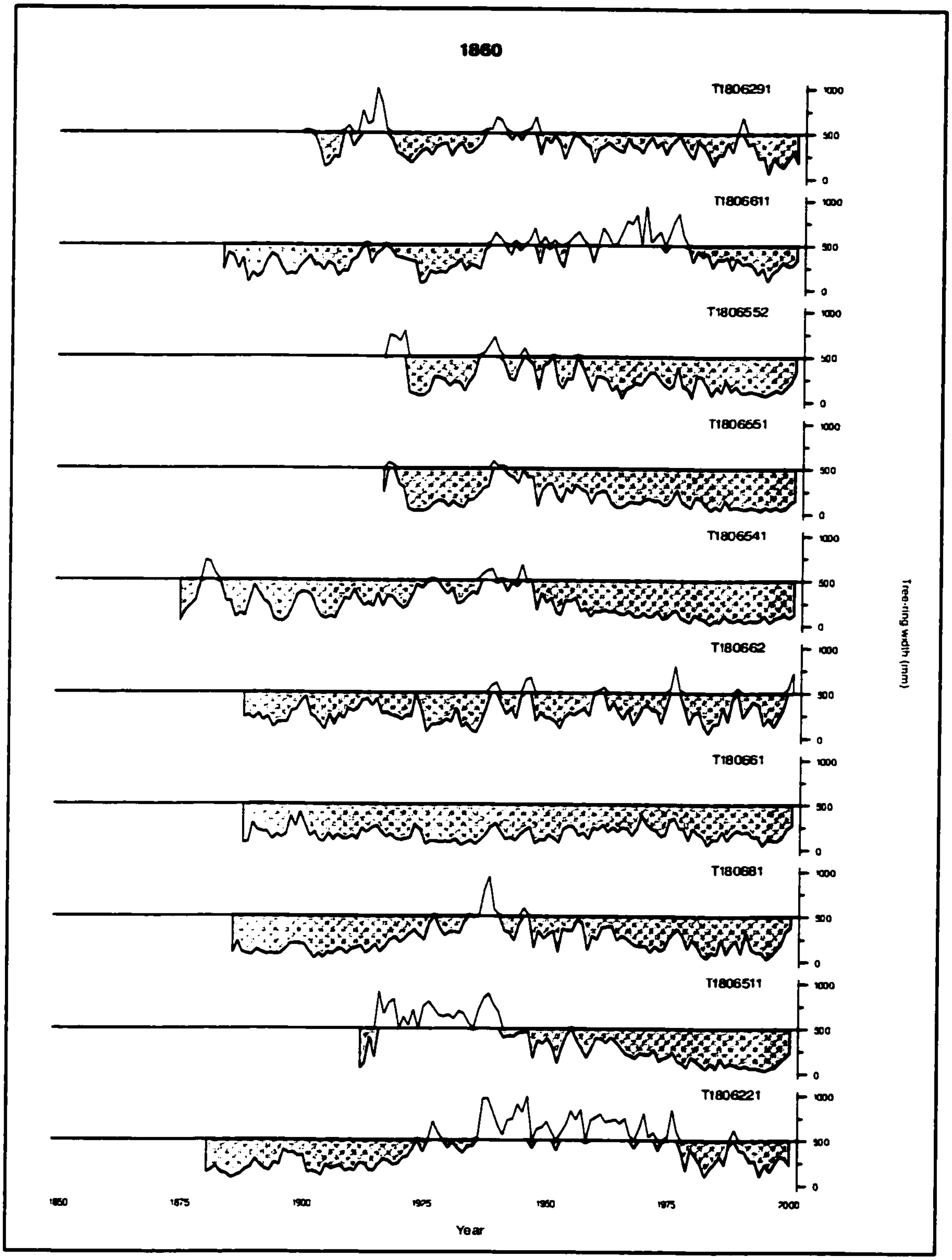
B1c. Ring widths of individual trees in the 1844 plot.



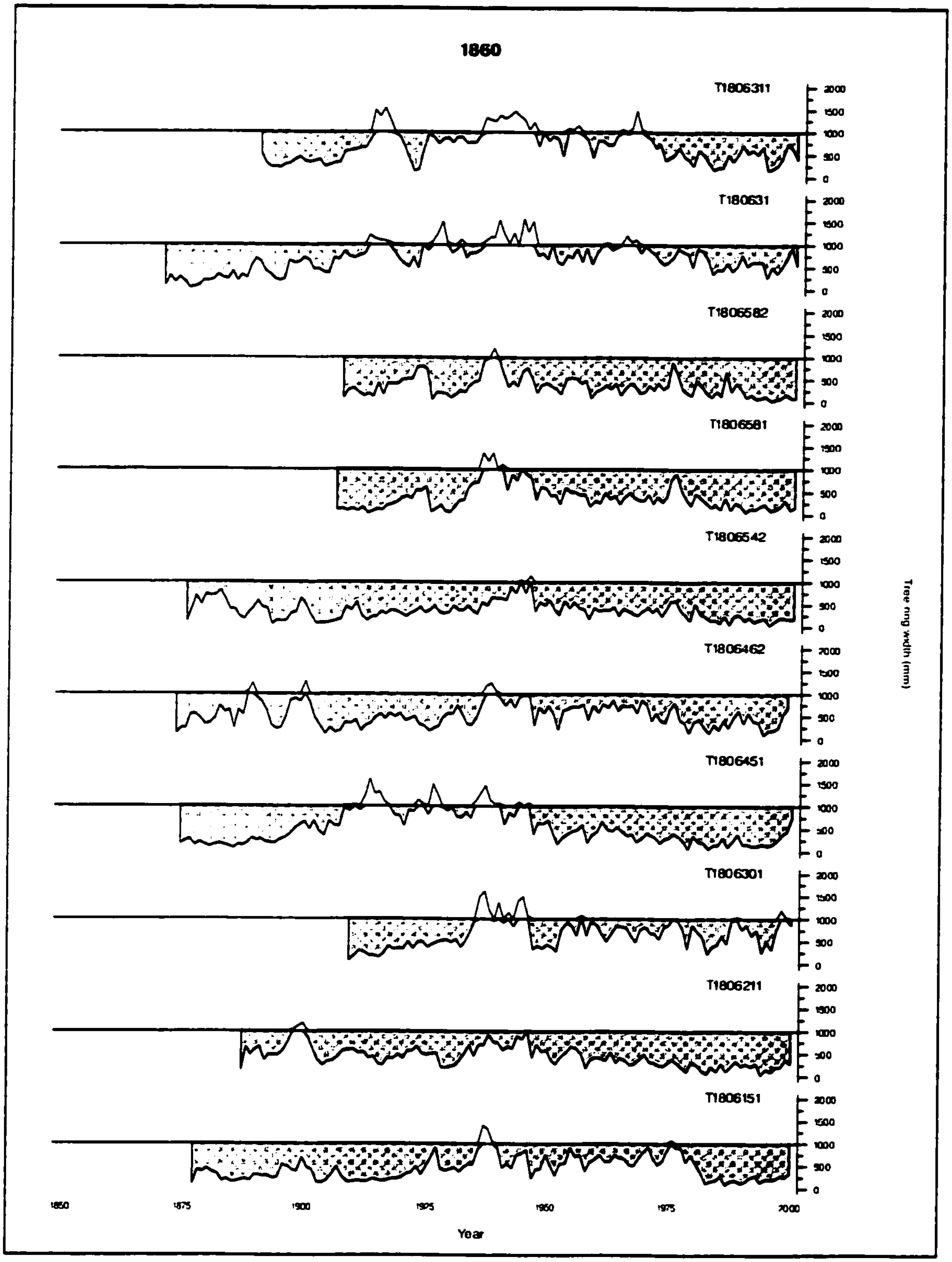
B1d. Ring widths of individual trees in the 1844 plot.



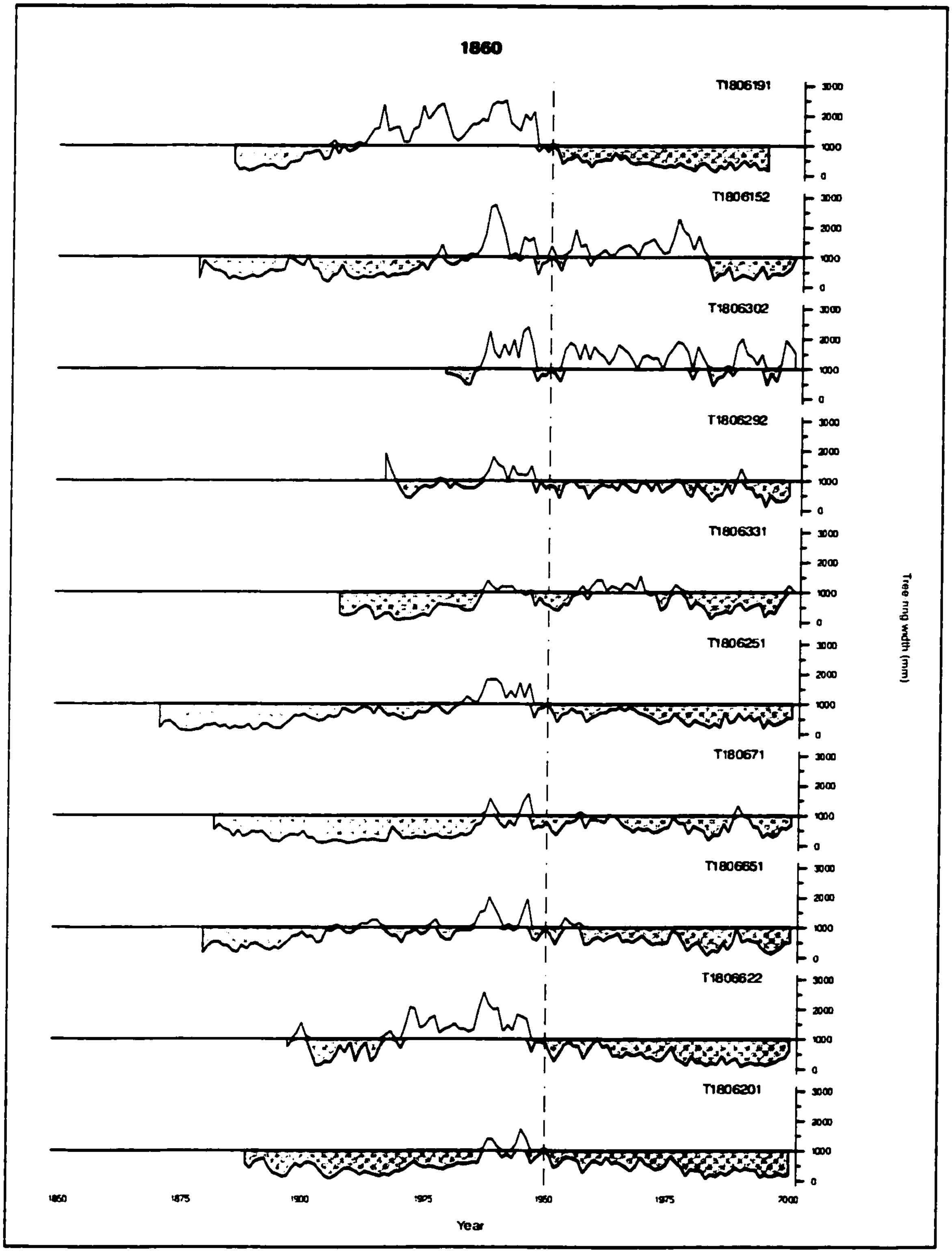
B2a. Ring widths of individual trees in the 1860 plot.



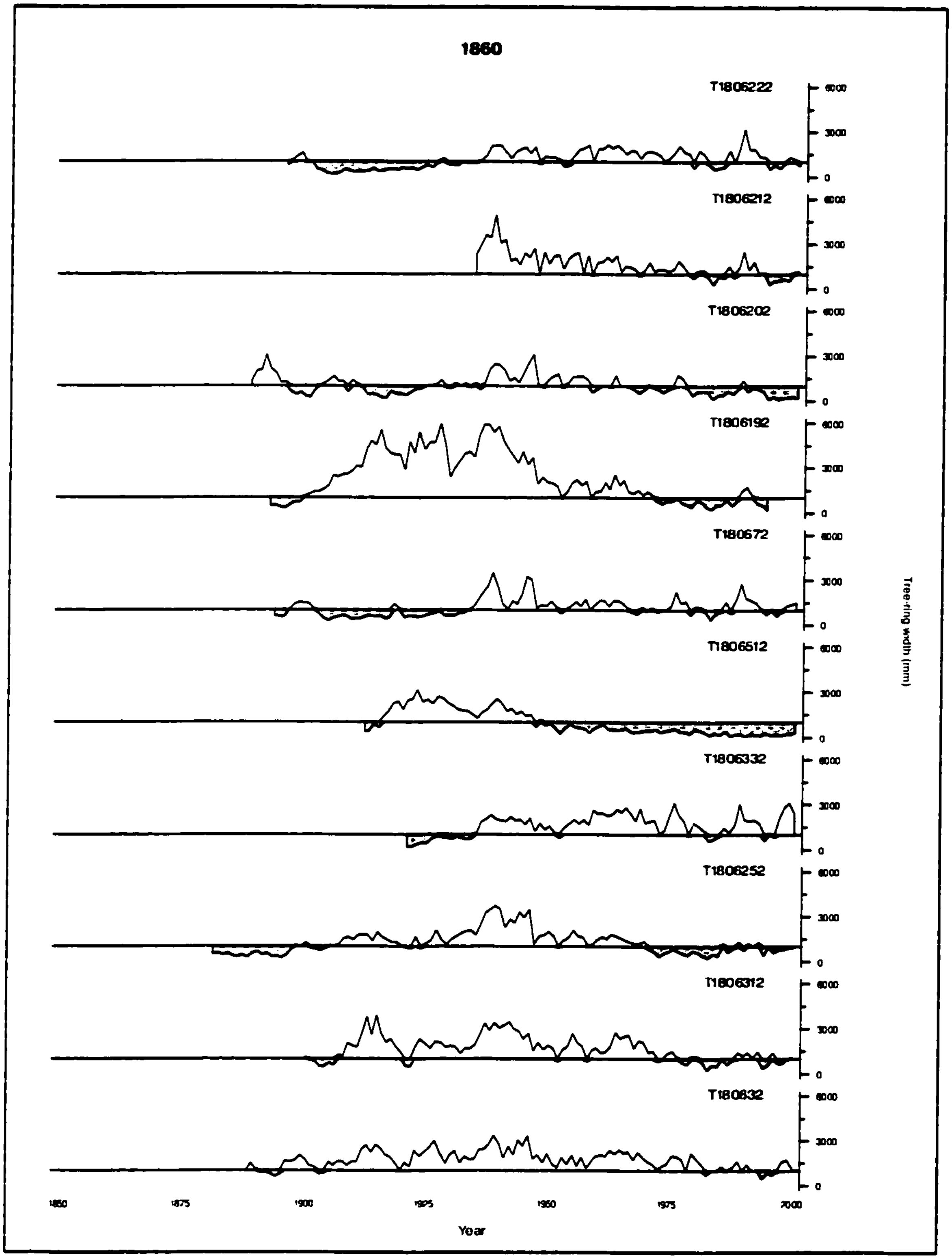
B2b. Ring widths of individual trees in the 1860 plot.



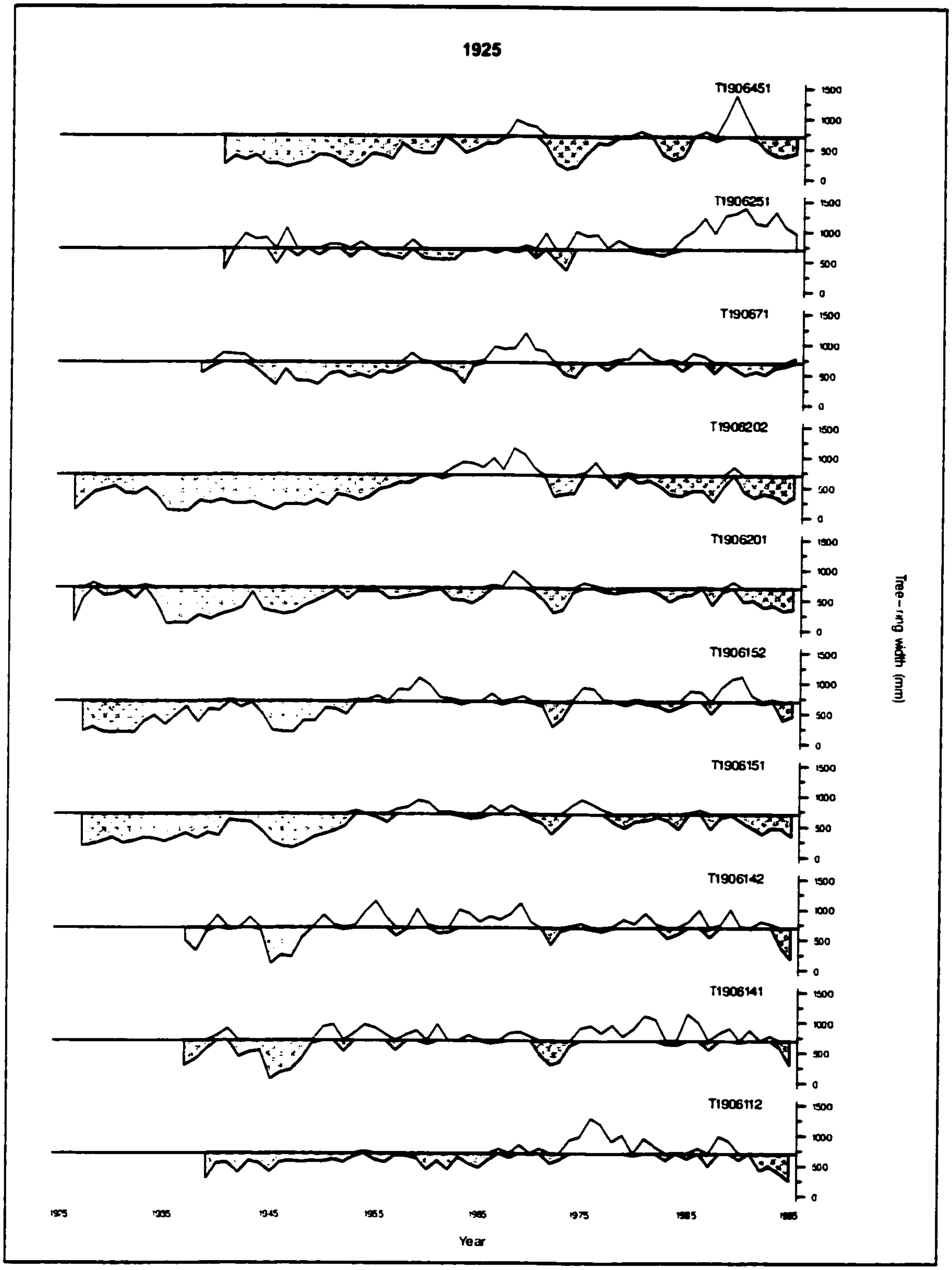
B2c. Ring widths of individual trees in the 1860 plot.



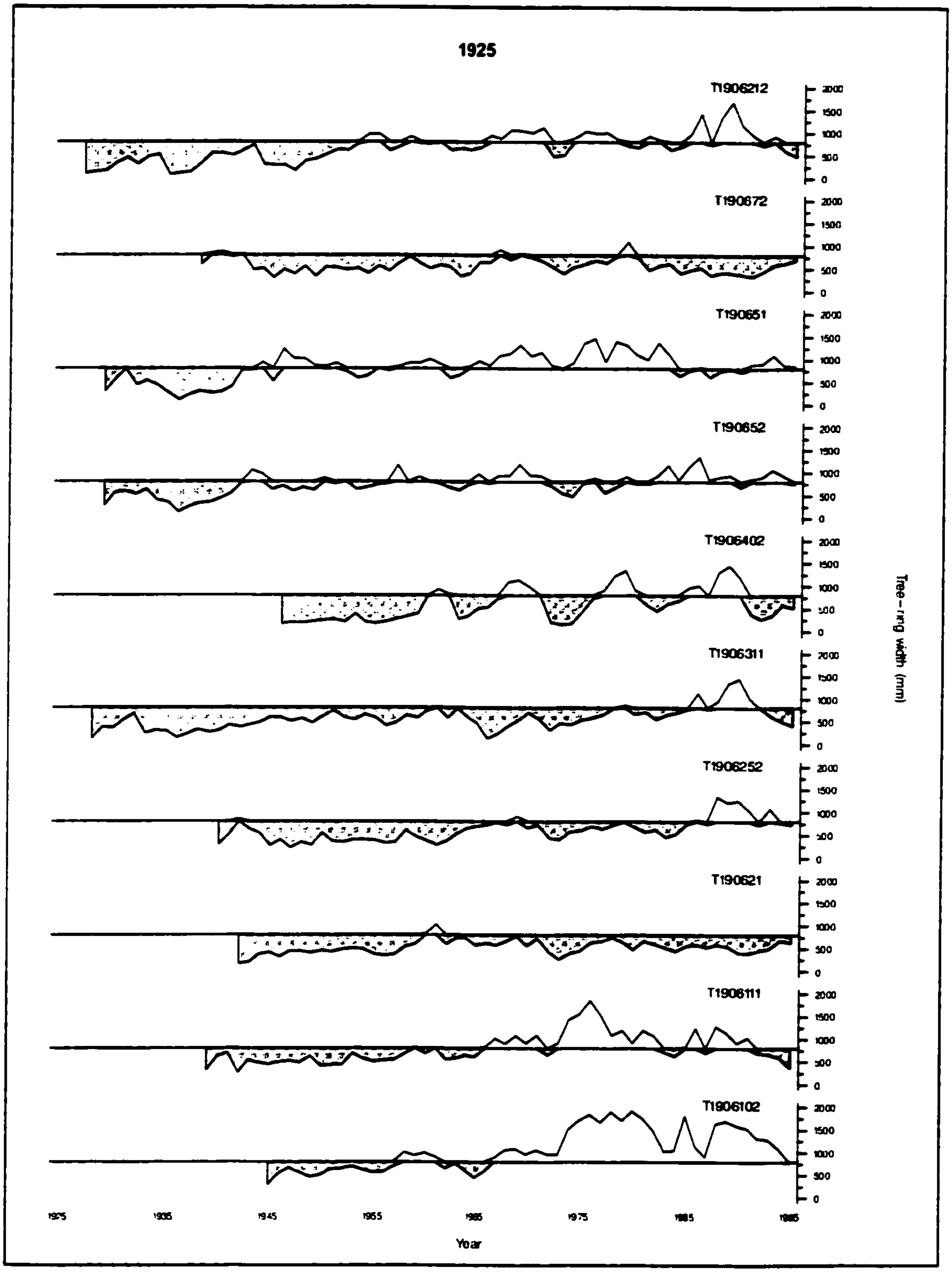
B2d. Ring widths of individual trees in the 1860 plot.



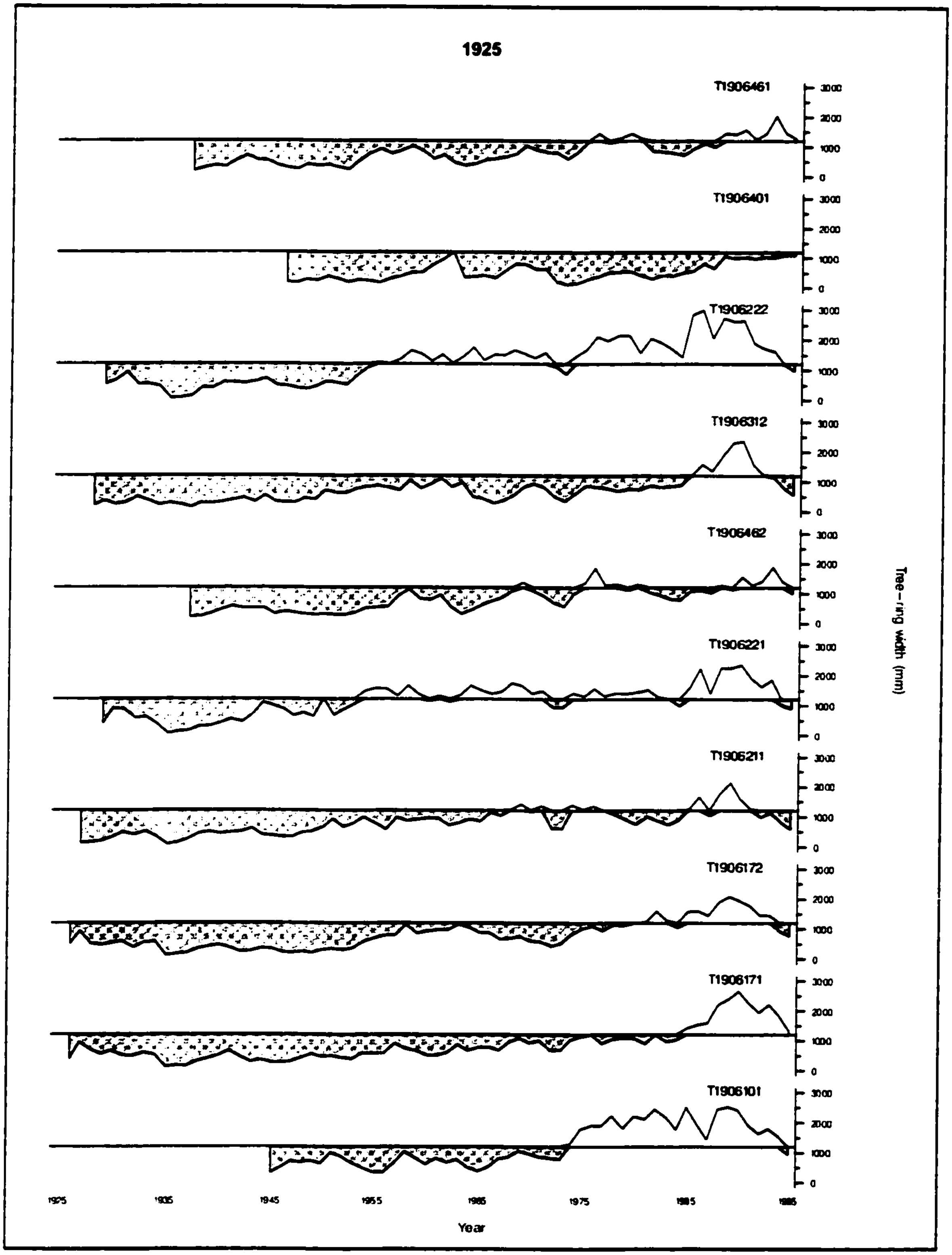
B3a. Ring widths of individual trees in the 1925 plot.



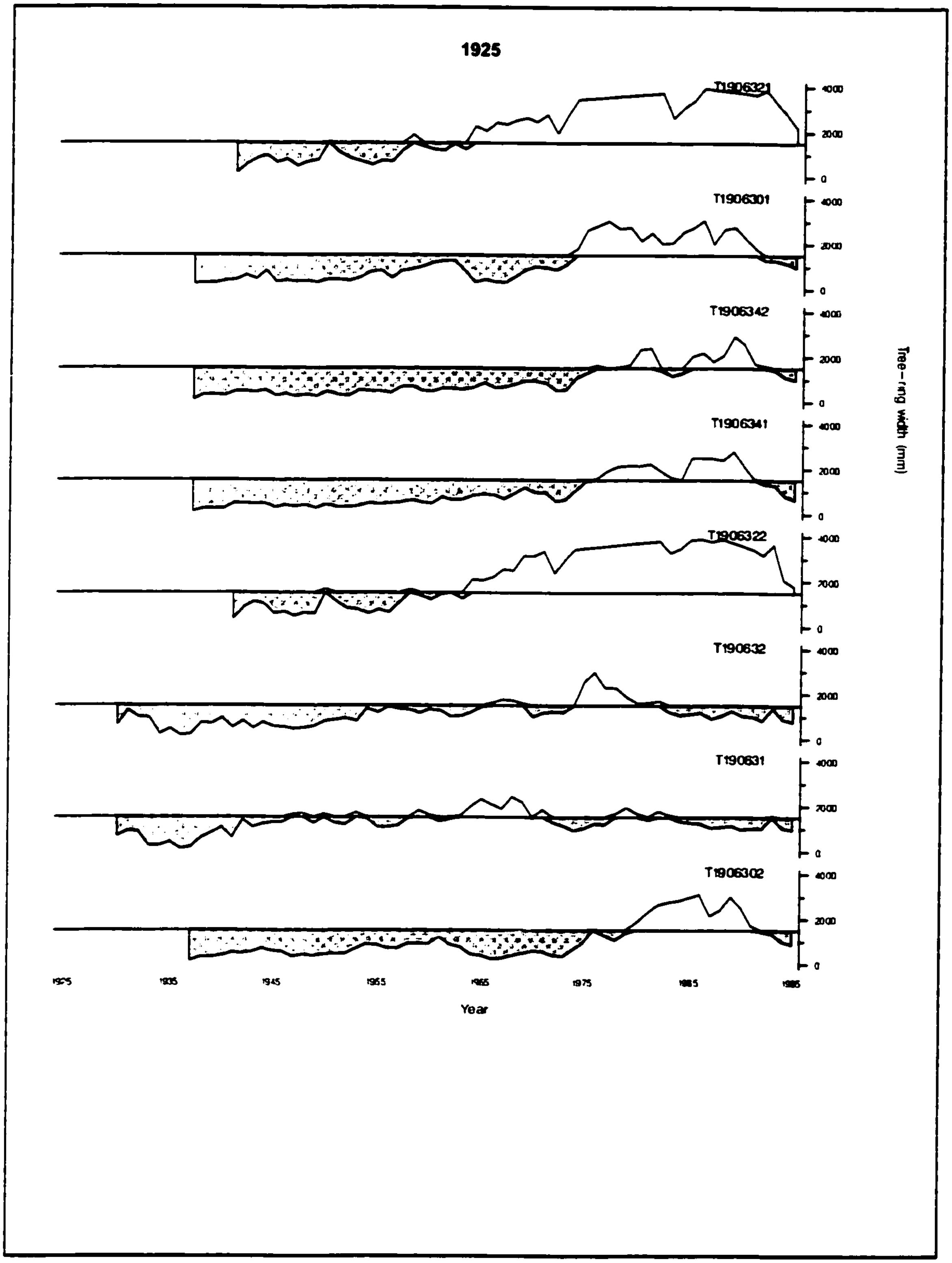
B3b. **Ring widths of individual trees in the 1925 plot.**



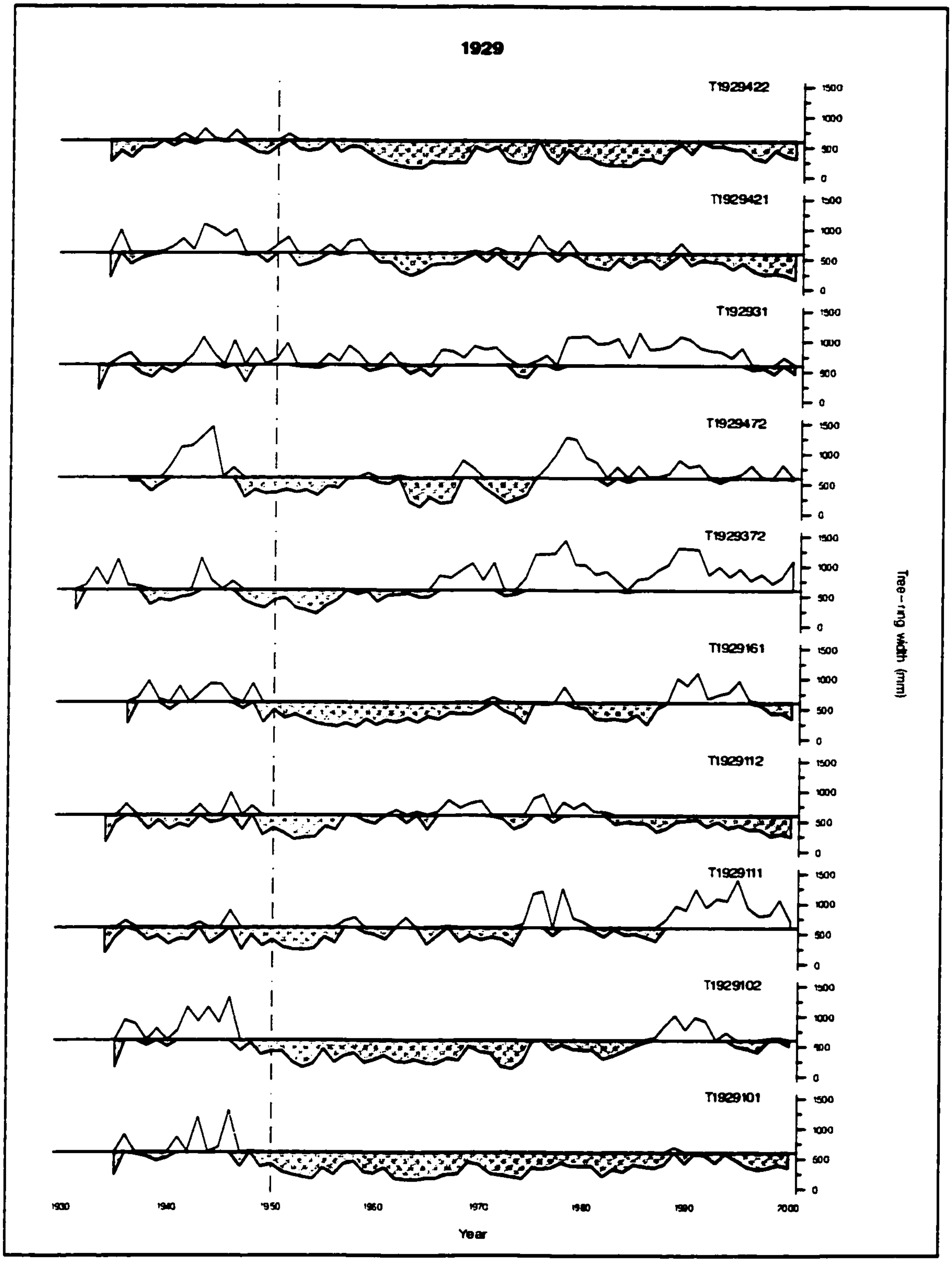
B3c. Ring widths of individual trees in the 1925 plot.



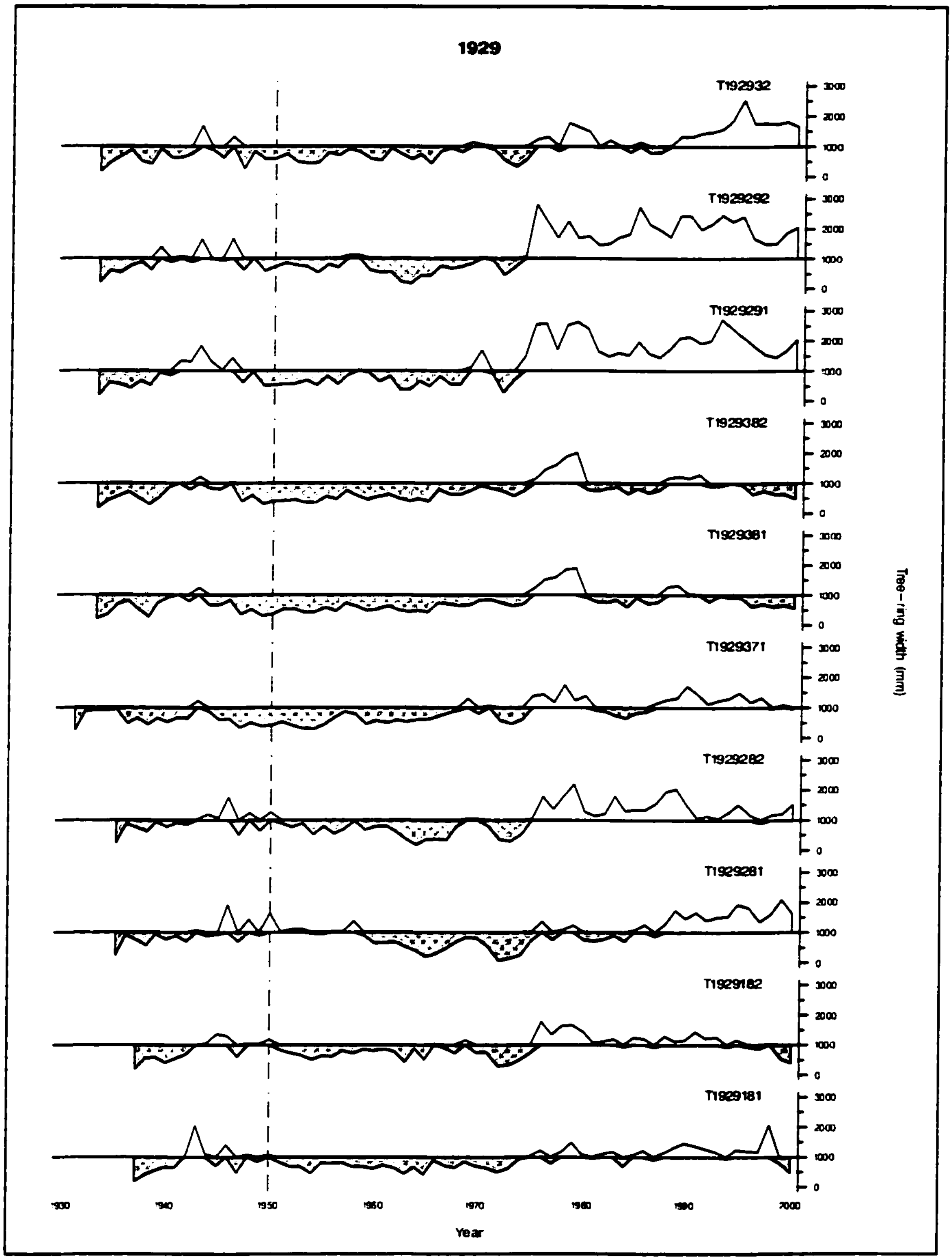
B3d. Ring widths of individual trees in the 1925 plot.



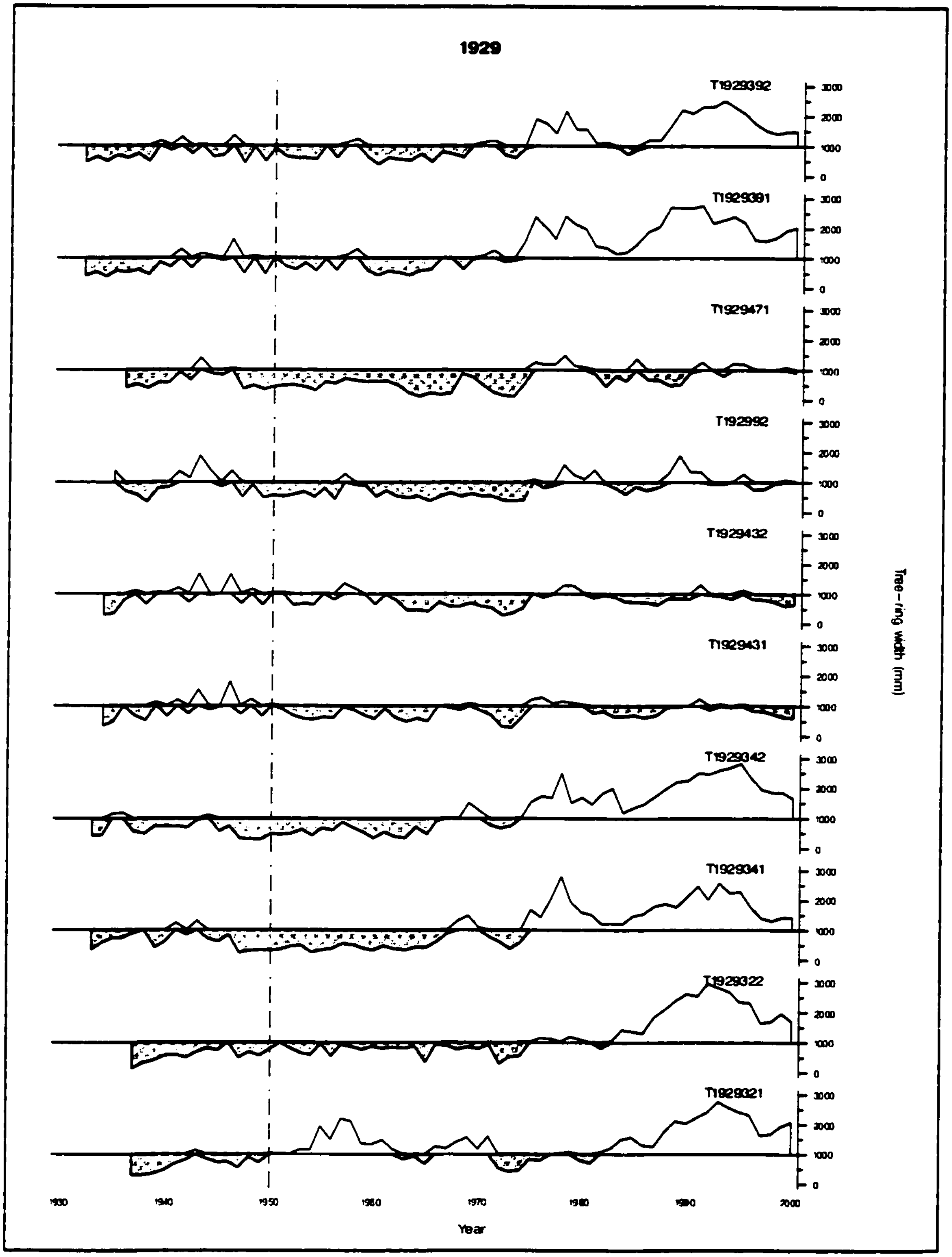
B4a. Ring widths of individual trees in the 1929 plot.



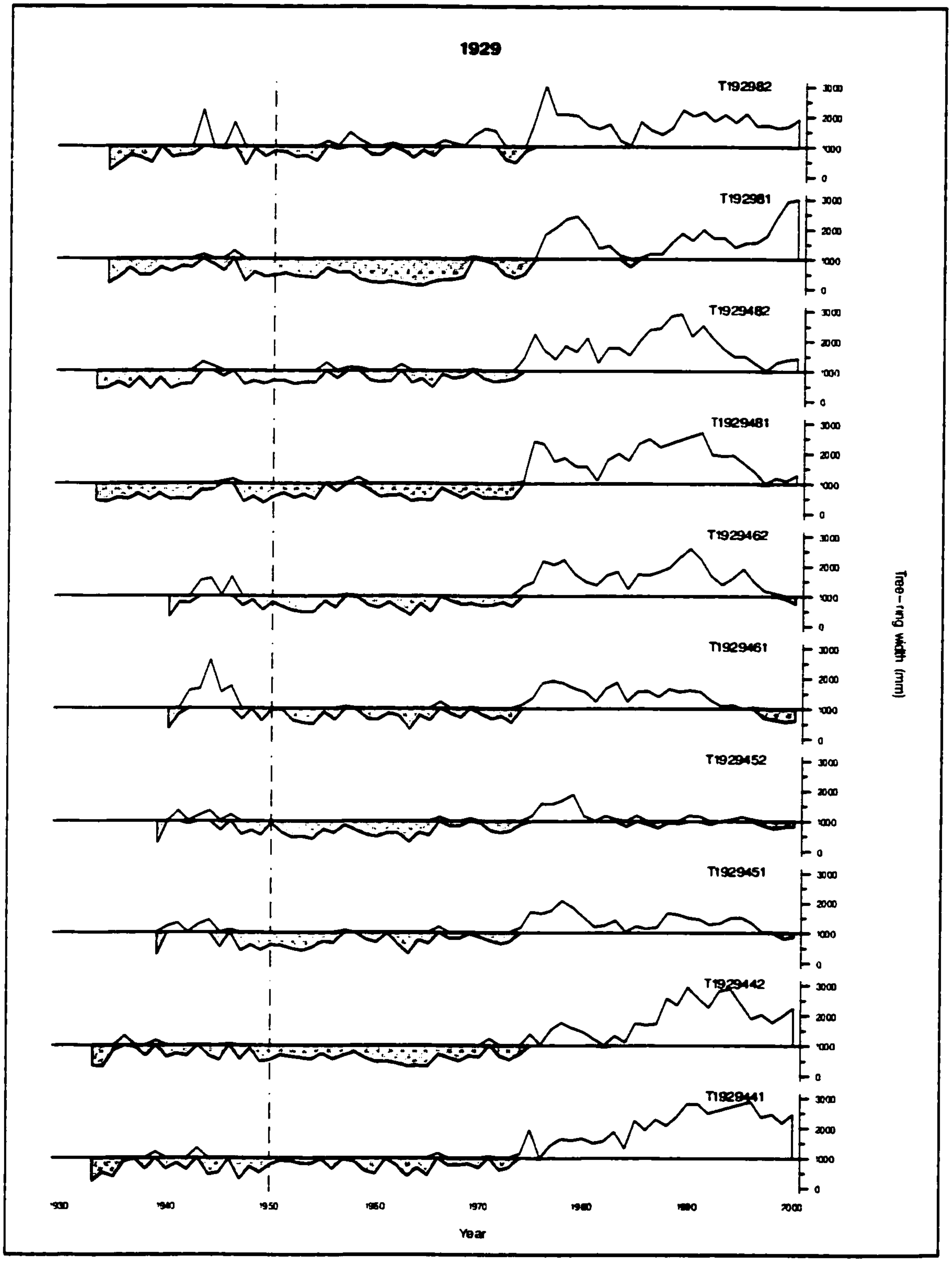
B4b. Ring widths of individual trees in the 1929 plot.



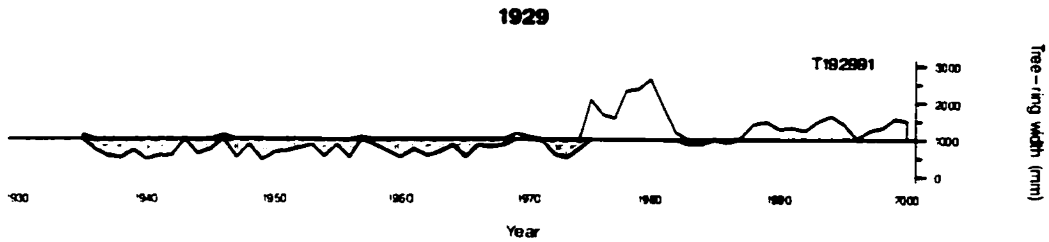
B4c. Ring widths of individual trees in the 1929 plot.



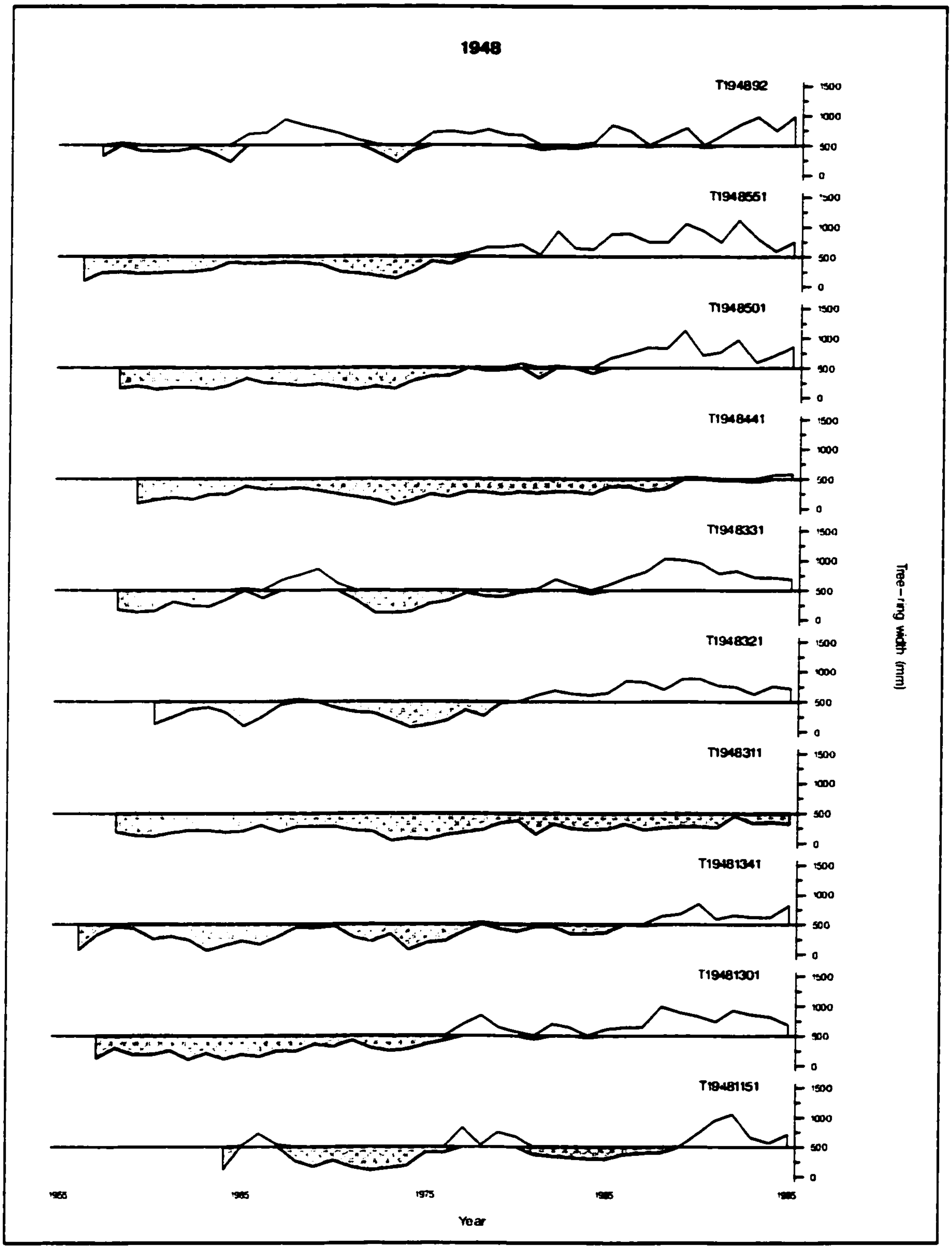
B4d. Ring widths of individual trees in the 1929 plot.



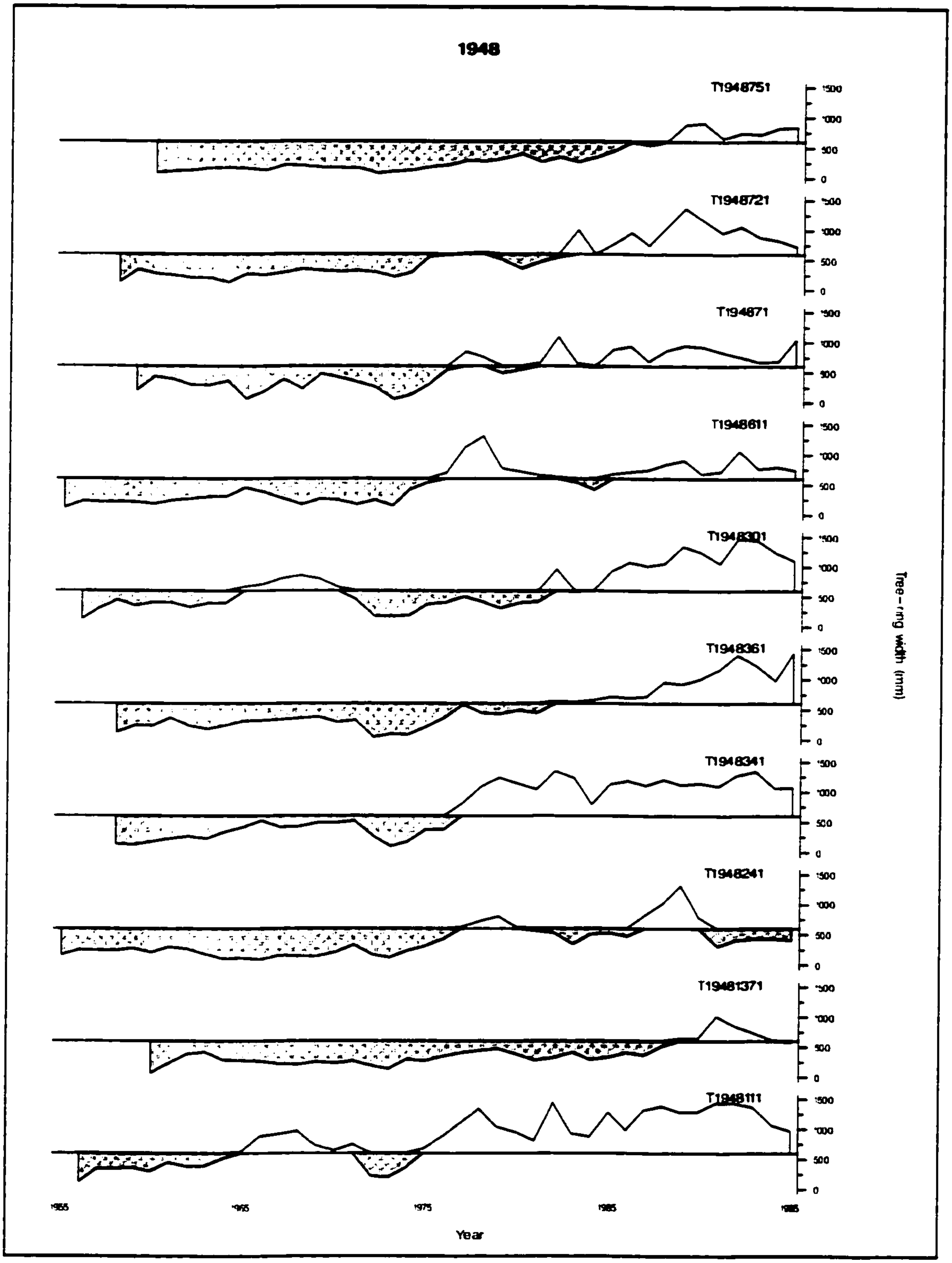
B4e. Ring widths of individual trees in the 1929 plot.



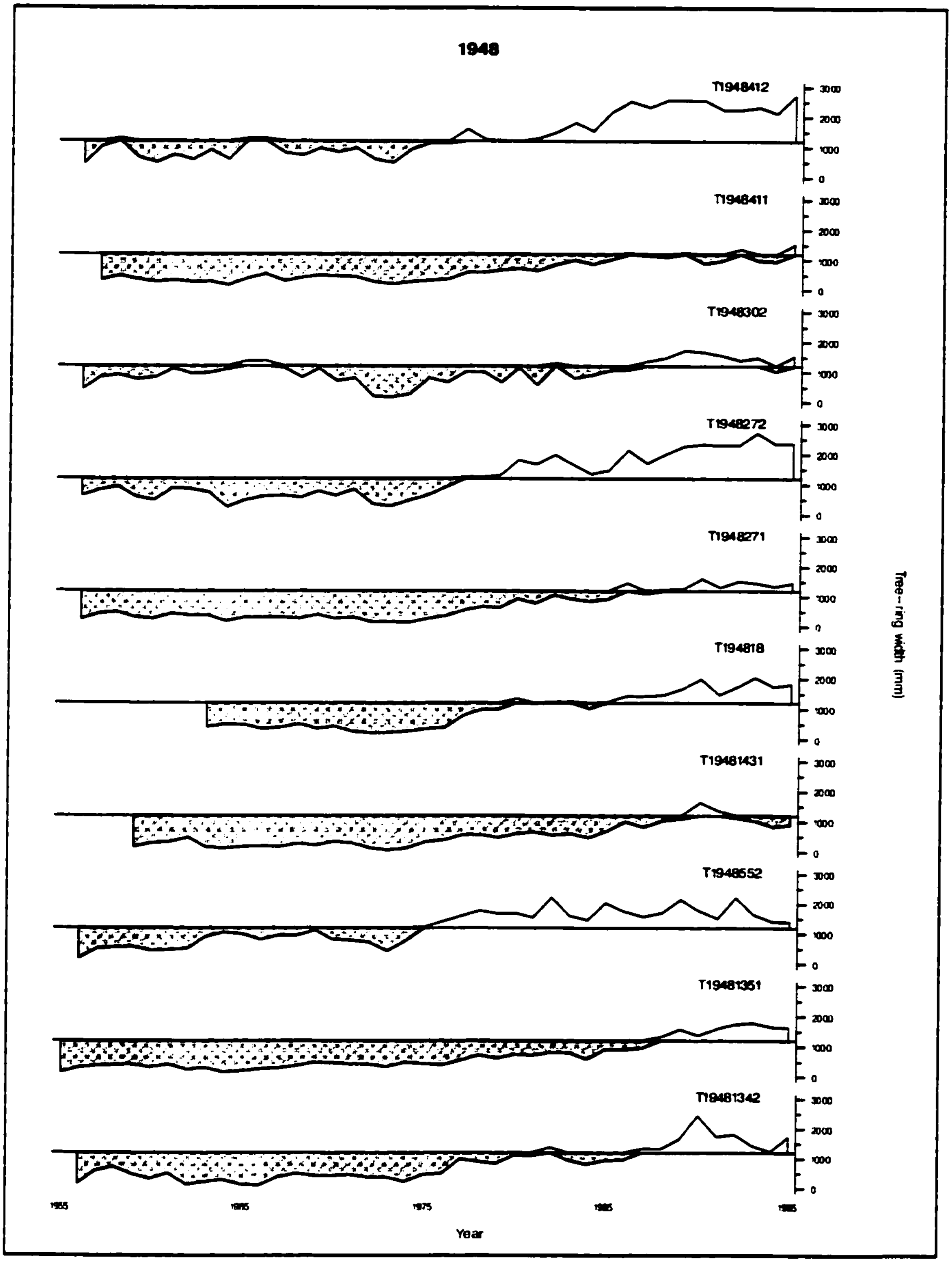
B5a. Ring widths of individual trees in the 1948 fire plot.



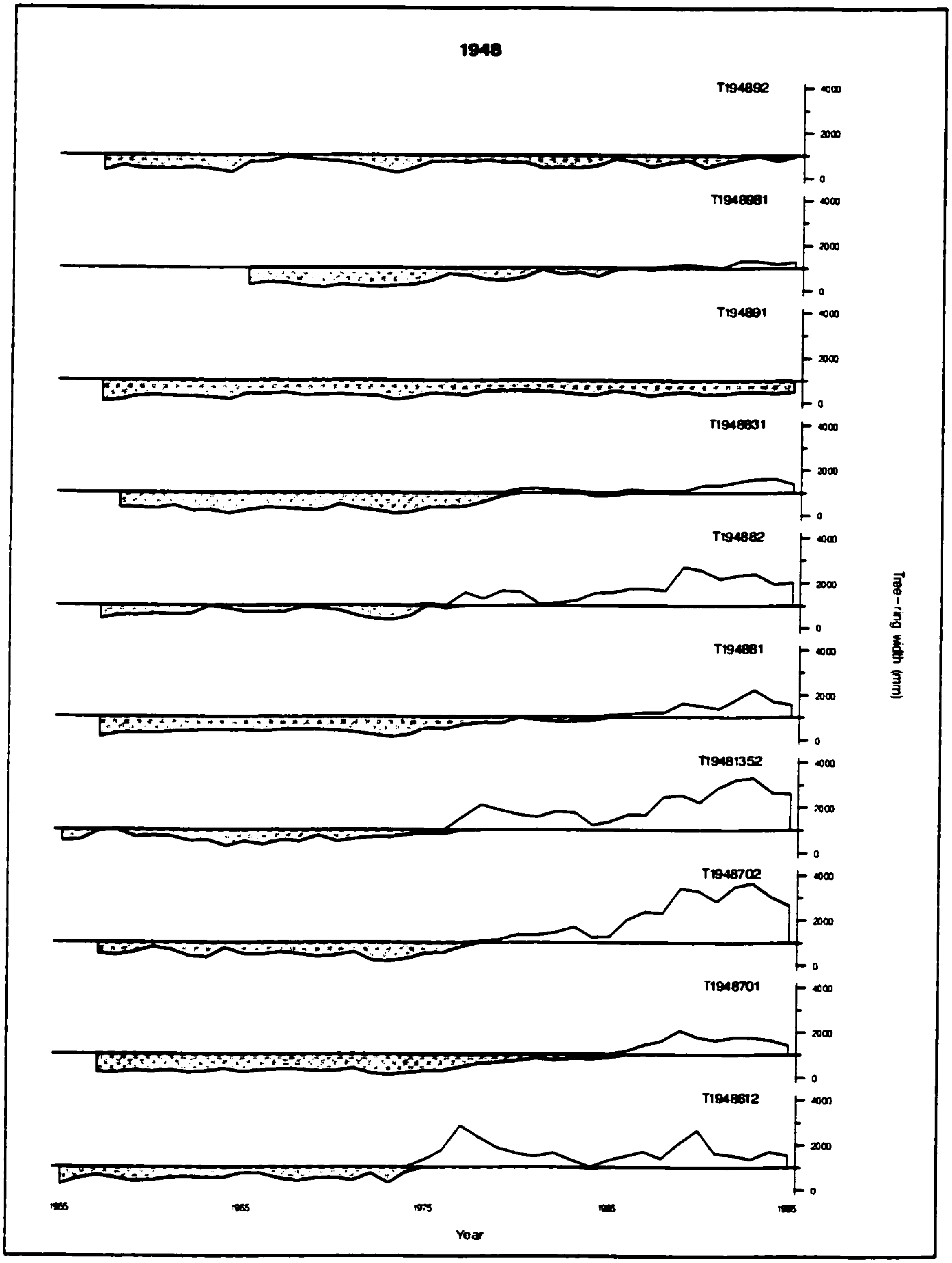
B5b. Ring widths of individual trees in the 1948 fire plot.



B5c. Ring widths of individual trees in the 1948 fire plot.



B5d. Ring widths of individual trees in the 1948 fire plot.



Appendix C:

Results of the principal components analysis performed on the ring-widths of the five chronologies in the Shakwak Trench, Yukon Territory.

Table C1a. Communalities (total explained variance) of the individual ring-width series from the 1860 plot.

Series	From 1 Factor	From 2 Factors	From 3 Factors	From 4 Factors	From 5 Factors	From 6 Factors	From 7 Factors	Multiple R^2
T1806151	0.49	0.71	0.73	0.78	0.85	0.92	0.95	0.98
T1806152	0.48	0.74	0.75	0.77	0.84	0.91	0.94	0.98
T1806191	0.51	0.91	0.91	0.91	0.91	0.93	0.95	0.98
T1806192	0.44	0.90	0.91	0.91	0.91	0.94	0.94	0.97
T1806201	0.69	0.78	0.84	0.84	0.87	0.88	0.89	0.94
T1806202	0.54	0.58	0.65	0.65	0.77	0.77	0.81	0.91
T1806211	0.57	0.58	0.59	0.67	0.70	0.76	0.80	0.90
T1806221	0.56	0.82	0.84	0.87	0.87	0.89	0.90	0.96
T1806222	0.22	0.77	0.77	0.80	0.82	0.83	0.83	0.94
T1806251	0.85	0.87	0.88	0.89	0.89	0.90	0.90	0.98
T1806252	0.83	0.85	0.86	0.89	0.90	0.92	0.92	0.98
T1806271	0.38	0.47	0.58	0.60	0.60	0.62	0.75	0.85
T1806272	0.21	0.23	0.35	0.38	0.42	0.63	0.91	0.78
T1806291	0.35	0.36	0.70	0.70	0.73	0.77	0.79	0.85
T180631	0.70	0.71	0.78	0.80	0.82	0.82	0.84	0.97
T180632	0.72	0.74	0.83	0.84	0.86	0.87	0.87	0.97
T1806311	0.58	0.59	0.66	0.87	0.90	0.92	0.93	0.96
T1806312	0.60	0.63	0.74	0.86	0.90	0.92	0.92	0.95
T1806371	0.52	0.58	0.60	0.64	0.80	0.81	0.82	0.91
T1806372	0.13	0.41	0.43	0.60	0.75	0.84	0.84	0.85
T1806421	0.29	0.29	0.54	0.65	0.65	0.67	0.67	0.86
T1806451	0.42	0.89	0.92	0.94	0.94	0.94	0.94	0.98
T1806452	0.49	0.92	0.94	0.94	0.94	0.94	0.95	0.98
T1806461	0.48	0.55	0.59	0.77	0.77	0.78	0.84	0.87
T1806462	0.59	0.74	0.75	0.76	0.76	0.81	0.84	0.92
T1806471	0.70	0.75	0.77	0.78	0.78	0.80	0.84	0.91
T1806541	0.67	0.87	0.89	0.90	0.90	0.90	0.92	0.97
T1806542	0.65	0.67	0.68	0.70	0.70	0.71	0.75	0.90
T180661	0.10	0.41	0.77	0.81	0.81	0.81	0.82	0.88
T180662	0.23	0.42	0.65	0.71	0.83	0.84	0.84	0.85
T1806611	0.17	0.59	0.68	0.70	0.77	0.78	0.78	0.86
T1806622	0.64	0.76	0.82	0.86	0.87	0.89	0.94	0.96
T1806651	0.73	0.79	0.81	0.81	0.86	0.86	0.88	0.95
T180671	0.35	0.77	0.77	0.79	0.89	0.91	0.93	0.98
T180672	0.44	0.72	0.72	0.72	0.83	0.85	0.87	0.97
T180681	0.70	0.70	0.76	0.77	0.77	0.88	0.88	0.90
T180682	0.35	0.37	0.50	0.63	0.65	0.81	0.84	0.80

Table C1b. Eigenvalues and explained variance of the first seven components of the 1860 plot.

Value	Eigenvalue	% Total Variance	Cumulative Eigenvalue	Cumulative %
1	18.4	49.7	18.4	49.7
2	6.0	16.4	24.4	66.1
3	2.5	6.8	26.9	72.8
4	1.6	4.2	28.5	77.1
5	1.3	3.6	29.9	80.7
6	1.2	3.1	31.0	83.9
7	1.0	2.7	32.0	86.6

Table C2a. Communalities (total explained variance) of the individual ring-width series from the 1925 plot.

Series	From 1 Factor	From 2 Factors	From 3 Factors	From 4 Factors	From 5 Factors	From 6 Factors	Multiple R^2
T1906111	0.53	0.71	0.71	0.85	0.9	0.9	0.97
T1906112	0.37	0.63	0.63	0.7	0.81	0.82	0.96
T1906141	0.42	0.63	0.64	0.67	0.69	0.73	0.91
T1906142	0.2	0.64	0.67	0.78	0.78	0.79	0.95
T1906151	0.27	0.62	0.64	0.73	0.77	0.77	0.96
T1906152	0.5	0.66	0.68	0.82	0.85	0.86	0.96
T1906171	0.55	0.87	0.88	0.88	0.88	0.93	0.99
T1906172	0.77	0.82	0.85	0.86	0.88	0.88	0.98
T1906201	0.33	0.75	0.76	0.84	0.87	0.88	0.94
T1906202	0.26	0.55	0.74	0.79	0.81	0.81	0.94
T190621	0.05	0.18	0.58	0.63	0.63	0.76	0.84
T190622	0.06	0.34	0.54	0.54	0.54	0.62	0.88
T1906211	0.81	0.82	0.83	0.86	0.86	0.88	0.98
T1906212	0.76	0.79	0.79	0.87	0.88	0.89	0.97
T1906221	0.7	0.72	0.76	0.8	0.82	0.85	0.95
T1906222	0.86	0.88	0.89	0.9	0.91	0.91	0.98
T1906241	0.12	0.24	0.25	0.45	0.87	0.9	0.94
T1906242	0.01	0.26	0.29	0.63	0.84	0.84	0.93
T1906251	0.31	0.56	0.63	0.63	0.65	0.8	0.87
T1906252	0.43	0.71	0.75	0.78	0.78	0.86	0.94
T1906301	0.65	0.67	0.69	0.82	0.84	0.93	0.98
T1906302	0.5	0.52	0.7	0.72	0.74	0.83	0.97
T190631	0	0.39	0.52	0.53	0.67	0.68	0.86
T1906311	0.41	0.5	0.7	0.73	0.73	0.8	0.96
T1906312	0.59	0.66	0.86	0.92	0.92	0.92	0.97
T190632	0.32	0.63	0.69	0.78	0.88	0.88	0.95
T1906321	0.75	0.8	0.81	0.93	0.93	0.93	0.99
T1906322	0.75	0.75	0.76	0.94	0.94	0.94	0.99
T1906341	0.78	0.8	0.82	0.87	0.88	0.93	0.99
T1906342	0.72	0.88	0.88	0.9	0.9	0.92	0.98
T1906451	0.64	0.65	0.67	0.77	0.81	0.81	0.97
T1906452	0.51	0.51	0.57	0.7	0.86	0.87	0.96
T1906461	0.58	0.69	0.69	0.72	0.75	0.85	0.97
T1906462	0.66	0.68	0.71	0.77	0.79	0.87	0.97
T190651	0.06	0.06	0.48	0.63	0.71	0.71	0.87
T190652	0.1	0.33	0.54	0.64	0.64	0.64	0.83
T190671	0.15	0.16	0.76	0.77	0.78	0.8	0.91
T190672	0.01	0.12	0.82	0.83	0.87	0.87	0.93

Table C2b. Eigenvalues and explained variance of the first six components of the 1925 plot.

Value	Eigenvalue	% Total Variance	Cumulative Eigenvalue	Cumulative %
1	16.5	43.4	16.5	43.4
2	5.7	15	22.2	58.3
3	4	10.6	26.2	68.9
4	2.8	7.3	29	76.2
5	1.7	4.4	30.6	80.6
6	1.2	3.2	31.9	83.8

Table C3a. Communalities (total explained variance) of the individual ring-width series from the 1929 plot.

	From 1 Factor	From 2 Factors	From 3 Factors	From 4 Factors	From 5 Factors	From 6 Factors	Multiple R^2
T1929101	0.18	0.72	0.85	0.85	0.85	0.85	0.92
T1929102	0.31	0.58	0.72	0.79	0.81	0.82	0.92
T1929111	0.64	0.66	0.66	0.67	0.80	0.83	0.93
T1929112	0.08	0.25	0.65	0.70	0.78	0.88	0.93
T1929161	0.31	0.44	0.51	0.70	0.72	0.79	0.83
T1929181	0.53	0.56	0.56	0.64	0.66	0.67	0.85
T1929182	0.49	0.51	0.60	0.68	0.72	0.72	0.91
T1929281	0.44	0.44	0.75	0.83	0.83	0.86	0.95
T1929282	0.65	0.66	0.66	0.66	0.77	0.83	0.93
T1929291	0.85	0.86	0.87	0.87	0.88	0.88	0.97
T1929292	0.80	0.81	0.81	0.82	0.82	0.83	0.98
T192931	0.37	0.41	0.49	0.63	0.74	0.76	0.82
T192932	0.72	0.74	0.75	0.79	0.91	0.92	0.98
T1929321	0.29	0.46	0.61	0.76	0.76	0.78	0.93
T1929322	0.57	0.76	0.88	0.89	0.89	0.92	0.96
T1929341	0.81	0.85	0.86	0.89	0.90	0.90	0.96
T1929342	0.78	0.92	0.92	0.92	0.92	0.92	0.97
T1929371	0.80	0.82	0.85	0.86	0.89	0.90	0.97
T1929372	0.70	0.70	0.81	0.83	0.83	0.86	0.96
T1929381	0.58	0.62	0.82	0.86	0.86	0.86	0.99
T1929382	0.61	0.66	0.83	0.86	0.86	0.87	0.99
T1929391	0.85	0.88	0.88	0.90	0.92	0.94	0.99
T1929392	0.84	0.86	0.88	0.89	0.90	0.94	0.98
T1929421	0.01	0.77	0.77	0.77	0.78	0.81	0.95
T1929422	0.05	0.55	0.80	0.81	0.81	0.83	0.94
T1929431	0.39	0.76	0.76	0.81	0.84	0.87	0.94
T1929432	0.25	0.71	0.72	0.79	0.80	0.80	0.92
T1929441	0.65	0.85	0.93	0.93	0.93	0.93	0.98
T1929442	0.73	0.86	0.94	0.95	0.95	0.95	0.98
T1929471	0.64	0.67	0.67	0.67	0.71	0.84	0.96
T1929472	0.39	0.58	0.59	0.62	0.63	0.84	0.97
T1929481	0.66	0.72	0.72	0.73	0.90	0.93	0.98
T1929482	0.64	0.70	0.71	0.72	0.88	0.90	0.96
T192981	0.69	0.73	0.73	0.74	0.75	0.86	0.96
T192982	0.84	0.85	0.87	0.90	0.90	0.90	0.97
T192991	0.64	0.66	0.77	0.77	0.80	0.82	0.96
T192992	0.60	0.75	0.76	0.76	0.77	0.78	0.94

Table C3b. Eigenvalues and explained variance of the first six components of the 1929 plot.

Value	Eigenvalue	% Total Variance	Cumulative Eigenvalue	Cumulative %
1	20.4	55.1	20.4	55.1
2	4.9	13.3	25.3	68.4
3	2.6	7.2	28.0	75.6
4	1.3	3.5	29.3	79.1
5	1.2	3.3	30.5	82.4
6	1.1	2.9	31.6	85.4

Table C4a. Communalities (total explained variance) of the individual ring-width series from the 1948 plot.

Series	From 1 Factor	From 2 Factors	From 3 Factors	From 4 Factors	Multiple R^2
T1948111	0.56	0.86	0.89	0.89	0.98
T19481291	0.90	0.91	0.91	0.91	1.00
T19481301	0.78	0.87	0.90	0.90	1.00
T19481341	0.77	0.82	0.82	0.84	0.99
T19481342	0.87	0.90	0.93	0.93	1.00
T19481351	0.86	0.93	0.93	0.94	1.00
T19481352	0.86	0.89	0.92	0.95	1.00
T19481371	0.65	0.83	0.84	0.88	1.00
T19481411	0.90	0.91	0.92	0.92	1.00
T19481431	0.76	0.90	0.92	0.93	1.00
T1948241	0.42	0.61	0.74	0.76	0.98
T1948271	0.92	0.93	0.93	0.94	1.00
T1948272	0.93	0.94	0.94	0.94	1.00
T1948301	0.75	0.78	0.92	0.92	0.99
T1948302	0.52	0.52	0.65	0.67	0.98
T1948311	0.48	0.57	0.59	0.65	0.98
T1948321	0.75	0.75	0.76	0.85	1.00
T1948331	0.63	0.64	0.79	0.82	0.99
T1948341	0.74	0.87	0.88	0.88	0.99
T1948361	0.88	0.90	0.91	0.91	1.00
T1948411	0.83	0.84	0.84	0.84	1.00
T1948412	0.86	0.86	0.86	0.87	1.00
T1948441	0.47	0.55	0.79	0.82	0.99
T1948501	0.87	0.88	0.89	0.90	0.99
T1948551	0.72	0.89	0.90	0.92	1.00
T1948552	0.62	0.88	0.89	0.89	1.00
T1948611	0.57	0.71	0.81	0.87	1.00
T1948612	0.57	0.63	0.82	0.85	1.00
T1948651	0.62	0.69	0.69	0.79	0.99
T1948701	0.85	0.96	0.96	0.96	1.00
T1948702	0.87	0.96	0.97	0.97	1.00
T194871	0.72	0.77	0.78	0.79	0.99
T1948721	0.82	0.82	0.83	0.84	0.99
T1948751	0.78	0.94	0.94	0.95	1.00
T194881	0.88	0.88	0.89	0.89	1.00
T194882	0.88	0.88	0.88	0.88	1.00
T1948831	0.87	0.87	0.87	0.87	0.99

Table C4b. Eigenvalues and explained variance of the first four components of the 1948 plot.

Value	Eigenvalue	% Total Variance	Cumulative Eigenvalue	Cumulative %
1	28.4	72.7	28.4	72.7
2	2.8	7.2	31.1	79.9
3	1.7	4.3	32.8	84.2
4	1.2	3.1	34.0	87.3

Figure C1a. Scores of the first six principal components of the 1860 ring-width series. The percentage of variance explained by each factor is listed in the upper right-hand corner of each plot. The first two components, comprising 66.1% of the total variance represent the overall climate signal for this site.

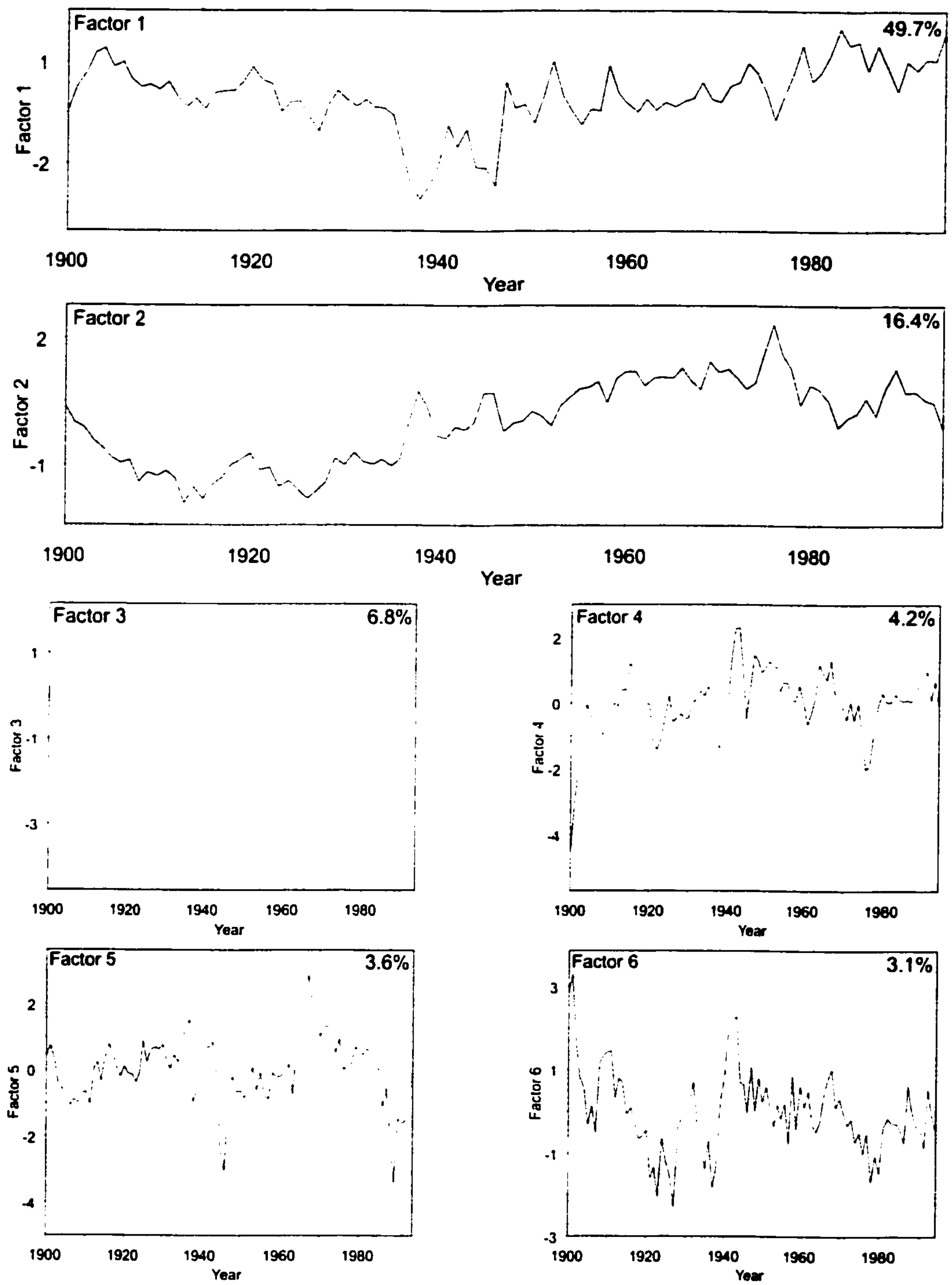
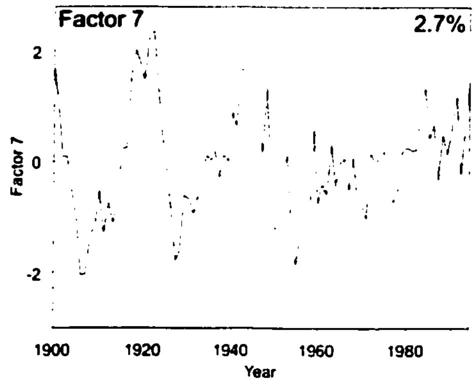


Figure C1b. Score of the seventh principal component of the ring-widths of the 1860 series. The variance explained by each factor has been listed in the upper right-hand corner of each plot. Factor loadings of the first two principal components of the ring-widths for the 1860 plot.



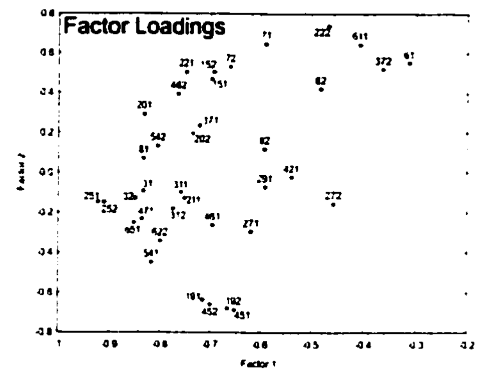


Figure C2a. Scores of the first six principal components of the 1925 ring-width series. The percentage of variance explained by each factor is listed in the upper right-hand corner of the plot. The first three components, comprising 69% of the total variance represent the overall climate signal of this plot.

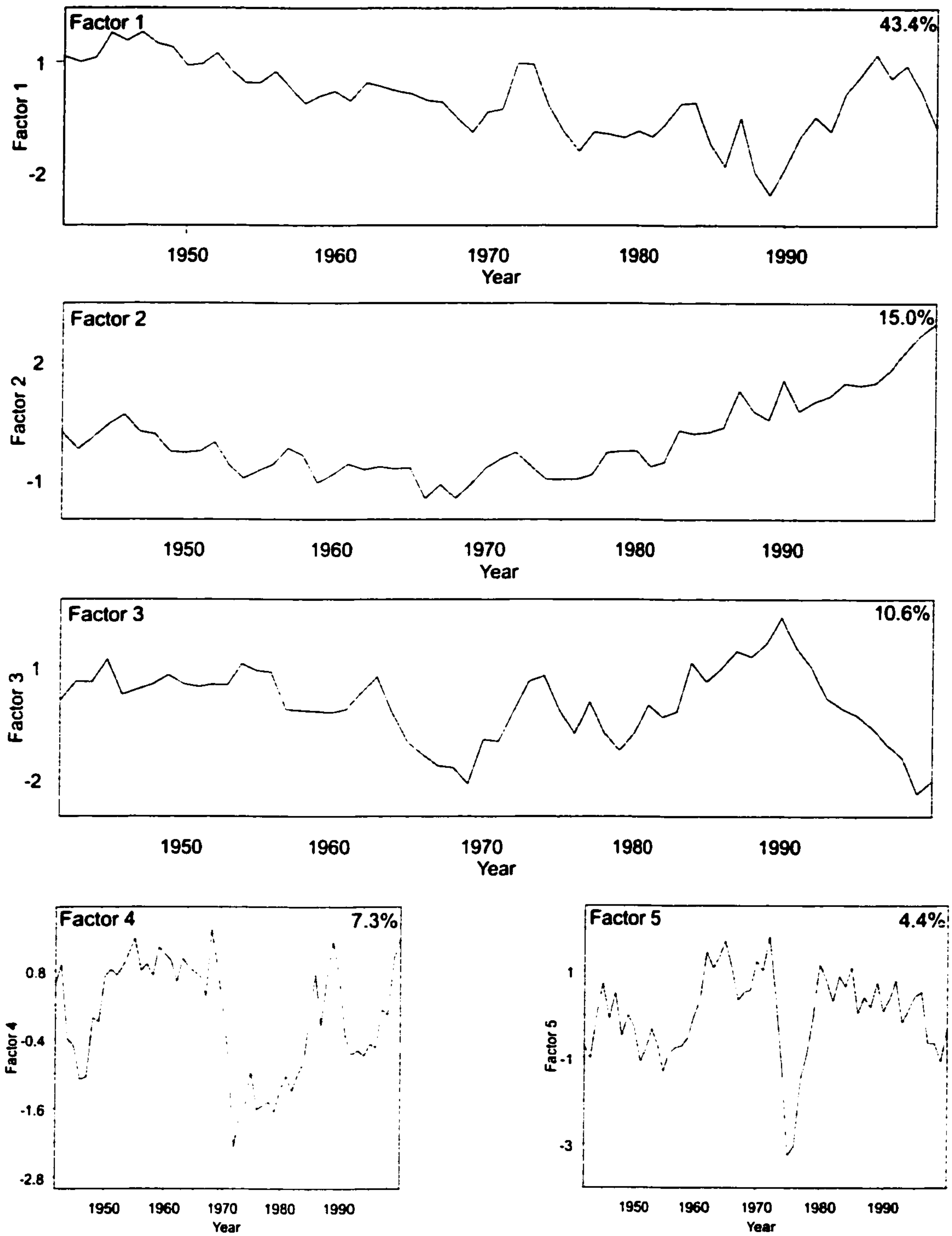
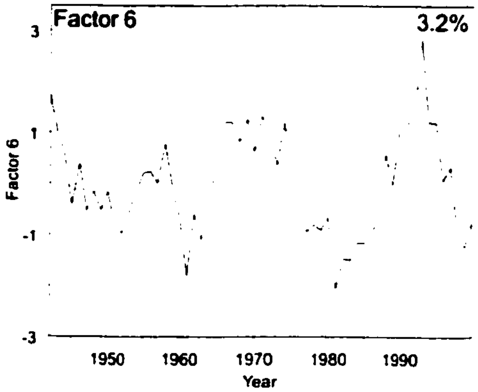


Figure C2b. Score of the sixth principal component of the 1925 ring-width series. The percentage of variance explained is listed in the upper right-hand corner of the plot. Factor loadings of the first two principal components of the ring-widths for the 1925 plot.



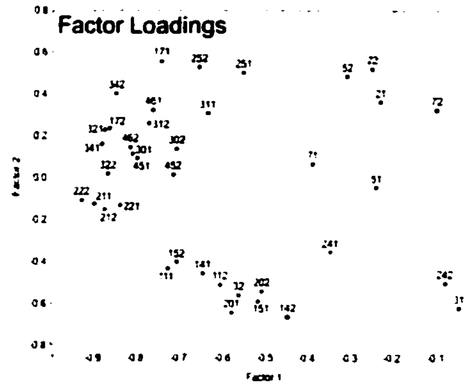


Figure C3a. Scores of the first six principal components of the 1929 ring-width series. The percentage of variance explained by each factor is listed in the upper right-hand corner of each plot. The first two components, comprising 68.4% of the total variance represent the overall climate signal of this plot.

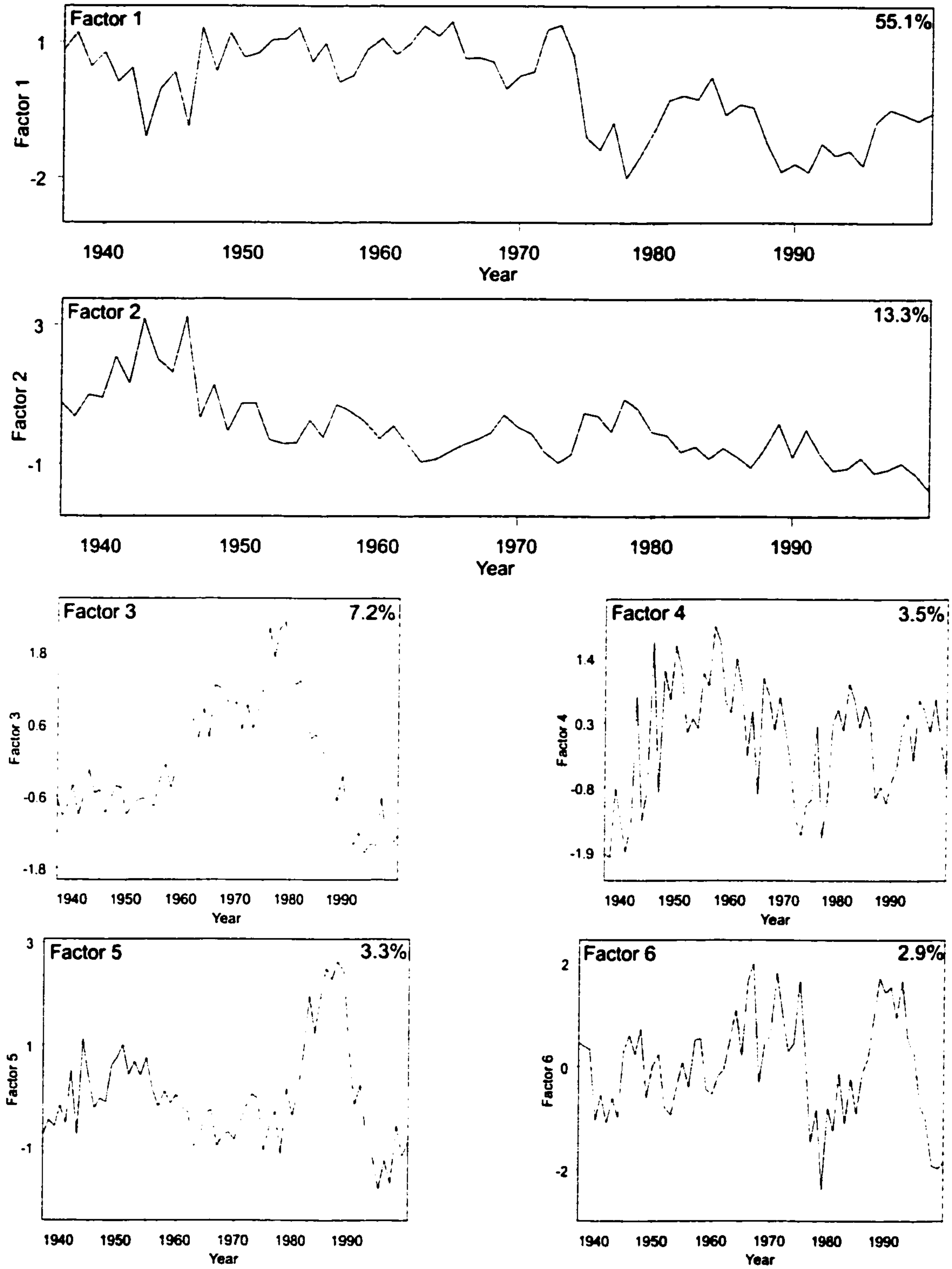


Figure C3b. Factor loadings of the first two principal components of the ring-widths for the 1929 plot.

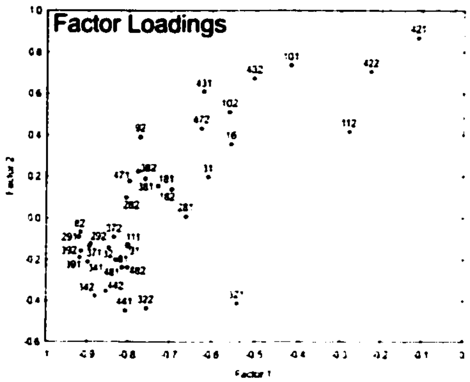
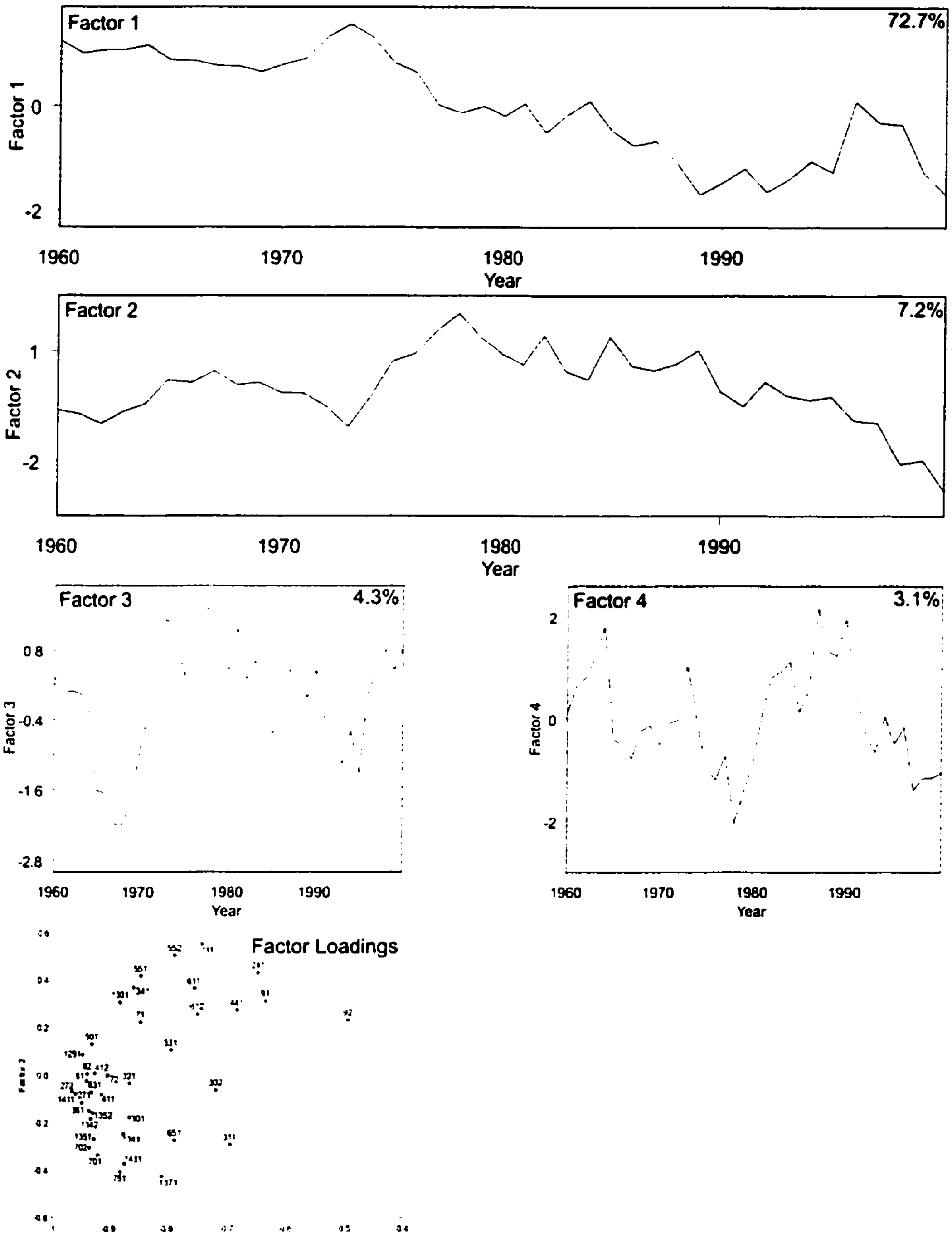


Figure C4. Scores of the first four principal components of the 1948 ring-width series. The percentage of variance explained by each factor is listed in the upper right-hand corner of each plot. The first two components, comprising 79.9% of the total variance represent the overall climate signal of this plot. Factor loadings of the first two principal components of the ring-widths for the 1948 plot.



Appendix D:
Nearest Neighbour Analysis of the 11 sites in the Shakwak Trench, Yukon Territory.

Figure D1. Spatial distribution of *Picea glauca* trees in 10 X 20 m plots. The number of trees and cluster pattern tendency determined from the nearest neighbor analysis is described for each plot.

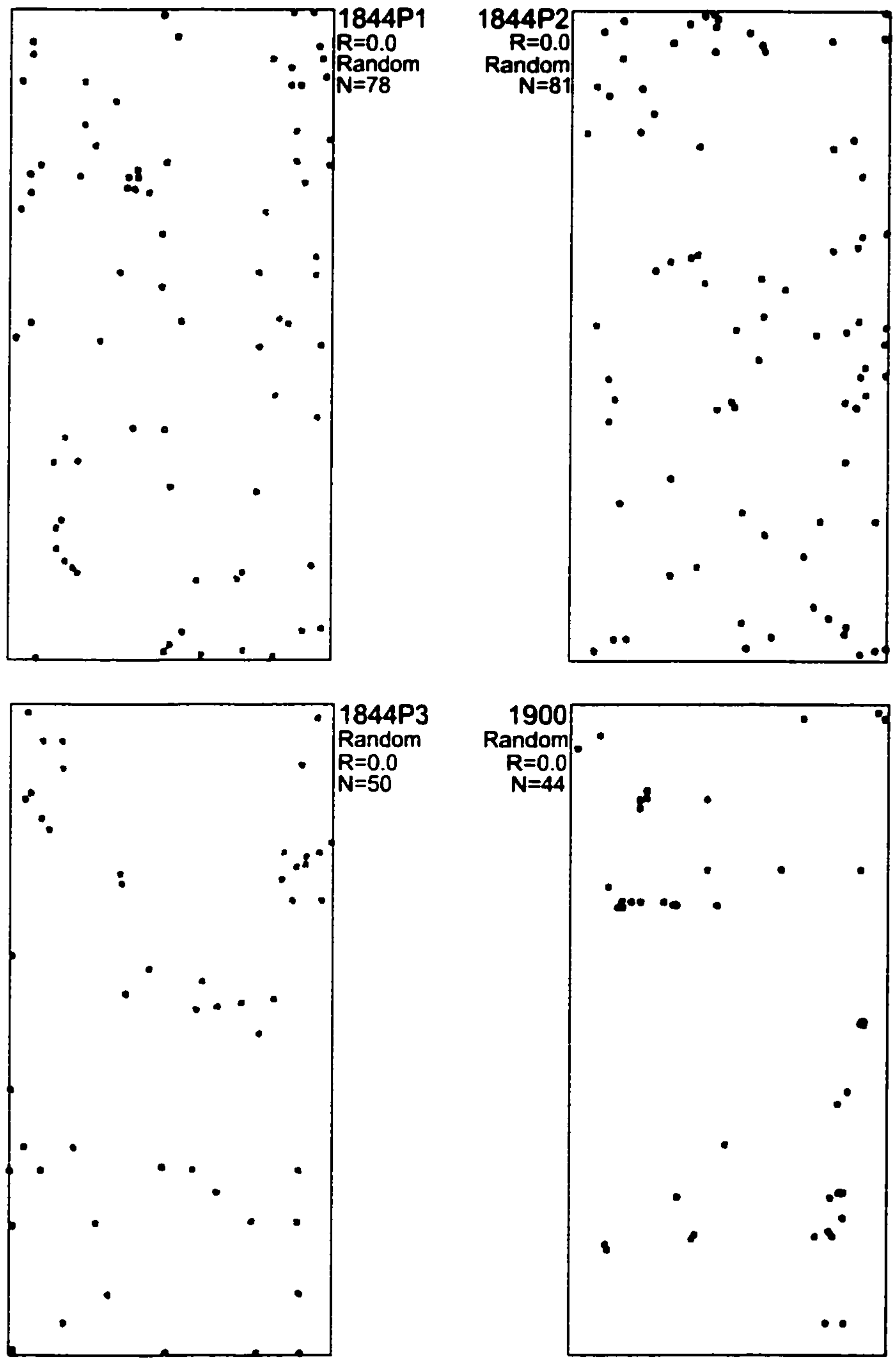


Figure D2. Spatial distribution of *Picea glauca* trees in 10 X 20 m plots. The number of trees and cluster pattern tendency determined from the nearest neighbor analysis is described for each plot.

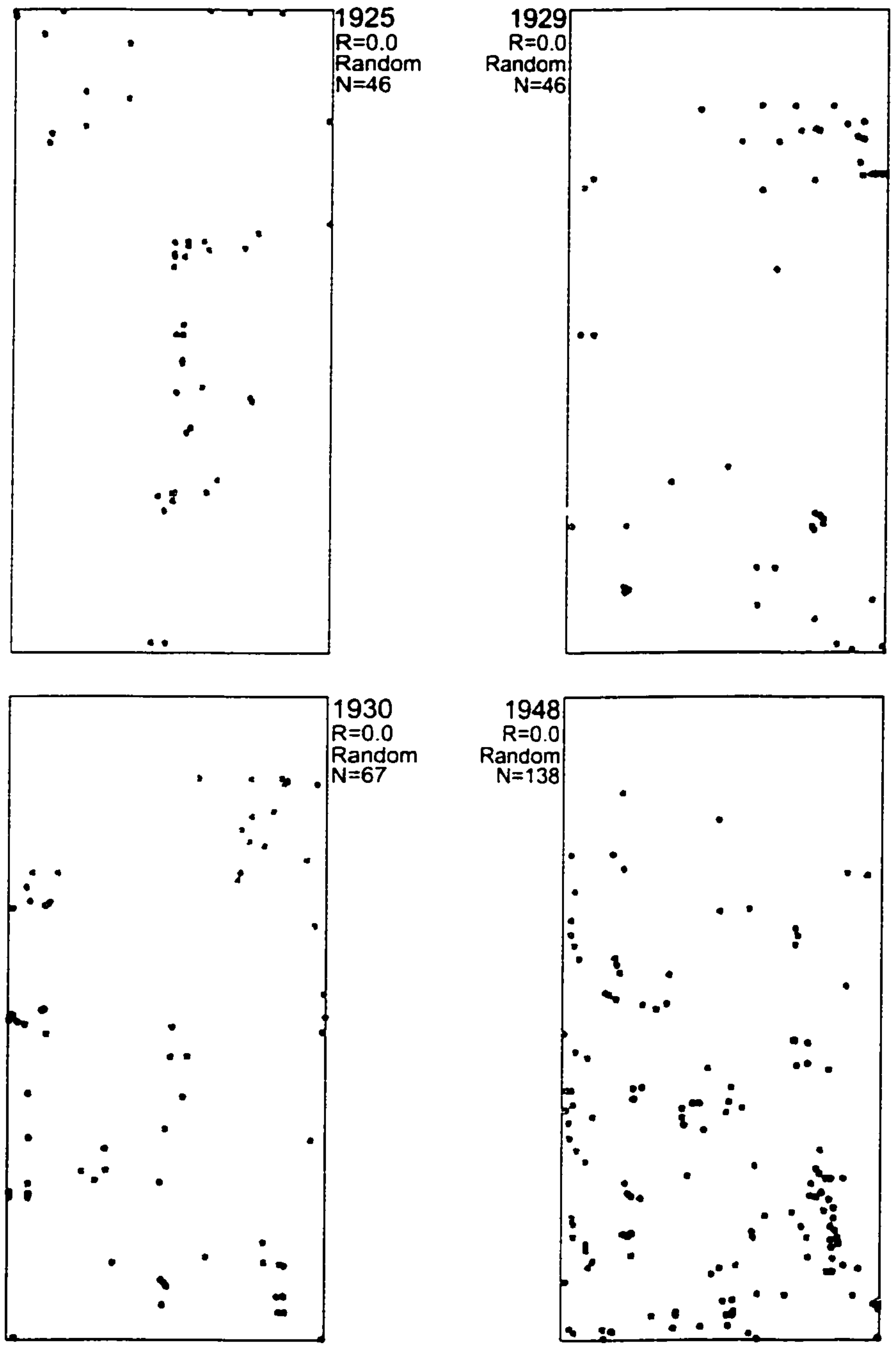


Figure D3. Spatial distribution of *Picea glauca* trees in 10 X 10 m and 10 X 20 m plots. The number of trees and cluster pattern tendency determined from the nearest neighbor analysis is described for each plot.