FIRE AND FIRE REGIMES IN THE FORESTS OF CENTRAL SIBERIA

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ABSTRACT

The paper addresses forest fire regimes in central Siberia. Past fire frequency was reconstructed for forest ecosystems situated at different latitudes. A method is proposed for rating lightning forest fire danger.

Key words: forest fire, fire regime, storm, central Siberia

INTRODUCTION

About 16,000 forest fires occur in Russia every year, with an average annual area burned of 900,000 hectares (Odintsov 1996). Current forests manifest quite clear signs of long-term fire effects. The Russian forests, how they look today, are to a big extent the result of past fires.

In Siberia, forest fires have been a major ecological factor since prehistoric time, and there is no forest stand now, which had not experienced fire at least once. Fire had considerably changed the taiga forest of Central Siberia. Dark-needled species replaced light-needle stands in vast areas and secondary deciduous forest become common in many regions (Popov 1982).

Every woody tree species has its specific fire regime characterized by particular fire behavior, fire return interval, and postfire forest regeneration dynamics. Fire regime is a historically evolved factor that determines conditions of fire occurrence, behavior, and long-term effects.

This report addresses fire regimes, conditions favoring fire occurrence, fire frequency and return intervals in the forests of central Siberia.

MATERIALS AND METHODS

In order to analyze central Siberian forest fire regimes, we used fire data provided by Aerial Forest Fire Protection Service (Avialesookhrana) of the Krasnoyarsk region and the Russian Forest Service and reconstructed fire history for some woody tree species of the Krasnoyarsk region, Evenkia, and Tuva Republic. Most data were collected in pine/lichen, pine/small shrub/green moss, and pine/grass stands along the Yenisei meridian. When building fire chronologies, we used traditional methods of dendrochronological and dendroclimatic data processing (Dieterich, Swetnam 1984; Fritts and Swetnam 1989; Methods of Dendrochronology 1990, and others).

FOREST FIRE OCCURRENCE IN CENTRAL SIBERIA

Central Siberia is one of Russia's vastest regions crossed by several climatic and vegetation zones. This accounts for diverse climatic and site conditions that contribute to annual fire occurrence in different parts of the region.

Three types of fire season are identified in forests of central Siberia (Valendik 1990):

- Short continuous season is characteristic of northern and central taiga. Fire extent and number are very big during 1-3 months:

- Long fire season prevails in southern taiga. Periodical fires can occur during 4-5 months; and

- Double-peak season is characteristic of southern mountain forests. The fire peaks occur in spring and fall.

Analysis of year-to-year number of fires and burned areas during 1984-1994 has revealed that their dynamics has a tendency to cycle (Figure 1). Lightning fires account for 34% of their total number, while the rest are human-caused (Figure 2).

High fire activity in summer is due to long dry periods, whose total duration amounts to 115 in some parts of the region, with average duration of 45 days. These droughts make all vegetation highly flammable, natural fire breaks disappear and fires spread freely.

Forest fuel loading and structure are key factors controlling fire danger rate. Fuel loading depends on lati-

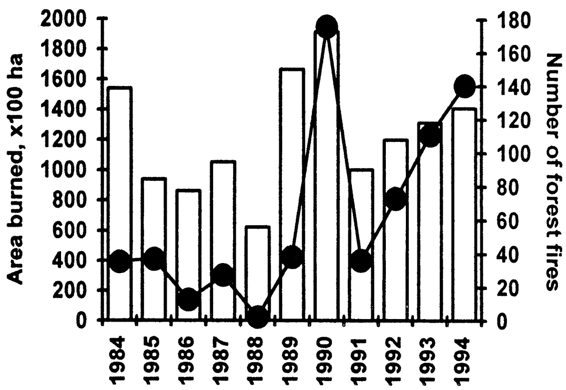

Figure 1. Number of forest fires and area burned in Central Siberia.
Bars equal area burned, ha.
Dots and lines equal the number of fires

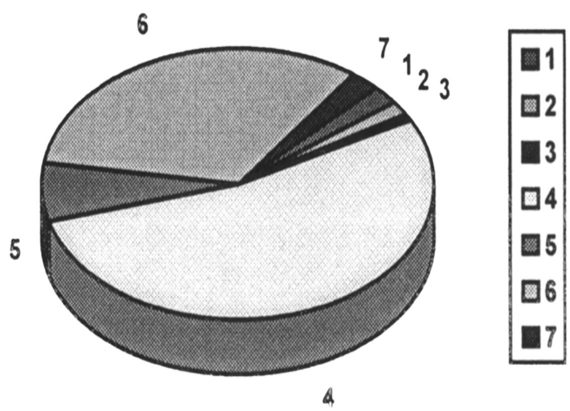

Figure 2. Distribution of forest fire cause (in % the total number of fires) during a 10-yr. period.
1 - forest harvesting (2.3%)
2 - agricultural burns (1.8%)
3 - geological expeditions (0.7%)
4 - undetermined cause (68%)
5 - lightning (33.7%)
6 - activity of different organizations (23%)

tude, forest type, composition, density of stocking and age, as well as fire and harvesting activities.

Frequent fires prevent excessive fuel accumulation and, as a result, potential area burned, combustion intensity, and fire-caused forest disturbance decrease.

EXTREME FIRE SEASONS ON BOREAL FOREST OF CENTRAL SIBERIA

We define extreme fire season as abnormal meteorological season characterized by long dry periods, high air temperature, strong winds, and low relative humidity that induce mass forest fire situations (Valendik and Ivanova 1993). In central Siberia, occurrence of these seasons vary in time and space. In some areas, they can occur in a number of successive years. Extreme fire season periodicity depends on drought frequency and latitude.

Big forest fires accompanied by mass small fires are the indicator of extreme fire seasons. Occurrence of big fires across central Siberia and dynamics of their number during 1950-1993 are shown in Figure 3 and 4. Extreme forest fire activity was recorded in 1950, 1953, 1956-58, 1962, 1964-65, 1967-69, 1976-77, 1984-85, 1989-1990, and 1993-1994. Among these,

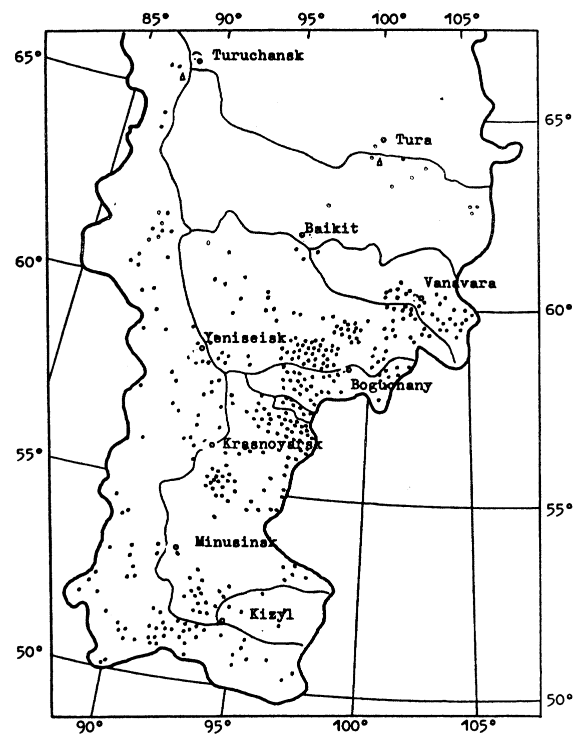

Figure 3. The distribution of large forest fires across Central Siberia (1984-1994).

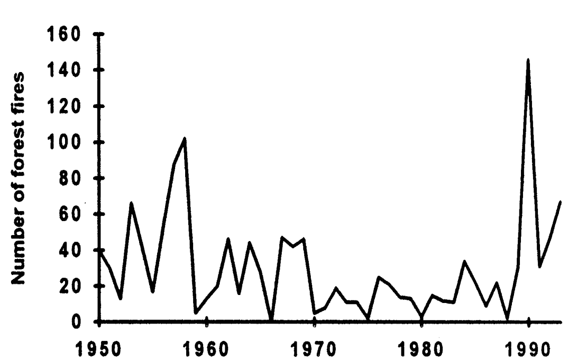

Figure 4. Large forest fire dynamics in Central Siberia (1950-1993).

1957 was the most catastrophic, when drought covered the whole of central Siberia (50 to 70 degrees N). Climatic diagrams for the 1957 extreme fire season, when all weather stations reported severe drought, are given in Figure 5. 10- and 30- day rainless period is required for big forest fires to occur in spring and summer, respectively.

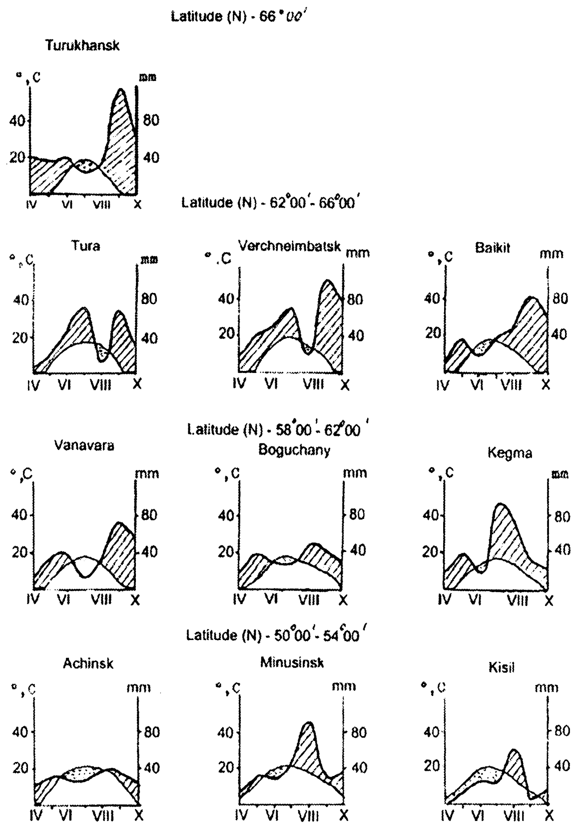

Figure 5. Gossen - Walter climate diagrams (1957 year).

Droughts promoting extreme fire events are induced by dry and warm air masses coming here from Central Asia, Mongolia, and the central part of eastern Siberia. In terms of drought frequency, especially notable are southern areas (50-55 degree N) of central Siberia, where they occur 7-10 times a decade, and its eastern part (56-62 degree N) - 5 to 7 droughts a decade. Moreover they repeat here 3-4 years in succession. As for the rest of the region, 2-3 droughts are observed a decade and they can occur in two successive years.

Monthly average air temperature and precipitation show that droughts of different severity accompanied by extreme fire events occurred in:

- Central and northern Evenkia (19 droughts 1935-1986).
- Southern Evenkia (27 droughts 1935-1986).
- The central part of Krasnoyarsk region (42 droughts 1886-1984).
- The southern part of Krasnoyarsk region (49 droughts 1916-1986).
- Tuva Republic (almost every year during 1944-1989).

LIGHTNING FOREST FIRES

In Central Siberia 34% of forest fires are started by lightning. Storm activity varies widely along the Yenisei meridian, from tundra open woodlands to southern mountain forests, increasing from north to south. Most storms (up to 45%) occur in July. During daytime, their biggest number is detected from noon to 6:00 p.m. Annual average duration of storms is 58 hours maximum. Local storms occur most often, accounting for 93% of their total number.

There are areas, where lightning fire potential is considerably higher than in the rest of central Siberia. In these areas, fuel-related fire danger is high and storms are frequent. Therefore, to increase lightning fire detection and control requires identification of such areas.

We attempted to estimate lightning fire danger in a forest area using an original methodology (Ivanov and Ivanova 1996). For this purpose we built a map showing sites of high lightning fire hazard (Figure 6).

We conducted our study in the northern part of Yenisei plain stretching from the Yelogui river in the north to the Ket river in the south (Yenisei tributaries). The study area is a rolling plain (150-300m a.s.l.). Forest covers 73% of the area: *Pinus sylvestris* (42.5%), spruce (34.0%), larch (7.0%), *Pinus sibirica* (5.5%), and deciduous species (11%). Pine forest are represented mainly by pine/green moss stands on sandy soil.

When estimating lightning fire situations and identifying sites of high lightning fire risk, we considered the following factors:

1. Most probable storm cloud origin points.

2. Storm cloud size and direction of movement.

3. Storm cloud life time and area of influence.

4. Presence and magnitude of magnetic anomalies.

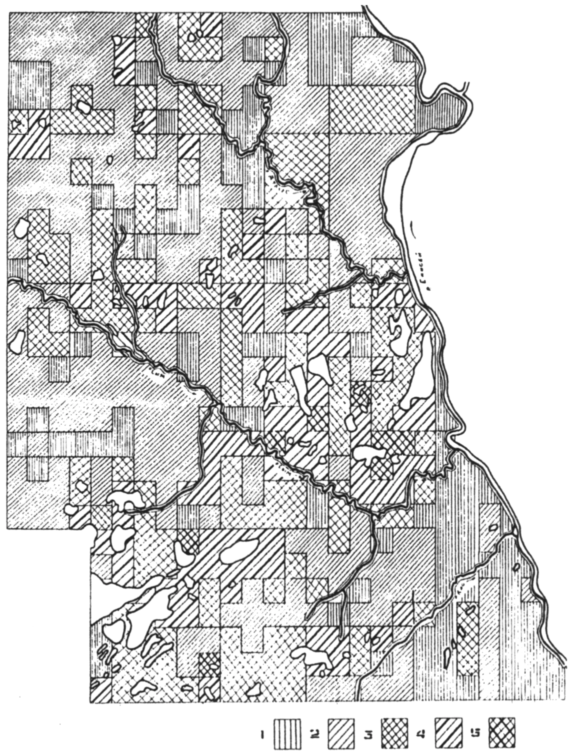

Figure 6. Map of lightning fire danger in forest sites of the Yenisei plain (a fragment). Lightning fire danger rate: 1 - very low; 2 - low; 3 - moderate; 4 - high; 5 - very high.

Storm Cloud Origin Points

Rough surfaces, water bodies, and forest/grassland boundaries are known to be the key factors that determine horizontal temperature difference, which leads to regular air convection. This, in turn, is prerequisite for storm cloud emergence (Khromov 1940). Storm occurrence is closely related with landscape diversity. High number of night storms are observed in boggy forest sites and along the boundaries of the biggest forest areas (Yagudin 1967).

Bogs and big water bodies influence daily dynamics and duration of storms (Ivanidze 1967). Precipitation occurrence, at high relative humidity, depends mainly on tropospheric circulation and underlying surface characteristics. The amount of precipitation is higher where underlying surface promotes updrafts (Zhakov 1982).

Boundaries of landscape elements can thus be considered as points of local storm cloud origin under favorable weather conditions, and occurrence of night storms is controlled mostly by the presence of bogs and lakes.

Storm Cloud Area of Influence

Evaluating the area that can experience lightning from a storm cloud requires consideration of the following parameters:

- The time of a storm cloud existence from the moment it begins to form to the moment of its complete destruction.
- Average storm cloud speed relative to Earth's surface.
- Average diameter of a storm cloud and the direction of movement it takes most frequently relative to parts of the world.
- Presence of geomagnetic anomalies.

Time of Storm Cloud Existence

The time needed for a storm cloud to form is 30-40 minutes. A storm could is electrically active for 30-40 minutes. Zero cloud stage lasts for 10-15 minutes. The mature cloud stage takes 15-30 minutes (Pchelko 1963; Shishkin 1964; Rogers 1979). The results of our study of cloud movement and time of existence allowed us to conclude that a storm cloud is active in terms of lightning for not more than 40 minutes.

Storm Cloud Speed

Radar investigation of clouds shows that 90 per cent of local storms move 7 km/h slower than the main air stream, with the speed of the latter being 20-25 km/h. A storm cloud moves along a curved trajectory and can deviate by an angle of over 90 degrees from the main air stream direction (Brylev, Gashina, Nizdoyminoga 1986). Our 1986-1988 study showed cloud speed of about 10 km/h during a local storm. In the case of a local storm, clouds usually stay where they are or move to small distances. A storm cloud, thus, covers a distance of about 10 km during its life time.

Storm Cloud Diameter and Direction of Movement

Investigations of storm clouds conducted in the Yenisei plain show that the clouds primarily go southwest and northwest. This agrees with S. I. Zhukov's (1982) observation of the prevalence of western and southwestern winds in western Siberia. Average storm cloud diameter is about 1 km (Tomilin 1986).

Influence of the Earth's Geomagnetic Anomalies

The study conducted in the northern part of the Yenisei plain established that lightning probably is higher where there are strong geomagnetic anomalies (Ivanov 1991).

Using our experimental and literature data on storm clouds, we built a map reflecting the rate of lightning fire danger in the Yenisei plain. To build the lightning fire danger map, we used:

- Topographic map of the region.
- Vegetation map of the west Siberian plain.
- Lightning forest fire coordinates for the past decade.
- Map of the Earth's anomaly magnetic field; and storm activity data for the region of interest.

The forest sites are divided into five groups in order of increasing lightning fire danger. Sites of groups 4 and 5 should receive special attention when making fire detection flights after storms. Early identification and permanent control of sites with high lightning fire potential will contribute to forest fire protection.

FOREST FIRE FREQUENCY AND RETURN INTERVAL

Forest fire is a key factor controlling forest cover dynamics and vegetation succession in central Siberian ecosystems. Also, forest fires are a big source of carbon emissions to the atmosphere.

Fire frequency and return interval depend on alternation of dry and wet years, seasonal and daily weather dynamics, temporal changes of forest vegetation patterns, distribution of forest stands across big areas, and human activity.

We reconstructed fire history in some of pine and larch forests of central Siberia using dendrochronological methods. Long master forest fire chronologies for the whole of central Siberia depending on latitude are given in Figure 7.

One thirtieth portion of the total central Siberian pine forest annually burns in surface fires. Frequency of past fires varied widely. Fire return interval decreases from north to south in forests of central Siberia. Mean fire return interval is in pine stands:

- in northern taiga (a) - 24.8-39.2 yr.;
- in central Yenisei region (b) - 17.0-22.0 yr.;

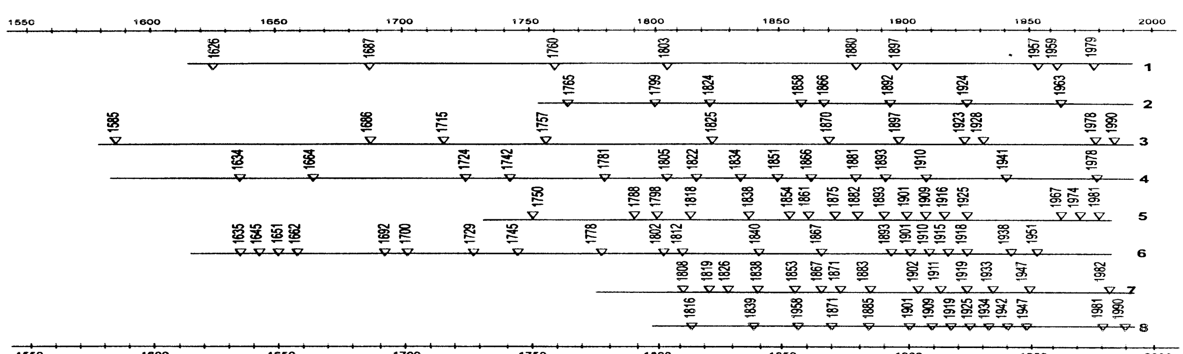

Figure 7. General forest fire chronologies for:

Latitude (N) 64º00' - 60º00'
1 – larch-mixed-green moss-shrubby forest type
2 – pine-mixed-green moss-shrubby forest type;
Latitude (N) 60º00' - 58º00'
3-4 – pine-mixed-herb-lichen forest type;
Latitude (N) 57º00' - 56º00'
5 – pine-mixed-herb-Vaccinium vitis-idaea forest type;
6 – pine-mixed-Vaccinium vitis-idaea-green moss forest type
Latitude (N) 56º00' - 55º00'
7 – pine-mixed – herb forest type;
Latitude (N) 53º00' - 50º00'
8 – pine-mixed – herb forest type;
? - indicates fire dates from fire scars.

- in Angara region (c) - 10.0-17.0 yr.;
- in East Sayan mountains (d, 4) - 11.6 yr.;
- in Krasnoyarsk forest steppe (d) - 6.0-9.3 yr.;
- in southern taiga (e) - 6.5-10.9 yr.

Fire frequency is strongly dependent on landscape characteristics. For example, fire frequency is higher in relatively big mainland areas bordering on each other than in isolated sites, e.g. on islands surrounded by bogs, or in the mountains. Fire return intervals are longer in isolated sites than in big areas. In central taiga pine/lichen stands, for example, they are 80-90 years and 20-40 years, respectively.

Colonizers began to settle in Siberia in 16-17-th cc. It was established that, before 1800 in the central and southern parts and before 1900 in the northern part of the region, fires occurred 4-5 times a century and were dependent mainly on periodicity of dry years. Since then, fire regime response to climate has changed - human activity was growing to become a stronger factor controlling fire regimes as compared with climate. This is because people began to actively cultivate forest lands in the central and southern parts of the region in the 1800's and in the north in the 1930's, when the Trans-Siberian railway was built to result in development of population centers in remote areas.

CONCLUSION

Fire is a major ecological factor in the boreal forest. Forest fires make a considerable contribution to global carbon emissions. Over recent decades, fire return interval has decreased almost twice due to growing human activity. Based on research results, we can expect fire return interval to further decrease under global climate change. All these factors can lead to changes in historically developed forest fire regimes. This, in turn, will result in changes of fire emission contributions to global carbon balance.

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