



Prescribed Burning in Russia and Neighbouring Temperate-Boreal Eurasia

A Publication of the Global Fire Monitoring Center (GFMC)
Edited by Johann Georg Goldammer

Contributing Authors: E. N. Valendik, J. G. Goldammer, Ye. K. Kisilyakhov,
G. A. Ivanova, S. V. Verkhovets, A. V. Bryukhanov, I. V. Kosov, Oyunsanaa
Byambasuren and the FIRESCAN Science Team

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Preface

In the landscapes of temperate-boreal Europe – the western part of the Euro-Siberian region of the Holarctic Floral Kingdom – the prevailing fire regimes are shaped by human-ignited fires. Direct fire application in land-use systems – agricultural burning and burning of pastures – and human-caused wildfires, ignited accidentally, by negligence or otherwise deliberately set, have influenced cultural and natural landscapes since the beginning of land cultivation.

However, in the Central Euro-Siberian region there are large tracts of forest ecosystems that have been shaped by natural fire, e.g. the forests dominated by pine (*Pinus* spp.) and larch (*Larix* spp.) that constitute the “light taiga” in Siberia and adjacent regions.

Starting with the first East-West international conference “Fire in Ecosystems of Boreal Eurasia” and the Fire Research Campaign Asia-North (FIRESCAN) and its “Bor Forest Island Fire Experiment”, organized in Krasnoyarsk, Russian Federation, in 1993, the dialogue between scientists and forestry authorities from Europe, North America and the Russian Federation revealed the rich knowledge of the fire ecology of temperate-boreal Eurasia (Goldammer and Furyaev 1996)¹. The results of the following two decades of joint scientific research, mirrored by numerous publications by the international wildland fire science community, encouraged forest authorities to participate in the dialogue, devise new concepts in fire management and replace fire exclusion policies by integrated fire management approaches, which would include the use of natural fire and prescribed burning (prescribed management fires).

In Part I of this volume fire scientists of the Sukachev Institute for Forest, Russian Academy of Sciences, Siberian Branch, Krasnoyarsk, and the Fire Ecology Research Group at the Global Fire Monitoring Center (GFMC), Freiburg University / United Nations University, Germany, have now summarized experience and provide targeted advice in the application of prescribed fire in advanced fire management.

Part II constitutes a summary of results of the first 19 years of the “Bor Forest Island Fire Experiment” of 1993, a long-term, 200-years experiment designed for the period 1993 to 2192. The participating scientists are large in number, and more will join in future when this project will be handed over to the next generation of fire scientists.

1 Goldammer, J.G., and V.V. Furyaev (eds.). 1996. Fire in ecosystems of boreal Eurasia. Kluwer Academic Publishers, Dordrecht, 528 pp.

Part III summarizes the knowledge of the history and ecology of forest and steppe fires in Mongolia, as well as the first experiences of prescribed burning research and practices in pine forest ecosystems initiated in 2008.

The results of the work published in the first three parts of this volume had considerable impact on the objectives and formulation of the “White Paper on Use of Prescribed Fire in Land Management, Nature Conservation and Forestry in Temperate-Boreal Eurasia”, which was developed by scientists who work together within the Eurasian Fire in Nature Conservation Network (EFNCN), and released in 2010. The White Paper provides rationale and recommendations for the future use of prescribed fire and is published as Part IV of this volume.

Finally, steps are required to convincing forestry and land-use policy makers to consider the scientific evidence and the first achievements in application of prescribed natural and management fires, and to inform the public accordingly. The First International Fire Management Week”, held in Krasnoyarsk, Russia, in September 2012, came up with a number recommendations that point into the direction for integrating the recommendations of the fire science community in policy and practice, including capacity building.

These efforts of advancing fire science and policies have received substantial financial and institutional support by the Max Planck Institute for Chemistry, Germany, the Sukachev Institute for Forest, Krasnoyarsk, the Federal Forest Agency of Russia *Rosleskhoz*, the Aerial Forest Fire Center of Russia *Avialesookhrana*, the German Agency for International Cooperation *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ) and the Federal Ministry for Food, Agriculture and Consumer Protection of the Federal Republic of Germany in the frame of the work of the bilateral Russian-German Cooperation in Sustainable Forest Management. Furthermore the contribution of members of the UNECE Team of Specialists of Forest Fire is acknowledged. The continuing scientific and technical support of Yegor K. Kisilyakhov, Sukachev Institute for Forest, in a number of wildland fire expeditions and field experiments in the Russian Federation and Mongolia, including the preparation of this book volume, has been crucial for the success of international cooperation in wildland fire research.

Most important for the success of the research and the policy dialogue was the contribution of Eduard Pavlovich Davidenko, former Chief of the Science and Technology Department of *Avialesookhrana*. At the stage of finalizing the edition of this book he passed away on 2 April 2013. In recognition of his professional and personal contribution to build a culture of cooperation between fire scientists and fire managers from Russia and other countries this book volume is dedicated to his memory.

Freiburg, Krasnoyarsk, Ulaanbaatar

6 May 2013

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Part I: Prescribed Burning in Russia

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Introduction

The term “prescribed burning” refers to the use of fire in natural environments for different objectives, such as forest and logging site fire hazard reduction, forest regeneration enhancement and elimination of undesired vegetation species and forest pests. Prescribed fires are conducted under environmental conditions that allow to meet fire intensity and rate of spread. As prescribed burning has not been permitted in Russia until recently, there are very little prescribed fire data in the Russian scientific literature. The USA, Canada, and Australia, where prescribed burning has been a common practice since as far back as the early 20th century, provide most scientific insight and experience in prescribed burning. There is an increasing use of prescribed fire in Western Eurasia, notably in nature conservation and management of cultural landscapes (GFMC 2010).

At present, opponents of use of fire in the forest still outnumber its supporters in Russia due to a long-term prescribed forest fire ban and perception of fire as a “disaster” by common people. However, “controlled fire” was recognized as an effective forest management tool by well-known Russian forestry specialists Tkachenko (1931) and Melekhov (1983). A number of foresters share their opinion nowadays. Studying negative and positive fire influences on forest ecosystem components and developing guidelines for the use of prescribed forest fire are the two major fire science priorities (Artsybashev 1984).

Prescribed fire was first used in Russia in 1952 through 1957, in western Siberian dark conifer forests killed by Siberian moth, in an effort to enhance forest regeneration.

Today, prescribed fire is permitted to be used for burning piled logging slash and creating fuel breaks by burning cured grass in treeless sites of the Russian forest fund in non-fire-season time (Anonymous 2007).

The V.N. Sukachev Institute of Forest, in cooperation with the Federal Forestry Committee of Krasnoyarsk Region, tested controlled broadcast burning of logging sites and forest sites damaged by insects or situated close to settlements to reduce fire hazard and stimulate forest regeneration. These fires were conducted in several forest districts as a part of a joint Russian-American project on forest management improvement in Siberia. These experimental prescribed burnings have grown to become a practical forest treatment since 1999. Mobile prescribed fire crews established in five Forest Management Areas (FMA) of Krasnoyarsk Region began to conduct prescribed burning.

The authors of this book tried to analyze the experience gained in prescribed burning so far and they are sure forest research scientists and forestry practitioners will find it useful.

1. Prescribed Burning Background in Russia: A Historical Overview

Cured grass burning was practiced for increasing grazing land productivity in forest-steppe and steppe landscapes of southern Urals, Kazakhstan, Trans-Baikal region, Yakutia, Khakassia, and Tuva as early as in the 5th and 6th Century. Cattle breeders noted that spring burning of cured grass resulted in proliferation of new grass, extended its growing season, and, hence, improved grazing conditions. As uncontrolled grass burning grew in scale and increasingly resulted in forest fires, this practice countrywide became a big problem in the 17th century. To cope with this situation, legal fines were imposed for arsons in the forest and the so-called “agricultural fires”. In the 18th century, Peter the Great promulgated a law that prohibited cured grass burning near forest and in forest glades. People conducting grass burns in areas adjacent to forests and disregarding fire safety rules were fined by penalties (Gaikovsky 1885; Shilov 1889).

Although the agricultural fire ban was extended to cover the entire snow-free period in the early 20th century (Nazarov and Sabinin 1913), agricultural burning still is practiced large scale.

Forest fires drastically grew in extent in Siberia and the Russian Far East in the early 18th century, as peasants from the European Russia began to move to these parts of the country, where they were given free non-forest and forest plots. Peasants burned forest to clear land for building settlements, sowing crops, and grazing cattle. Residents of settlements situated in taiga forest conducted burns in Scots pine (*Pinus sylvestris* L.) stands to increase productivity of red whortleberry (*Vaccinium vitis-idaea* L.) sites and in deciduous stands to improve conditions for bee keeping. Importantly, burning was done under control of peasant communities. This was actually when prescribed fire was started to be used for agricultural purposes.

In Russia, use of prescribed fire has always raised contradictory attitudes, from its full support to absolute aversion. Positive forest fire influence, namely, fire-caused increase in Scots pine stand regeneration rate, was noted as long ago as the beginning of the last century (Tkachenko 1911; Turin 1925). Therefore, it was concluded that fire could be used as a forest management tool (Tkachenko 1931) and first steps were taken in using fire as a tool to enhance forest regeneration (Kazansky 1931).

Clearing logging site from slash by fire was first approached scientifically in Karelia, European Russia, with burning methodologies and effective use manpower being the two

priorities. As a result, logging slash was burned on logging sites accounting 8% of the total Karelia's logging area. Prescribed fire tests showed that logging site clearance methods, such as post-logging burning of piled logging slash, piling logging slash and leaving the piles stay without burning, and burning of logging slash in the course of forest harvesting, failed to meet forest management requirements. Broadcast burning of logging slash and its burning on plots where logging slash occurs were introduced later. With broadcast burning, logging sites and remaining in-site seed tree pockets were recommended to be surrounded by 30-meter wide fire lines prior to burning. With the later method, firelines were established around logging sites and the plots were earthed up (Davydov 1934).

Pobedinsky (1955) reported that mineral soil can account for up to 40% of the total logging site area as a result of logging slash burning as compared to 5-10% resulting from logging itself. Mineral soil surface stimulates both natural forest regeneration and planted woody species growth. Logging slash burning should be conducted in summer, on calm days, at high slash moisture content on clearcuts having no healthy regrowth.

Belov (1973) proposed controlled burning in mature Scots pine and larch stands, as well as in those approaching maturity (5-10 years before logging) in order to ensure pre-logging forest regeneration. Also, he believed that burning of deep forest floor organic layer and feather moss layer can result in decreasing forest fire hazard for as long as 20-30 years, which decrease is beneficial for future forest generations. Burning of natural vegetation on permafrost increases soil thaw depth. Fires of moderate intensity were found to favor Scots pine stand development, provided that the mean fire interval (MFI) is 40-50 years (Belov 1973).

Melekhov (1983) considered prescribed fire as an important tool to achieve forestry objectives. He recommended to conduct fire-hazard-reduction controlled fires in Scots pine and larch stands aging 40-50 and older, when trees become fire resistant.

In Siberia, particularly in Krasnoyarsk Region, controlled fire was used by Prozorov (1956) to eliminate pine looper (*Bupalus piniaria* L.) pupae from the forest floor and reduce thereby the population of this forest pest. In this effort, litter and forest floor organic matter were broadcast burned or piled and then burned.

About four million hectares of dark conifer forests were damaged by Siberian moth (*Dendrolimus superans sibiricus* Tschetw.) in western Siberia in 1952-1957; thereof 40,000 hectares were completely killed forest (Furyaev 1966). This area was annually subjected to large forest fires that disturbed economical activities. Not one of all the costly efforts made to suppress these fires ever succeeded. Furyaev proposed to treat the Siberian moth-damaged conifer forest area with controlled fire in attempt to enhance forest regeneration. The USSR Ministry of Forestry approved the recommendation of Sukachev Institute of Forest not to suppress but contain wildfires in this area in order to prevent their spread into adjacent forest stands for 20 years. These activities led to forest regeneration resumption through woody species conversion only 18 year following the Siberian moth outbreak. This damaged area was colonized by deciduous species, such as birch and aspen, with fir, spruce, and Siberian pine seedlings occurring under their canopy.

Prohibition of prescribed burning on logging sites had negative consequences for forest protection and hampered forest regeneration drastically. As a result, thousands of hectares of treeless logging sites have high loads of logging slash and are covered by tall grasses. Windfall and infestation by Siberian moth and over-stocked light coniferous stands are commonly found. Fires occurring on these types of sites are particularly destructive, and post-fire forest regeneration is hampered for decades due to extreme severities.

Up to 70% of all wildfires begin on logging sites from where they are spreading to adjacent forests. In this situation, any forest restoration efforts are often jeopardized. Logging sites remain highly flammable during 3-4 months due to fuel overloading. Even prolific new green grass and shrubs fail to reduce high fire hazard on logging sites (Valendik et al. 2000).

Experience gained by other countries show that prescribed burning can be effective in reforesting logging sites and reducing their fire hazard levels. Fire burns logging slash and, hence, adds nutrients to soil that are available for plant growth. As a result, woody seedling vigor and competitive ability increases. Additionally, logging slash burning reduces the risk of invasion of xylophagous insects to neighboring stands.

It should be noted that wildfire suppression is very expensive, whereas controlled vegetation residue burning is nowadays the only effective and economical method to clear logging sites, stimulate forest regeneration, and prevent high-intensity fires.

The V.N. Sukachev Institute of Forest has conducted test underburning and prescribed fires on logging sites (Valendik et al. 1997; Valendik 1998; Valendik et al. 2000, 2001) and sites defoliated by Siberian moth (Valendik et al. 2006, 2007) in cooperation with Krasnoyarsk Regional Forest Committee since 1996.

These prescribed burning tests should be replicated in a range of natural environments to gain experience sufficient for developing prescribed fire use legislation.

2. Fire Regimes of Siberian Forest Regions Covered by Prescribed Burning

The current boreal forests of Eurasia have been shaped, among other factors, by fire (Goldammer and Furyaev 1996). At present, every Siberian forest stand has signs of at least one wildfire (Buzykin 1975). Since Siberia is a vast area containing several vegetation zones, it encompasses a wide diversity of climatic conditions and forest growing environments. Therefore, forest fires occur annually in different parts of this region. The general atmospheric circulation characteristic of this region, its great extension, remoteness from oceans, and complex orography are the main factors controlling Siberian climate. This is extremely continental climate, with continentality increasing west-eastward (Shumilova 1962).

Two types of fire regimes can be identified in Siberia (Valendik and Ivanova 2001). A fire regime characterized by a long MFI is common in western Siberian boggy dark conifer forests, and a short-MFI fire regime is dominating in low-mountain light conifer forests of eastern Siberia.

Severe droughts initiate exceptional fire seasons, when numerous fires occur simultaneously and produce large fires (Valendik 1990; Valendik and Ivanova 1996; Ivanova 1996; Furyaev 1996). As a result, extended wildfires occur. Fire seasons characterized by numerous forest fires have become frequent in certain parts of Siberia (the 2003 fire season in Irkutsk and Trans-Baikal regions, the 2006 fire season in Yakutia and Krasnoyarsk region). Extreme, largely climatically-driven fire situations are usually uncontrollable. These situations cover big areas, cause great economic losses, and threaten people's lives and property.

A fire regime is characterized by fire frequency, size, seasonality, and intensity (Crutzen and Goldammer 1993). Fire frequency expressed by fire interval is the number of fires that occurred in a given forest stand or area within a given period of time. The MFI has both direct and indirect influence on plant species life cycle, vegetation structure and species composition, and forest fuel accumulation rate.

Information on past fire regimes can be obtained from dendrochronological analysis. Fire scars, i.e. signs of surface fires visible in the lower parts of tree stems, provide past fire data. Past fire chronologies can be obtained by cross-dating series of fire scars (Melekhov 1947; Molchanov 1976; Madany et al. 1982). Fire scars are indisputably useful because they

allow us to reconstruct fire chronologies as far back as 300-500 years (Swetnam 1993) and date them to year and even to season.

Expected climate change is presumed to result in changing forest fire frequency (Kasischke et al. 1995; Goldammer and Price 1998). Fires are predicted to increase in frequency and extent and, hence, in their impact on vegetation in boreal forest ecosystems (Weber and Flannigan 1997). However, regional- and local-scale prediction of future fire regimes is problematic, as they will depend on probable changes of fire suppression methods and ignition sources, such as increasing lightning activity (Flannigan and Wotton 1990).

Human activities have marked impacts on fire regimes. Fire statistics for several recent years shows that human-caused fires account for over 85% of all forest fires in Russia. Although efforts are made to control fires, no noticeable reduction of Russia's annual area burned has been achieved (Korovin 1996). While there is much evidence that increasing fire frequency is a result of human activities, this frequency trend can also be attributed to changing weather conditions and forest fire management strategies. Burned area is dependent on changes of mean fire interval (MFI), which changes have a profound effect on boreal forest fuel accumulation (Kasischke et al. 1995). This dependence allows to conclude that fire regimes are greatly influenced by both human and climatic factors and that knowledge of fire regimes is critical for estimating ecosystem ecological state and predicting fire occurrence.

2.1. Research Methods

Central Siberian forest fire activity was evaluated using fire records and area burned data provided by the Aerial Forest Protection Service *Avialesookhrana*. Spatial and temporal patterns of fire seasons were analyzed in terms of indicators of the regional forest fire activity and extreme fire situation development. To do this analysis, the data on large forest fires from 1947 through 2003 were used. Dendrochronological analysis helped to reveal fire periodicity and MFIs for Siberian larch and Scots pine, the two major woody species of central Siberia that have distinct tree rings and well-pronounced early and latewood. Also, these species enjoy long life cycles, although larch trees older than 150 years often suffer from butt rot.

Full tree cross sections were taken to date past fires using a conventional methodology (Madany et al. 1982) that enables fire dating by cross dating of the dendrochronological data obtained. Fire dates identified on the collected tree slabs were united to build past fire composites (Madany et al. 1982; Baisan and Swetnam 1990; Caprio and Swetnam 1993), which allowed us to obtain highly accurate fire dates for the forest sites of interest. The fire chronologies obtained were used to determine characteristics of the regional temporal fire activity variability, such as MFI, MFI standard deviation, and fire periodicity. MFI was calculated as a ratio between the length of the composite chronology obtained and the number of fires recorded over the period of time covered by the chronology.

2.2. Forest Fire Activity in Central Siberia

Forest fires occur annually in Siberia. Three types of fire seasons are characteristic of central Siberian forests: (1) a short and continuous fire season with very high fire activity during 1-3 months common in northern and central taiga forests; (2) a long fire season with fires periodically occurring during 4 to 6 months in the southern taiga; and (3) a fire season with two fire activity peaks, a spring and fall, prevailing in southern mountain regions (Valendik 1990).

Our analysis of the forest fire distribution by vegetation zone between 1986 and 2000 showed that the biggest number of fires and area burned occurred in southern taiga (Figure 1), where most Scots pine stands and logging sites rapidly becoming highly flammable are found.

Number of fires reaches its maximum in June-July and July in the northern and central taiga subzones, respectively, whereas two fire activity peaks (in May and July) are observed for southern taiga. In the subtaiga and forest-steppe zones, the biggest number of fires occurs in May, after snowmelt, in forest stands with grass-dominated ground vegetation. However, fires can occur in these zones throughout the growing season in dry years.

Periodical extreme fire seasons are common in Siberia. Their onset is usually indicated by large forest fires occurrence following long droughts. In this case, vegetation characteristics become unimportant, because forest fire can spread over any forest site type under drought.

A 10-day rainless spell is the critical period of time in spring. Large forest fires can occur across Siberia's entire forest area. These fires occur in different parts of Siberia after 30 days of drought and 66 to 100% of all fires occur following 40-50 dry days. Large fires are few in fall (Valendik 1990).

Forest fire periodicity refers to their temporal distribution within a given area depending on periodical climatic changes, such as alternation of dry and wet periods of time. Time needed for forest fuel to build up to a critical level and its occurrence across a given area also control fire temporal pattern (Kurbatsky 1964).

Past fire dating provides a possibility to determine natural fire regimes in certain forest stands or landscapes. Comparison of fire occurrence data with tree-ring chronologies obtained for Scots pine stands of central Siberia revealed that responses of fire regimes to climate has changed since 1880. Fire occurrence closely correlated with dry years before, whereas human activity became an important fire regime control after 1880 due to building of the Trans-Siberian main line followed by active settlement of the area (Swetnam 1996). Increasing human influences have resulted in decreasing fire interval in southern taiga Scots pine stands (Vaganov et al. 1996).

We reconstructed past fires for southern taiga and forest-steppe Scots pine stands found where prescribed burns were conducted. Slabs of trees with fires scars taken on forest sites in Lower Angara region, Krasnoyarsk forest-steppe zone, and eastern Sayan Mountains (the sample site locations are shown in Table 1) allowed us to reconstruct fire chronologies as far as over 400 years back.

2.3. Past Fire Chronology Reconstruction for Scots Pine Stands of the Southern Taiga Subzone

Current forest age structure is largely a result of fire in Angara region (Buzykin 1975). While even-aged light coniferous stands usually occur after catastrophic (crown) fires, surface fires account for uneven-aged forest stand establishment.

To study forest fire periodicity in Lower Angara Scots pine stands, southern taiga, Scots pine stands with feather moss- and grass-dominated ground vegetation were chosen, as these stands represent the two major forest types in this region. Fires were reconstructed for a Scots pine/feather moss/red whortleberry stand found on the right bank of Angara river for the past 420 years (Table 1, Site 1, Figure 2).

Several sample trees recorded 10 to 12 fires. The past fires reconstructed for this site totaled twenty. MFI was calculated to be 21.1 years. Seven fires were recorded by 30% of all trees on the site, with an MFI of 39.4 years, and five fires scarred 50% of trees (MFI was 55 years) between 1672 and 1951. Most of sample trees recorded the 1774, 1798, 1832, and 1948 fires, indicating thereby that fires occur here every 58 years on average. It can thus be concluded that the landscape MFI was 39 years on Site 1 during the above period of time.

Twenty three past fires were found in a Scots pine/feather moss/small shrub stand (Sites 2 and 2a) situated on the right Angara bank for the period between 1537 and 1998. MFI appeared to be 20.0 years here. Scars of six fires were observed in 30% of all trees (an MFI of 31.8 years), and four fires left scars in 50% of all trees (once every 48 years on the average). The landscape-scale MFI was found to be about 32 years here over the past 300 years. Before Angara region began to be settled (i.e. before 1750), MFI was 71 years, whereas it decreased 3-4-fold after this area had been settled. Although forest fuel has accumulated to large amounts, MFI has shown a trend to increase over recent decades. This increase might be a result of timely fire detection and suppression.

Past fire reconstruction period and number of fires varied considerably among four sites (Sites 3-6) established in Scots pine stands with herbs in ground vegetation found at the southern taiga boundary with the forest-steppe zone, the left bank of Angara river. The biggest number of fires identified on these sites was 30 and MFI was calculated to range 12.3 to 20.7 years. As these Scots pine stands experience severe human impacts, they are subject to fire much more often as compared to southern taiga.

MFI decreases proceeding from north to south in the southern taiga subzone. MFI appeared to be 18.0-28.0 years near Boguchany village, the right bank of Angara river, whereas it was found to range 12.3 to 20.7 years near the village of Taseyevo, about 200 km south of Boguchany. These short MFIs are attributable to almost continuous forest cover and intensive human activities, which contribute to the amount on ignition agents. A study conducted in Angara region (Vaganov et al. 1996) revealed a human-caused decrease in fire intervals.

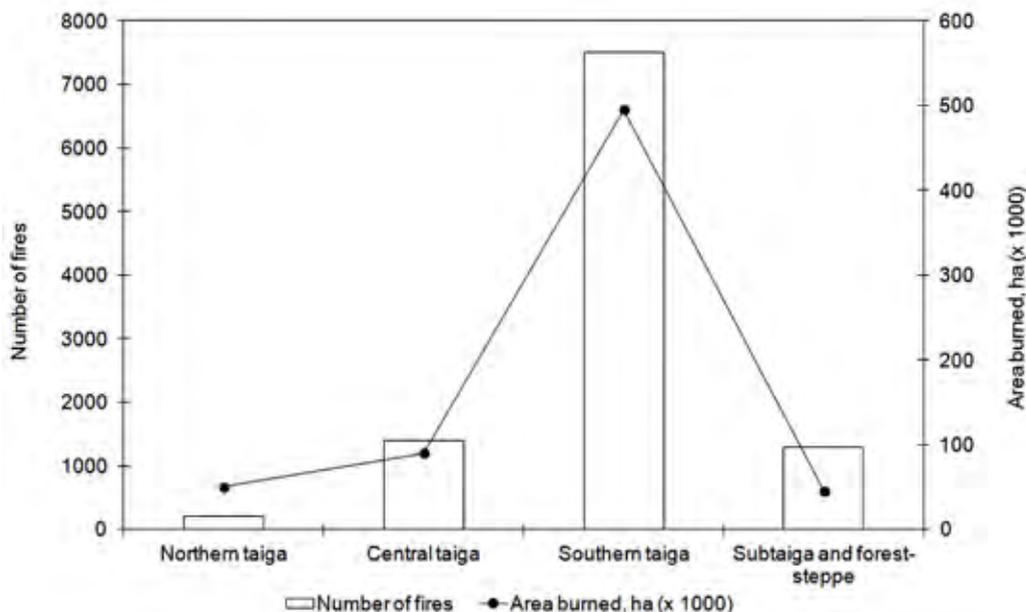


Figure 1. Distribution of fires and area burned by vegetation zone in central Siberia (1986-2000)

2.4. Reconstruction of Past Fire Periodicity in Forest-Steppe Scots Pine Stands

Forest fire periodicity was studied in Yukseyevo Scots pine stand located in the north of Krasnoyarsk forest-steppe. This stand includes several forest types, such as Scots pine/herb/red whortleberry, Scots pine/sedge/herb, and Scots pine/feather moss/herb types.

Full tree stem cross-sections containing fire scars were taken in two parts of the stand (Site 7). Several trees appeared to record up to 11 fires between 1845 and 1997, with the oldest fire scar in 1880. While a number of fires scarred all sample trees, other fires were recorded by only one of our sample trees. A possible explanation of the latter is that fire intensity varied due to variability of fuel loading and weather conditions and, as a result, fire damaged trees to different levels. Moreover, fire is known to be able to spread in a part or across a forest stand depending on living ground vegetation species distribution and moisture content. MFI was found to be 10.1 years for the stand of interest. The fires that left their signs on trees were recorded here before 1983. Although fires did occur here after 1983, they did not burn deep into the forest floor organic layer or were suppressed by forest protection service when small. For example, the last fire that occurred in 1995 was small in size and left no scars in trees.

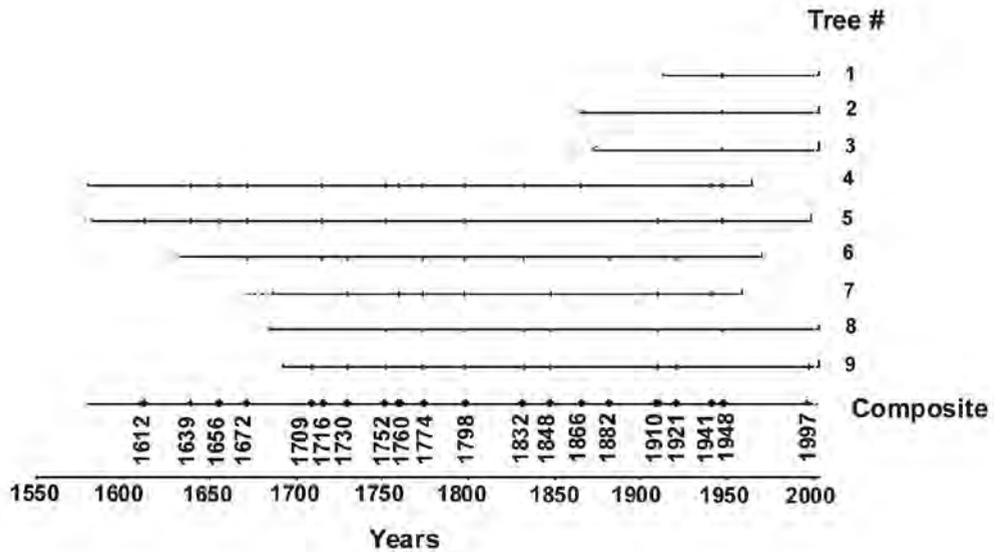


Figure 2. Forest fire chronology obtained for a Scots pine/feather moss/red whortleberry stand, Lower Angara region (Site 1 in Table 1)

A fire scar analysis done for a Scots pine/feather moss/herb/ stand adjacent to Masleyevo lake (Site 8), Kansk forest-steppe, revealed 23 fires from 1705 to 1994. MFI was calculated to be 12.1 years. Masleyevo lake has long been a recreation and, hence, a high-fire-risk area.

Fourteen fires were identified based on fire scar analysis for a Scots pine/feather moss/red whortleberry stand (Site 9) situated in Krasnoyarsk forest-steppe, 50 km south of Yukseyevo stand, over the period between 1880 and 1998. MFI was calculated to be 8.4 years here.

MFI ranges 8 to 12 years in forest-steppe Scots pine stands close to villages, fires occurring mainly in spring and early summer. Only 5% of all fires occur in mid- and late summer and fall. High fire frequency characteristic of these stands is attributed to both dry spells and strong human impacts.

2.5. Reconstruction of Fire Chronologies in Mountain Scots Pine Stands

We built a past fire chronology for two Scots pine stands found in Mana river basin, eastern Sayan Mountains. One is a Scots pine/sedge/spiraea (*P. sylvestris*, / *Carex* spp. / *Spiraea alba*) stand growing on a 20-degree southeast-facing slope (Site 10) and the other is a Scots pine

stand with herb-dominated ground vegetation located on a 30-degree south-facing slope (Site 11). Rock outcrops are common on both slopes. The sample sites are moist, as they receive much precipitation.

The Scots pine/herb stand site conditions are more xerophytic. Eleven fires (1782, 1800, 1819, 1834, 1851, 1871, 1884, 1902, 1921, 1931, and 1954) were identified for this stand using fire scars between 1748 and 1998. MFI appeared to be 22.7 years, which interval is typical under these conditions.

A fire scar analysis done for the moister Scots pine/sedge/spiraea stand allowed to identify fires in 1808, 1819, 1826, 1838, 1846, 1853, 1857, 1871, 1883, 1902, 1911, 1919, 1933, 1947, and 1982 for the period from 1782 to 1998, with MFI being 14.4 years. MFI has decreased here twice over the past two centuries due to the close proximity of this site to a settlement.

As is evident from fire scar examination, fires occur usually in late May-early June under these conditions. A particular feature of Scots pine stands growing on south-facing mountain slopes is that they rapidly become highly flammable and stay in this condition both under drought and throughout the entire fire season. Well-pronounced mountain relief and considerable ground fuel amounts favor high-intensity forest fire development. However, many fires spread as spot fires and scar very few trees. This is presumably due to the presence of rock outcrops that serve as fire barriers.

The sample stand structure was determined to have been influenced by fire. The Scots pine/herb stand consists of trees of several age groups, which resulted from fires that occurred here in different years. Trees of 180 years of age established after the 1819 fire make up the major tree age group in this stand. The oldest trees dying nowadays are 215 years old. The presence of old trees might be attributed to fire characteristics. High-intensity surface fires usually spread upslope and they become crown fires only where the forest canopy is vertically closed and woody regrowth is present, i.e. there exists a fuel ladder. Stone outcrops often prevent crown fire occurrence.

The MFI depends on conditions of forest growing and ranges between 15 and 24 years in eastern Sayan and southern taiga Scots pine stands. This period of time is sufficiently long for forest fuel accumulation to the critical level. In dark coniferous forests the MFI is 90-120 years. These MFI values have presumably been characteristic in mountain forests over the past five or six centuries.

MFI varies depending on latitude, topography, site conditions, and human influence in central Siberian Scots pine stands and decreases north-southward.

MFI is determined by fire season duration. For example, MFI is 47.2 years at the northern Scots pine range boundary, central taiga, where fire season lasts for 65 days. Further south, MFI decreases to 35 years, with fire season increasing to 100 days. It should be noted that MFI is shorter (20-40 years) on non-isolated sites, where fire can come from adjacent areas, as compared to isolated sites (up to 97 years) (Ivanova et al. 2007).

Fire season increases to 110 days and MFI ranges 18.0 to 28.0 years in Scots pine stands with ground vegetation dominated by feather moss or small shrubs found at the northern

boundary of the southern taiga subzone. Further south, fire season is 120 days long, human impact increases, and MFI decreases to 12.3-20.7 years.

Forest type also controls MFI. Fires occur most frequently in Scots pine/lichen stands found on sandy soil and loamy sand. Here, MFI is twice less than in Scots pine stands with ground vegetation dominated by herbs and red whortleberry or feather moss.

Fires occur annually in central Siberia. The fire regime of this region is characterized by frequent low-intensity surface fires, while high-intensity fires occur only in exceptional fire seasons. The data we obtained and other research scientists' data allow us to conclude the identified spatial fire dynamics, including MFI and fire season, has prevailed in this region over the past five centuries.

Table 1. Characteristics of the forest fire chronologies obtained for central Siberian Scots pine stands

Site #	Site location	Forest type	Study period, years	Fire years	MFI, years
The southern taiga subzone					
1	Angara river basin, Lower Angara region, 58°42' N, 98°25' E	Scots pine/ feather moss/ red whortleberry stand	1580-2003	1612, 1639, 1656, 1672, 1709, 1716, 1730, 1752, 1760, 1774, 1798, 1832, 1848, 1866, 1882, 1910, 1921, 1941, 1948, 1997	21.1
2	Irkineyevo river basin, Lower Angara region, 58°41' N, 98°18' E	Scots pine/ feather moss/ small shrub stand	1602-1999	1617, 1678, 1744, 1760, 1771, 1779, 1798, 1812, 1823, 1840, 1848, 1860, 1864, 1878, 1885, 1888, 1905, 1915, 1927, 1951, 1959, 1987	18.0
2a	Irkineyevo river basin, Lower Angara region, 58°41' N, 98°18' E.	Scots pine/ feather moss/ small shrub stand	1691-1999	1744, 1798, 1812, 1823, 1848, 1860, 1878, 1888, 1905, 1915, 1951	28.0
3	Bakchet river floodplain, Lower Angara region, 57°05' N, 94°56' E	Scots pine/herb/ sedge stand	1808-1994	1819, 1883, 1899, 1908, 1925, 1946, 1954, 1978, 1990	20.7

4	Bakchet river flood-plain, Lower Angara region, 57°01' N, 95°05' E	Scots pine/red whortleberry/herb stand	1713-1994	1750, 1788, 1798, 1818, 1838, 1842, 1854, 1864, 1875, 1882, 1893, 1901, 1909, 1916, 1925, 1967, 1974, 1981	15.6
5	Bakchet river flood-plain, Lower Angara region, 57°02' N, 95°10' E	Scots pine/tall grass/herb stand	1725-1994	1752, 1800, 1828, 1848, 1861, 1873, 1892, 1899, 1910, 1915, 1929, 1935, 1945, 1957, 1969, 1987	16.8
6	Bakchet river flood-plain, Lower Angara region, 57°04' N, 95°00' E	Scots pine/red whortleberry/herb stand	1624-1994	1635, 1645, 1651, 1662, 1692, 1700, 1716, 1725, 1729, 1745, 1778, 1797, 1802, 1809, 1818, 1840, 1847, 1859, 1867, 1874, 1884, 1893, 1901, 1909, 1915, 1918, 1926, 1938, 1951, 1959	12.3
The forest-steppe zone					
7	Yukseyevo Scots pine stand, Yenisei river terrace, Krasnoyarsk forest-steppe, 56°51' N, 93°25' E	Scots pine/sedge/herb stand	1845-1997	1880, 1896, 1899, 1903, 1911, 1916, 1921, 1926, 1929, 1935, 1944, 1946, 1953, 1961, 1983	10.1
8	Masleyevo lake, Kansk forest-steppe, 57°00' N, 95°13' E	Scots pine/feather moss/herb stand	1715-1994	1738, 1751, 1784, 1791, 1800, 1804, 1813, 1828, 1837, 1847, 1863, 1873, 1880, 1900, 1904, 1908, 1915, 1928, 1936, 1948, 1954, 1970, 1980	12.1
9	Pogorelsky Scots pine stand, Krasnoyarsk forest-steppe, 56°23' N, 93°00' E	Scots pine/feather moss/red whortleberry stand	1880-1998	1891, 1898, 1909, 1911, 1917, 1925, 1929, 1932, 1934, 1939, 1943, 1946, 1958, 1978	8.4
Mountain forests					
10	Talovka river valley, Sayan foothills, 55°20' N, 93°14' E	Scots pine/sedge/spiraea stand	1748-1998	1782, 1800, 1819, 1834, 1851, 1871, 1884, 1902, 1921, 1931, 1954	22.7
11	Zherzhul river valley, Sayan foothills, 55°21' N, 93°17' E	Scots pine/herb stand	1782-1998	1808, 1819, 1826, 1838, 1846, 1853, 1867, 1871, 1883, 1902, 1911, 1919, 1933, 1947, 1982	14.4

3. Prescribed Burning of Logging Sites in Plain and Low-Mountain Dark Coniferous Forests

3.1. The Region of Interest

Prescribed fires and their estimation regarding environmental effects were done in central Siberian southern taiga dark conifer forest stands found in plains and low mountains. Descriptions of this region were taken from the following literature sources: Volobuyev (1960), Galakhov (1964), Gerasimov (1964), Yerokhina and Kirillov (1964), Zhukov et al. (1969), Lapshina et al. (1971), Smagin et al. (1977), Babintseva and Cherednikova (1983), Gorbachev and Popova (1992), and Atlas of Krasnoyarsk Region (1994).

The region of interest encompassed the Angara-Kan part and Angara Lowland of Yenisei Mountain Ridge. Yenisei Mountain Ridge is a low-mountain massif found at the western edge of Central Siberian Plateau. This mountain massif stretches, as a fairly narrow strip, along Yenisei river, north of Trans-Siberian Main Line. Regarding topography and tectonic features, the region can be divided into three parts: northern the (trans-Angara), Angara Lowland, and the southern (Angara-Kan).

The Angara-Kan part is a folded region dissected due to the latest block lifts (Volobuyev 1960). The highest elevation (550-660 m a.s.l.) was measured at the axis of the mountain ridge. The massif is characterized by flat-top, heavily dissected mountain relief with denuded chimney rocks and rocky crests.

The eastern slope of Yenisei mountain ridge is soft, heavily dissected, and has small flat-convex ridges. Its western slope is also diverse in topography.

Angara Lowland (Kazachinsk Depression) is found at the northern boundary of the mountain ridge. This area includes flat watersheds dissected by small flat-bottom valleys at places. Angara and Yenisei river terraces can be clearly seen.

Although climate prevailing over Yenisei mountain ridge is continental, it is milder than in other parts of central Siberia found at the same latitude. The ridge receives 450-600 mm

of precipitation annually, as compared to 300-400 mm in Kan hollow (Galakhov 1964; Atlas of Krasnoyarsk Region 1994).

No dry spells occur in the southern part of Yenisei mountain ridge due to steady, fairly high air humidity in summer and a long-standing deep snow layer in winter (Lapshina et al. 1971).

Angara-Kan part of Yenisei mountain ridge reflects soil and vegetation characteristics observed in the southern taiga subzone.

The southern Yenisei mountain ridge soil cover is represented by podzolic soils (Lapshina 1971), which stay frozen for a long time, however, no permafrost is present (Yerokhina and Kirillov 1964). While soil horizons are hard to distinguish in the upper parts of slope, they appear to be quite distinct in the lower parts.

Apart from podzolic soils, grey forest soils having a fairly high fertility potential underlain by loamy sand and loess-like loams can be found under dark coniferous woody canopy in Kazachinsk Depression.

3.2. Vegetation

Today's vegetation cover of Yenisei mountain ridge reflects diverse effects of its geomorphologic, lithologic, and climatic conditions. Yenisei mountain ridge towering above West Siberian Plain receives a considerable amount of precipitation carried by Atlantic air masses and is, therefore, a natural precipitation break. The air and soil thermal regimes of the Yenisei-side part of Central Siberian Plateau experience a noticeable warming effect of Yenisei and Angara stream water (Gorbachev and Popova 1992).

The western macro-slope of Yenisei mountain ridge is characterized by multi-dominant taiga woody vegetation cover. Its structure, as well as species composition of ground vegetation is almost the same as in western Siberia. However, bog vegetation is not as abundant here as in western Siberia. The downwind eastern macro-slope is under more continental climate than the western slope and its vegetation composition is fairly similar to that of light conifer taiga forests of central Angara region.

Dark coniferous taiga forest vegetation of the western macro-slope is dominated by Siberian fir, because the slope environmental conditions are most favorable for this woody species, Siberian pine (*Pinus sibirica* Du Tour) and spruce occurring as co-dominants (Figure 3). Scots pine (*Pinus sylvestris* L.), Siberian larch (*Larix sibirica* Ledeb.), Asian white birch (*Betula pendula* Roth), and European aspen (*Populus tremula* L.) can also be found in these stands, with the contributions of the latter two species varying widely, from few individuals to 20-30% of the total number of trees of a stand. These stands are multi-dominant, well-stocked, and have closed woody canopies.

The eastern macro-slope that faces Kan hollow promotes Scots pine due to increasing climate continentality and decreasing humidity. Dark coniferous stands are limited to valleys and lower parts of non-south-facing (i.e. shaded) slopes.

Today's forest cover of Yenisei mountain ridge has a markedly complex pattern. Ecosystems differ in dynamic state. The major fir/spruce and fir/Siberian pine stands remained in the main watershed and someplace in the axis part of the ridge, whereas a considerable area is now under secondary forest stands representing different stages of the major woody species regeneration. Forests of Yenisei mountain ridge have experienced intensive logging with the use of heavy machinery. These logging practices have negative impacts on forest regeneration. Different forest regeneration stages were identified on logged sites.

Mountain taiga dark coniferous forests consist largely of mixed fir/spruce or spruce/fir stands with Siberian pine as a minor woody component and ground vegetation dominated by herbs (Babintseva and Cherednikova 1983). Fir and spruce stands with feather moss (*Hylocomium splendens* Hedw.) /short grass- or reed grass (*Calamagrostis obtusata* Trin.)-dominated ground vegetation found on flat interfluvial sites are the most common forest types. These are mostly uneven-aged two-storied high-productivity stands of varying tree density and canopy closure ranging 0.5 to 1.0. Minor woody components are represented by spruce (up to 40% of the total tree numbers), Siberian pine (10-20%), and aspen (10-20%). The major woody species regeneration is fairly good, 12-18,000 individuals, mainly fir, per hectare. Siberian pine and spruce seedlings are taller and occur in canopy gaps. Few boggy fir stands with tall grasses as ground vegetation, Siberian pine/tall grass, spruce / reed grass, spruce/feather moss, Scots pine/sphagnum, and Scots pine/lichen stands are also present.

Although these forests are characterized by generally low fire activity, forest harvesting presents a big problem in terms of forest fire protection. Logging sites increase in size year-to-year and, as a result, high-fire-hazard area and fire protection costs also increase. This is especially true with dark coniferous forest logging sites found on south-facing slopes, on which sites grasses proliferate. Fire is highly probable on these sites right after snow melting. Therefore, young woody regeneration growing on logging sites not covered by fire prevention measures is highly threatened by potential fire.

As fuel loading is great here (up to 70 t/ha), these sites stay highly ignitable during three or four months and even abundant green grasses and shrubs fail to reduce this high fire hazard level. Fires starting on these logging sites burn freely into the surrounding forest stands. For this reason, developing measures to reduce fire hazard on logging sites is a challenging task of the highest priority.