FIRE HISTORY OF THE PONDEROSA PINE STAND IN SOUTHWESTERN NORTH DAKOTA

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Jesse Miles Beckers

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

ABSTRACT

Beckers, Jesse Miles, M.S., Program of Natural Resources Management, College of Graduate and Interdisciplinary Studies, North Dakota State University, November 2007. Fire History of the Ponderosa Pine Stand in Southwestern North Dakota. Major Professor: Dr. Joseph D. Zeleznik.

A study on the fire history of the ponderosa pine (*Pinus ponderosa* P. & C. Lawson) forest in northern Slope County, North Dakota, was completed. The objectives of this study were to determine the pre- and post-settlement fire history of this location and to relate that fire history to topography. Samples were collected in 2005-2007 and analyzed using standard dendrochronological techniques.

Three data-reduction methods and three calculation techniques were used to determine fire intervals (FIs). Method 1 assumed that all scars were created by fire; Method 2 required 10% or 20% of samples to have scars in a given year; Method 3 attempted to use visual cues to separate fire-caused scars from those created by other agents. The calculation techniques determined the FI for each tree individually, 1) utilizing or 2) not utilizing the origin-to-scar (OS) interval, followed by averaging all samples, or 3) compositing all samples before calculating the FI. Results of this study varied, depending on data-reduction method and calculation technique. The most realistic results were obtained with Method 2 utilizing the 10% criterion. With this method, the pre- and post-settlement FIs are 28.5 and 52 years, respectively. Composite calculations in Methods 1 and 3 showed low FIs; utilizing individual FIs with the OS interval showed overly large estimates of the FI. When conservative Method 2 was utilized, the average age of a ponderosa pine when the first fire scar was recorded is 58 years. Fires in 1882 and 1893 traveled the farthest distances, 2893 and 3276 meters, respectively.

ACKNOWLEDGMENTS

First and foremost I would like to thank my Dad and Mom, Dave and Deb Beckers. Without their continued love and support, the accomplishments I have made in my life would not have been possible. My brother Jeff has also been an inspiration for me to always play like a champion no matter what I am striving to accomplish. My girlfriend Beth Horner has stood by my side through my graduate career sharing times of stress, hardship, and happiness. Sample collection in the summer of 2006 could not have been possible without Chris Augustin.

This study would not have been possible without the landowners. Mr. John Hanson and Mr. Loren Jacobson allowed us to collect samples on their property and were a great source of land information. Also, permission was granted by North Dakota to sample on state-owned property, and the National Forest System lands too. I would also like to thank the United States Forest Service, especially Dr. Mark Gonzalez, for providing the funding and guidance for this project.

Dr. Joseph Zeleznik was vital for my professional and personal growth over the past two years. He was an advisor I could look up to. Dr. Carolyn Grygiel has been a terrific motivator throughout my college career and has been an excellent undergraduate and graduate advisor. Dr. Grygiel is in large part responsible for my success as a student. Dr. Shawn Dekeyser has been my professor in three classes and assisted me with attaining job opportunities in the past. He was a tremendous asset to this committee. Mr. Jack Norland provided GIS and statistical expertise in this project. He has always taken time to assist his students, and is a vital source of information and knowledge to Natural Resources Management students.

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INTRODUCTION

Prior to Euro-American settlement, frequent fires along with grazing by large ungulates established the ecotone between the ponderosa pine woodlands and the vast prairie that spreads eastward from the Badlands in western North Dakota. Fires spread naturally and were directed by topography, wind, available fuel, and prevailing climate conditions before Euro-American colonization reached the western states. After settlement, livestock grazing and fire suppression reduced or completely excluded fire in many ecosystems (Savage and Swetnam 1990, Swetnam and Baisan 1996). Large, catastrophic fires are more common due to fuel-load increases from suppression and the lack of low-intensity fires that occurred prior to Euro-American settlement (Pierce et al. 2004).

On September 4, 2004, the Deep Creek Fire burned approximately 289 hectares of the ponderosa pine forest found in the Little Missouri Badlands, northwest of Amidon and south of Medora in northern Slope County, North Dakota (Figure 1). The fire burned across several ownerships, including a part of the Little Missouri National Grassland, an area of state-owned land, and private property. A detailed fire history of the Little Missouri Badlands has never been developed, and the dead trees inside the burned area offer an opportunity to reconstruct a fire history for the area.

I received permission to sample dead trees and stumps within the burned area from the various landowners and managers. These include the USDA Forest Service–Dakota Prairie Grasslands, the ND State Lands Department, Mr. Loren Jacobson, and Mr. John Hanson. Written permission was obtained from Mr. Jacobson to sample on leased ND state lands.

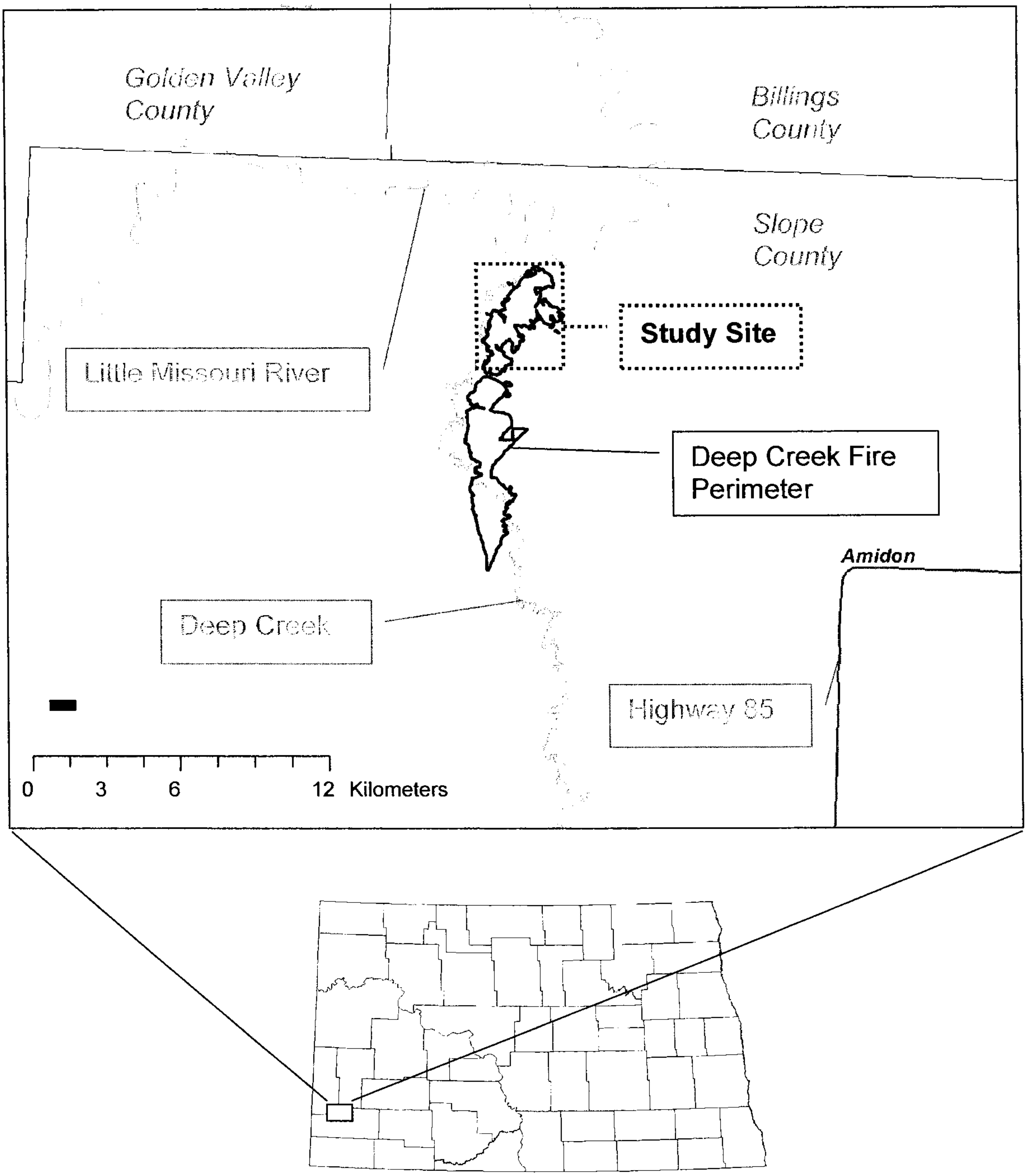

Figure 1. The Deep Creek Fire of September 2004 study area located in the Little Missouri Badlands of Slope County, North Dakota.

The purpose of this project is to determine the fire history of this location and to relate that fire history to climate and topography. This will aid land managers in determining how to presently manage the area using historic conditions as a model. Three specific objectives were established to fulfill the purpose in this study: 1) determine both pre-settlement and post-settlement fire return intervals, 2) determine the spatial extent and variability of previous fires, and 3) relate the spatial variability of fires to topography of the area through the use of a Geographic Information System (GIS).

LITERATURE REVIEW

Open park-like stands characterized ponderosa pine forests prior to Euro-American settlement. Pioneers traveling through the American West described ponderosa pine forests as being free of underbrush and vegetated with fine grasses surrounding the trees (Arno and Fiedler 2005). Open fire-resistant ponderosa pine stands were maintained by frequent surface fires leaving tree-free areas for grass to grow (Weaver 1951). In most ponderosa pine stands today, forests are dense and blanket the landscape with few large trees, many small trees, and sparse grass cover (Arno and Fiedler 2005). Fisher et al. (1987) stated that the area of pine forest around Devils Tower National Monument in Wyoming has dramatically increased while the area of the surrounding prairie has decreased. Paired photographs from the Black Hills of South Dakota show increases in ponderosa pine densities and invasion into meadows since 1874 (Progulske 1974). A similar invasion into prairies along with increases in tree density is also seen in the ponderosa pine forests of Arizona, New Mexico, Oregon, and Washington (Arno 2000). Archer (1994) explained that the dramatic tree invasion into prairies in recent decades is due to two causes: high-intensity grazing and fire suppression following Euro-American settlement.

Oliver and Ryker (1990) classified three regions of ponderosa pine in the United States (Figure 2). These regions are governed by dissimilar climatic regimes and therefore their fire intervals also differ. Fire-history studies have been conducted throughout the three regions with the Rocky Mountain Region relating most to this study.

Fire ecologists have developed several methods to reconstruct fire intervals and fire histories in ponderosa pine. The most common method to calculate fire intervals is the mean fire interval (MFI), where the FIs are calculated for each sample and the average is

Figure 2. Three regions of ponderosa pine found throughout the western United States (Little 1971). Region 1, Rocky Mountain Ponderosa Pine; Region 2, Pacific Ponderosa Pine; and Region 3, Arizona Ponderosa Pine.

obtained from the combined intervals. For example, if a tree exhibits three fire intervals, the average of those three values will be the MFI for that sample. Therefore, MFI is the average number of fire years in composite fire chronologies and is widely used to describe fire frequency (Heyerdahl et al. 1995). The median fire interval (MeFI) and Weibull median probability interval (WMPI) are used less frequently. WMPI is the fire interval with a 50% exceedance probability of a modeled Weibull distribution of all fire intervals in a fire chronology (Swetnam and Baisan 1996). The Weibull distribution can be used to estimate the range of fire-history data and central tendency, expressing the results as exceedance probabilities (Grissino-Mayer 1995).

MFI values ranged from six to 27 years in the Rocky Mountain Region (Table 1). In the Black Hills of South Dakota and Wyoming, the climate is often cooler with high levels of moisture when compared to the surrounding Great Plains (Hoffman and Alexander 1987). However, moisture levels decrease rapidly from the northwestern part of the range to the southeastern portion (Bunkers et al. 1996). Variations along latitudinal gradients were also studied by Brown and Shepperd (2001). Their study was conducted along a 5° gradient in the Rocky Mountains from Wyoming to Colorado. They found that northern stands in Wyoming generally had longer fire intervals than in the southern stands of Colorado. This could be caused by shorter growing seasons coupled with a cooler climate in the north, resulting in fewer years where fire could occur (Brown and Shepperd 2001), therefore increasing fire-frequency intervals.

Besides climate, fire intervals could also have been influenced by native peoples at the time. In their study of Devils Tower National Monument, Fisher et al. (1987) found a dramatic rise in fire frequency between 1770 and 1900. Around 1765, the Sioux entered the Black Hills area and often used fire to drive and harvest game, and this is a possible cause for the increased fire intervals around Devils Tower (Table 1).

Table 1. Fire-history studies conducted in the Rocky Mountain Ponderosa Pine Region that include the calculation methods Mean-Fire Interval (MFI), Weibull Median-Probability Interval (WMPI), and Median-Fire Interval (MeFI).

Location	State	Calculation Method	Time Period	Fire Interval (years)	Source
Wind Cave Nat'l. Park	SD	MFI	1564-1896	12.3 ± 6.9	Brown and Sieg (1999)
		WMPI	1564-1897	11.6	
Upper Pine Creek	SD	MeFI	1580-1887	23	Brown et al. (2000)
Upper Pine Creek Middle	SD	MeFI	1668-1890	22	Brown et al. (2000)
Jewel Cave Nat'l. Mon.	SD	MFI	1388-1900	16 (± 14 SD)	Brown and Sieg (1996)
Bitterroot National Forest	MT	MFI	1735-1900		Arno (1976)
Onehorse				6	
Tolan				11	
West Fork				10	
Devils Tower Nat'l. Mon.	WY	MFI	1600-1770	27	Fisher et al. (1987)
			1770-1900	14	
			1600-1900	19	
Ashenfelder Lower	WY	MeFI	1436-1911	26	Brown and Shepperd (2001)
Ashenfelder Upper	WY	MeFI	1460-1909	33.5	Brown and Shepperd (2001)
Merrill Kaufmann's Cabin	CO	MeFI	1609-1878	16	Brown and Shepperd (2001)
Old Tree Cluster	CO	MeFI	1325-1851	16	Brown and Shepperd (2001)
Manitou Old Growth	CO	MeFI	1598-1846	22.5	Brown and Shepperd (2001)
Manitou Demonstration Plot	CO		1521-1865	7.5	Brown and Shepperd (2001)
Wet Mountains South	CO		1514-1908	10	Brown and Shepperd (2001)
Black Mountain	CO		1608-1805	19	Brown and Shepperd (2001)
Hot Creek	CO		1528-1896	9.5	Brown and Shepperd (2001)

Fire studies conducted in the Arizona Ponderosa Pine Region show that fire intervals are generally shorter than in the northern regions of the ponderosa pine range (Table 2). MFI values for the Arizona Ponderosa Pine Region range from 3.45 to 23.5 years (Table 2). The shorter intervals can be attributed to a much drier and warmer climate in the south compared to Rocky Mountain Region. In their study of the San Bernardino Mountains, McBride and Laven (1976) stated that the area of their study is characterized by summer droughts and intermittent thunderstorms, causing an average of 34 fires annually.

Fire-interval calculations may be recorded in three ways. The composite-fire interval takes into account all the fires found in a stand even if a particular fire did not leave a scar in every tree under study (Baker and Ehle 2001). Individual-tree fire intervals are calculated by taking the mean interval found in each tree and averaging all of the fire intervals together. Individual-tree-fire interval calculations may or may not include the origin-to-scar (OS) interval. Each method has advantages and disadvantages. The composite fire interval is area-explicit, whereas the individual-tree fire interval is not. The larger the area being studied, the shorter the composite fire interval will be. Therefore, a composite-fire-interval analysis typically results in an overestimation of fire occurrence (Van Horne and Fule 2006). The OS interval is a point of uncertainty in fire-interval calculations. Baker and Ehle (2001) reviewed the work of five studies and concluded that a ponderosa pine must be at least 50 years old before it can successfully regenerate, and the OS time period should be included in the fire-interval calculations. However, this argument was countered by maintaining the impossibility of knowing the true fire-free interval as many trees survive fire without ever scarring (Stephens et al. 2003).

Table 2. Fire-history studies conducted in the Arizona Ponderosa Pine Region that include the calculation methods Mean-Fire Interval (MFI), Weibull Median-Probability Interval (WMPI), and Median-Fire Interval (MeFI).

Location	State	Calculation Method	Time Period	Fire Interval (years)	Source
McKenna Park	NM	MFI	1633-1801	4.3	Swetnam and Dieterich (1985)
			1801-1904	6.4	
			1837-1904	6.1	
			1904-1951	23.5	
Langstroth Mesa	NM	MFI	1635-1801	5.7	Swetnam and Dieterich (1985)
			1801-1904	5.4	
			1837-1904	4.5	
			1904-1978	14.8	
Gilita Ridge	NM	MFI	1650-1803	16.9	Swetnam and Dieterich (1985)
			1803-1907	4.7	
			1837-1907	4.1	
Rose Canyon	NM	MFI	1700-1900	5.5	Swetnam and Baisan (1995)
		MeFI	1700-1900	5	
		WMPI	1700-1900	5.26	
Castle Creek	AZ	MFI	1700-1900	3.45	Swetnam and Baisan (1996)
		MeFI	1700-1901	3	
		WMPI	1700-1902	3.18	
Limestone Flats	AZ	MFI	1700-1900	2.51	Swetnam and Baisan (1996)
		MeFI	1700-1901	2	
		WMPI	1700-1902	2.27	
Chimney Springs	AZ	MFI	1700-1900	2.62	Swetnam and Baisan (1996)
		MeFI	1700-1901	2	
		WMPI	1700-1902	2.14	
San Bernardino	CA	MFI	1797-1905	10	McBride and Laven (1976)
			1905-1965	22	

Filtering and bracketing are also used when calculating the fire interval in an attempt to correct uncertainties in the fire record. Filtering uses only scars found in the same year on a certain percentage of trees, discarding all other scars. Scars seen in only individual trees may be the result of some other type of disturbance besides fire and are discarded. Bracketing represents those fires which are likely to have been more widespread within the study area (Van Horne and Fule 2006). The disadvantage of this method is that a single scar seen in one year may have been caused by a fire, but is not included in the fire-interval calculations.

Uncertainties in fire-interval calculations are inherent regardless of the method used. Ponderosa pine is a fire-tolerant species (Arno 2000); and therefore scars are not consistently recorded on individual trees, so the fire record is partially missing or incomplete (Van Horne and Fule 2006). Furthermore, trees are often charred but not scarred in a fire, although a scar may later be revealed (Baker and Ehle 2001). When a scar is created – by fire or other means – the tree will be more susceptible to fire damage in later years, which in turn can consume the remnant fire record (Van Horne and Fule 2006).

Sampling ponderosa pine

The primary goal of sampling in fire-history studies has been to obtain a long and complete fire record (Baker and Ehle 2001). Trees are sought for potentially having long fire records and multiple scars (Swetnam and Baisan 1995), showing open wounds (cat-faces; Arno and Sneck 1977), or being in an area that has never been harvested (Arno et al. 1995).

Targeting samples based on these criteria has multiple advantages and disadvantages. Trees that are old with multiple scars will make the fire history of the stand as complete as possible (Swetnam and Baisan 1995). Furthermore, a tree showing a cat-face will likely be a better recorder of fire events because of increased susceptibility to scarring (Arno and Sneck 1977). However, targeted sampling localizes the study area which, in turn, may give an inaccurate estimate of the fire interval within the entire stand

(Baker and Ehle 2001). Targeting has further been criticized by Baker and Ehle (2001) for being a statistically invalid method to sample a population because it is not a random sample and can lead to unknown accuracy of fire-interval results. However, trees are a natural archive of fire-history events and not consistent recorders of fire, so they should not be treated as if they belong to the same statistical population (Swetnam and Baisan 1996).

Remote sensing and fire extent

Remote sensing and geographic information systems (GIS) have become valuable tools for resource managers and scientists to monitor fire effects and fire-prone resource conditions. Remote-sensing systems are used for detecting active fires from satellites; mapping fuel types, fuel conditions, and fuel moistures; assessing long-term fire risk; and mapping burned areas and fire effects (Chuvieco and Kasischke 2007). GIS is also used to analyze fuels, topography, and vegetation (Arno and Fiedler 2005). GIS maps may have several layers of data and may help in planning burns for ecosystems most in need of fire. Remote-sensing imagery provides information for fire scientists by providing spatially comprehensive information such as land-surface characteristics and distances fires travel (Chuvieco and Kasischke 2007). In their study of the Monongahela National Forest, Van Gundy et al. (2007) used spatial imaging to calculate the number of hectares covered by previous fires and separate study areas based on the type of vegetation present. Remote-sensing images show the topography of the area and extent of the Deep Creek Fire. Post-fire inspection, along with spatial imaging, confirms that the Deep Creek Fire was a high-intensity fire (P. Sjursen 2007, personal correspondence), and the remaining forest could be subject to similar fires if fuel management is not implemented.

The Deep Creek Fire

The Deep Creek ponderosa pine forest in southwestern North Dakota has a dense distribution of trees and abundant surface debris. Surface fuels have accumulated over many decades and are likely one of the reasons the Deep Creek Fire was so destructive, killing most of the trees and woody vegetation within the fire perimeter. In studying the Deep Creek fire history, resource managers will have a better idea of how often pre-settlement fire burned in the area to create the open park-like stands described by early pioneers. The results found in the ponderosa pine forest of the Little Missouri Badlands should be similar to those of other fire-interval studies undertaken in the Rocky Mountain Ponderosa Pine Region, as they have a similar climate.

MATERIALS AND METHODS

Site description

The area in and around the ponderosa pine forest of southwestern North Dakota has been an oasis for wildlife and livestock by providing shade, shelter, and forage diversity. As Euro-Americans moved into the area, the forest provided a source of firewood and building materials for property establishment. However, the vast majority of timber was used for railroad ties (Potter and Green 1964). During the settlement period, many large and presumably old trees in the forest were harvested, leaving a cohort of young and/or small trees still standing. Large trees were left only in areas where they were not easily accessible or if the trees were undesirable.

The forest in the Little Missouri Badlands of North Dakota is very small compared to other ponderosa pine forests (Figure 2). The topography in the study area is characterized by sharp ridges and eroded buttes with pines being most common where clinker and sandstone are exposed (Potter and Green 1964). Ponderosa pine grows readily in these areas due to its fast-growing tap root, which follows cracks and crevices through the clinker and sandstone until moisture is reached. The average temperature in southwestern North Dakota is -8.3°C in the winter and 22.8°C in the summer (Jensen, no date). Precipitation in the winter is around 3 cm and is 18.5 cm in the summer. High temperatures and sporadic precipitation dominate the climate during the summer months.

The Brandenburg-Cabba complex series is the most dominant soil found in the study area (USDA-NRCS 2008). These soils are excessively drained with a silty loam composition and are found on knobs and ridges where ponderosa pine readily grows. The second most dominant soil found in the study area consists of the Cabbart series. The

Cabbart series is a well drained, silt-loam soil and like the Brandenburg series, is found on ridges.

The Deep Creek Fire originated in Section 25, T135N, R103W, approximately 8 kilometers south of the ponderosa pine forest on September 1, 2004 (Figure 3). The fire burned within the study area from September 1 to September 4. The Deep Creek Fire burned ponderosa pine in sections 17, 18, 19, 20, 30 and 31 of T136N, R102W, and sections 24, 25 and 36 of T136N, R103W (Figures 3 and 4).

Methods

Samples were collected within the Deep Creek fire perimeter during the summers of 2005, 2006, and 2007 by USDA Forest Service employees and by NDSU personnel. Samples were collected from Sections 19, 20, 30, 31 of T136N, R102W and Sections 25 and 36 of T136N, R103W. Trees killed in the Deep Creek Fire were felled with a chainsaw and cross sections (cookies) were collected from the trunk of the tree near the base. Samples were also collected from stumps of previously-killed trees if they showed visual evidence of scars. Tree samples were primarily chosen based on the presence of cat-faces. Trees with flat tops, flat on one side of the stem, or a large diameter at breast height (DBH) were other characteristics sought during sample collection as these characteristics are an indication of tree age. This was done to achieve the longest fire history possible. Sample locations (Appendix A) were recorded using a Trimble GeoXH global positioning system (GPS) receiver. Slope position, aspect of the slope, slope angle, and stand properties were recorded at individual sample points (Appendix B). Tree conditions were reported as being a standing snag or stump.

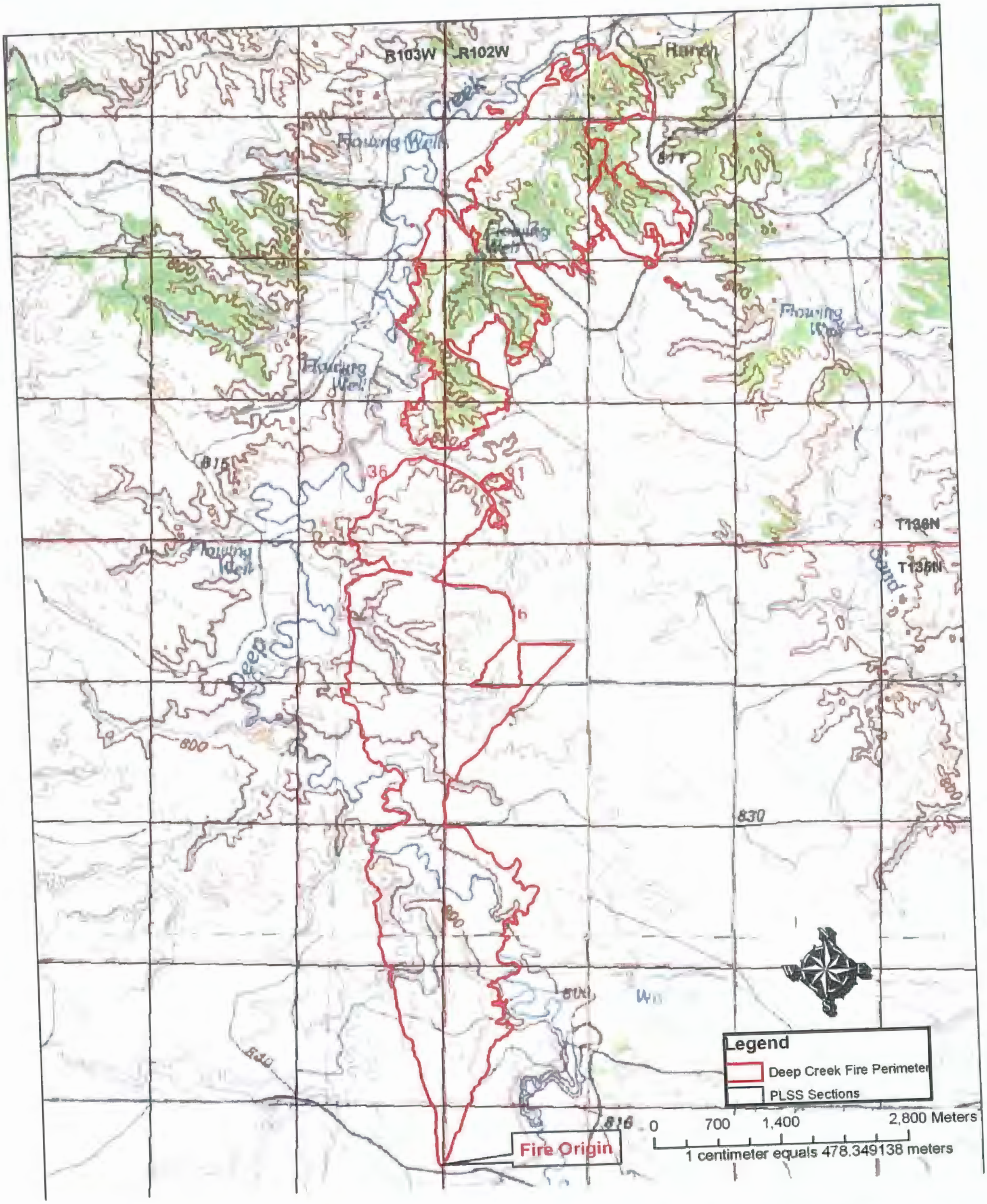

Figure 3. A topographic map showing the extent of the Deep Creek Fire of September 1-4, 2004, in the Little Missouri Badlands of southwestern North Dakota. The ponderosa pine forest is shown in green.

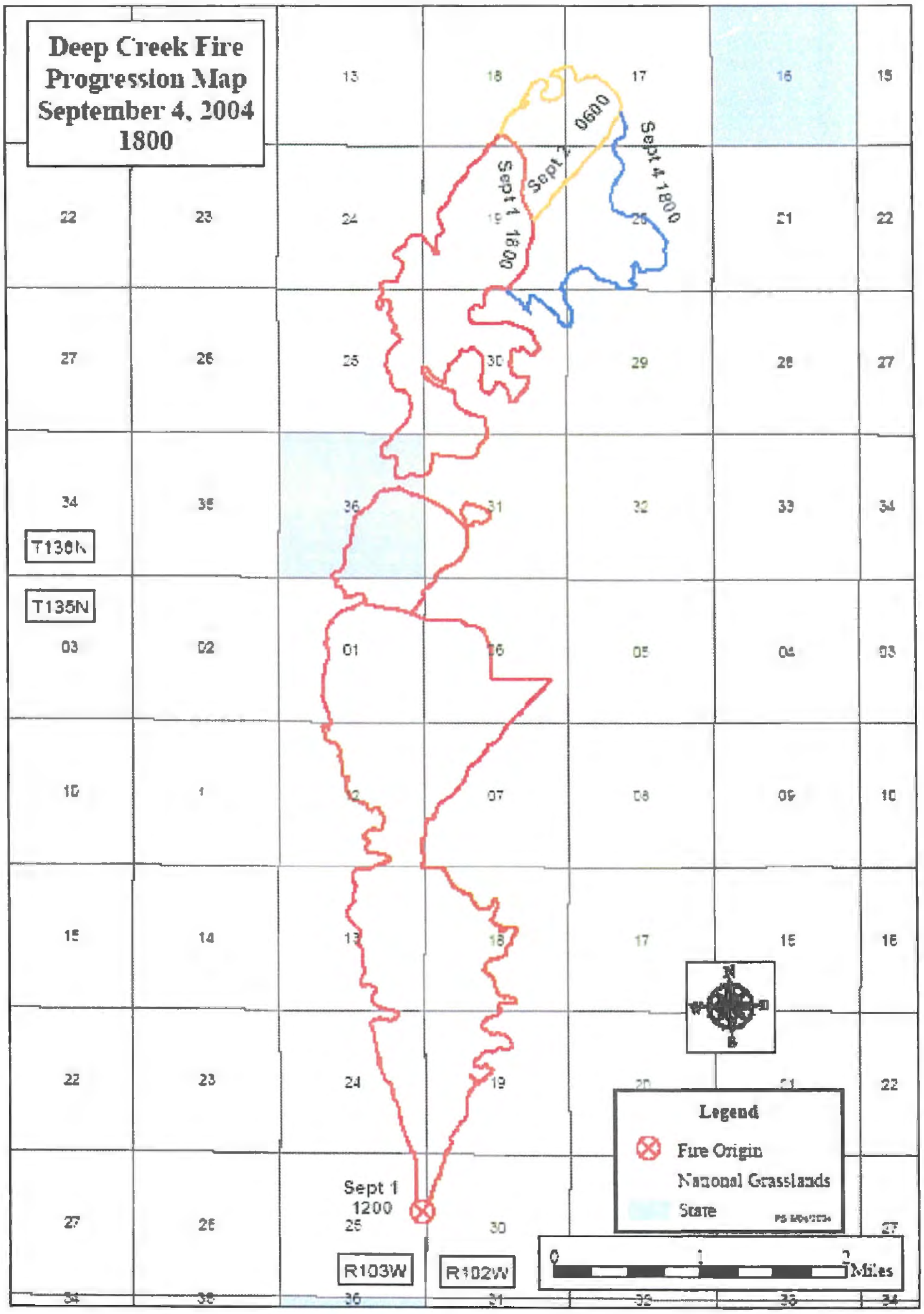

Figure 4. Location of fire origin, perimeter of the fire, and land ownerships for the Deep Creek Fire, September 1-4, 2004, in the Little Missouri Badlands of southwestern North Dakota (P. Sjursen 2007, personal correspondence).

A standing snag is a tree that was already dead or killed in the Deep Creek Fire but still standing, and a stump was cut before the Deep Creek Fire by another party. Slope position was categorized visually with trees located on the crest, shoulder, backslope, footslope (Schoeneberger et al. 1998), level ground or upland. The aspect of a hill slope was recorded as facing north, northeast, east, southeast, south, southwest, west, northwest, or NA (very little to no aspect). The angle of the slope was measured with a clinometer, and aspect was measured with a compass. Stand properties were recorded as open park, dense park, or dog haired. Open-park stands are those where ponderosa pine trees are relatively scattered, with the majority of sunlight reaching ground level. Dense-park areas are where trees are close together, and the amount of sunlight reaching ground level is considerably less than in open stands. Dog-haired stands are those which had complete canopy coverage before the 2004 fire.

All of the cookies collected from snags were located within one meter of the soil surface to attain the greatest number of scars. Only samples that had scars were brought to the lab for further analysis. Often, multiple cuts were made at the base of the tree to be certain that there were no scars. Of the original 214 trees marked in the field, 85 were used in the analysis (Appendix C).

Cross-sectional samples were air dried, followed by sanding a smooth finish on each sample to assure that annual rings and scars could be distinguished. Samples were first treated with a belt sander equipped with 50-grit sandpaper, followed by an orbital sander with 100, 150, 220, 320, 400, and 600-grit paper being applied sequentially. Between each treatment a tack cloth was used to pick up dust particles and wood debris to allow for a more uniform finish.

Samples were viewed under a boom-mounted Fisher Scientific dissecting microscope, 7X-45X. First, rings were counted starting at 2004, working back towards the pith, to give an approximate age for each sample. For each individual sample collected in

2005, a skeleton plot was constructed starting with the last year of growth and ending at the pith (Stokes and Smiley 1968). Scar years were then recorded into the skeleton plots. After skeleton plots were constructed for individual samples, they were cross-dated with each other and marker years were established into a master chronology (Stokes and Smiley 1968). Narrow rings, wide rings, or rings containing other distinguishing characteristics were used as marker years (Table 3).

Ring widths were measured using an Acu-Rite slide scale and Measure J2X software (Voortech 2004). Samples were placed on the sliding scale and each ring was measured to nearest 0.001 millimeter. For rings that were missing, a value of zero was used. A total of 46 samples were measured with this system for the purpose of confirming marker years already established with skeleton plots and locating missing or partial rings. COFECHA software (Holmes 1999) was used to crossdate difficult samples and to locate possible partial or missing rings. COFECHA identifies tree-ring data that may have possible errors associated in establishing a chronology.

The pre-settlement/post-settlement separation date used for this study was 1900 as this is the time widespread fires ceased due to Euro-American suppression (Arno 1976, Fisher et al. 1987, Brown and Sieg 1996). The year 1910 was also tested as a separation date as this was near the time the Dakota National Forest was established, and widespread porcupine-eradication efforts took effect to protect ponderosa pine from being damaged by feeding porcupines (Green 1960).

Three methods of scar interpretation were used in the analysis. The first method (Method 1) assumes that every scar was created by a fire. Method 2 applies "filters" with the assumption that fires occurred only in years in which 10% or 20% of the sample

Table 3. Ponderosa pine rings with distinguishing characteristics used as marker years in the Deep Creek Fire of southwestern North Dakota dendrochronological study (M. Gonzalez 2006, personal correspondence).

Marker Year	Characteristic	Marker Year	Characteristic
2002	Narrow Ring	1870	Narrow Ring
1998	Narrow Ring	1865	Narrow Ring
1980	Narrow Ring	1864	Narrow Ring
1977	Narrow Ring	1863	Narrow Ring
1974	Thin Latewood	1849	Narrow Ring
1964	Narrow Ring	1848	Narrow Ring
1961	Narrow Ring	1847	Narrow Ring
1956	Narrow Ring	1823	Narrow Ring
1954	Narrow Ring	1818	Narrow Ring
1952	Narrow Ring	1817	Narrow Ring
1949	Narrow Ring	1808	Narrow Ring
1946	Thin Latewood	1796	Narrow Ring
1942	Wide Ring	1760	Narrow Ring
1936	Narrow Ring	1759	Narrow Ring
1934	Narrow Ring	1758	Narrow Ring
1926	Narrow Ring	1757	Narrow Ring
1921	Narrow Ring	1756	Narrow Ring
1920	Narrow Ring	1736	Narrow Ring
1919	Narrow Ring	1725	Narrow Ring
1911	Narrow, Thin Latewood	1718	Narrow Ring
1902	Wide Ring	1712	Narrow Ring
1900	Narrow Ring	1698	Narrow Ring
1893	Narrow, Thin Latewood	1650	Narrow Ring
1886	Narrow Ring	1649	Narrow Ring
1875	Narrow Ring	1637	Narrow Ring
1874	Narrow Ring	1618	Narrow Ring

Narrow Ring = Low annual precipitation.
Wide Ring = High annual precipitation.
Thin Latewood = Growing season ended abruptly.

population showed scars. For example, only one tree had a scar in 1883. By Method 2, it is assumed that that scar was created by something other than a fire. First-scar characteristics were also analyzed in Method 2 (Appendix D). Filtered composites are used to represent those fires that may be more widespread in the area being studied (Van Horne and Fule

2006), and remove uncertainty of scars being created by another entity. Filtered composites also offset the potential impact of smaller fires in an area by focusing on just the fires that affected a large portion of the landscape (Grissino-Mayer 1995). Method 3 was visually based, removing scars not appearing to be caused by fire (Appendix E). Characteristics that were sought were the presence of charcoal in and around the scar along with evidence in rings interior to the scar showing a dark color. Tree-ring widths were also measured to determine if fires affect annual-ring growth post-fire (Appendix F).

The individual-tree FI with or without OS and composite FI were calculated in Methods 1 and 3. In Method 2, the scars were filtered and only the composite FI was used as a calculation method. In some of the samples in all of the calculation methods, a pith date could not be obtained or the only scar contained in the tree was determined not to be caused by a fire, and the sample was dropped from the analysis.

To better understand how the trees respond to scarring, several measurements were taken on the first scar in Method 2. The measurements included the radius and age of the tree at the first scar (= OS interval) and the percent of the circumference covered by the scar. The samples used in this analysis had to meet the 10% filter.

A t-test was used to determine if there was a significant difference between the means of the two populations assuming unequal variances. The separation dates of 1900 and 1910 were tested in Method 1.

Initially, sample locations were entered into ArcView GIS (ArcGIS, Version 9.2, Environmental Systems Research Institute, Redlands, California, USA) and overlain on a topographic map to ensure that sampling surveys covered the entire burned area. Later sampling was focused in areas where no samples had previously been collected to assure the entire stand was inspected. When all samples were collected, one hectare grids were randomly placed over the entire ArcView map starting in the northwest portion of the fire perimeter. Grids were then removed if they did not contain at least one sample. Maps were created for each fire year using Method 2. The distance between the farthest grids that contained scar samples was measured to determine how far a fire may have traveled. A ratio of grids containing a given scar year to the total number of grids was used as an index of fire coverage.

RESULTS

Method 1: Assume all scars are created by fire

Scars were found in at least one tree in 91 separate scar years. Scar years were recorded in 1 to 15 samples (Table 4).

Table 4. Scar years, number of trees which contained scars, and sample depth in ponderosa pine samples from the Little Missouri Badlands of southwestern North Dakota.

Scar Year	# Trees Affected	Sample Depth	Scar Year	# Trees Affected	Sample Depth	Scar Year	# Trees Affected	Sample Depth
1595	1	2	1862	3	31	1912	1	69
1690	1	4	1865	1	34	1914	1	70
1691	1	4	1870	4	45	1917	1	73
1712	1	6	1873	2	51	1918	1	74
1729	2	6	1874	4	52	1924	1	75
1730	1	6	1876	1	53	1926	3	75
1732	1	7	1878	2	58	1929	1	75
1735	1	7	1879	2	58	1930	2	75
1740	1	11	1880	1	58	1931	5	75
1748	1	15	1882	15	58	1936	2	76
1752	1	16	1883	1	58	1937	2	76
1759	1	16	1884	5	58	1938	1	76
1760	1	16	1885	1	58	1941	1	76
1762	1	18	1887	5	58	1945	1	76
1763	1	18	1888	2	58	1947	1	76
1772	1	20	1889	3	59	1952	3	77
1780	1	23	1891	1	60	1955	1	77
1785	1	25	1892	3	60	1957	1	77
1791	2	26	1893	15	60	1959	1	77
1797	1	26	1894	5	61	1964	3	77
1798	1	26	1895	6	63	1967	1	77
1808	2	26	1896	3	63	1968	1	77
1809	1	26	1897	1	63	1969	1	77
1811	1	26	1900	7	63	1971	3	77
1820	1	26	1902	7	65	1973	2	77
1824	1	26	1903	1	66	1977	1	77
1847	1	26	1904	3	66	1978	1	77
1848	1	26	1905	1	67	1992	1	77
1852	7	26	1906	1	67	1998	1	77
1855	1	26	1908	3	67			

Pre- and post-1900

There is a large difference (40 years) between the individual tree mean-fire intervals (MFIs) without the OS interval, with the MFI being shorter in the pre-1900 era (Table 5). When the OS interval was included, the pre-1900 individual tree MFI more than doubled to 38 years while the post-1900 individual tree MFI dropped to 35 years. The composite MFIs for pre- and post-1900 were within one year of each other. There is a significant difference (<0.001) pre- and post-1900 between the individual tree MFIs without the OS. There is no significant difference pre- and post-1900 in the means of the individual tree MFI with the OS or the composite MFI. The medians for pre- and post-1900 were also included because of the non-normal distribution of the data. Medians ranged from 8 to 21 years pre-1900 and 35 to 52 years post-1900.

Table 5. Median, mean, range, and number of observations for fire-interval (FI) calculations of the ponderosa pine forest in the Little Missouri Badlands of southwestern North Dakota for (a) pre-1900 and (b) post-1900.

	Median	Mean Fire Interval ± (SD)	Range	# of Obs.
(a) pre-1900				
Individual FI with OS	21	37.8 ± 43.1	3.8 - 200	55
Individual FI without OS	11	14.7 ± 13.9***	1 - 107	35
Composite FI	8	3.8 ± 4.6	1 - 23	45
(b) post-1900				
Individual FI with OS	35	35.2 ± 16.1	11.4 - 45.5	14
Individual FI without OS	52	54.9 ± 28.6***	6 - 104	38
Composite FI	35	3 ± 2.6	1 - 14	35

SD = Standard Deviation.
*** = Significance Level of < 0.001.

Pre- and post-1910

A separation date of 1910 yields similar results to where 1900 was the separation date. The difference between the individual tree MFIs without the OS was almost 30 years, with a shorter MFI pre-1910 compared to post-1910 (Table 6). When the OS interval was included, the pre-1910 MFI more than doubled to 39 years, while the post-1910 individual tree MFI dropped to 32 years. The composite MFI results are nearly unchanged from the MFI results for pre- and post-1900. There is a significant difference between the individual tree MFIs without the OS when 1910 is the separation date. There is no significant difference in the means when the same tests are applied to the individual tree MFI with the OS and the composite interval.

Table 6. Median, mean, range, and number of observations for fire-interval (FI) calculations of the ponderosa pine forest in the Little Missouri Badlands of southwestern North Dakota for (a) pre-1910 and (b) post-1910.

	Median	Mean Fire Interval ± (SD)	Range	# of Obs.
(a) pre-1910				
Individual FI with OS	20	38.8 ± 44.5	4 - 200	59
Individual FI without OS	11	15.9 ± 16.7***	1 - 146	38
Composite FI	8	3.6 ± 4.4	1 - 28	50
(b) post-1910				
Individual FI with OS	35	31.7 ± 13.9	11 - 45.5	9
Individual FI without OS	40	45.8 ± 23.5***	2 - 92	29
Composite FI	33	3.4 ± 2.8	1 - 14	27

SD = Standard Deviation.
*** = Significance Level of < 0.001.

Method 2: 10% and 20% filters

The year 1900 is used both as the end separation pre-1900 and the beginning separation of post-1900. Eleven samples were excluded from the post -1900 analysis as they were from stumps that were either cut or killed by some other disturbance prior to 2004. Seven fire years were greater than or equal to the 10% filter pre-1900 and two fire years were greater than or equal to the 10% filter post-1900 (Figure 5). When using the 20% filter, there were four fire years pre-1900, and zero fire years post-1900 (Figure 6). Statistical comparisons were only done for the composite FI and not for the individual-tree FIs to determine the FI for the entire stand. The pre-1900 composite MFI with a 10% filter is 23.5 years shorter than post-1900 (Table 7). There were only three observations when a 20% filter was used pre-1900 (MFI 54.7 years) and zero observations post-1900, as no samples (post-1900) met the 20% filter (Table 8).

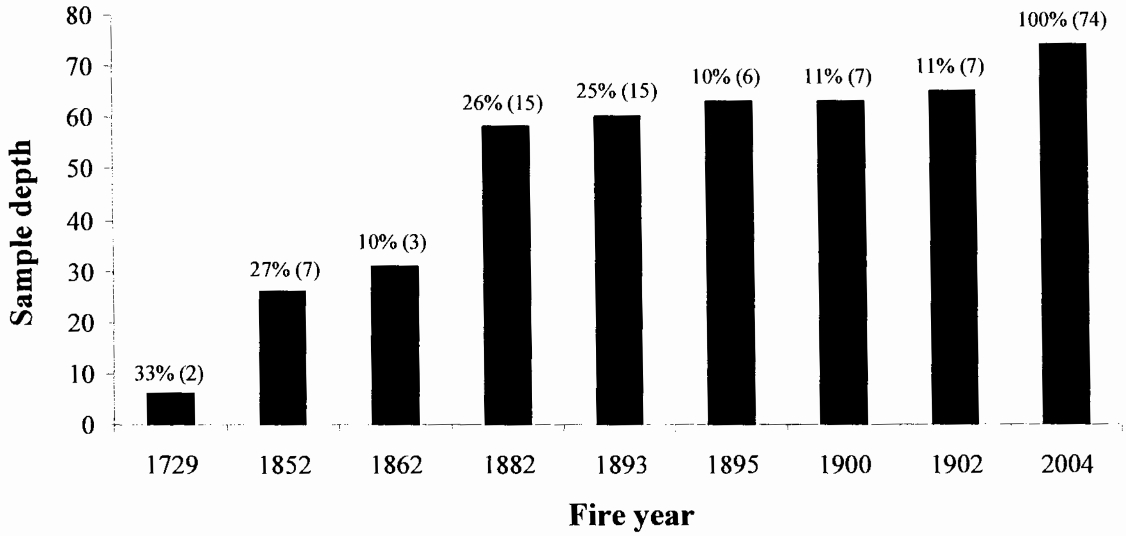

Figure 5. Fire-scar year and sample depth using a filter that excludes scars not seen in at least 10% of samples for the ponderosa pine forest in the Little Missouri Badlands of southwestern North Dakota. The percentage of samples showing scars and the corresponding sample depth for each fire year are shown above individual bars.

Characteristics of the first scar

The majority of samples (63%) used in the OS analysis recorded their first scar when samples were less than 50 years old, with the number of observations decreasing as the tree aged (Figure 7). Nearly one fourth (24%) of the trees were >100 years old when

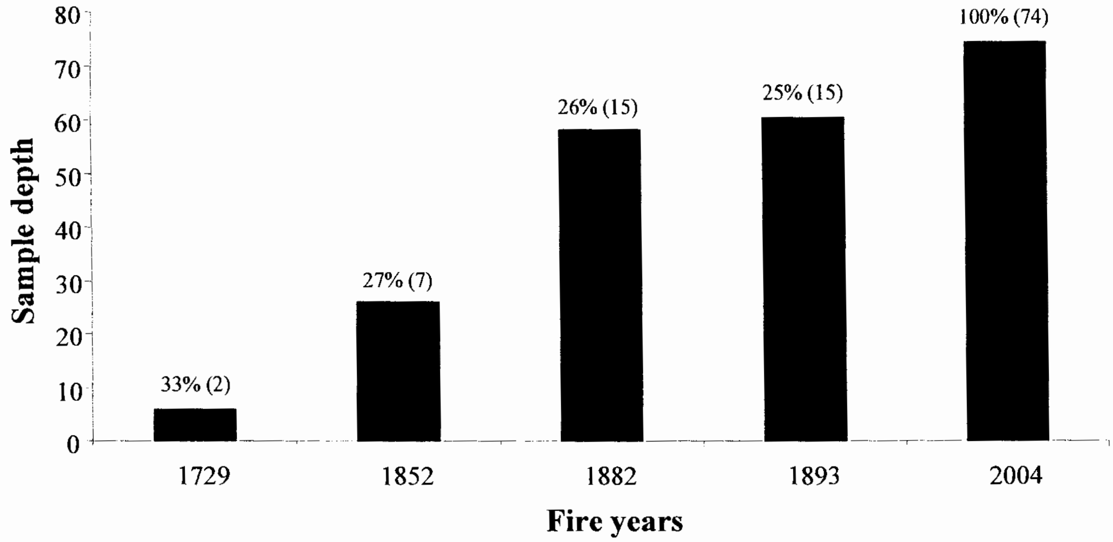

Figure 6. Fire-scar year and sample depth using a filter that excludes scars not seen in at least 20% of samples for the ponderosa pine forest in the Little Missouri Badlands of southwestern North Dakota. The percentage of samples showing scars and the corresponding sample depth for each fire year are shown above individual bars.

Table 7. Median, mean, range, and number of observations for fire-interval (FI) calculations of the ponderosa pine forest in the Little Missouri Badlands of southwestern North Dakota using a 10% filter for (a) pre-1900 and (b) post-1900.

	Median	Mean Fire Interval ± (SD)	Range	# of Obs.
(a) pre-1900				
Composite FI	10.5	28.5 ± 46.7	2 - 123	6
(b) post-1900				
Composite FI	52	52 ± 70.7	2 - 102	2

SD = Standard Deviation.

they suffered their first scar. The first scar is generally formed when the tree is relatively small; seventy-eight percent of the samples had a radius less than 100 mm at the time of their first scar, and 92% were ≤ 150 mm (Figure 8). The average distance from the pith to

Table 8. Median, mean, range, and number of observations for fire-interval (FI) calculations using a 20% criterion in the ponderosa pine forest in the Little Missouri Badlands of southwestern North Dakota. Three observations met the 20% criteria pre-1900 and no observations post-1900.

	Median	Mean Fire Interval ± (SD)	Range	# of Obs.
Composite FI	30	54.7 ± 59.9	11 - 123	3

SD = Standard Deviation.

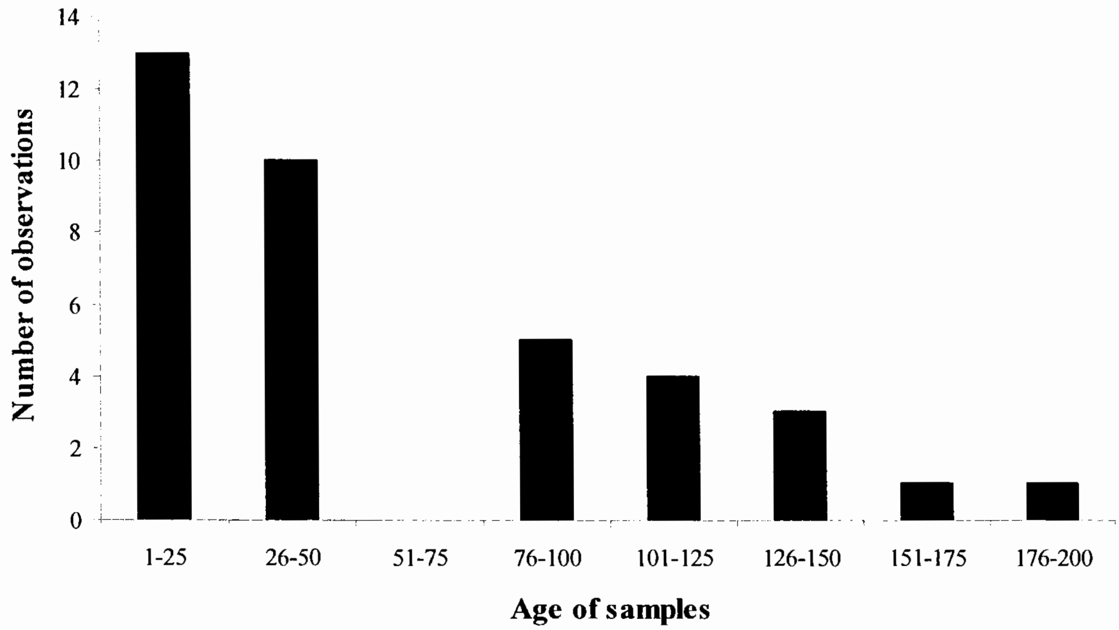

Figure 7. Age when the first scar is formed with the number of observations for the ponderosa pine of the Little Missouri Badlands in southwestern North Dakota.

the first scar was 93.3 mm, with a range of 12 to 456 mm. The majority of samples (95%) show less than 50% cambial damage at the first scar (Figure 9).

Measure of spatial extent of fires using grids

There were a total of 43 one-hectare grids used in the analysis to determine distances traveled by previous fires. Distances were measured for fires that affected at least 10% of the sample base. Estimated distances traveled by previous fires did not cover the

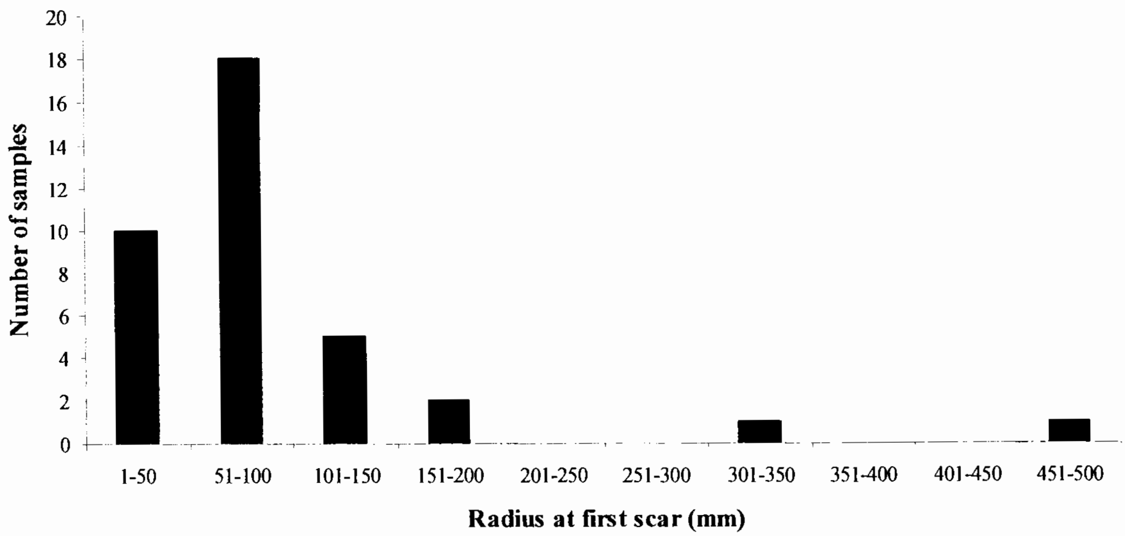

Figure 8. Distance from the pith to the first scar and number of samples for the ponderosa pine of the Little Missouri Badlands in southwestern North Dakota.

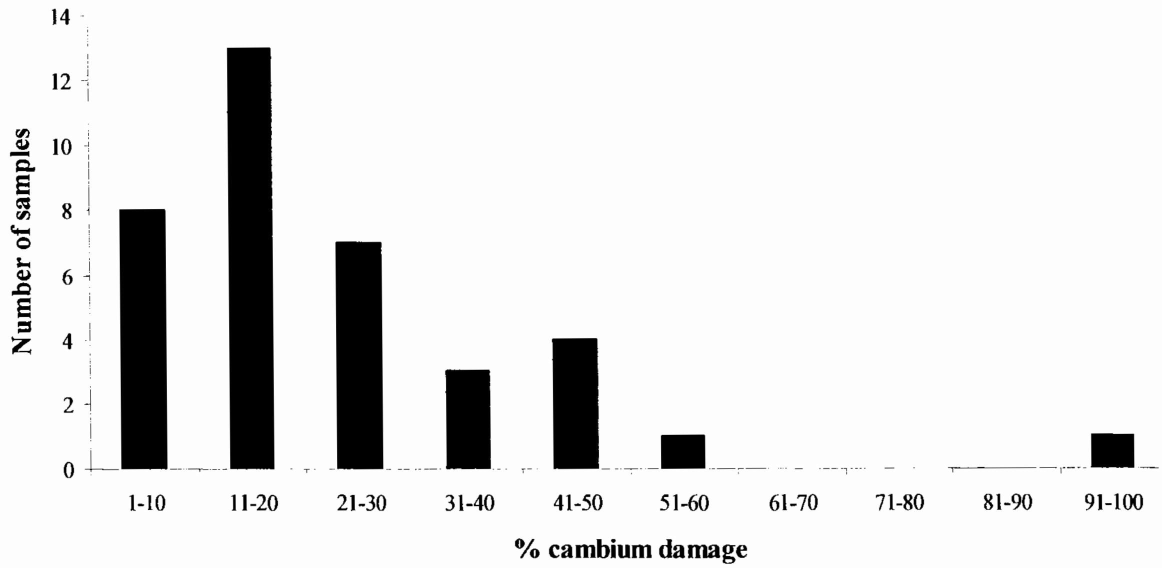

Figure 9. Percent of cambium damaged at the first scar and number of samples in ponderosa pine from the Little Missouri Badlands in southwestern North Dakota.

4310 meters traveled by the Deep Creek Fire (Figure 10). The 1882 and 1893 fires were seen in the most grids and had distances of 2893 and 3276 meters between the farthest grids, respectively (Table 9, and Figures 11 and 12).

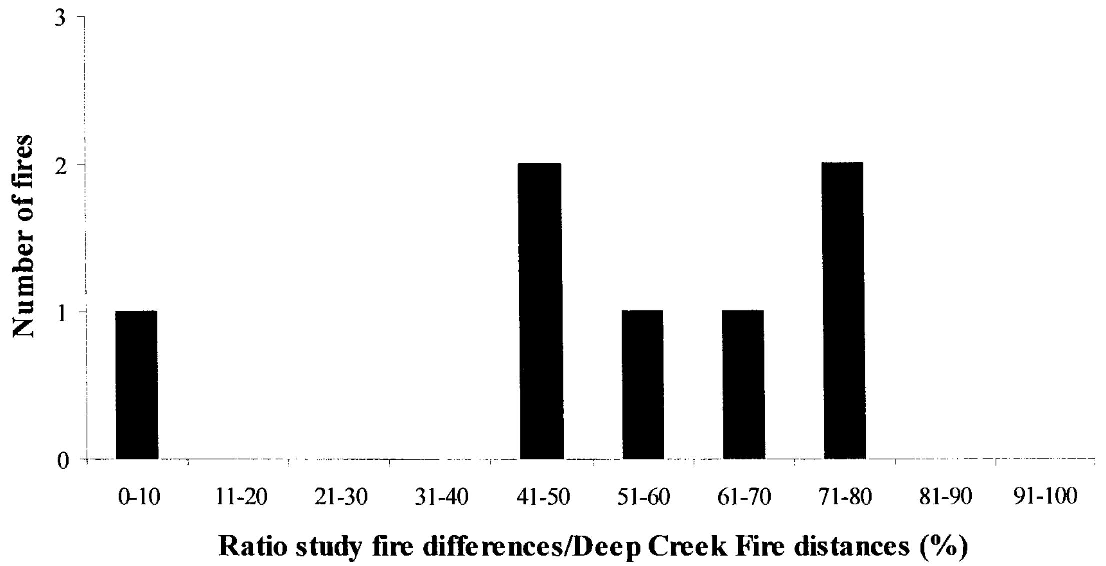

Figure 10. Ratio of distances traveled by pre-1900 fires compared to the distance traveled by the 2004 Deep Creek Fire that occurred in the Little Missouri Badlands of southwestern North Dakota.

Table 9. Estimated distance between the two farthest samples that were scarred by historic fires within the perimeter of the 2004 Deep Creek Fire in the Little Missouri Badlands of southwestern North Dakota and percent of grids that contained a scarred tree.

Year	Distance (m)	% Grids	% Distance of Deep Creek Fire
1852	304	8	7%
1862	2481	6	58%
1882	2893	29	67%
1893	3276	24	76%
1895	2085	12	48%
1900	3202	12	74%
1902	2164	14	50%

Method 3: Evidence of charring at scar

Method 3 visually assessed all of the scars in every sample for signs of charring. Fifty-five samples were excluded from the analysis because the scars they contained did not meet the charring stipulation, decreasing the number of samples analyzed to 30 and the

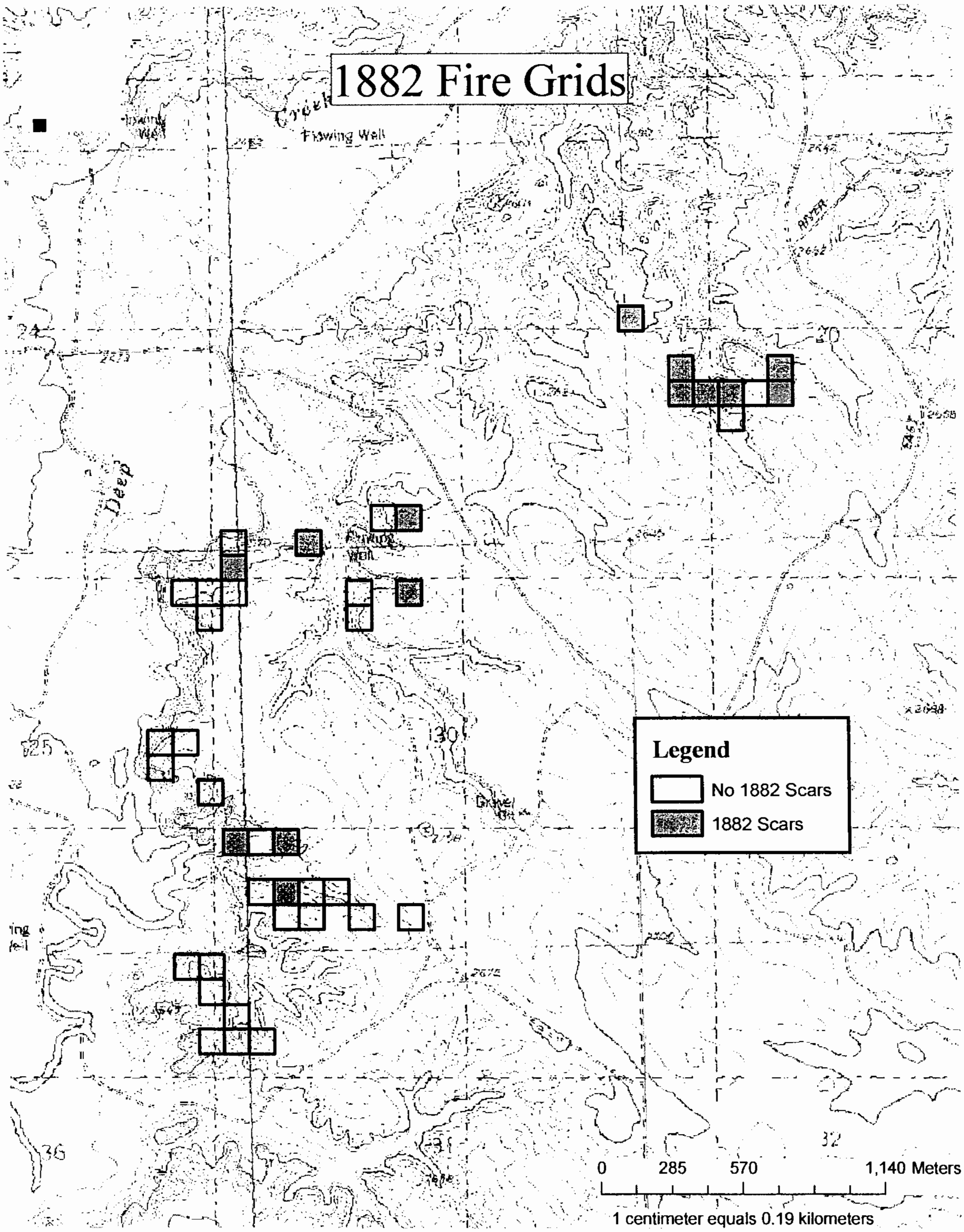

Figure 11. Grids showing the extent of the 1882 fire among areas where ponderosa pine samples were collected for the fire-history study in the Little Missouri Badlands in southwestern North Dakota.

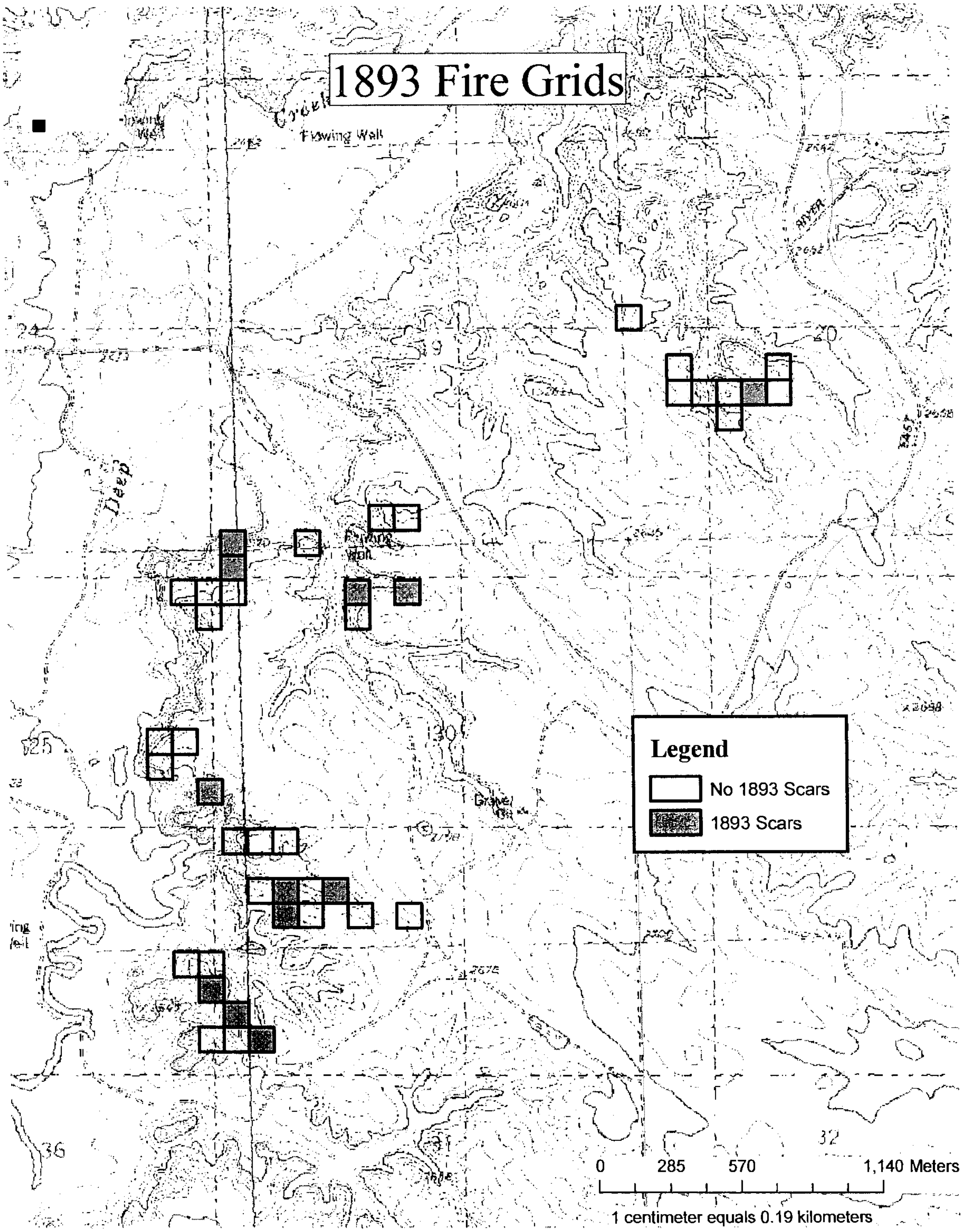

Figure 12. Grids showing the extent of the 1893 fire among areas where ponderosa pine samples were collected for the fire-history study in the Little Missouri Badlands in southwestern North Dakota.

number of separate fire events to 19. Ten of the original 57 individual scar years had only one fire scar and the remaining fires were represented by two to six scars (Table 10).

Table 10. Fire-scar year, number, and percentage of trees affected with visual charring from ponderosa pine samples collected in the Little Missouri Badlands in southwestern North Dakota.

Fire Years	# Trees Affected	Sample Depth	% Trees Affected
1852	3	10	30%
1870	2	20	10%
1878	1	28	4%
1880	1	28	4%
1882	3	28	11%
1887	2	28	7%
1888	1	28	4%
1889	2	28	7%
1892	1	28	4%
1893	6	28	21%
1894	1	28	4%
1900	4	28	14%
1902	2	28	7%
1905	1	29	3%
1924	1	30	3%
1926	1	30	3%
1930	1	30	3%
1952	1	30	3%

Pre- and post-1900

There was a 5.1 year difference between the individual-tree FIs with the OS, with the MFI being 54.1 years pre-1900 and 49 years post-1900 (Table 11). There was a 14.3 year difference between the individual tree FIs without the OS, with the MFI being 15.7 years pre-1900 and 30 years post-1900 (Table 11). The composite MFI is shorter pre-1900 than post-1900, four and 12 years, respectively. There is no significant difference between the means before and after 1900 (Table 11).

Table 11. Median, mean, range, and number of observations for fire-interval (FI) calculations after visual analysis removed scars not appearing to be caused by fire in the ponderosa pine forest in the Little Missouri Badlands of southwestern North Dakota for (a) pre-1900 and (b) post-1900.

	Median	Mean Fire Interval ± (SD)	Range	# of Obs.
(a) pre-1900				
Individual FI with OS	27	54.1 ± 48.9	16-200	26
Individual FI without OS	12	15.7 ± 10	12-27	3
Composite FI	2.5	4 ± 4.7	1-18	12
(b) post-1900				
Individual FI with OS	49	49 ± 2.8	47-51	2
Individual FI without OS	30	30	30	1
Composite FI	3	11.6 ± 16.6	1-52	9

Tree-ring widths

Tree-ring widths were measured in 11 samples for 10 years before and after the 1882 fire (Table 12). Pre- and post-fire widths were compared to determine if fire reduced annual ring growth. There is a significant difference assuming unequal variances between the means ($p = 0.05$) when 10 years before and after 1882 were compared, with wider ring growth observed post-1882. There are no significant differences when other time intervals are compared.

Table 12. Tree-ring widths compared for 10 years before and after the 1882 fire which occurred in the ponderosa pine stand in the Little Missouri Badlands of southwestern North Dakota.

Years Before and After 1882	p-value
10	0.05
9	0.21
8	0.88
7	0.54
6	0.33
5	0.27
4	0.73
3	0.41
2	0.91
1	0.35

DISCUSSION

Method 1: Assume all scars are created by fire

The pre-settlement (pre-1900 and pre-1910) individual FI without OS values (14.7 and 15.9 years) are within the range of MFI values (6 to 27 years) found in other studies of ponderosa pine forests in the surrounding region (c.f. Table 1, Arno 1976, Fisher et al. 1987, Brown and Sieg 1996, Brown and Sieg 1999, Brown et al. 2000, Brown and Shepperd 2001). When the OS interval was included in the calculations, the individual FI results (37.8 and 38.8 years) were generally higher than results of other studies. The pre-settlement composite FI results are shorter (3.8 and 3.6 years) and are more similar to results found in Arizona and New Mexico (3.45 to 23.5 years; Swetnam and Dieterich 1985; Swetnam and Baisan 1995, 1996). However, they are shorter than those commonly found in this region (6 to 27 years).

Findings from research in the Rocky Mountain region do not support the composite MFI findings in this study using Method 1, as fire suppression should have increased the fire-interval values dramatically after Euro-American settlement. Furthermore, the pre-1900/1910 interval results are shorter than other studies in the region indicate (Swetnam and Dieterich 1985, Fisher et al. 1987, Swetnam and Baisan 1995, Arno and Fiedler 2005). One possible explanation of the composite data being short pre-1900/1910 involves the number of samples available. The pre-settlement sample depth is smaller than the post-settlement sample depth, resulting in fewer scars. Furthermore, there were fewer trees which could be scarred because the forest contained few trees that were large in size, with fire possibly eliminating smaller trees until Euro-American settlement (Arno and Fiedler 2005). The second explanation considers that, as the area was settled, the large ponderosa pine trees were harvested and used for railroad ties, housing, and fence posts (Potter and Green 1964). These actions removed a high number of trees containing historic fire information, lowering the sample depth of this study. The only trees that were left were those too small or trees which could not be retrieved because of topographic location.

From this point on in the study the year 1900 was used as the separation date between pre- and post-settlement. There did not appear to be a difference in the calculation results when comparing 1900 and 1910. Furthermore, the year 1900 is most often used by researchers as a separation date in historic fire interval studies as this was the time Euro-American settlement established in the western states (Arno 1976, Fisher et al. 1987, Swetnam and Baisan 1995, Swetnam and Baisan 1996, Brown and Sieg 1996).

In comparing the three calculation methods, only the individual FI without OS gave results that are somewhat consistent with those found in the literature. The composite fire-interval results of Method 1 are short, even with the consideration that composite FIs are much shorter than the individual tree FIs since they are not area explicit (Arno and Peterson 1983, Baker and Ehle 2001). An increase in study area does not affect the individual tree MFI as a single tree is independent from other trees being studied in the area (Baker and Ehle 2001). The individual FI with the OS interval gave results that have longer FIs than literature suggests (Brown and Sieg 1999, Brown et al. 2000, Brown and Sieg 1996, Arno 1976, Fisher et al. 1987, Brown and Shepperd 2001). Stephens et al. (2003) further stated that the OS should not be included in FI calculations as many trees survive fire without ever charring. Also, neither the composite calculation nor the individual-tree FI with OS changed results pre/post-settlement.

Interpretation of every scar as being created by fire has several advantages and disadvantages. First, this method assures that no true fire-scars have been removed from the analysis. Filtering methods may exclude some true fire scars. Second, there is an increase in the number of observations for comparing pre- and post-separation statistical information. However, if scars were created by other disturbances or agents, this method may make the statistical information invalid. Furthermore, fire scars are not consistently recorded on individual trees making the scars an incomplete source of data (Dieterich and Swetnam 1984). This method is not recommended for calculating the FI of a ponderosa pine forest.

Method 2: 10% and 20% filters

Method 2 for the Deep Creek Fire analysis used the 10% and 20% filter techniques. The pre-1900 value of MFI calculations (28.5 years) is slightly higher than MFI values (six to 27 years) recorded by other researchers in the Rocky Mountain Region (Brown and Sieg 1999, Brown et al. 2000, Brown and Sieg 1996, Arno 1976, Fisher et al. 1987, Brown and Shepperd 2001). The post-1900 value of 52 years is acceptable for the region being studied.

When using the 20% filter, four fire years were found pre-1900, and only the Deep Creek Fire occurred post-1900. The pre-1900 composite MFI is 54.7 years. This is a high interval in the Rocky Mountain Region (Brown and Sieg 1999, Brown et al. 2000, Brown and Sieg 1996, Arno 1976, Fisher et al. 1987, Brown and Shepperd 2001). This may be caused by larger trees being harvested around 1900 by Euro-American settlers, and the trees containing scars pre-1900 were removed and unable to be analyzed. The post-1900 value of 104 years is acceptable as grazing practices were established and fire was excluded from forest ecosystems after Euro-American settlement (Archer 1994). However, while working in the field we were approached by a local landowner who relayed an anecdote of a fire that he remembered from 1947 (R. Hanson 2007, personal correspondence). Only one sample from this study recorded a scar in 1947. Trees containing scars from the 1947 fire may have been missed while sampling the ponderosa pine, or all of the trees in the fire were destroyed.

The 10% and/or 20% filter data-reduction method has an advantage – the likelihood of these scars being created by fire increases over single scar events, especially as the number of scars increases. The disadvantage is that true fires may have been missed because they didn't leave behind many scarred trees. This method eliminates those scars and therefore may give a much higher FI than expected. Baker and Ehle (2001) suggested using 10% and 20% filters to calculate FI information to eliminate scars which may not have been created by fire. Grissino-Mayer (1995) suggested filtering the composite data by including only fire dates that occur on a greater than determined percentage of trees. Results from this study suggest this is an accurate way to determine stand-level fire parameters using the 10% filter. No filtering method is perfect, but this may be the best way to exclude those scars not created by fire and focus only on those scars that most likely are formed by fire.

The number of years, distance to the first scar, and circumference of cambial damage was collected for all samples meeting the 10% filter. The data indicate that a ponderosa pine does not have to be a certain number of years old before it can survive a fire event. Most of the samples used in this study (63%), recorded their first scar when they were less than 50 years old. Trees were also relatively small (<150 mm) when they recorded their first scar. This may be due to the tree having relatively thin bark and being more susceptible to heat damage than a tree that is larger with thick bark. There is a very distinct cutoff in the amount of cambial damage a ponderosa pine can survive. Ninety-five percent of the samples had less than 50% cambial damage. This is a strong indication of what individual stems can take in terms of cambial damage, and still survive.

Baker and Ehle (2001) suggested that a ponderosa pine must be at least 50 years old before it can survive a fire event. However, in Arizona, Van Horne and Fule (2006) found the average number of years to the first scar to be 101.5. The data from this study do not support the statement that a ponderosa pine must be at least 50 years old before it can withstand a fire. This value is somewhat arbitrary as the rate of ponderosa pine growth is dependent on climate and topography, and it is impossible to know the true fire-free interval because ponderosa pine can often burn without scarring (Stephens et al. 2003). However, the average OS interval in Method 2 is 58 years, with a range of five to 200 years. These data suggest that there is no minimum number of years a ponderosa pine must be before it can survive a fire disturbance.

Also, the data suggest that a ponderosa pine tree may be very small when the first scar is created and does not have to be a certain size before it can survive a fire. The rate at which a ponderosa pine will grow and the intensity of fire are both variable.

Grids used in Method 2 allowed distances to be measured between the two farthest separated grids for a given fire year. Distances calculated from the grids found that pre-settlement fires traveled less distance than the Deep Creek Fire. This is to be expected as post-1900 fires are greatly increased in size and intensity compared to pre-1900 fire due to an increase of woody fuels as a result of fire suppression (Swetnam and Baisan 1996). The distances between samples which met the 10% and 20% filters show the extent historic fires may have traveled. Compared to the extent traveled by other fires, the 1852 fire was estimated to travel a relatively short distance, only 304 m. Other fires meeting the filter were estimated to travel between 2085 and 3276 m. However, two or more separate trees may have been damaged by a disturbance other than fire in the same year. For example, porcupines may feed on multiple trees in a given year, creating several scars. Several recent porcupine-created scars were observed while collecting samples for this study. Nevertheless, the grids help to minimize inaccurate data.

Method 3: Evidence of charring at scar

The pre-settlement results of Method 3 are similar to those of Method 1. The pre-settlement FI without the OS interval included is 15.7 years, well within the range of MFI values (six to 27 years) found in other studies of ponderosa pine around the region (Brown and Sieg 1999, Brown et al. 2000, Brown and Sieg 1996, Arno 1976, Fisher et al. 1987, Brown and Shepperd 2001). When the OS interval is included, the pre-1900 MFI value is very high, 54.1 years. The composite FI is four years, shorter than the results from studies conducted in the Rocky Mountain Region.

The individual-tree FIs with and without the OS interval included are acceptable as post-1900 values. The composite FI is only 11 years, which is shorter than expected. Despite increases in values for individual FI with and without the OS interval included, there are no statistical differences between the means.

Elimination of all scars that contained no discernible charring has the advantage of excluding those scars formed by processes other than fire. However, this method may inadvertently eliminate some fire-produced scars. For example, trees are often charred but not scarred (Baker and Ehle 2001) by fire, or a scar may develop at a later time but will lack the evidence of charring in the rings. Samples killed in 2004 did not show charring within the rings that supposedly shows up in rings after a fire event. Furthermore, some scars may have been counted as fires when they were created by some other disturbance. If an open wound is created by a disturbance such as porcupine feeding, the xylem may be exposed for many years. A fire may burn the tree before the wound can callus over creating the appearance that the original wound was caused by a fire. Therefore, it is not always possible to know how the scar was originally created (T. Swetnam 2007, personal correspondence). Filters such as the 10% and 20% filter were created to remove some of the uncertainty in FI calculations. It may not be possible to positively discern fire scars from scars created by other disturbances upon visual analysis, and no literature could be found to support this method.

Tree-ring widths were measured for the 10 years before and after the 1882 fire event. There is a significant difference assuming unequal variances between the means when 10 years before and after 1882 were compared. However, there is wider annual-ring growth the 10 years after 1882 than the 10 years prior to 1882, which is the opposite of what is expected after a fire event. Therefore, measurement of annual-ring growth before and after a fire event is not an acceptable method to confirm if a scar was created by fire.

Comparison of calculation methods

Research suggests that the best method for determining the FI for a stand is using a 10% and/or 20% filter (Grissino-Mayer 1995, Baker and Ehle 2001, Van Horne and Fule 2006). Elimination of single-scar events and including only scar years seen in multiple trees reduces the level of uncertainty in the MFI calculations. Scars may be caused by a multitude of variables including porcupine feeding, wind damage, frost damage, and even collisions from other trees. There is no FI calculation that is perfect, but for this study area it appears that eliminating single scar events will yield the best results for calculating FIs. The visual analysis eliminated scars that met the 10% and 20% filter used in Method 2. For example, many of the scars recorded in 1882 and 1893 were removed after the visual analysis, 12 and nine scars, respectively. Therefore, this is not the best method for determining the FI of a ponderosa pine stand.

Considerations for future study

Trees sampled in this study were located inside the perimeter of the 2004 Deep Creek Fire. Much of the ponderosa pine forest was unaffected by the Deep Creek Fire and these areas were not sampled. Collecting samples from outside the 2004 fire perimeter would greatly enhance the results. For this study trees were targeted based on physical characteristics such as being older than the majority of the forest and showing relicts of previous scars. The targeted method was chosen for this study as it is the best way to compile historical fire information (Swetnam and Baisan 1996). Van Horne and Fule (2006) also found that targeting samples is an acceptable technique for calculating FIs. They also stated that all of the sampling methods used in their analysis (targeted samples, random samples, area sampled, and grid-based samples) result in an accurate estimate of a stand FI. Therefore, the targeting method of sampling is recommended for future studies.

The area of the ponderosa pine forest topography is highly variable. Because of this variability, some areas, such as backslopes, were likely more prone to burning than others. Focusing sampling on these topographic positions may show a clearer picture of the fire history in the area. More scars may be recorded in the same year using this sampling method, which may increase confidence that those scars were created by fire. Many trees were cut on the crests of slopes, but very few were collected as many of them did not contain any scars. This is due to lower fuel loads being present at many of the crest positions, so less-intense fires were carried close enough to affect the tree.

An area of concern that must be addressed in the North Dakota ponderosa pine forest is the effect of porcupine feeding on the trees. While selecting samples and covering the terrain, it was obvious there was a considerable population of porcupines in the area. In some cases entire trees were stripped of their bark and in other cases only a small portion of the tree was affected. This type of damage, like fires, creates an open wound that the tree must callus over to survive. This may be a consideration when calculating FIs for an area and further dissecting recent scars created by porcupines to differentiate between porcupine and fire scars. There is, however, a way to determine which trees were fed upon by porcupines from those that were not. Porcupines will only feed on ponderosa pine that has low levels of monoterpene limonene (Snyder and Linhart 1997), and the xylem of trees collected for fire history studies can be tested for these levels as an indication of what disturbance created the scar. More time should have been spent studying porcupine-created scars in the field. This may have helped in distinguishing fire scars from porcupine scars in the lab.

Sampling procedures that would have been done differently in this study if more time was allowed would be taking multiple cuts from each tree sampled to be sure that all of the scars have been accounted for. Multiple cookies were taken from some trees but not for all of them.

Many of the studies that determine historic fire information use MFI as the calculation method (Tables 1 and 2). However, calculating the MeFI may be a better way to determine fire history because the data are not distributed normally.

LITERATURE CITED

Archer, S. 1994. Woody plant encroachment into southwestern grasslands and savannas: Rates, patterns, and proximate causes. pp. 13-68 *in* Ecological implications of livestock herbivory in the West. Varva, M., W. A. Laycock and R. D. Pieper *eds*. Society of Range Management, Denver, CO. 300p.

Arno, S.F. 1976. The historical role of fire on the Bitterroot National Forest. USDA For. Serv. Res. Pap. INT-187. 29p.

Arno, S.F. 2000. Fire in western forest ecosystems. pp. 97-120 *in* Wildland fire in ecosystems. Vol. 2. Effects of fire on Flora. Brown, J.K., and J.K. Smith *eds*. USDA For. Serv. Gen. Tech. Rep. RMRS-GTR-42. 257p.

Arno, S.F., and C.E. Fiedler. 2005. *Mimicking nature's fire: restoring fire-prone forests in the West*. Island Press, Washington, D.C. 256p.

Arno, S.F., and T.D. Peterson. 1983. Variation estimates of fire intervals: A closer look at fire history on the Bitterroot National Forest. USDA For. Serv. Res. Pap. INT-301. 8p.

Arno, S.F., J.H. Scott, and M.G. Hartwell. 1995. Age-class structure of old growth ponderosa pine/Douglas-fir stands and its relationship to fire history. USDA For. Serv. Res. Pap. INT-RP-481. 25p.

Arno, S.F., and K.M. Sneck. 1977. A method for determining fire history in coniferous forests of the mountain west. USDA For. Serv. Gen. Tech. Rep. INT-42. 28p.

Baker, W.L., and D. Ehle. 2001. Uncertainty in surface-fire history: The case of ponderosa pine forests in the western United States. Can. J. For. Res. 31: 1205-1226.

Brown, P.M., M.G. Ryan, and T.G. Andrews. 2000. Historical surface fire frequency in ponderosa pine stands in Research Natural Areas, central Rocky Mountains and Black Hills, USA. Nat. Areas J. 20: 133-139.

Brown, P.M., and W.D. Shepperd. 2001. Fire history and fire climatology along a 5° gradient in latitude in Colorado and Wyoming, USA. Palaeobotanist. 50: 133-140.

Brown, P.M., and C.H. Sieg. 1996. Fire history in interior ponderosa pine communities of the Black Hills, South Dakota, USA. Int. J. Wildland Fire. 6: 97-105.

Brown, P.M., and C.H. Sieg. 1999. Historical variability in fire at the ponderosa pine – Northern Great Plains prairie ecotone, southeastern Black Hills, South Dakota. Ecoscience. 6: 539-547.

Bunkers, M.J., J.R. Miller, and A.T. DeGaetano. 1996. Definition of climate regions in the Northern Plains using an objective cluster modification technique. J. Clim. 9: 130-146.

Chuvieco, E., and E.S. Kasischke. 2007. Remote sensing information for fire management and fire effects assessment. J. Geophysical Res. 112: 1-8.

Dieterich, J.H., and T.W. Swetnam. 1984. Dendrochronology of a fire-scarred ponderosa pine. For. Sci. 30: 238-247.

Fisher, R.F., M.J. Jenkins, and W.F. Fisher. 1987. Fire and the prairie-forest mosaic of Devils Tower National Monument. Am. Mid. Nat. 117: 250-257.

Green, J.M. 1960. The Dakota National Forest. MS Thesis. North Dakota State University, Fargo, North Dakota. 80p.

Grissino-Mayer, H.D. 1995. Tree-ring reconstructions of climate and fire history at El Malpais National Monument, New Mexico. Ph.D. dissertation, University of Arizona, Tucson, Arizona. 407p.

Heyerdahl, E.K., D. Berry, and J.K. Agee. 1995. Fire history data-base of the western United States. U.S. Environmental Protection Agency. Report EPA/600/R-96/081. Washington, D.C. 51p.

Hoffmann, G.R., and R.R. Alexander. 1987. Forest vegetation of the Black Hills National Forest of South Dakota and Wyoming: A habitat type classification. USDA For. Serv. Res. Pap. RM-276.

Holmes, R.L. 1999. Quality control of crossdating and measuring: A user's manual for program COFECHA. pp. 41-49 *in* Tree-ring chronologies of western North America: California, eastern Oregon, and northern Great Basin. Holmes, R.L., R.K. Adams, and H.C. Fritts. *eds*. University of Arizona Press, Tucson.

Jensen, R.E. No Date. Climate of North Dakota. National Weather Service, North Dakota State University, Fargo, North Dakota. Jamestown, ND: Northern Prairie Wildlife Research Center Online.
http://www.npwrc.usgs.gov/resource/habitat/climate/index.htm
(Version 02APR98) Accessed 15.July.2008

Little, E.L., Jr,, 1971. Atlas of United States trees, Volume 1, Conifers and important hardwoods: US Dep. Ag. Misc. Pub. 1146. 9p.

McBride, J.R., and R.D. Laven. 1976. Scars as an indicator of fire frequency in the San Bernardino Mountains, California. J. For. 79: 439-442.

Oliver, W.W., and R.A. Ryker. 1990. Pinus ponderosa Dougl. ex Laws. Ponderosa pine. pp. 413-424 *in* Conifers, Vol. 1 of Silvics of North America, Burns, R.M., and B.H. Honkala *tech. coords*. Ag. Handbook 654. USDA For. Serv., Washington, DC.

Pierce, J.L., G.A. Meyer, and A.J.T. 2004. Fire-induced erosion and millennial-scale climate change in northern ponderosa pine forests. Nature 432: 87-90.

Potter, L.D., and D.L. Green. 1964. Ecology of ponderosa pine in western North Dakota. Ecol. 45: 10-23.

Progulske, D.R. 1974. Yellow Ore, Yellow Hair, Yellow Pine; a Photographic Study of a Century of Forest Ecology. South Dakota State Univ. Ag. Exp. Sta. Bull. 616. 169 p.

Savage, M., and T.W. Swetnam. 1990. Early and persistent fire decline in a Navaho ponderosa pine forest. Ecology. 70: 2374-2378.

Schoeneberger, P.J., D.A. Wysocki, E.C. Benham, and W.D. Broderson. 1998. Field book for describing and sampling soils. USDA Nat. Res. Cons. Serv. National Soil Survey Center. Lincoln, NE. 182p.

Snyder, M.A., and Y.B. Linhart. 1997. Porcupine feeding patterns: Selectivity by a generalist herbivore? Can. J. Zool. 75: 2107-2111.

Stephens, S.L., C.N. Skinner, and S.J. Gill. 2003. Dendrochronology-based fire history of Jeffrey pine – mixed conifer forests in the Sierra San Pedro Martir, Mexico. Can. J. For. Res. 33: 1090-1101.

Stokes, M.A., and T.L. Smiley. 1968. An introduction to tree-ring dating. University of Chicago Press, Chicago. 73p.

Swetnam, T.W., and C.H. Baisan. 1995. Historical fire regime patterns in the southwestern United States since AD 1700. pp. 11-32 *in* Fire effects in Southwestern Forests: Proceedings of the Second La Mesa fire symposium. C.D. Allen. *ed.* USDA For. Serv. Gen. Tech. Rep. RM-GTR-286.

Swetnam, T.W., and C.H. Baisan. 1996. Fire histories of montane forests in the Madrean Borderlands. pp. 15-36 *in* Effects of fire on Madrean Province Ecosystems. P.F. Pfolliott, L.F. DeBano, M.B. Baker, Jr., G.J. Gottfried, G. Solis-Garza, C.B. Edminister, D.G. Neary, L.S. Allen, and R.H. Hambre. *eds.* USDA For. Serv. Gen. Tech. Rep. RM-GTR-289.

Swetnam, T.W., and J.H. Dieterich. 1985. Fire history of ponderosa pine forests in the Gila Wilderness, New Mexico. pp. 390-397 *in* Proceedings-Symposium and Workshop on Wilderness Fire. J.E. Lotan, B.M. Kilgore, W.C. Fischer, and R.W. Mutch. *eds.* USDA For. Serv. Gen. Tech. Rep. INT-182.

USDA-NRCS. 2008. Soil Survey of Slope County, North Dakota. Web Soil Survey. http://websoilsurvey.nrcs.usda.gov/app/ Accessed 14.June.2008

Van Gundy, T.M.A., G.J. Nowacki and T.M. Schuler. 2007. Rule-based mapping of fire-adapted vegetation and fire regimes for the Monongahela National Forest. USDA For. Serv. Gen. Tech. Rep. NRS-12. 24 p.

Van Horne, M.L., and P.Z. Fule. 2006. Comparing methods of reconstructing fire history using fire scars in a southwestern United States ponderosa pine forest. Can. J. For. Res. 36: 855-867.

Voortech. 2004. Measure J2X User's Guide. http://www.voortech.com/projectj2x/docs/userGuide.htm Accessed 14.June.2008

Weaver, H.A. 1951. Fire as an ecological factor in the southwestern ponderosa pine forests. J. For. 49: 93-98.

APPENDIX A. SAMPLE LOCATIONS AND LAND OWNERSHIP FOR ALL SAMPLES COLLECTED

Sample ID	Section	Township	Range	Ownership	Coordinates	
					Latitude	Longitude
JAC 007	31	T136N	R102W	Federal	-103.55054	46.55170
JAC 008	31	T136N	R102W	Federal	-103.55059	46.55173
JAC 009	31	T136N	R102W	Federal	-103.55045	46.55183
JAC 010	31	T136N	R102W	Federal	-103.55094	46.55213
JAC 011	31	T136N	R102W	Federal	-103.55099	46.55221
JAC 013	36	T136N	R103W	State	-103.55135	46.55183
JAC 014	36	T136N	R103W	State	-103.55284	46.55186
JAC 016	36	T136N	R103W	State	-103.55350	46.55395
JAC 018	36	T136N	R103W	State	-103.55235	46.55395
JAC 020	36	T136N	R103W	State	-103.55219	46.55377
JAC 021	36	T136N	R103W	State	-103.55198	46.55361
JAC 023	36	T136N	R103W	State	-103.55150	46.55276
JAC 024	36	T136N	R103W	State	-103.55142	46.55273
JAC 025	36	T136N	R103W	State	-103.55155	46.55173
JAC 027	30	T136N	R103W	Private	-103.54278	46.55551
JAC 031	30	T136N	R103W	Private	-103.54610	46.55665
JAC 032	30	T136N	R103W	Private	-103.54658	46.55669
JAC 033	30	T136N	R103W	Private	-103.54663	46.55668
JAC 034	30	T136N	R103W	Private	-103.54675	46.55675
JAC 035	30	T136N	R103W	Private	-103.54770	46.55702
JAC 036	30	T136N	R103W	Private	-103.54803	46.55723
JAC 037	30	T136N	R103W	Private	-103.54950	46.55700
JAC 038	30	T136N	R103W	Private	-103.54913	46.55679
JAC 039	30	T136N	R103W	Private	-103.54904	46.55636
JAC 040	30	T136N	R103W	Private	-103.54904	46.55636
JAC 043	30	T136N	R103W	Private	-103.54791	46.55613
JAC 044	30	T136N	R103W	Private	-103.54810	46.55859
JAC 045	30	T136N	R103W	Private	-103.54806	46.55865
JAC 046	30	T136N	R103W	Private	-103.54802	46.55869
JAC 048	30	T136N	R103W	Private	-103.54905	46.55838
JAC 049	30	T136N	R103W	Private	-103.54924	46.55914
JAC 050	30	T136N	R103W	Private	-103.54958	46.55859
JAC 051	30	T136N	R103W	Private	-103.55029	46.55836
JAC 054	30	T136N	R103W	Private	-103.55081	46.55887
JAC 055	30	T136N	R103W	Private	-103.55081	46.55895
JAC 059	25	T136N	R103W	Private	-103.55281	46.56082

Sample ID	Section	Township	Range	Ownership	Coordinates	
					Latitude	Longitude
JAC 060	25	T136N	R103W	Private	-103.55291	46.56090
JAC 061	25	T136N	R103W	Private	-103.55288	46.56098
JAC 063	25	T136N	R103W	Private	-103.55311	46.56143
JAC 065	25	T136N	R103W	Private	-103.55365	46.56214
JAC 067	25	T136N	R103W	Private	-103.55454	46.56193
JAC 068	25	T136N	R103W	Private	-103.55458	46.56197
LCR 001	20	T136N	R102W	Private	-103.52265	46.57427
LCR 005	20	T136N	R102W	Private	-103.52393	46.57434
LCR 008	20	T136N	R102W	Private	-103.52404	46.57446
LCR 010	20	T136N	R102W	Private	-103.52319	46.57483
LCR 018	20	T136N	R102W	Private	-103.52170	46.57553
LCR 019	20	T136N	R102W	Private	-103.52322	46.57498
LCR 021	20	T136N	R102W	Private	-103.52372	46.57528
LCR 026	20	T136N	R102W	Private	-103.52502	46.57587
LCR 035	20	T136N	R102W	Private	-103.52496	46.57370
LCR 037	20	T136N	R102W	Private	-103.52493	46.57385
LCR 047	20	T136N	R102W	Private	-103.52152	46.57382
LCR 056	20	T136N	R102W	Private	-103.52715	46.57557
LCR 057	20	T136N	R102W	Private	-103.52696	46.57498
LCR 061	20	T136N	R102W	Private	-103.52626	46.57432
LCR 072	20	T136N	R102W	Private	-103.52627	46.57271
LCR 087	20	T136N	R102W	Private	-103.52953	46.57778
LCR 089	20	T136N	R102W	Private	-103.52804	46.57905
LCR 093	19	T136N	R102W	Private	-103.54545	46.57099
LCR 094	19	T136N	R102W	Private	-103.54541	46.57103
LCR 096	19	T136N	R102W	Private	-103.54312	46.57064
LCR 102	19	T136N	R102W	Private	-103.54154	46.57011
LCR 104	30	T136N	R102W	Private	-103.54209	46.56789
LCR 107	30	T136N	R102W	Private	-103.54275	46.56740
LCR 109	30	T136N	R102W	Private	-103.54383	46.56737
LCR 110	30	T136N	R102W	Private	-103.54407	46.56737
LCR 112	30	T136N	R102W	Private	-103.54446	46.56694
LCR 113	30	T136N	R102W	Private	-103.54449	46.56652
BEK 203	30	T136N	R102W	Private	-103.54452	46.56688
BEK 204	30	T136N	R102W	Private	-103.54654	46.56929
BEK 207	25	T136N	R103W	Private	-103.55112	46.56861
BEK 209	25	T136N	R103W	Private	-103.55097	46.56861

Sample ID	Section	Township	Range	Ownership	Coordinates	
					Latitude	Longitude
BEK 210	25	T136N	R103W	Private	-103.55098	46.56865
BEK 211	25	T136N	R103W	Private	-103.55097	46.56890
BEK 212	25	T136N	R103W	Private	-103.55133	46.56890
BEK 213	25	T136N	R103W	Private	-103.55101	46.56921
BEK 214	25	T136N	R103W	Private	-103.55129	46.56878
BEK 215	25	T136N	R103W	Private	-103.55140	46.56886
BEK 217	25	T136N	R103W	Private	-103.55147	46.56738
BEK 218	25	T136N	R103W	Private	-103.55174	46.56719
BEK 219	25	T136N	R103W	Private	-103.55226	46.56707
BEK 220	25	T136N	R103W	Private	-103.55272	46.56777
BEK 221	25	T136N	R103W	Private	-103.55329	46.56735
BEK 222	25	T136N	R103W	Private	-103.55281	46.56751

APPENDIX B. SAMPLE ATTRIBUTE INFORMATION FOR ALL SAMPLES COLLECTED

Sample ID	Landscape	Aspect	Slope %	Stand Properties
JAC 007	Shoulder	N	8	Open Park
JAC 008	Backslope	NW	15	Open Park
JAC 009	Backslope	NE	50	Open Park
JAC 010	Shoulder	N	10	Open Park
JAC 011	Shoulder	N	40	Open Park
JAC 013	Backslope	W	27	Open Park
JAC 014	Backslope	NE	46	Open Park
JAC 016	Shoulder	SW	30	Open Park
JAC 018	Backslope	NW	65	Open Park
JAC 020	Shoulder	S	15	Open Park
JAC 021	Backslope	SE	35	Open Park
JAC 023	Backslope	NE	45	Open Park
JAC 024	Shoulder	NE	35	Open Park
JAC 025	Backslope	NE	40	Open Park
JAC 027	Footslope	N	40	Open Park
JAC 031	Backslope	NE	44	Dense Park
JAC 032	Shoulder	N	34	Dense Park
JAC 033	Shoulder	N	34	Dense Park
JAC 034	Shoulder	N	35	Dense Park
JAC 035	Shoulder	NE	15	Open Park
JAC 036	Shoulder	N	31	Dense Park
JAC 037	Shoulder	N	8	Dense Park
JAC 038	Backslope	NE	18	Dog Haired
JAC 039	Backslope	N	32	Dog Haired
JAC 040	Backslope	N	32	Dog Haired
JAC 043	Backslope	NE	60	Dog Haired
JAC 044	Backslope	SW	80	Open Park
JAC 045	Backslope	SW	10	Open Park
JAC 046	Backslope	SW	26	Open Park
JAC 048	Crest	E	30	Dense Park
JAC 049	Backslope	E	10	Dense Park
JAC 050	Backslope	S	70	Open Park
JAC 051	Backslope	SE	45	Open Park
JAC 054	Crest	SW	12	Open Park
JAC 055	Shoulder	N	40	Dense Park
JAC 059	Backslope	SE	60	Open Park
JAC 060	Backslope	SE	45	Open Park
JAC 061	Backslope	E	50	Open Park

Sample ID	Landscape	Aspect	Slope %	Stand Properties
JAC 063	Crest	NA	0	Dense Park
JAC 065	Backslope	S	27	Dense Park
JAC 067	Backslope	SW	50	Dog Haired
JAC 068	Backslope	SW	40	Dog Haired
LCR 001	Upland	NW	NA	NA
LCR 005	Crest	SE	NA	NA
LCR 008	Shoulder	NW	NA	NA
LCR 010	Shoulder	W	NA	NA
LCR 018	Crest	NA	NA	NA
LCR 019	Shoulder	W	NA	NA
LCR 021	Crest	NA	NA	NA
LCR 026	Shoulder	W	NA	NA
LCR 035	Backslope	SW	NA	NA
LCR 037	Backslope	W	NA	NA
LCR 047	Upland	NA	NA	NA
LCR 056	Backslope	N	NA	NA
LCR 057	Crest	NE	NA	NA
LCR 061	Crest	NA	NA	NA
LCR 072	Backslope	E	NA	NA
LCR 087	Backslope	NE	NA	NA
LCR 089	Crest	NA	NA	NA
LCR 093	Crest	SW	NA	NA
LCR 094	Crest	SW	NA	NA
LCR 096	Shoulder	SW	NA	NA
LCR 102	Crest	E	NA	NA
LCR 104	Crest	S	NA	NA
LCR 107	Shoulder	NW	NA	NA
LCR 109	Shoulder	NW	NA	NA
LCR 110	Backslope	W	NA	NA
LCR 112	Crest	W	NA	NA
LCR 113	Crest	S	NA	NA
BEK 203	Crest	W	0	Dense_park
BEK 204	Shoulder	E	24	Dense_park
BEK 207	Backslope	NW	18	Dense_park
BEK 209	Backslope	NW	20	Dense_park
BEK 210	Backslope	NW	20	Dense_park
BEK 211	Shoulder	W	22	Dense_park
BEK 212	Shoulder	W	32	Dense_park

Sample ID	Landscape	Aspect	Slope %	Stand Properties
BEK 213	Backslope	E	20	Dense_park
BEK 214	Shoulder	W	10	Dense_park
BEK 215	Backslope	W	20	Dense_park
BEK 217	Shoulder	NW	15	Dense_park
BEK 218	Backslope	N	14	Dense_park
BEK 219	Shoulder	N	14	Dense_park
BEK 220	Shoulder	W	27	Dense_park
BEK 221	Level	NA	2	Dense_park
BEK 222	Backslope	N	17	Dog-haired

APPENDIX C. INDIVIDUAL SAMPLES AND SCAR YEARS

Sample ID	Pith Date	Scar Years
JAC 007	1866	1893, 1902, 2004
JAC 008	1872	1894, 1908, 2004
JAC 009	unknown	1883, 1893, 2004
JAC 010	1870	1952, 2004
JAC 011	unknown	1865, 1893, 1941, 2004
JAC 013	1876	1900, 1903, 2004
JAC 014	1901	1971, 1973, 2004
JAC 016	1949	1955, 1964, 1969, 1977, 2004
JAC 018	1862	1894, 2004
JAC 020	1869	1929, 2004
JAC 021	1870	1880, 1884, 1885, 1888, 1891, 1893, 1896, 1900, 1971, 2004
JAC 023	1876	1896, 2004
JAC 024	1868	1893, 1895, 1902, 2004
JAC 025	1908	1926, 2004
JAC 027	1913	1937, 2004
JAC 028	1914	1931
JAC 031	1741	1772, 1780, 1852, 2004
JAC 032	1739	1852, 1893, 2004
JAC 033	1740	1762, 1852, 1893
JAC 034	unknown	1852, 2004
JAC 035	1761	1852, 1874, 2004
JAC 036	1876	1882, 1884, 1893, 1902, 2004
JAC 037	1736	1852, 2004
JAC 038	1775	1797, 2004
JAC 039	1888	1893, 2004
JAC 040	1869	1889, 1895, 1896, 1902, 1912, 2004
JAC 043	1774	1785, 1791, 1809, 1852, 1879, 2004
JAC 044	1730	1791, 1820, 1862, 1873, 1874, 1882, 1894, 2004
JAC 045	1865	1884, 1888, 1900, 2004
JAC 046	1870	1892, 2004
JAC 048	1904	1978, 2004
JAC 049	1865	1889, 1900, 1968, 2004
JAC 050	1894	1998, 2004
JAC 051	1771	1870, 1878, 2004
JAC 054	unknown	1798, 1824, 1873, 1882, 1895, 1900, 1964, 1973, 2004
JAC 055	unknown	1892, 2004
JAC 059	1862	1887, 1895, 2004
JAC 060	1789	1855, 1870, 2004

Sample ID	Pith Date	Scar Years
JAC 061	1856	1870, 1893, 2004
JAC 063	1893	1992, 2004
JAC 065	1871	1887, 1889, 1895, 1908, 2004
JAC 067	1691	1712, 1938, 1964, 2004
JAC 068	1916	1952, 2004
JAC 083	1684	1724, 1731, 2004
LCR 001	1876	1882, 1884, 2004
LCR 005	1865	1887, 1892, 1893, 2004
LCR 008	1738	1882, 2004
LCR 009	1739	1882
LCR 010	1874	1887, 1894, 2004
LCR 018	1784	1808, 1811, 1870, 1874, 1882, 2004
LCR 019	1682	1690, 2004
LCR 021	1761	1880, 2004
LCR 026	1574	1595, 1868, 2004
LCR 035	unknown	1900, 1926, 1931, 2004
LCR 037	1873	1900, 1930, 2004
LCR 047	1934	1945, 2004
LCR 056	1682	1882, 2004
LCR 057	1872	1878, 1882, 2004
LCR 061	1782	1808, 1862, 1882, 1967, 2004
LCR 072	unknown	1947, 2004
LCR 087	1866	1882, 2004
LCR 089	1744	1752, 1759, 1905, 2004
LCR 093	1694	1729, 2004
LCR 094	unknown	1729, 1730, 1732, 1735, 1740, 2004
LCR 096	1868	1874, 1895, 1902, 1908, 2004
LCR 102	1862	1879, 1882, 2004
LCR 104	1856	1882, 1893, 2004
LCR 107	1765	1848
LCR 109	1750	1847, 2004
LCR 110	unknown	1893, 2004
LCR 112	1570	1691, 2004
LCR 113	1772	1862
BEK 203	1745	1748, 1760, 2004
BEK 204	unknown	1882, 2004
BEK 207	1894	1904
BEK 209	1876	1882, 1893

Sample ID	Pith Date	Scar Years
BEK 210	1865	1904
BEK 211	1855	1887, 1894
BEK 212	1855	1929, 2004
BEK 213	1869	1876, 1893, 1897, 1902, 1904, 1917, 1931, 2004
BEK 214	1889	1902
BEK 215	1910	1926, 1957, 2004
BEK 217	1917	1936, 2004
BEK 218	1918	1931, 2004
BEK 219	1901	1906, 1929, 1959, 2004
BEK 220	1861	1884, 2004
BEK 221	1914	1918, 1931, 1937, 1952, 1971, 2004
BEK 222	1902	1924, 1930, 1936, 2004

APPENDIX D. ORIGIN-TO-SCAR (OS) INFORMATION FOR METHOD 2

Sample ID	Pith Date	Fire Scar	OS Years	OS Distance (mm)	First Scar Width (mm)	Circumference Damaged
JAC 007	1866	1893	27	155	160	20%
JAC 013	1876	1900	24	45	76	37%
JAC 021	1870	1893	23	41	36	16%
JAC 024	1868	1893	25	129	80	11%
JAC 031	1741	1852	111	166	146	16%
JAC 032	1739	1852	113	105	131	25%
JAC 033	1740	1852	112	96	105	21%
JAC 035	1761	1852	91	456	166	6%
JAC 036	1876	1882	6	60	9	2%
JAC 037	1736	1852	116	127	254	47%
JAC 039	1888	1893	5	44	50	22%
JAC 040	1869	1895	26	53	31	10%
JAC 043	1774	1852	78	128	142	21%
JAC 044	1730	1862	132	82	190	58%
JAC 045	1865	1900	35	92	81	16%
JAC 049	1865	1900	35	82	94	22%
JAC 059	1862	1895	33	89	154	38%
JAC 061	1856	1893	37	44	43	18%
JAC 065	1871	1895	24	78	64	15%
LCR 001	1876	1882	6	12	20	36%
LCR 005	1865	1893	28	62	58	18%
LCR 008	1738	1882	144	92	184	47%
LCR 009	1739	1882	143	87	174	47%
LCR 018	1784	1882	98	85	19	4%
LCR 037	1873	1900	27	69	38	10%
LCR 056	1682	1882	200	322	230	13%
LCR 057	1872	1882	10	34	32	18%
LCR 061	1782	1862	80	54	57	20%
LCR 087	1866	1882	16	48	9	3%
LCR 093	1694	1729	35	89	44	9%
LCR 102	1862	1882	20	63	131	50%
LCR 104	1856	1882	26	15	46	95%
LCR 112	1570	1729	159	127	26	3%
LCR 113	1772	1862	90	55	72	26%
BEK 209	1876	1882	6	92	84	17%
BEK 213	1869	1893	24	42	40	18%
BEK 214	1889	1902	13	33	36	21%

APPENDIX E. FIRE YEARS AFTER VISUAL ANALYSIS HAD REMOVED THOSE SCARS NOT APPEARING TO BE CAUSED BY FIRE

Sample ID	Pith Date	Scar Years
JAC 007	1866	1893, 1902
JAC 011	unknown	1893
JAC 013	1876	1900
JAC 018	1862	1894
JAC 024	1868	1893
JAC 031	1741	1852
JAC 033	1740	1852
JAC 036	1876	1893
JAC 040	1869	1902
JAC 040	1869	1889
JAC 043	1774	1852
JAC 045	1865	1900
JAC 045	1865	1888
JAC 046	1870	1892
JAC 049	1865	1889
JAC 051	1771	1878
JAC 051	1771	1870
JAC 054	unknown	1900
JAC 054	unknown	1873
JAC 059	1862	1887
JAC 060	1789	1870
JAC 065	1871	1887
LCR 005	1865	1893
LCR 008	1738	1882
LCR 021	1761	1880
LCR 036	1873	1900
LCR 056	1682	1882
LCR 072	unknown	1947
LCR 104	1856	1893
BEK 209	1876	1893
BEK 211	1855	1894
BEK 213	1869	1893
BEK 222	1902	1924

APPENDIX F. TREE-RING WIDTHS FOR THE 10 YEARS SURROUNDING THE 1882 FIRE EVENT

Year	Samples										
	LCR 018	LCR 104	LCR 087	LCR 057	LCR 009	BEK 209	LCR 061	LCR 056	BEK 204	LCR 008	LCR 102
1872	362	439	1380	1222	263	994	375	246	336	256	565
1873	858	374	2369	1231	147	1359	770	336	927	568	1007
1874	503	216	1340	378	216	960	563	90	673	272	880
1875	524	71	818	309	173	693	848	233	1642	132	847
1876	1152	296	1474	1857	367	1046	1017	410	2378	488	2272
1877	1888	527	2227	2291	541	1439	1133	401	2277	991	3453
1878	4791	557	2161	2011	856	1635	1365	469	3795	1052	3404
1879	5209	905	1190	3762	1181	2315	1494	669	5109	1746	3599
1880	1775	1226	1373	4178	1287	2239	1103	314	2920	2273	3014
1881	2658	1284	3310	3305	2351	2292	1475	510	2105	2265	3040
1882	4031	2085	4571	3536	2809	2861	1609	705	2621	2896	3713
1883	2391	2452	1301	3699	1893	3722	1386	752	2940	2576	3582
1884	3098	3218	1016	2222	1805	3379	1731	797	5390	3124	4387
1885	3443	3881	1328	1868	1548	2936	1598	643	6027	2302	3278
1886	827	2083	502	1710	610	1536	1020	492	2744	1809	1744
1887	927	1280	1025	1788	489	1150	1016	773	1627	1056	537
1888	1800	1089	1977	1688	775	1007	1543	958	4397	1617	883
1889	1154	1206	2188	1431	618	2528	946	434	4667	1088	1142
1890	1281	2143	4095	623	901	1706	823	598	2674	1882	1467
1891	2081	1940	2508	1280	2725	1925	1641	1121	3944	3008	3105
1892	3289	1809	2718	1121	1797	1786	1007	713	3001	2315	2940

Ring-widths measured in micrometers (μm).