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Wildfires dynamic in the larch dominance zone

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[1] A fire return intervals (FRI) for zone of larch dominance and "larch-mixed taiga" ecotone was studied. Extreme fire events were connected with summer air temperature deviations. Average FRI determined from stem fire scar dating was 82 ± 7 years for the zone of larch dominance, and 77 ± 20 for the "larch-mixed taiga" ecotone. For the zone of larch dominance FRI on north-east facing slopes was 86 ± 11 years, for south-west facing slopes at 61 ± 8 years, for flat terrain at 68 ± 14 years, and for bogs 139 ± 17 years. FRI decreased from 101 years in the 19th century to 65 years in the 20th century, for the zone of larch dominance, and from 97 years to 50 years for the "larch-mixed taiga" ecotone. A climate and anthropogenic impact on this phenomenon was analyzed. The decrease of FRI may interfere with climate-driven migration of competitor species into zone of larch dominance, affecting biodiversity at high latitudes. **Citation:** Kharuk, V. I., K. J. Ranson, and M. L. Dvinskaya (2008), Wildfires dynamic in the larch dominance zone, *Geophys. Res. Lett.*, *35*, L01402, doi:10.1029/2007GL032291.

1. Introduction

[2] Larch is the widest-spread species in Russia, and is found from the tundra zone in the north to the steppes in the south. Larch on its southern and western margins is contacting with evergreen conifers (Siberian pine, *Pinus sibirica*, pine, *Pinus silvestris*, spruce, *Picea obovata*, fir, *Abies sibirica*) and hardwoods (birch, *Betula pendula*, *B. pubescens*, and aspen, *Populus tremula).* Wildfires are typical for this territory with the majority occurring as ground fires due to low crown closure. The vast area of larch dominant forests is generally considered as a "carbon sink"; however positive long-term temperature trends at higher latitudes [*Hansen et al.*, 2002] will result increase of the fire frequency, and may convert this area to a source for greenhouse gases. Regional climatic factors and topographic and environmental gradients are the fundamental processes that determine fires cycles [*Beaty and Taylor*, 2001; *Rollins et al.*, 2002; *Kharuk et al.*, 2005a].

[3] The purpose of this work is to investigate wildfire history and long-term trend in fire occurrence in larch dominated communities, to analyze impact of the air temperature deviations on the extreme fires, and to examine the relation between fires and topography.

2. Study Area

[4] The focus of this study is the larch dominated communities in central Siberia (Figure 1, area 1). The supplementary area was selected in the larch-mixed taiga ecotone (Figure 1, area 2). The stand-replacing wildfires were studied. The larch-dominated communities are composed of Gmelinii larch (*Larix gmelinii*) with a mixture of birch (*Betula pendula*). The larch dominance area is within the Central Siberian plateau with maximum elevation of about 900 m; this is a permafrost zone. The climate is severe continental with average annual temperatures within −8 to −14°C. The precipitations are of about 250–400 mm for area 1, and 500–800 mm for the area 2. The "larch-mixed taiga" ecotone (along the Yenisey ridge, with the heights up to 1000 m) is formed by *L. sibirica*, Siberian pine, Scotch pine, spruce, fir, birch and aspen.

3. Methods

[5] The on-ground data were collected on 38 test-sites (TS) along the area #1, and 24 TS for the area #2. For each TS the following parameters were described: coordinates, relief, vegetation type, forest and regeneration structure, tree diameters and heights, shrubs and ground cover, soil type. For fire return interval (FRI) measurements, three to five trees on each TS with fire scars were sampled. The FRI was calculated as the number of tree rings between consecutive fire scars: D_i-D_{i-1}, where D_i, D_{i-1}-dates of i and i-1 fires. In the temporal trend analysis the FRI values were referenced to the midpoint of an interval; COFECHA software was used for data processing [*Grissino-Mayer*, 2001]. For the purpose of estimating the accuracy of dating wildfires about 10% of the specimens (35 out of ~300) were analyzed using a "master" chronology method [*Naurzbaev et al.*, 2004]. A combination of cross-correlation analysis and graphical cross-dating was used to detect double counted and missing rings [*Rinn*, 1996]. "Master" chronology includes statistics of all tree rings (for a given period and given area). It was used as a reference for detecting fire-cased deleted rings in the samples. Thus, non-biased wildfires data were obtained. A good agreement between "tree ring counting" and "master chronology" methods was found: the data difference was 0.97 ± 0.4 yr. For analysis of the wildfire cycle the number of fires was plotted on the time axis. This data set was then filtered by standard "moving sum" filter of 11 years size to smooth fluctuations [*Naurzbaev et al.*, 2004]. The relationship between fires and summer (June–July) temperatures deviations was examined using reconstructed temperatures [*Panyushkina et al.*, 2003; *Mann and Jones*, 2003; *Naurzbaev et al.*, 2004]. The analysis of the relationship between wildfires and topography was based on the ground-based measurements of slope, aspect, and elevation. The distribution over the area was referenced to northern (azimuths 315°–45°), eastern (45°–135°), southern (135°–225°), western (225°–315°), south-east (45°–225°), southwest (135°–315°), north-east (315°–135°), and north-west (225°–45°) aspects, and level

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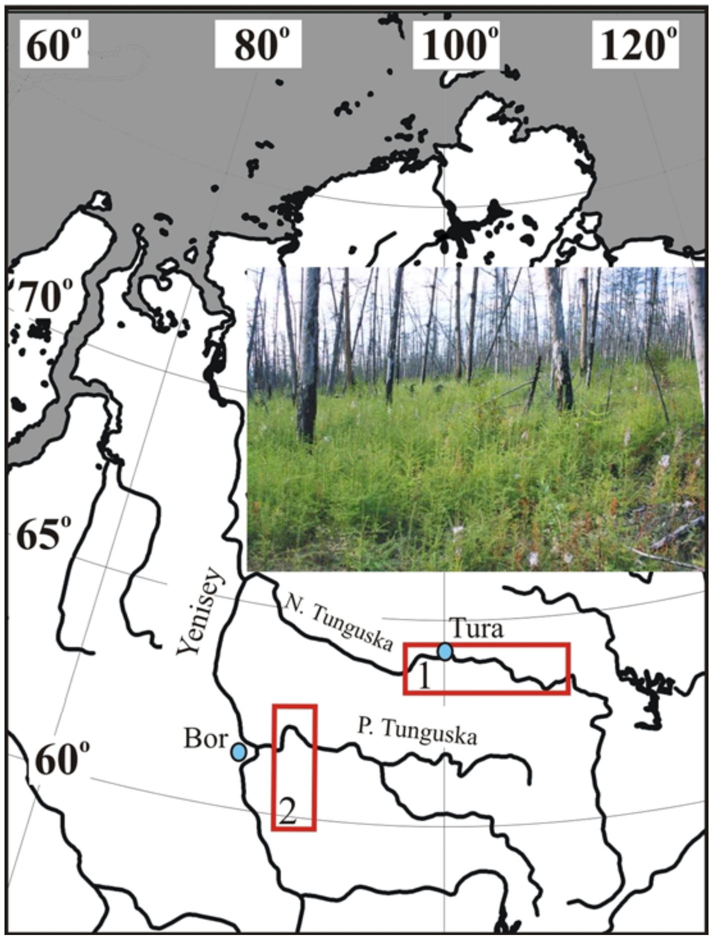

Figure 1. Map of field measurement locations. Area 1 is the zone of larch dominance, area 2 is the ‘‘larch-mixed taiga’’ ecotone. (insert) A regenerating burn in the zone of larch dominance caused by late summer groundfire. Fire coincides with the year of high cone production. Number of saplings is about 700 000 thousand/ha.

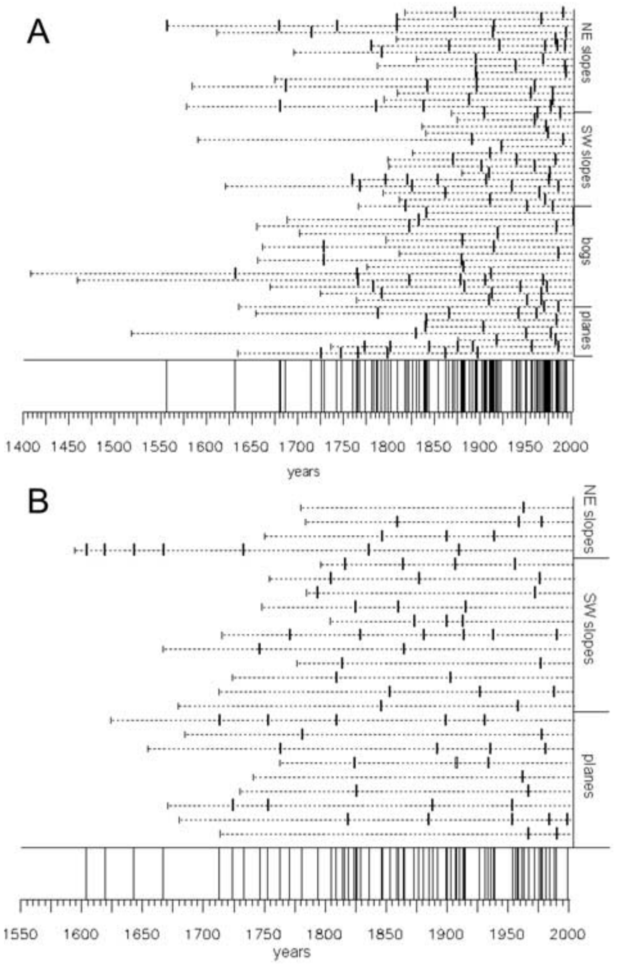

Figure 2. (a) Fire dating for the larch dominance zone. (b) Fire dating for the "larch mixed taiga" ecotone. NE slopes, SW slopes are the slopes with northeast and southwest expositions, respectively. Thick and thin strokes show dates of fires and tree establishment, correspondingly.

bogs and plains (sites with slopes 0° to 2°). Student's ***t***-criteria and Kendall tau non-parametric statistic were used in the data analysis (StatSoft, Inc., Nonparametric statistics, available at http://www.statsoft.com/textbook/stnonpar.html).

4. Results

4.1. FRI and Landscape Characteristics

[6] The results of wildfire dating with respect to the landscape type are presented on Figure 2a (larch dominance zone) and Figure 2b (the supplementary area). Based on this, the FRI was calculated for period covered from 1410 to 2002 (Figure 2). FRI in the larch stand depends on terrain characteristics Table 1. Cool and wet northeast facing slopes have the longest FRI. Southwest facing slopes with drier conditions have the shortest FRI. The differences between SW and NE slopes are significant at $p > 0.1$; bogs are different from all the other landscape elements at $p > 0.01$. For the "larch-mixed taiga" ecotone mean FRI was 77 ± 20 yr, and not differ statistically significant with respect of relief elements.

4.2. Temporal Trends in the FRI

[7] The data in Figure 3 shows the fire number deviations (ΔF) from long-term mean annual fire number distribution. These dataset indicates a trend of increasing number of fires in the 20th century in comparison with the 19th century ($p >$ 0.05). But this conclusion may be biased due to "fading effect", e.g., variable number of tree samples for the different time periods (Figure 2). To exclude the effect of decreasing sample size only the trees with age exceeding 200 years were examined for the FRI temporal trends analysis. This enabled even sampling for the both, 19th and 20th centuries. The result of analysis shows a FRI decrease in 20th in comparison with 19th century: a reduction of mean FRI in the zone of larch dominance from 101 ± 12 years to 65 ± 6 years ($p > 0.01$). For the "larch-mixed taiga" ecotone the FRI decreased from 97 ± 22 in 19th century to 50 ± 14 in 20th century (p > 0.05).

4.3. FRI and Summer Air Temperature

[8] Relation between FRI and summer air temperature was based on data set for the larch dominance zone since its higher sample size. The observed increase in fire frequency was occurring against the background of a significant (p > 0.05) upward summer temperature trend in the 20th century (Figure 3). Figure 3 represents reconstructed records of regional summer air temperature for northeast Siberia [*Panyushkina et al.*, 2003], northern Eurasia [*Naurzbaev et al.*, 2004], and northern hemisphere [*Mann and Jones*, 2003]. For the analysis, temperature deviations (Δt,°C) were calculated as the difference with a mean summer temperatures for the 200 year period. A significant (p > 0.01) cross-correlation was found for ΔF (fire number deviations from long-term mean) with the regional summer temperatures record ($\boldsymbol{R_{ns}}$ = 0.44), where $\boldsymbol{R_{ns}}$ is a cross-correlation coefficient for northeast Siberia. The cross-correlation coefficients for northern Eurasia ($\boldsymbol{R_{na}}$), and northern hemisphere ($\boldsymbol{R_{nh}}$) were not significant.

[9] The next step in the analysis was based on the observation that catastrophic wildfires were observed in 1914–1916 yr, when wildfires were known to be present continuously from May until August. In that year the total affected area in Siberia was 160,000 km^2 [*Kirillov*, 1961]. The spike in the fire frequency distribution for this period is clearly visible on Figure 3. After this catastrophic event an interval of reduced wildfires was observed, which was due to the fact that the majority of fire susceptible forests were burned in the preceding period. Thus, in spite of positive temperature trends, the number of fires during periods

Table 1. The Mean FRI Values for Various Terrain Aspects[a]

Terrain Aspect	FRI, years mean ±s	Numberof Test Sites
SW	61 ± 8	11
NE	86 ± 11	13
Bogs	139 ± 17	7
Plains	68 ± 14	7
All test sites	82 ± 7	38

[a]SW, south-west facing slopes; NE, north-east facing slopes; s, standard deviation.

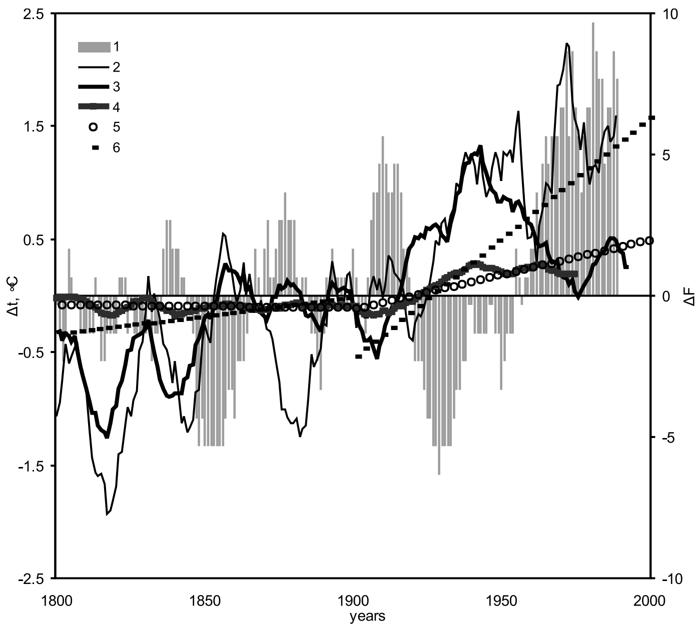

Figure 3. The fire chronology in the zone of larch dominance and summer air temperatures. Line 1 shows fire number deviations (ΔF) from long-term (200 yr) mean annual fire number distribution. Lines 2, 3, and 4 are temperature deviations (Δt,°C) from long-term (200 yr) mean of northeast Siberia, northern Eurasia, and Northern Hemisphere temperature. Straight lines indicate the temporal trends for Northern Hemisphere temperatures deviations (symbol 5), and for number of fires (symbol 6).

following catastrophic fires was minimal, because of a deficiency of combustible material. The consequences of such exceptional events do not match the regular ''cause-effect'' pattern, and should be analyzed separately. According to our observations, about 30 years are required for a severely burned area to accumulate enough combustible material to sustain another fire. Based on this, in the second step of analysis we excluded this ''lag period'' of 30 yr after the 1914–1916 events. After this correction the cross-correlation becomes: $\boldsymbol{R_{ns}}$ = 0.67 $\boldsymbol{R_{na}}$ = 0.43, $\boldsymbol{R_{nh}}$ = 0.37 (p > 0.01). The Kendall tau statistic becomes: $\boldsymbol{T_{ns}}$ = 0.48, $\boldsymbol{T_{na}}$ = 0.35 (p > 0.05) ($\boldsymbol{T_{nh}}$ is not significant).

[10] The last step of the analysis was the study of the relationship of wildfire anomalies (>1σ) with temperature deviations (Figure 4). Deviations from the mean in Figure 4 were calculated separately for both the 19th and 20th centuries. This minimized the impact of temporal trends in fires, which are significantly different in both centuries. The results show increased correlation with the reconstructed temperature record. All coefficients are significant (p > 0.01) with highest correlations for the northeast Siberia temperatures ($\boldsymbol{R^2_{ns}}$ = 0.62). A decrease of the relationship with temperatures from regional to subcontinent and global levels is observed (Figure 4), showing, in particular, global processes impact on fire events in Siberian larch-dominated communities.

5. Discussion

[11] FRI reduction (one-third for the zone of larch dominance and twice for the ''larch-mixed taiga ecotone'') is the result of the increase of anthropogenic impact, and influence of climate warming. For the ''larch-mixed taiga ecotone'' the leading factor is an anthropogenic, since this area has recent gold mining history. But in the zone of larch dominance anthropogenic impact is minimal, since population density is <0.03 people/km^2. Published data [*Ivanova and Ivanov*, 2004; *Kovacs et al.*, 2004] indicates that in the northern taiga about 90% of fires were caused by lightning. It should be added that in the permafrost zone lightning strikes are approximately twice as likely to ignite a fire because of sharp conductivity change in the boundary layer between thawed soil and permafrost, where energy released [*Sapozhnikov and Krechetov*, 1982]. Thus, we consider that the leading role in the FRI reduction belongs to the air temperature increase. This coincides with a recent finding by *Gillett et al.* [2004] showed increase of the area burned in Canada the last four decades of the 20th century and that climate change had a influence on the forest fires over recent decades. On the contrary, in the areas with intensive fire suppression measures fires frequency decreased [*Heyerdahl et al.*, 2001; *Buechling and Baker*, 2004].

[12] The relation of FRI and topography generally agrees with reported results from other forest regions [e.g., *Beaty and Taylor*, 2001]. The topography affects fire recurrence through different fuel loading, temperature conditions on the different slope and aspects, and even frequency of lightning strikes. For example, with an elevation increase of 400 to 600 m, lightning strikes increase by a factor of 3 to 4 [*Sapozhnikov and Krechetov*, 1982].

[13] Fires are inherent to larch forests and are necessary fore its maintenance. Larch is a ''pyrophyte'' (i.e., ''likes fire'') species: light larch seeds need a mineralized surface of fresh burns for germination (Figure 1, insert), whereas competitor species (Siberian pine, spruce) are

more abundant on old burns (Figure 5). Thus, the decrease of FRI may interfere with climate-driven invasion of "southern species" into zone of larch dominance [*Kharuk et al.*, 2005b]. The climate-driven increase of fire impacts will support larch dominance in the northern forests also because larch is protected by thick bark, whereas Siberian pine, spruce and fir are not. The main cause of larch forest mortality is damage of the root system by ground fires since the root system is restricted to the narrow strata above the permafrost. With a climate-induced increase of summer thawing depth and, consequently, increased rooting depth and overall increase of larch resistance to fires may be expected. On the other hand, since wildfires cause increase of seasonal thawing depth (by factor of 3 to 5, according our observations), decreasing FRI will have synergetic effect with climate-induced permafrost thawing, accelerating conversion of larch dominance zone from carbon-sink area to source of greenhouse gases. The issues of larch dynamics in the face of changing climate and human activities are complex and require substantial further research.

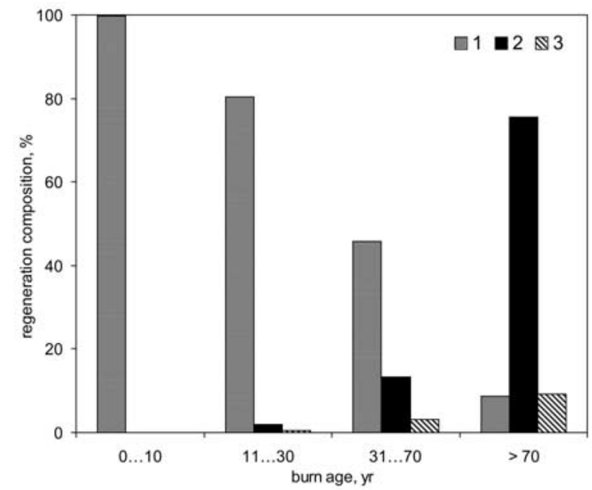

Figure 5. Proportion of tree species vs. burn age. 1, larch; 2, Siberian pine; 3, spruce.

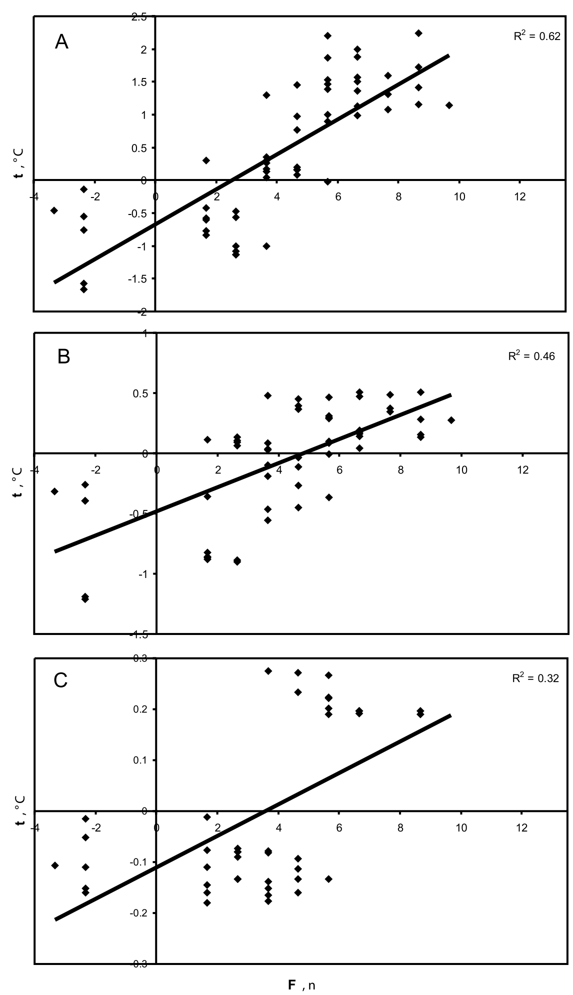

Figure 4. The relationship of wildfire anomalies (ΔF,n, deviations from long-term mean; $\Delta F,n > 1\sigma$) with deviations of the mean summer temperature record (Δt,°C, deviations from long-term mean) for (a) northeast Siberian, (b) northern Eurasia, and (c) the Northern Hemisphere.

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