Fire Return Interval Within the Northern Boundary of the Larch Forest

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Introduction

Larch (*Larix spp*.) dominant forests compose a large proportion of the forests of Russia (i.e., about 40% of forested areas). These forests range from the Yenisei ridge on the west to the Pacific Ocean on the east, and from Lake Baikal on the south to the 73rd parallel in the north. Larch stands comprise the world’s northern most forest at Ary-Mas (72º28´ N, 102° 15´ E). Larch dominated forests occupy about 70% of the permafrost areas in Siberia. Larch forms high closure stands as well as open forests, and is found mainly over permafrost, where other tree species barely survive. Wildfires are typical for this territory with the majority occurring as ground fires due to low crown closure. Due to the thin active layer in permafrost soils and a dense lichen-moss cover, ground fires may cause stand mortality. The vast areas of larch-dominant forests is generally considered as a “carbon sink" (Schimel et al., 2001); however, positive long-term temperature trends at higher latitudes (IPCC, 2007) are expected to result in an increase of fire frequency, and thus may convert this area to a source for greenhouse gases. There are recent observations regarding the increase of fire frequency within non-protected territories (e.g., Gillett et al. 2004; Kharuk, et al. 2008; Girardin et al. 2009). Surprisingly, there are few publications on fire chronoseqences for the huge forested territory between the Ural Mountains and the Pacific Ocean (Swetnam, 1996; Vaganov and Arbatskaya, 1996; Kharuk et al, 2005, 2007, 2008). Also there is a general understanding that bimodal (late spring – early summer and late summer-beginning of fall) fire seasonal distribution in the south becomes uni-modal (late spring – early summer) in the north (Korovin, 1996).

The purpose of this study is to investigate the wildfire history at the northern edge of the zone of larch dominance.

Study area

The study area is located within the Anabar plateau, a northeastern part of the Central Siberian plateau (Fig. 1). The topography is gently sloping with elevations of up to 900 m. The climate is strongly continental, approximating an arctic climate, with a long winter and a short, cold and rainy summer. Frequent and extreme weather changes are typical. The period with negative temperatures is about 250 days (with a mean temperature about - 18°C, and minimum about -57°C). Mean temperature of the frost-free period is about +8°C with maximum temperature of about +30°C. Winds are more frequent in spring and winter, with usual speeds ranging between 4.5 - 15 m/sec, occasionally reaching 45 m/sec. The study area is underlain by permafrost.

The forests are composed of larch (*Larix gmelii*) with lichen and moss as a typical ground cover. Bushes are represented by *Betula nana*, *Salix* sp, *Ribes* sp, *Rosa* sp, *Juniperus* sp, *Vaccinium* sp, and *Ledum palustre (*Labrador tea). Southern-facing terraces are partly occupied by forests with grass on-ground cover and grass communities. Watersheds with an elevation of 500–600 m are occupied by stony tundra. Data on wildfire frequency within the study area are lacking.

Materials and method

Temporary test sites were established along the Kotuykan and Kotuy rivers because the these rivers provided the best logistical access to those remote areas (Fig. 1). There are no roads in this area. Trees with burn marks were sampled within a maximum distance of 3 km from the rivers and within the elevation range from ~100 m (at the river banks) up to ~ 350 m which is the approximate upper tree limit. Disks for analysis were cut at the root neck level. The total number of sample sites was 13 and the number of trees with fire scars sampled was 25. The sample size was limited due to low fire frequency within the study area.

The tree ring width was measured with 0.01 mm precision using a linear table instrument (i.e., LINTAB-III). Some samples contained very thin tree rings with widths of only two cells, and this complicated the measurements. Due to the harsh growth conditions even some very old trees (400-700 year old) had a diameter of only 13-15 cm (Fig. 2). In some cases burn marks were masked by regenerated wood tissues and bark, but could be detected on the cross-section of the tree. Within the upper tree limit area winter dissection and snow abrasion caused damage to the tree stems which appeared similar to fire damage. In fact, such marks were typical for trees at the upper elevational limit. Weather and “burn” damage to boles were differentiated based on charcoal microscopy detection - burn marks contained charcoal and winter damage did not. The fire dates were determined based on the master chronology method described by Fritts (1991). The master chronology for the study area was based on the material sampled within the study area (Naurzbaev et al., 2004). The COFECHA (Holmes, 1983) and TSAP (Rinn, 1996) computer programs were used to detect double counted and missing rings.

FRI is routinely determined by tree ring counting between consecutive fire scars: $D_i - D_{i-1}$, where D_i, D_{i-1} - dates of i and $i-1$ fires. In our case this approach doesn’t work because fires are very rare events within the study area. Consequently the majority of the samples have only one fire burn mark (Fig. 3). To overcome this limitation the data of tree natality was also used in the analysis. It is known that the majority of fires within larch-dominated communities are stand-replacing, which promotes the formation of even-age stands. Typically, freshly burned areas are quickly covered by dense regeneration (up to 700 thousands stem/ha; Kharuk et al, 2008), because ground fires (which are by far the most common in northern forests) do not usually damage cones. Thus, even fire-killed stands can be a seed source. Moreover, cones of the previous 2-3 years are still viable seeds source (Sofronov et al, 1999). Fresh burns with mineralized soil are favorable for the establishment of seedlings. Over time, increasing moss and lichen pillows retarding larch regeneration (Kharuk et al, 2008). Consequently, the date of post-fire tree natality can be considered as an approximation of the date of the fire. This approximation entails errors due to the 0 - 5 years lag of the post-fire tree establishment (Sofronov, private communication). The natality date also has to be adjusted to the “stump age”, i. e., the difference of tree natality date and tree age determined at the sampled stump height. Even if tree was cut at the root neck level the difference can be 2-5 yr. To be conservative, it can be assumed that the approximations outlined above caused an error of about 15 in fire date; this value was used for the FRI value adjustment. Since the mean FRI value within the study area was about 300 yr (see below), the resulting error was about 5%. Thus, FRI was calculated based on stem burns and the dates of trees natality. Data on the FRI were calculated for each test site (Fig. 1) separately and the mean FRI value was averaged throughout all sites.

Results and discussion

Fire chronology data are presented in Fig. 3. The mean FRI within the study area was about 320 ±50 yr (Table). This value is about twice the reported FRI for boreal conifer forests (60-150 years: Payette, 1992; Swetnam, 1996, Sannikov, Goldammer 1996; Vaganov, Arbatskaya, 1996; Larsen, 1997; Kharuk et al, 2008; Niklasson and Granstrom, 2000). Very long FRI (up to 300 yr) were reported for northern European, southern Canada and western US fire-protected forests (Niklasson and Granstrom, 2000; Weir et al, 2000; Heyerdahl et al., 2001; Buechling and Baker, 2004; Bergeron et al. 2004). Within the study area, as well as within the majority of Siberian larch forests, fires are not suppressed. The forests studied are pristine with a minimal anthropogenic impact. Published data indicates that in the northeast Siberian taiga about 90% of fires were caused by lightning (Ivanova and Ivanov, 2004; Kovacs et al., 2004). This proportion is more likely to be nearly 100% at the northern edge of larch forests. Even though, lightning frequency decreases northward, lightning strikes on permafrost are approximately twice as likely to ignite a fire. This is attributed to the large energy release from lightning due to the abrupt conductivity change in the boundary-between the thawed soil and permafrost (Sapozhnikov and Krechetov, 1982). On the other hand, topography could decrease lightning-caused fire ignition because lightning strikes increase as elevation increases. A study by Sapozhnikov and Krechetov, 1982, showed that 200 m increase in elevation increased lightning strike incidence by a factor of 3 to 4. Since the upper forest limit is about 350 m (and summit heights of about 400-600 m), lightning should primarily strike non-forested (tundra) areas. Along with the causes described an important reason for the long FRI is low incoming solar radiation at high latitudes. This low solar radiation is hardly sufficient to dry fuel material, such as moss and lichen cover and woody debris, thus decreasing fire hazard. At lower latitudes and higher zenith angles FRI decreased to about 200 yr at Polar Circle latitude (Kharuk et al, in press), and to 80-90 yr at 60° - 64°NL (Vaganov, Arbatskaya, 1996; Kharuk et al, 2008).

The advanced age of some sampled trees (500 - 700 yr) allows estimation of the fire history within the study area back to the beginning (16th century) of the Little Ice Age Period Dendrochronology data showed that cooling during this time caused depression in the annual growth of tree rings (Fig. 3). Comparing data from fires occurred in the 17th and 18th centuries (6 fires) with fire data covering the 19th and 20th centuries (14 fires) showed an increase of approximately double the fires in the last two centuries (Fig. 2). This agrees with the hypothesis that the observed climatic warming will result in increase in fire frequency (Gillett et al, 2004; Kharuk, et al, 2008; Girardin et al, 2009).

Low fire frequency is not favorable for larch forests, because larch is a pyrophytic species (Kurbatsky, 1962) and as such fires promote the establishment of larch regeneration. The main constraint on larch growth is permafrost thawing depth and soil water drainage. Depth of seasonal thawing is dependent on exposure, moss-and-lichen layer thickness, and fire history. Fires not only increase with permafrost thawing depth but, which also very importantly, increase with soil drainage. With time, an increase of a thermal insulator layer composed of the surface moss and lichen cover caused expansion of the permafrost layer toward the surface, and compressing the active root zone within a decreasing (30 cm and less) layer.

Finally, information on the fire events may potentially be contained in the radial growth ring dynamics (i.e., acceleration of interannual tree ring width; Fig. 2). We suggest that dates of growth acceleration may also indicate light and medium (i.e., not stand-replacing) fires. Regularly these accelerations were considered as climate - driven (e.g., Shiyatov, 2003). Also the growth accelerations could be fire-induced. It is known that fresh burns provide better temperature for growth, enriched soil nutrients, increased soil thawing depth and improved drainage, and decreased competition between and within species. The fire-induced origin of that acceleration is supported by the fact that in some cases the date of accelerations coincides with the burn marks on the trees from the same test site (Fig. 3). Limited sample size doesn't allow to proof of this hypothesis, and it will be checked in further investigations.

In conclusion, FRI within larch-dominated forest communities are increasing northward, reaching about 320 ±50 yr within the northern boundary of larch forests. Cooling during the Little Ice Age period resulted in a 50% decrease in the number of fires in the larch forest studied.

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Figure legends

Fig. 1. Sketch-map of the study sites location.

Insert: site numbers are noted on a Landsat scene background.

Insert. A typical burn mark on a larch stem.

Fig. 2. Larch trunk sample with a burnmark on the cross-section.

Insert: microphotography of the fire event zone with visible fire-induced tree ring width increase.

Figure 3. Dates of tree natality (light bars), fire events (heavy bars), and radial growth acceleration (diamonds) as observed on tree cross sections. Test site numbers (1-13, Fig. 1) and number of samples at each location are shown at right of graph. The vertical lines along the abscissa denote all fire occurrences.

Figure 4. Individual (gray lines) and mean (dense solid line) radial increment data of sampled trees (N=25), and northern Siberia reconstructed air temperatures deviations ((thin solid line; (Briffa, 2000)).

Figures

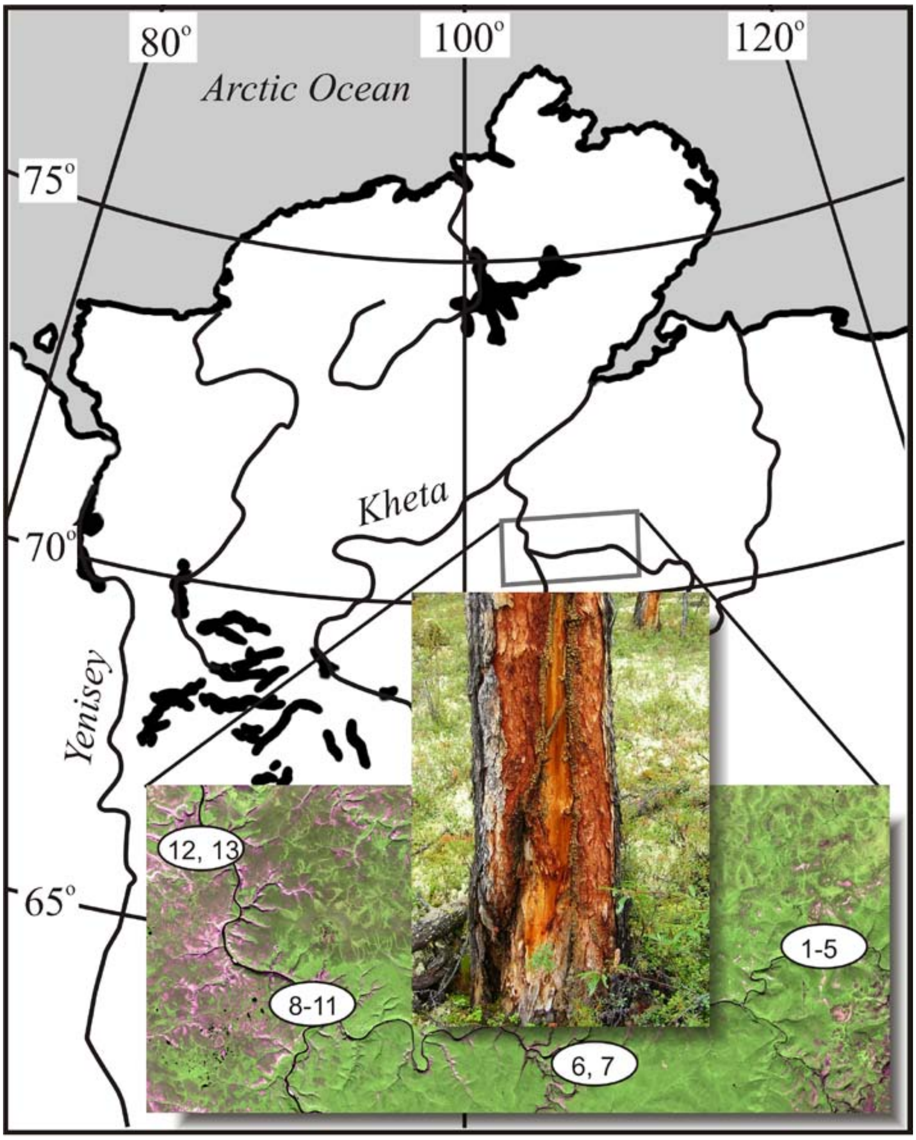


Figure 1

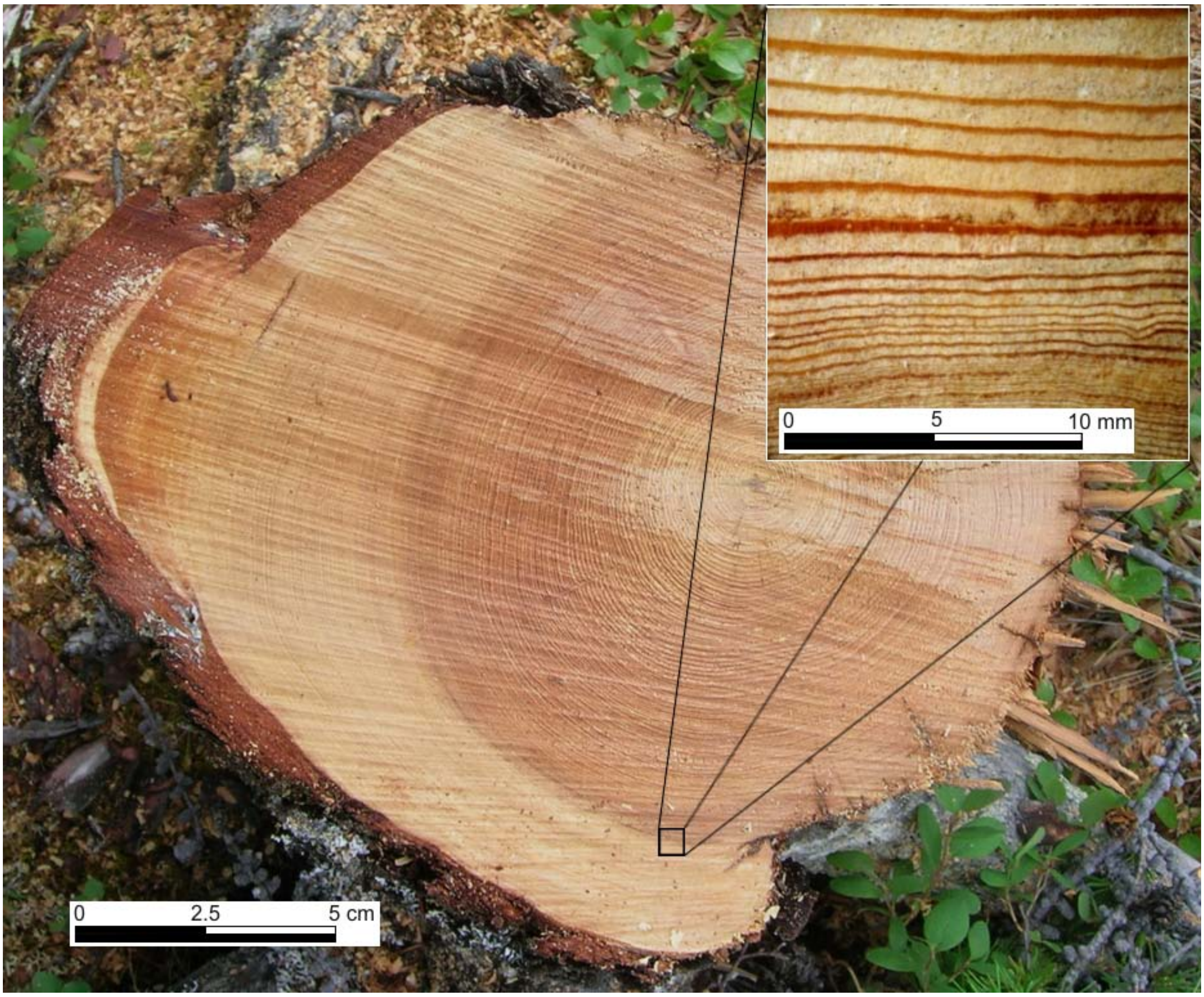


Figure 2

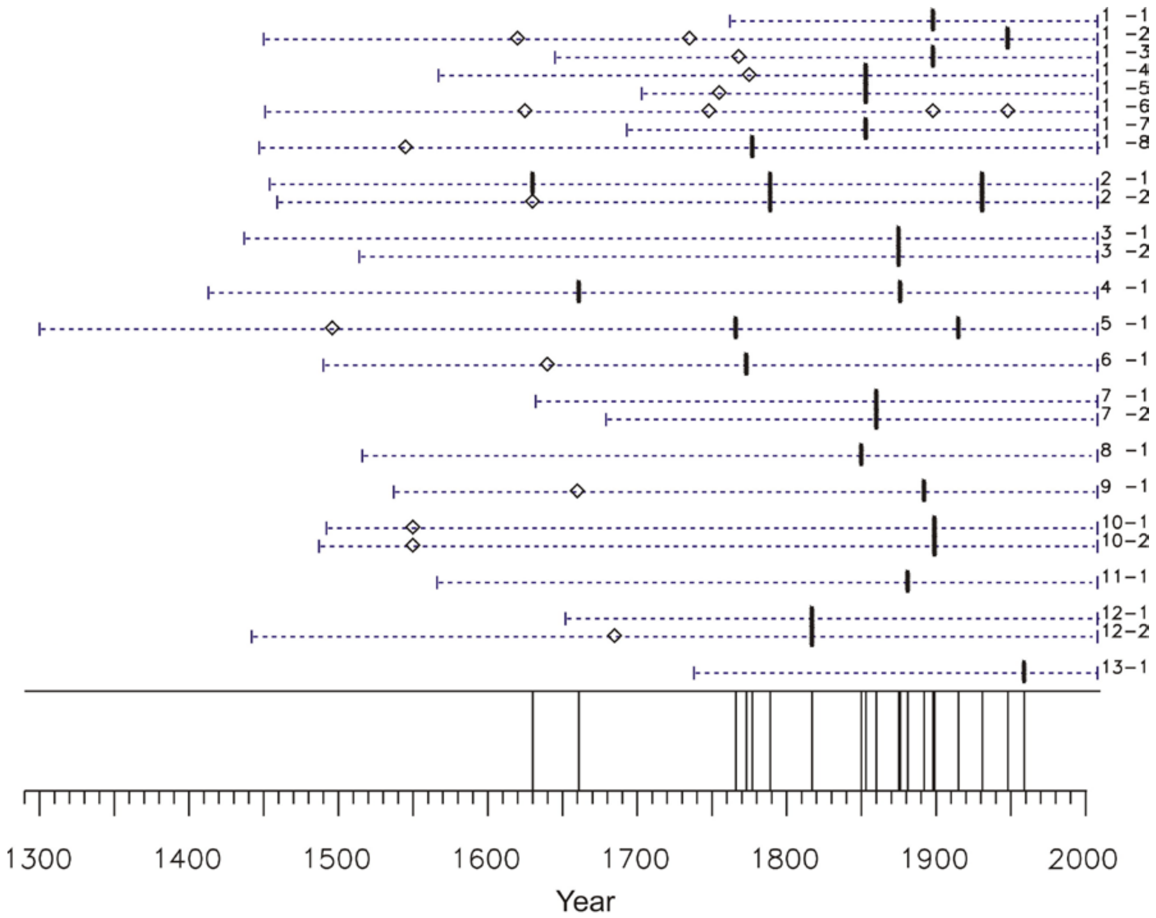
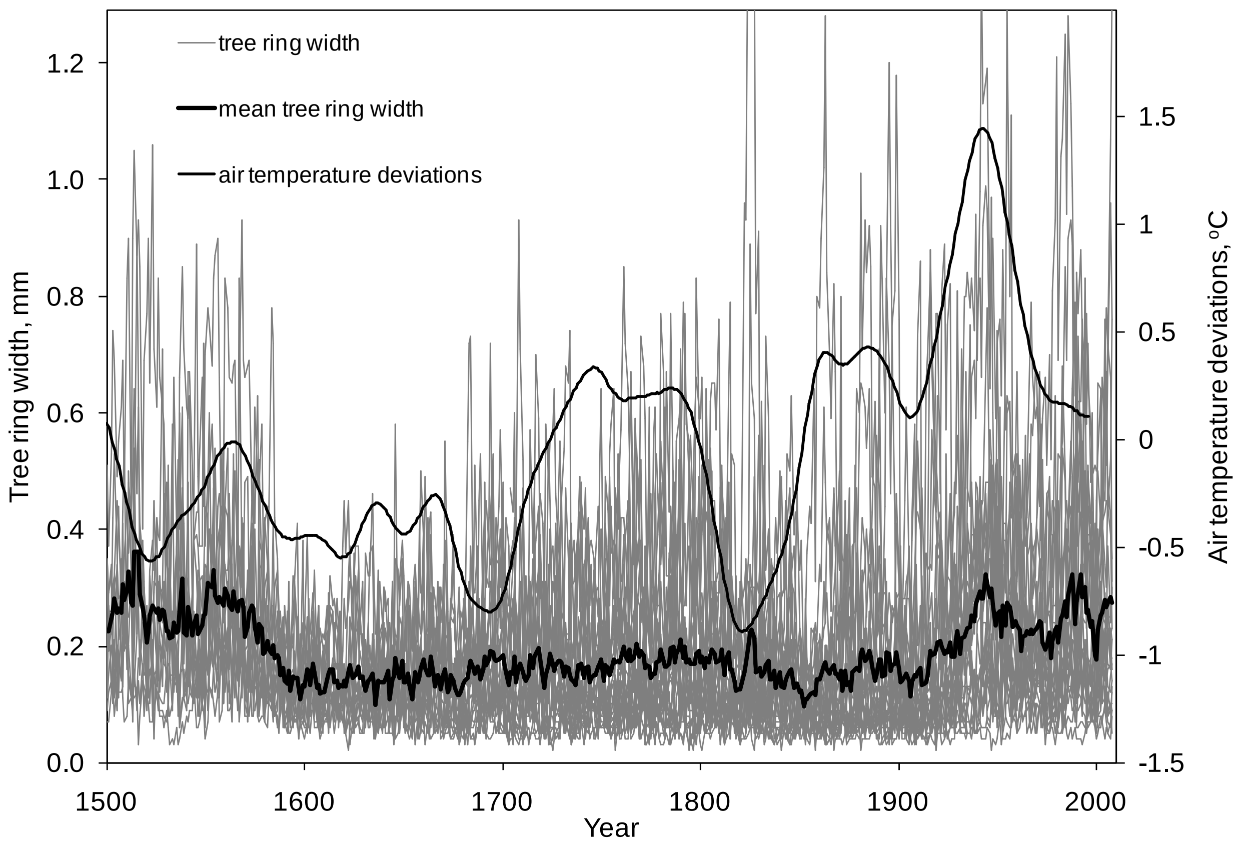

1 −1
1 −2
1 −3
1 −4
1 −5
1 −6
1 −7
1 −8
2 −1
2 −2
3 −1
3 −2
4 −1
5 −1
6 −1
7 −1
7 −2
8 −1
9 −1
10−1
10−2
11−1
12−1
12−2
13−1
1300
1400
1500
1600
1700
1800
1900
2000
Year

Figure 3



tree ring width
mean tree ring width
air temperature deviations
Tree ring width, mm
Air temperature deviations, °C
Year
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1.5
1
0.5
0
-0.5
-1
-1.5
1500
1600
1700
1800
1900
2000

Figure 4

Table. Fire return intervals measured at each sample site. The mean is over 300 years in this area.

Site number	FRI, yr
1	258
2	253
3	400
4	248
5	466
6	283
7	205
8	334
9	355
10	410
11	315
12	270
13	221
Mean FRI	309 ±43 ($p>0.05$)
Adjusted mean FRI	318 ±48 ($p>0.05$)