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The first forest fire history of the Burabai Region (Kazakhstan) from tree rings of *Pinus sylvestris*

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Abstract: Forest fires are one of the most important events causing an abrupt decrease in tree-ring width. Although humans are the main cause of forest fires, extreme weather or climate change may promote the frequency and severity of fires. The purpose of this study is to reconstruct historical fires in the Burabai Region of Kazakhstan including their frequency and seasons. Five tree cross-sections with fire scars were collected from two different sites, Akylbai and Burabai. After sanding the transversal surfaces of the cross-sections, the year and season of fire scars were determined. We identified 15 fires during the last 300 years in the region. The mean fire interval is 27 years, with minimum and maximum fire intervals of 9 and 53 years, respectively. The seasonally determined fire scars generally occurred during the middle earlywood formation (77%), and less in early earlywood (22%). Three site chronologies of *Pinus sylvestris* L. were also used to find the effect and extent of the fires. The negative effect of fires on tree growth lasted 1 to 8 years after the fire. Four of the fire scars had long-term negative effects (up to 10 years) on tree growth in the years of 1759, 1779, 1871, and 1952. Fires of 1759, 1797, 1824, 1833, 1852, and 1871 are seen in both sites, suggesting that these fires spread over large areas.

Key words: Burabai region, dendrochronology, forest fire, fire scar, fire regime, tree ring, Kazakhstan

1. Introduction

Forest fires are one of the most important natural or anthropogenic events for grazing and forestry in dry lands. Extreme weather or climate change, usually characterized by hot and dry summers, is associated with high levels of forest fires. Another important issue is strong summer winds causing fires to spread at high speeds. Bassi and Kettunen (2008) stated that research on climate change indicated that increased fire hazards were likely to arise from global warming. Moreover, a combination of livestock grazing, fire exclusion, and logging disturbances has resulted in increases in tree density, canopy closure, vertical diversity, aerial fuel continuity, and surface fuel loads (Covington and Moore, 1994). As a consequence of these events and increasing human impact, the history of fire within a region and how these fires impact forests has become important information.

Tree rings are one of the most comprehensive tools to find the years of past wildfires, their frequency, and their areas (Swetnam and Dieterich, 1983). In recent decades, fire events, their statistics, and magnitudes have been recorded throughout the world. Using tree rings the histories of many fires were determined in some dry lands in the United States and Europe (e.g., McBride, 1983; Swetnam and Dieterich, 1983; Swetnam, 1993; Baisan and Swetnam, 1996; Grissino-Mayer, 2001; Heyerdahl et al., 2002; Niklasson and Drakenberg, 2001; Lombardo et al. 2009; Falk et al., 2010, 2011), and in Mongolia (e.g., Swetnam, 1996; Hessl et al., 2011; Saladyga et al., 2013; Hessl et al., 2016). Natural forest fires are generally related to dry periods (e.g., Bachelet et al., 2000; Flannigan, 2000; Taylor and Skinner, 2003; Brown and Wu, 2005; Wessterling et al., 2006) and grazing (e.g., Madany and West, 1981; Belsky and Blumenthal, 1997). The frequency of fires increases in dry years or dry periods in general and decreases in high grazing periods (e.g., Savage and Swetnam, 1990; Belsky and Blumenthal, 1997; Bachelot et al., 2000).

However, forest fires in past centuries are not well known in many parts of the world. For example, a fire history is lacking in the Burabai Region of Kazakhstan, which is a relatively dry region. On the other hand, several tree ring-based studies were performed in areas around

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Kazakhstan, such as Mongolia and Siberia. Hessl et al. (2012) revealed that grazing may have had an important effect on past fire regimes in Mongolia, which is covered by a large area of semiarid forest with a grass understory. Hessl et al. (2016) found limited fire activity in recent decades due to the combined effect of drought and intensive grazing, while more historical fires and higher fire frequencies were detected from tree rings before 1900 in Mongolia. Temperatures, which are among the most important factors for fires, are increasing in the region and reached the highest values in the 20th century (D'Arrigo et al., 2001; Davi et al., 2015). Swetnam (1996) emphasized the increasing effect of people as a source of fire in central Siberia. In central Siberia the warmer and drier climate characteristics that currently typify southern Siberia are responsible for high fire frequency and large areas burned in this region. Area burned has increased over the past few decades, largely due to climate change (Ivanova et al., 2010).

Although comprehensive studies provided fire history information in neighboring areas, information on historical fires in Kazakhstan is lacking. In this study, we performed tree-ring analysis on cross-sections obtained from the Burabai Region to present the first long-term fire history of Kazakhstan. In the region, fire records only started being kept in recent decades (personal communication: Burabai Forest Service). Therefore, knowing the fire history in this area will be significant to provide information for forestry planning, recreational planning, and governmental decisions.

In the Burabai Region, the primary tree species are *Pinus sylvestris* and *Betula verrucosa* Ehrh., and these species are also used in afforestation. Fire risk is higher in pine forest types such as very dry stony or rocky pine forests, dry stony lichen–pine forests, and dry cereals–berry pine forests. The fire season begins in the middle of April and continues to the end of October, and the main ignition source of forest fires is human activity. The causes of recent forest fires, which have a major impact on the forest economy, was explained as 99.5% human and 0.5% lightning (Arkhipov et al., 2000).

During field work for dendroclimatology studies in the Burabai Region, we found some living and dead trees with 2–6 fire scars that could be used to reconstruct fire history patterns. The purpose of the study is to reconstruct the first fire history of the Burabai Region based on cross-sections and tree-ring chronologies of *Pinus sylvestris*, to study the effect of fires on tree-ring width, and to investigate the relationships between fires and climate.

1.1. Study area

Kazakhstan, which is a large country, covers a total of 2.7×10^6 km^2 in central Asia. The total area of forest land in Kazakhstan is 12.5×10^6 ha (4.6% of the total land area of the country). About 70% of the forest growth is composed of *Haloxylon* and mallee scrubs of the desert zone, and the other 30% is conifer and broad-leaved forests. Approximately 80% of the conifer forests are in the northern and northeastern parts of the country (Sultangazina and Petrova, 2015). Forest lands of Kazakhstan are under serious fire risks. Coniferous forests are considered to have the highest fire risk. Fire type is generally surface fires during the fire season (Figure 1) (Arkhipov et al., 2000).

The study area, the Burabai Region, which is one of the Natural National Parks of Kazakhstan, is located in the north of central Kazakhstan (called the Akmola Region) and covers an area of 129,000 ha including forests, lakes, and villages (Figure 2). The area is situated in forest steppe, where *Pinus sylvestris* and mixed forests are combined with steppe meadows and meadow steppes (Figure 2). *Pinus sylvestris* covers a large forest area in the region. Most parts of the region have pure *P. sylvestris* forests, while it forms mixed forests with *Betula pendula*, *B. verrucosa*, and *Populus tremula* in other parts of the region. These four species are the dominant forest tree species in the region (Petrova and Sultangazina, 2015).

The climate is continental with long cold winters and short hot summers. The average annual temperature for the period between 1950 and 2014 (65 years) was 1 °C. The average low temperature in January is –16.7 °C and the average high is in July at 18.6 °C. Absolute minimum temperature is –52 °C and the absolute maximum is 42 °C. The frostless period is between 100 and 125 days, and the frost season starts in early autumn. Annual rainfall for the period of 1950–2014 was about 300 mm, reaching it maximum during the summer (https://climexp.knmi.nl) (Figure 3). Snow cover is established from October to April.

2. Materials and methods

We had limited permission to take wood samples with fire scars from dead trees. Therefore, we could only collect five cross-sections from dead trees with a chainsaw. Each cross-section includes at least three fire scars. The samples were coded as ATF01, ATF02, ATF03, BUF01, and BUF02 (Figure 2).

In addition to five cross-sections, we also analyzed 176 increment cores from 100 trees at three different sites (AKT, AKP, and BUR) in the region. These cores were taken during

Figure 1. Fire risk areas and forest types in Kazakhstan (Arkhipov et al., 2000). Arrow shows the sampling area. Fire risks were grouped from 1 to 5: 1) very high, 2) high, 3) medium, 4) low, and 5) very low. Because the conifer forests are considered as number 1, which means having very high risk, our sampling area is under very high fire risk.

the studies of the second author's doctorate thesis, and three site chronologies were built for dendroclimatological research. We used these chronologies to cross-date dead trees and find the exact dates of fire scars. In addition, the chronologies were used to evaluate the relative extent of each historic fire.

Figure 2. Locations of cross-sections (red) and three site chronologies (green) in the Burabai Region. Three of them are from Akylbai Mountain (ATF) and two of them are from Burabai (BUF).

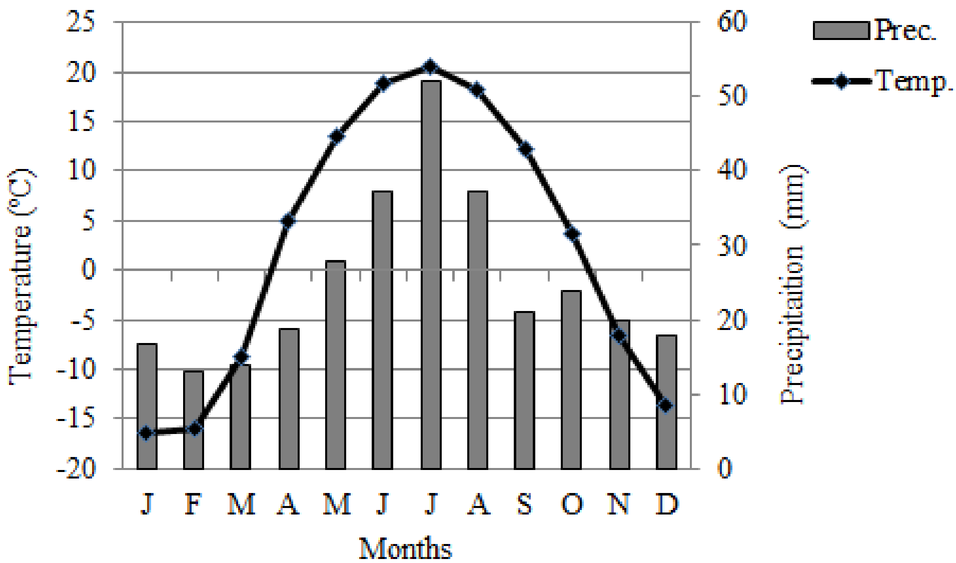

Figure 3. Climate diagram of the region. Annual precipitation is about 300 mm and about half of this amount falls in summer. These values are averages of the records covering the years 1950–2014.

The AKT site chronology covers the period between 1699 and 2016 based on 37/20 cores/trees. The AKP site covers the period between 1859 and 2014 based on 58/29 cores/trees, and the BUR site covers the years between 1797 and 2015 and was built from 48/27 cores/trees.

In the first step of analysis, transversal surfaces of the five cross-sections were sanded to see tree rings clearly (Figure 4). Measurements of ring widths were then performed using the LINTAB-TSAP-Win measuring system (Rinntech, Germany).

Figure 4. The cross-sections studied. These entire cross-sections were cut from dead trees at two different sites, called Akylbai and Burabai.

In the second step, we dated the 5 cross-sections using the AKP, AKT, and BUR site chronologies from the same region (Figure 2) and recorded the calendar years of the rings on the discs. The years of observed fire scars were then determined using the Leica binocular microscope of the LINTAB-TSAP-Win measuring system.

Forest fires cause an abrupt growth depression, which can be correlated with fire scars detected from tree rings in the same stand (Niklasson et al., 2010). We combined the fire scars with the site chronologies having growth depressions in the same years. On the cross-sections, the years of the fire scars were found clearly in general and all fire scar years were recorded and analyzed using the FHAES program (http://www.fhaes.org). Ivanova et al. (2010) used samples from the same forest to a distance of 10 km to build a composite fire chronology. We combined 5 cross-sections into one site because two sites (BUF and ATF) are only 8 km away from each other. A fire year was defined only when a fire scar was indicated by at least two trees (Fule et al., 2003). The mean, minimum, and maximum fire intervals and the fire index, which is the percentage of scarred trees of the total number of analyzed trees in a certain fire year, were determined. A fire card (Grissino-Mayer et al., 2001; Niklasson et al., 2010) was created showing the fires on the five cross-sections.

The intraannual place of a scar provides information about the season of a fire (Baisan and Swetnam, 1990). We determined the position of the fire scars within the annual rings based on the seasonal categories described by Baisan and Swetnam (1990) as early earlywood and middle earlywood, and seasons of some fires could not be determined.

The approximate area of the fires and their duration of negative growth effects were studied based on these five cross-sections from two sites and three site chronologies from the Burabai Region. Duration of sudden growth depressions were studied for both the fire years obtained from five cross-sections and the three site chronologies, which were AKP, AKT, and BUR. To find the duration of negative effects of fires we also calculated z-scores of the regional chronology built from these tree sites.

3. Results and discussion

3.1. Detection of fire years

Of the five samples collected, ATF01 and ATF03 had bark, which dated to 1997 and 2015, respectively. The last visible outer ring of the remaining samples without bark dated to 1950, 1977, and 1937 respectively. Tree rings of the five cross-sections covered three centuries, from the 18th to 20th. The oldest tree is ATF01, which dates back to 1699. The youngest one is BUF01, dating back to 1800.

The fire card based on dated fire scars samples (Figure 5) showed 13 fire scar years in the region. The number of fire scars per cross-section ranged from 3 (BUF01) to 11 (ATF01). The fires that occurred in 1797, 1833, and 1871 were recorded on four cross-sections at both sites. A fire scar in 1824 was recorded on three cross-sections in both sites. Fire scars in 1759, 1852, 1899, and 1952 were recorded on two cross-sections and also at both sites. The fire scars in 1749, 1779, 1807, 1817, and 1840 were recorded only on one sample (BUF02).

The ATF01 site recorded the most fire events with 11 dated fire scars. Fire scars in some years can be dated easily and their exact dates are given. However, in some cases it is extremely difficult, or even impossible, to determine the exact fire year (McBride, 1983). We could date all visible fires on the cross-sections. Fire scars are generally seen in dry years, and in the years of fire scars trees produce narrow rings (Figures 6 and 7). The reason for narrow ring formation in these years may be drought, fire effects, or both.

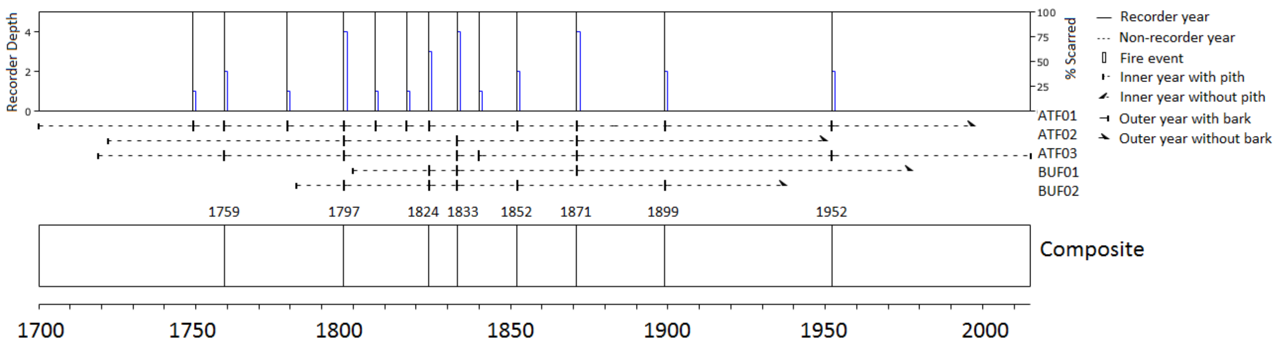

Figure 5. The fire card and fire index obtained using 5 tree cross-sections from two different sites. Fire index is the percentage of scarred trees of the total number of analyzed trees in a certain fire year (Niklasson et al., 2010).

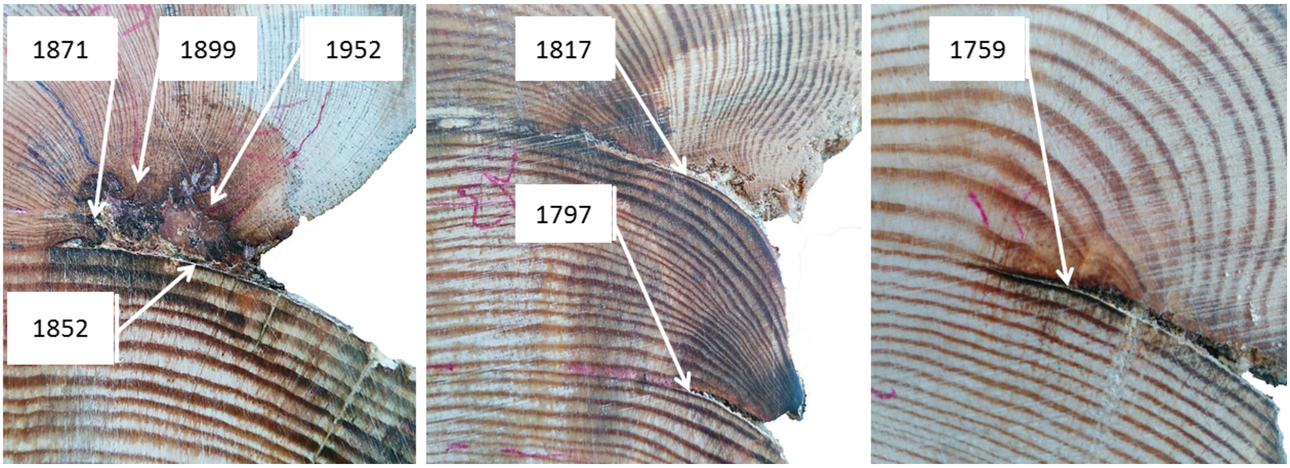

Figure 6. Some fire scars on ATF01. The fire in 1759 was determined to be middle earlywood because of having some part of the earlywood ring. The fire scars in the years of 1871, 1899, and 1952 look like fire scarlets. However, we observed these years on at least one more cross-section as a fire scar.

During the period between 1750 and 1975, a total of 13 fire events occurred (Table). The mean fire interval during this period was 27 years, and the minimum and maximum intervals were 9 and 53 years, respectively (Figures 5 and 7).

In the Burabai Region, because of a lack of information on the forest structure, logging activities. and livestock grazing in past centuries, it is difficult to understand the reason for the decrease in fire numbers in the last century. On the other hand, in Mongolia, decreasing fire activity in recent decades is correlated to intensive grazing (Hessl et al., 2012, 2016). The lower frequency of fires during the last century in Burabai may be due to similar reasons.

3.2. Seasons of forest fires

We found good agreement among the seasonal timing of fire scars. All seasonally determined fires occurred during

Table. Dated fire events in the region and their seasons.

Fire years	ATF01	ATF02	ATF03	BUF01	BUF02	Fire season
1750	M	--	--	*	*	M
1759	M	--	M	*	*	M
1779	M	--	--	*	--	M
1797	E	E	E	*	E	E
1807	E	--	--	--	--	E
1817	M	--	--	--	--	M
1824	M	--	--	M	M	M
1833	--	M	M	M	M	M
1840	--	--	U	--	--	U
1852	M	--	--	--	M	M
1871	U	U	M	M	--	M
1899	U	--	--	--	u	U
1952	U	--	M	--	--	M

E: Early earlywood; M: middle earlywood; U: undetermined;
--: no fire record; *: no data.

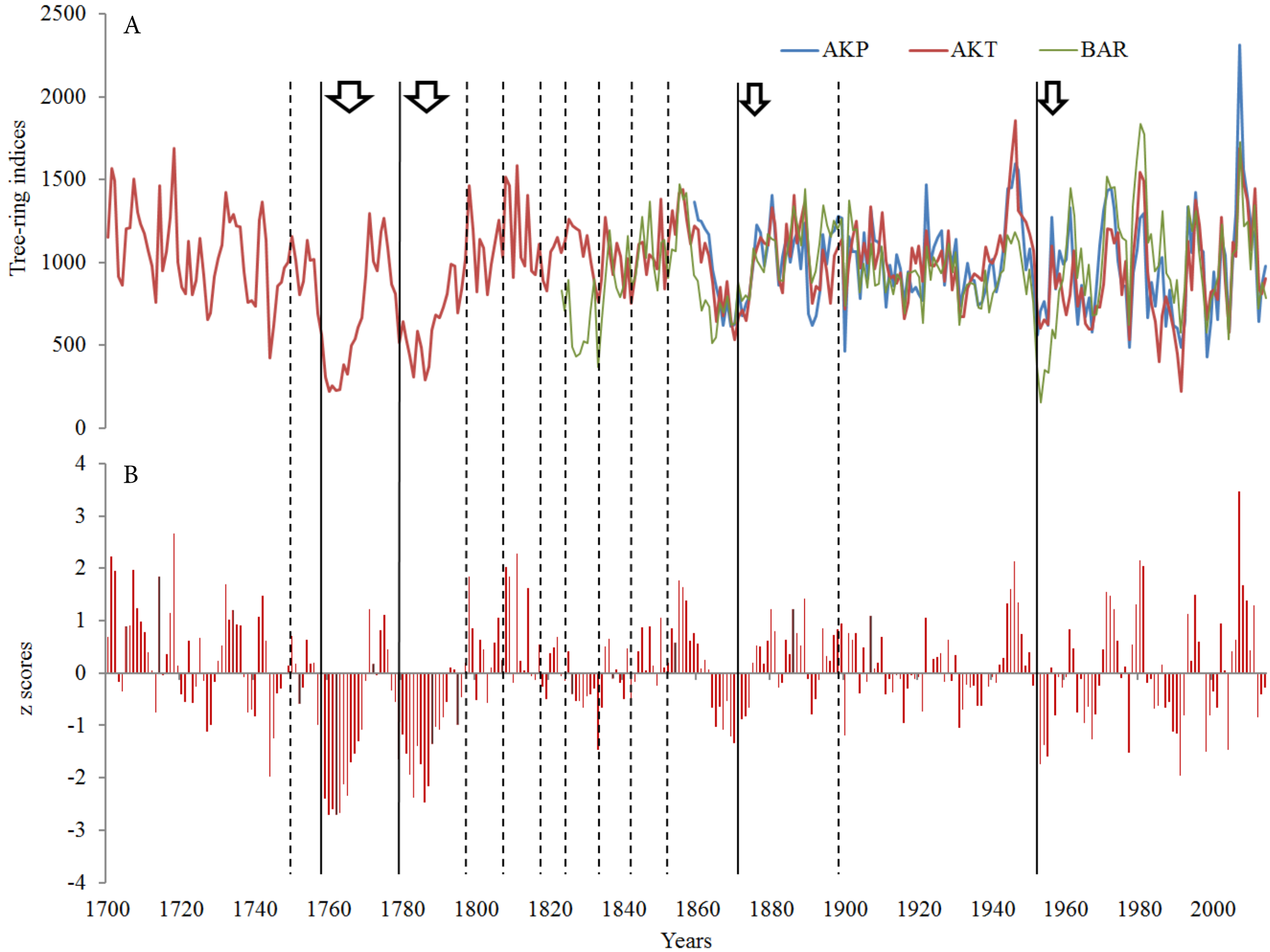

Figure 7. A) Tree-ring chronologies from three sites; B) z-scores of the mean chronology. Vertical lines indicate the fire years. Solid lines show long-lasting fires, and dotted lines show the years of other fires. Wide and narrow arrows on top indicate duration of depression interval. The fire years indicated with arrows are generally seen in the 2nd or 3rd year or the middle of the depression period.

the earlywood formation (Table). Moreover, most of them were recorded in the middle of earlywood. We determined the seasons for 11 fire years, but we could not determine the seasonality for fires in 1840 and 1899. We could not determine seasonality for half of the fire scar samples in 1871. However, the seasonality was visible for the remaining affected samples, and so we concluded that the fire in that year occurred in the middle of the earlywood. Percentages of events with undetermined season and with season recorded were calculated as 21% and 78%, respectively. When the fire season was determined, 77% of the fires occurred during the middle earlywood formation, and the remaining 22% occurred during the early earlywood ring formation. Arkhipov et al. (2000) stated that the growing season starts in the middle of April in the Burabai Region. The beginning of earlywood formation may be the end of April and early May for the breast height of trees. Kozlowski and Pallardy (1997) stated that cambial activity starts at the top of conifer trees and reaches the bottom within 2–3 weeks. The middle part of earlywood formation in the Burabai Region may be in June, and a high percentage of the fires occurred at that time.

3.3. Duration of fire effects and their spatial coverage

Fire scars in 1797, 1824, 1833, 1852, 1871, and 1899 were detected on at least one sample at both sites, which were about 8 km away from each other. Events in these years could be considered large-scale fires covering wide areas. However, because of the small sample size, we need other evidence to support our findings. For better understanding of the spatial coverage of the historical fires obtained from these five cross-sections and the duration of their effect on tree growth, we also used three site chronologies from the region. We graphed these chronologies and dated fires to build a regional chronology for the Burabai Region using all samples and sites (Figure 7A). We calculated z-scores of the chronology, which show tree growth depression with negative values (Figure 7B). Five of the fire scars had long-term negative effects on tree growth in 1759, 1779, 1871, and 1952. These long-term effects are visible on the cross-sections as growth depressions. Fire scars were observed generally in the 2nd or 3rd year or the middle of the depression period (Figure 7).

The fire scars in 1779 and 1817 were recorded only on one tree (ATF01). Niklasson et al. (2010) stated that if a sudden depression after a fire event is determined on a cross-section, but other trees also had sudden depressions in the same year and at the same site, then these could also be considered as having fire effect. As a result, these three fire years recorded by only one sample were considered as site-scale fire years because of sudden growth depression.

Fire scars in 1871 were recorded on four cross-sections from two sites. Tree-ring widths are extremely narrow in this fire year and narrow ring formation continued for 4–8 years (Figure 7). The fire of 1952 caused a missing ring especially in 1953 across the region, and many trees did not produce tree rings at the breast height of their stems. Narrow ring formations from 1952 to 1956 were seen in three site chronologies. In the AKP chronology, tree-ring widths are narrower than in other years. This result suggests that the forest fire in 1952 covered a large area in the Burabai and Akylbai plain and mountainous parts. The Forest Administration in Burabai stated that a fire occurred in the 1950s, but there was not any official record of the fire (personal communication: Forest Administration of Burabai).

In 1871 and 1952 long-term narrow ring formation occurred at three sites. After these two fire events the effects continued for up to 10 (3–10) years. Baisan and Swetnam (1990) stated that 2–10 years of typical depression could be seen just after a fire. Similar events were observed five other times (1759, 1779, 1871, and 1952) in the Burabai Region (Figure 7).

3.4. Conclusions

This study revealed the first forest fire history of the Burabai Region. Because of forestry activities and forest protection, big forest fires were not recorded in recent decades. The lack of fire in recent decades compared to the high fire frequency in the historical record suggests that fuels have been accumulating for several decades. The lack of fire could also be allowing more trees to become established compared to historical conditions and hence a potential shift from surface fires to crown fires could occur in the future. Duration of the effect of forest fires on tree growth ranges from 1 to 10 years. Some trees were affected by the fires and tried to repair the burnt region on the stem. Because these trees are damaged by fires, they produce narrow rings for several years to repair the scars. In 1759, 1779, 1871, and 1952, the fires caused long-lasting negative effects on tree-ring growth. Therefore, we can conclude that these fires were relatively large in the region. The reason for this may be protective forestry activities in the region. Because of working on only five cross-sections from two different sites, we could only provide preliminary results. After receiving official permission to work with more samples we will be able to give regionally based results for the past forest fires.

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