Fire returning intervals in larch dominated communities: variability along a south-north transect

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Larch dominated forests are an important component of the global circumpolar boreal forests.

Larch is the most widely spread species in Russia (>40% of forests).
Larch forms high closure stands as well as open forests 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.
The annual burn rate is about 0.25% of the forested territory.
Topography (slope aspect, steepness, and elevation) has an important role in the occurrence, frequency and extent of wildfires.
The larch forests are “carbon sink”; however positive temperature trends at higher latitudes will result in an increase of the fire frequency, and may convert this area to a source for greenhouse gases.
Study Area

The study sites covered the meridian gradient of larch areal – starting from “larch- mixed taiga” ecotone on the south (1), through zone of larch dominance (2, 3), with end nearby larch northern limit (4).
The stand-replacing wildfires were studied.
The “larch-mixed taiga” ecotone is formed by *L. sibirica*, 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*).
The larch-dominated communities in Central Siberia are composed of Gmelini larch (Larix gmelini) with a mixture of birch (Betula pendula), and with a small proportion of “dark-needle” conifers (Siberian pine and spruce).
The stands nearby the northern forest limit composed by Gmelinii larch (Larix gmelinii).
Climate severity is increasing along the transect. Average annual temperatures are within – 8 °C on the south to - 14 °C - 16 °C on the north. The precipitations are of about 500-800 mm/yr on the south, and 250-350 mm/yr on the north.
Site 1 is a zone of non-continuous permafrost.
Sites 2-4 are the zone of permafrost.
The growing period is about 100 days on the south and 70 days on the north.
• On the south fires were both, natural and anthropogenic origin.

• On the sites 2 -4 the majority of fires were lighting origin (up to > 90% cases).
Fires are inherent to larch forests and are necessary for its maintenance. Larch is a “pyrophyte” species: larch seeds need a mineralized surface of fresh burns for germination.
On the south of larch dominance burns regenerates by larch plus the other species (“evergreen conifers”, birch and alder). On the north larch follows larch.
To reach study sites, we used helicopters....
We had also some virtual connection with civilized world.
The goals of studies were:

An analysis of
1. FRI variability along south-north transect (61°N - 71°N);  
2. relation between FRI and warming;  
3. relation between fires and topography;  
4. fire impact on the permafrost thawing depth.  
And (5) “ecological reflections” about wildfires impact on the climate-driven species migration.
Methodology

The on-ground data were collected on 38 test-sites (TS) along the area #1, and 24 TS for the area #2. The total sample size was ~300.

Area 3: ~30 test-sites;
sample size was about 115.

Area 4: ~10 test-sites;
sample size was about 45.

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.

“Tree ring counting” and “master chronology” methods were used for determine fire events.
Preliminary TS selection was based on RS data. On-ground distance to TS was about 0.1-4.0 km away of rivers.
We cut a lot of trees while sampling.
Some preliminary analysis was combined with cooking.
• Very narrow rings (north sites) caused difficulties in fire dating.
In same cases rings width was about two (!) cells.
This was observed mainly for Little Ice Age period (15th-18th centuries).

Samples age is ~500yr
The other problem was discrimination between “burn marks” and “burn-like” damage caused by winter desiccation and snow abrasion. Those “burn-like” damage was especially pronounced for “Little Ice Age “ period.

For this purpose microscopy was applied.
The “fire burns” were characterized by traces of charcoal along and within tree ring...
...and resin which filled tree ring cells.
For the part of “southern” samples rot also creates a problems.

On the northern (esp. site 3 and 4) wood rot was rare (except some samples within river valleys). Wood was very dense, with narrow rings.

And mean age of sampled trees was about 300-400 yr.
Results

1. FRI along the south-north transect

Fire chronology

Left: Fire dating for the larch dominance zone.
Right: Fire dating for the “larch mixed taiga” ecotone.
Thick and thin strokes show dates of fires and tree establishment, correspondingly.
FRI along the transect

- Site 1 (61º-62ºN): 77± 20 yr;
- Site 2 (64ºN): 80yr ± 7;
- Site 3 (65º - 66º30'N): ~120 yr;
- Site 4 (71ºN): ~200+yr.
2. Wildfires and warming: Temporal trends in the FRI

The number of fires in the 20th century is increasing in comparison with the 19th century ($p > 0.05$).

1 - fire number deviations ($\Delta F$) from long-term (200 yr) mean annual fire number distribution,
2, 3, 4 – temperature deviations ($\Delta t, ^\circ C$) from long-term (200 yr) mean of northeast Siberia, northern Eurasia and northern hemisphere temperature.
But this conclusion probably biased due to “fading effect”, i.e., variable number of tree samples for the different time periods.

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.
“Normalized” data analysis showed decrease of mean FRI in 20th in comparison with 19th century:

- **FRI in larch dominated communities (site 2)** decreased from $101 \pm 12$ yr to $65 \pm 6$ yr ($p > 0.01$).

- **FRI “larch –mixed taiga” ecotone (site 1)** decreased from $97 \pm 22$ in 19th century to $50 \pm 14$ yr in 20th century ($p > 0.05$).
• In the “larch-mixed taiga ecotone” FRI reduction was a synergy of anthropogenic and climate warming impact: this area has recent gold mining history.

• For the zone of larch dominance (sites 2-4) anthropogenic impact was minimal, since population density is <0.03 people/km². About 90% of fires were caused by lightning.
Wildfire and air temperature: wildfires anomalies relates with deviations of the mean summer air temperature

A relationship between wildfires anomalies and temperatures is observed at regional, subcontinental and global levels showing.

The relationship of wildfire anomalies (ΔF,n: >1SD) with deviations of the mean reconstructed temperature record for (A) the northeast Siberian, (B) northern Eurasia, and (C) northern hemisphere. All coefficients are significant (p>0.01).
3. Relation between fires and topography

*Larch dominated communities* (site 2):
Table 1. The mean FRI values for various terrain aspects. SW = south-west facing slopes; NE = north-east facing slopes; s = standard deviation.

<table>
<thead>
<tr>
<th>Terrain aspect</th>
<th>FRI, years mean ±s</th>
<th>Number of test sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW</td>
<td>61±8</td>
<td>11</td>
</tr>
<tr>
<td>NE</td>
<td>86±11</td>
<td>13</td>
</tr>
<tr>
<td>Bogs</td>
<td>139±17</td>
<td>7</td>
</tr>
<tr>
<td>Plains</td>
<td>68±14</td>
<td>7</td>
</tr>
<tr>
<td>All test sites</td>
<td>82±7</td>
<td>38</td>
</tr>
</tbody>
</table>

Blue: significant at p>0.1, P >0.05
4. *Wildfires and permafrost seasonal thawing*

Wildfires cause increase of seasonal thawing depth (by factor of 3 to 5).
With time, growing moss cover promotes decreasing of seasonal permafrost thawing. The post-fire rate of moss and lichen cover depths increase was ~0.07 cm/yr. The accumulation of combustible material forms conditions for the follow-on wildfire cycle.
In the absence of following-on fires stands become dense and suppressed.
Larches are “sleeping”, waiting for next fire….
5. “Ecological reflections: Wildfires and climate-induced species migration

Burns are the “starting places” for climate-induced “southern” tree species migration into zone of larch dominance.
A climate – driven Siberian pine, spruce and fir migration to the zone of larch dominance

A – overstory, B – regeneration, C - propagation coefficient
1 – larch, 2 – Siberian pine, 3 – spruce + fir
On the other side,
Larch better regenerates on fresh burns, whereas competitor species (Siberian pine, spruce) are more abundant on old burns.
Larch is also protected by thick bark, whereas Siberian pine, spruce and fir are not.
The main cause of larch mortality is damage of the root system since roots are 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. Thus, fire impacts increase will support larch dominance.
Final remark

There is widely accepted view that with warming carbon-sink area of larch dominance will be converted into carbon source.
But this is not the only scenario. Wildfires caused soil melioration, which caused larch radial increment increase (i.e., increase of productivity).

Warming impact may have a similar effect.

Sample location: ~ Polar Circle
Conclusions

1. Within zone of larch dominance mean FRI along south-north direction are increasing >2 times approx: from ~80 yr on south to 200+ yr nearby northern forest line. Mores analysis is going on FRI in nearby northern larch forest limit.

2. There was decrease of FRI in 20th in comparison with 19th century: 65±6 yr (20th century) vs 101±12 yr (19th century) [the mid of the zone of larch dominance].
3. Wildfire anomalies relates with deviations of the mean summer air temperature at regional, subcontinent and global levels.
4. FRI relates to landscape features. For the zone of larch dominance FRI on north-east facing slopes was $86\pm11$ years, for south–west facing slopes at $61\pm8$ years, for flat terrain at $68\pm14$ years, and for bogs $139\pm17$ years.
5. The climate-driven increase of fire impacts may support larch dominance.
Speculations

With climate warming zone of larch dominance will stay the zone of carbon sink!
Acknowledgement

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Спасибо!
Thank you!