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Prescribed Fire Experiments in Krasnoyarsk Region, Russia

In Russia understory burning and prescribed burning on logged areas are prohibited for use. All forest fires starting on forested areas and logged sites obligatory should be suppressed immediately. However, many scientists had been noted about positive effects of surface fires and offered different kind of their use in silviculture. Starting from 1996 experimental prescribed fires in slash fuels in Siberia have been conducted under the auspices of the Russian-American Central Siberian Sustainable Forest Management Project. High load of slash fuels is the main cause of logged areas high fire danger. Often wildfires start on logged areas and then move to surrounding forests. Mechanical removal of slash fuels practically impossible due to the labour-consuming character and the absence of suitable equipment. Removal of natural forest and slash fuels using broadcast burning on logged areas starting from 1996 by 2001 in area summed more than 900 ha in Krasnoyarsk Region (Central Siberia) allow to solve 3 main issues. First, logged area fire danger fully disappears during 2-3 years and it is very low during 5-10 years after prescribed burning. Second, prescribed burning creates conditions for natural and artificial regeneration. The last involves planting seedlings or sowing seeds. Third, prescribed fire exclude soil erosion inherent in mechanical treatment and strengthen fireweed growth favouring the development of coniferous seedlings. Along with fires starting from logged sites wildfires in forests damaged by pests represent big problems for foresters and forest fire fighters. Mechanical treatment and prescribed fire were used to restore a mixed conifer stand (*Picea-Abies-Pinus*) following mortality from an outbreak of Siberian moth (*Dendrolimus superans sibiricus*). Moth-killed stands often become dominated by *Calamagrostis*, a sod-forming grass. The large amount of woody debris and the sod hinder coniferous seedling establishment and development as well as creating conditions favourable to the establishment and spread of wildfires. Fire has been demonstrated to be an effective method of reducing woody debris and eliminating sod, but the random nature and timing of wildfires often do not create conditions favourable for conifer regeneration. Following treatment, the potential for wildfire was reduced and the area was suitable for either natural conifer regeneration or planting without further mechanical site preparation. Also fires in wildland-urban interface have great potential to be catastrophic due to high forest fuels load after many years of intensive suppression policy. These kind of catastrophic fires occur not only in Eurasian boreal forests but also in other forests of our planet. People can be injured in fire, homes and properties could be destroyed not only in small populated areas but small cities. Experimental prescribed understory burns had been carried out to decrease surface fuel load and to remove regeneration thickets having high potential for crown fires. It was established that creation of park like forest stand without regrowth and understory with minimal surface fuel load near populated areas will help to exclude catastrophic forest fires.

Introduction

Fires in forests of Siberia always have been as constantly active factors of forests shaping and their biodiversity. In most cases they define plant types and their dynamics. Due to many studies each forest plant formation has "fire regime" characterized by definite fire type and its intensity, fire frequency, levels of biogeocenosis destruction and its post fire recovery dynamics. In Russia it was the common practices of spring burning, firing for berries and honey production, burning to flush pasture and assist hunting (Pyne, 1997). The history of forestry shows a wide use of fire as understory “refreshing” measure for fuel reduction and stimulation of mushroom growth, as well as for fuel reduction burns on logged areas by broadcast burning (Tkachenko, 1931). Until the middle of the 20th century the use of fire in Russian forest management was almost fully forbidden, with the exception of slash burning on piles during the winter period.

However, positive influence of surface fires on a forest had been noted in the beginning of last century and it was offered to use fire as helpful instrument for planting (Tkachenko, 1911). Some authors offered prescribed fires for broadcast burning of slash fuels after logging (Pobedinsky, 1955), understory burning in mature pine stands 5-10 years before logging (Belov, 1973), surface fire using as thinning instrument of pine saplings (Furyaev, 1974), broadcast prescribed understory burning of pine and larch stands of 40-50 years for wildfire hazard reduction (Melekhov, 1983). But in a reality these studies were only as recommendations and the use of understory burning and prescribed burnings on logged sites were prohibited. Only after 1995 the use of early spring burns in grass fuels near roads had been permitted to mitigate fires starting near roads during fire season (Valendik, 1996).

The new era of fire use in forestry of Russia encouraged foresters and scientists to look for more effective and cheap methods of cleaning logged areas and facilitating reforestation. Following the large basic scientific experiment and a regional fire analysis in the frame of the Fire Research Campaign Asia-North (FIRESCAN) in Krasnoyarsk Region in 1993 (FIRESCAN Science Team, 1996; Goldammer and Furyaev, 1996) the development of prescribed burning techniques was supported by international projects, such as Sustainable Forestry, FIREBEAR, ROLL USAID (Valendik et al., 2000).

Starting from 1996 experimental prescribed fires in logging slash in Siberia have been conducted under the auspices of the Russian-American Central Siberian Sustainable Forest Management Project, which is a joint venture between the V.N. Sukachev Institute of Forest (Siberian Branch of the Russian Academy of Sciences), the Krasnoyarsk Forest Committee of the Russian Federal Forest Service, and the USDA Forest Service (Valendik et al., 1997, 2000, 2001, 2004).

The experimental prescribed fires were studied on clearcuts at dark coniferous forests on flat and mountainous terrains, as well as understory burning in pine stands and broadcast burning of stands dead after defoliation by insects, notably the Siberian silk worm (*Dendrolimus superans sibiricus* Tschetverikov). Below these prescribed experimental fires are described separately.

Prescribed fires on logged sites

Problem of forest fires is very high in regions where forests actively are in use for logging. Often clearcuts without regeneration have natural high fire hazard due to their peculiar microclimate and high load of slash fuels mainly fire carriers. As a result there is high probability to start high intensity wildfires during all fire season. Localization and suppressing of these wildfires are impossible without using of expensive heavy machinery. As a rule wildfires starting on logged areas then move into adjacent forests for industrial use and make huge damage. Also wildfires on planted logged areas without slash fuels removal have adverse effects killing planted seedlings.

Mechanical removal of slash fuels practically impossible due to the labour consuming character and the absence of suitable equipment. As the costs of mechanical slash and debris piling and removal increased considerably during the last decades, the forest enterprises rejected these mechanical methods. So currently forest loggers make slash removal not properly or leave them without cleaning. So it is important to find more cheap methods for slash removal after logging.

Fire management on logged areas envisages the solving of two issues, first, their fire hazard decreasing and second, creating optimal conditions for first stage of forest regeneration.

Areas for study were in dark coniferous forests of southern taiga subzone (western macro slope of Yenisey Ridge) where mixed spruce-fir-kedar forests with green mosses and different grasses in understory are dominating.

Natural conditions of forest zone are favorable for natural regeneration of main forest forming species. But in many cases pine stands are replaced by other species. And only forest fires and selective cutting could provide pine species domination in forest regeneration structure.

Logged areas usually are covered after logging mainly by *Calamagrostis* and different grasses. Often also they covered by fireweed and *Calamagrostis* and then later they transform into *Calamagrostis* and raspberry cover and these logged areas have unsatisfactory regeneration (Ogievsky, 1966).

All logged areas covered by *Calamagrostis* are considered as areas hardly regenerating by coniferous species and so they should be as highest priority objects for artificial seeding or planting. *Calamagrostis* forms thick sod in these logged areas and areas has long period for coniferous regeneration whereas deciduous species are regenerating during 3-5 years after logging. Also these logged areas have clear form of prolonged species replacement.

Currently in forestry practice striving is dominating for coniferous regeneration saving when logging forest stand. However studies in these forests show that this method of saving regeneration doesn't justify itself due to poor saving of them during logging using heavy machinery and also regeneration high mortality after drastic changes of microclimate and growing competition with grass and brush cover after logging. Poor regeneration also could be explained by *Calamagrostis*, thick sod forming grass, saved regeneration can't compete with this grass (Valendik et al., 2006).

Coniferous regeneration inventory before and after logging carried out on 12 logged areas showed that number of regeneration was 3-10,000 small trees per hectare and 5-40% of them was saved after logging. After immediate removing of trees on forest stand regeneration drying begin due to changed microclimate conditions. One year after logging healthy regeneration consisted 25% of saved young trees. This quantity of viable regeneration can't restore coniferous forest. Following years further mortality of saved small trees is watched and the competition with grass-brush layer is strengthened.

Studies on logged areas burned in wildfires showed that after intensive fires they are covered by fireweed. This kind of logged areas covered by fireweed had successful coniferous regeneration especially after wildfire where there were abundant seeds on conifers (Valendik et al., 2000). Also it was noted that after low intensity wildfires *Calamagrostis* growth even strengthens.

So we can conclude that

- study areas on spruce-fir forests logged sites with podzol soils usually are covered by *Calamagrostis*. After medium intensity wildfires logged areas are covered by fireweed and after low intensity creeping wildfires by C*alamagrostis* mixed by fireweed.
- It is extremely difficult to make natural and artificial seeding or planting on logged areas covered by *Calamagrostis* due to thick sod layer.
- Saving of natural regeneration during logging using heavy machinery is not satisfactory. First years after logging regeneration has 100% mortality or falls down. Partially regeneration survives only in small stands left after logging.

In 1996 and 1997 a series of experimental plots were prepared at 9 dark coniferous logging slash clearcuts near Predivinsk (Krasnoyarsk Region). Experimental burning sites were selected in Bolshaya Murta leskhoz (an administrative forest management enterprise) and firelines were prepared for prescribed burn by Predivinsk lespromkhoz (an administrative forest industry enterprise, chiefly connected with logging) staff immediately after logging. Slash fuels resulted from clearcut logging of dark coniferous stand (fir, spruce) on the sites 1 to 2 years before burning. Logging was done in winter using LP49 felling machines. Clearcuts were 20 ha to 50 ha in area and surrounded by firelines 4 m to 6 m wide made by bulldozer. Some clearcuts were divided by firelines into small 2 ha to 3 ha plots. Advance regeneration left after logging had red needles due to sudden exposures to light in many clearcuts.

Preburn sampling of all fuels was made on each experimental site. Fuel loads of surface fuels were determined on the transect using small sampling plots (0.2 x 0.25 m) for 1-hr forest fuels and (0.5 x 0.5 m) for live forest fuels every 10 m. Fuel loads of downed woody materials were defined on transects 15 m long from these sampling points. Post-fire sampling of fuels was also done near the same points to determine fuel consumption (more about fuel sampling procedure see next chapter).

Forest fuels – fire carriers of Groups I and II (Kurbatsky, 1970) cover logged area with load up to 35 t/ha. Forest fuels of Group III and fire spread delayers are burning after ignition of Group I fuels. Their load reaches 200 t/ha and combustion continues up to several hours. When they are burning in concentrated piles burning firebrands are intensively arising up and could be transported by winds to long distances. Due to stable intensive combustion of these fuels even plenty of vegetating grasses and brushes cannot stop the spread of the fire.

Most of fire carriers of Group I and fuels of Group III are concentrated on logs processing area, where branches are cut. On felling area fuels structure and load are close to natural fuel load in dark coniferous forests. Skidding roads are used for transportation of logs and so fuels of Groups I and II are concentrated there.

Table 1. Structure and load of fuels- fire carriers of Groups I and II (up to 0.7 cm in diameter)

Number of logged area	Fuel Loads of different Groups (t/ha)			
	Fire spread delayers	Fire Carriers		Total
		Group I	Group II	
1/97	0.58	8.59	10.40	19.57
2/97	0.70	3.16	3.70	7.57
3/97	0.21	5.32	4.85	10.38
4/97	2.52	1.26	13.14	16.91
5/97	2.53	5.67	8.93	17.13
6/97	1.75	0.97	14.14	16.86
7/97	1.76	2.24	14.36	18.36
8/97	0.42	11.32	16.56	28.30
9/97	0.61	6.83	20.67	28.11
2/99	0.30	13.92	9.51	23.72
4/99	1.01	15.94	11.48	28.43
5/99	0.13	20.95	13.50	34.57
6/99	0.21	10.75	9.21	20.17

Table 2. Structure and load of fuels of Group III (t/ha)

Number of logged area	Diameter			Total
	0.7-2.5 cm	2.5-7.5 cm	>7.5 cm	
1/97	53.10	74.90	15.40	143.40
2/97	67.50	63.60	0.00	131.10
3/97	57.10	53.10	47.60	157.80
4/97	24.00	29.90	0.00	53.90
5/97	25.10	26.30	0.00	51.40
6/97	44.40	36.90	68.40	149.70
7/97	20.10	60.00	49.40	129.50
8/97	50.70	51.40	61.60	163.70
9/97	50.70	36.30	35.70	122.70
2/99	16.42	16.17	54.13	86.72
4/99	7.80	37.24	145.66	190.70
5/99	7.39	3.92	32.75	44.06
6/99	13.55	21.56	40.09	75.20

Fire hazard on logged areas depends not only from fuels and their load but also from density of fuel layer. Forest fuel complexes under canopy and on logged areas achieve their readiness to burn in different times.

Table 3. Fire carriers load on different elements of logged area (t/ha)

Logged area element	Fire Carrier Groups					Total	Portion of logged area, %
	I	II	III				
			0.7-2.5 cm	2.5-7.5 cm	>7.5 cm		
Logs processing area	14.4	8.7	25.5	24.8	67.4	140.8	8
Felling area	13.4	10.8	10.1	17.5	61.0	112.7	88
Skidding road	1.4	3.9	1.8	0	0	7.1	4

In study area fire season starts in a middle of April and ends in September. Its duration is between 140 and 160 days. Dark coniferous stands readiness to burn not exceeds 35 days. They are ready to burn 15-25 % of fire season duration but on logged areas it equals 75%. All of this define high fire hazard on logged areas and so it increases costs for fire protection of forests.

Table 4. Duration of dark coniferous stands and clearcuts readiness to burn (days)

	Weather station					
	Taseyevo		Kazachinsk		Bolshaya Murta	
	Days	%	Days	%	Days	%
Fire season duration	141	100	162	100	160	100
Dark coniferous stand fire readiness	34	24	21	13	25	16
Clearcuts fire readiness	116	82	123	77	124	78

So state of logged areas could be characterized as highly fire hazardous and poorly supported with coniferous species for further forest restoration. Forest restoration on these logged areas is prolonged for many decades. Therefore, the use of prescribed fire on logged areas for slash removal is quite approved and is needed (Valendik et al., 2007).

The use of prescribed fire has been studied on autumn-winter logged areas. It is connected with the fact that slash fuels load 40% higher on winter logged areas that summer ones. Also on winter logged areas slash fuels arranged more uniformly and are not packed and mixed with soil. So completeness of combustion is higher on winter logged areas than on summer ones. Third, litter and duff layer are not disturbed and so under slash fuels they are wet and could prevent soils overheating during prescribed fires.

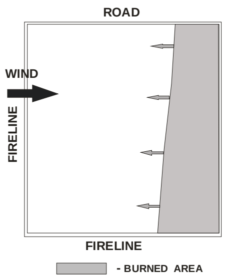
After inspection of fresh clearcuts prescribed burn plan had been prepared for each of them. Special prescribed fire sheet had been prepared and after filling it was approved by local forest management area director and then by Krasnoyarsk forest committee officials. In sheet there have been prepared fields for filling of logged area location, characteristics of saved regeneration after felling and its state, slash fuels loads and then sketch of logged area have been prepared with characteristics of surrounding stands or openings. Also there it should be written purpose and objectives of prescribe burn with information who should be informed about the prescribed burn. Prescription windows with recommended optimal conditions for prescribed fire describing relative humidity, wind velocity, fire carriers moisture content, air temperature etc. should be filled in the sheet. On clearcut plan should be drawn ignition sequence and arrangement of firefighters and heavy machinery for holding of RX fire. Planning of firefighters actions in a case of unforeseen and in extreme situations should be defined in a sheet. Fire safety should be prepared on sheet and discussed before burn. Responsible persons for prescribed burning, firing, holding, mopup and patrolling after burn should be appointed before burn (Valendik et al., 2000).

In preparation of this document person responsible for prescribed fire should be guided by document “Guidelines for prescribed fires on dark coniferous forests logged areas of Krasnoyarsk Region” prepared based on these experiments. In guidelines it was written about RX burn planning and approval process before burn. Requirements for logged areas selection for RX burn, preparations for safe RX burn on logged area (firelines etc.), RX burn technologies, burning methods and ignition techniques, optimal conditions for RX burn are fully described in guidelines. RX fire holding, mop-up operations, patrolling after burn are given also. Safety requirements, saving of environment, documentation should be taken into attention (Valendik et al.,1999).

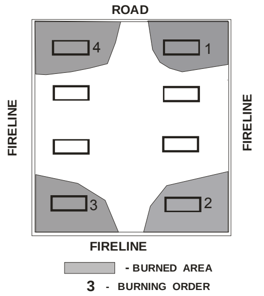
Based on peculiarities of wildfires arising and spreading on logged areas next prescribed fires technologies have been used. They include methods of burning and ignition techniques.

Three methods have been used for prescribed burning on logged sites (Valendik et al., 2007):

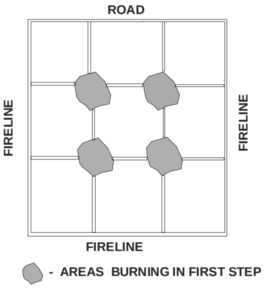
1) broadcast burning – on clearcuts with uniformly distributed slash fuels;
2) two stages burning – on clearcuts where large downed woody fuels have been piled
3) local burning – on logged sites with alive regeneration.



A) **BROADCAST BURN**



B) **LOCAL BURN**



C) **TWO STEPS BURN**

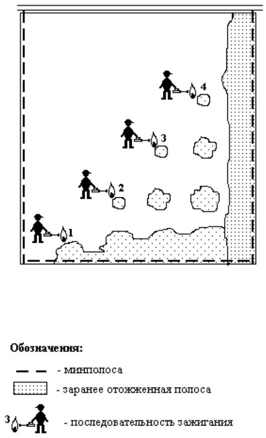
- Selection of prescribed burn methods depend on forest type before logging and weather.
- Prescribed burn characteristics also depend on forest fuels moisture content, loading, their structure and arrangement, relief etc.
- Flame height and other characteristics of burning define possibility to control burning and define needed man power and heavy equipment.
- So it is needed to forecast prescribed burn characteristics before the burn for that we used software BEHAVE which allowed to forecast fire behavior and make prescriptions for burning (Kisilyakhov et al., 1997).

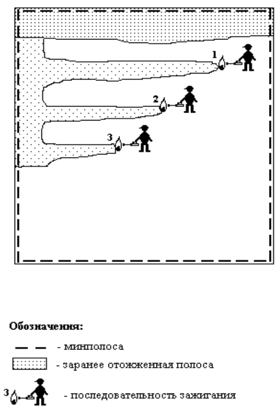
Then suitable weather patterns for prescribed burns were determined using images received from NOAA satellites by Krasnoyarsk downlink station installed by NASA in Krasnoyarsk Scientific Center, Siberian Branch, Russian Academy of Sciences (Sukhinin, 1996). Besides, images also were used for detecting the experimental prescribed fire burned areas. Slash fuels burned very intensively and it was possible to detect these fires on small areas.

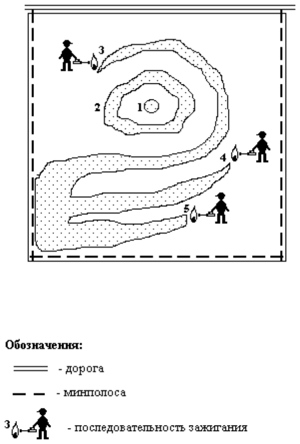
On each logged area weather data as air relative humidity, average wind velocity etc. have been defined before, during and after prescribed burn.

For ignition we used procedures:

- Point ignition
- Line ignition
- Circle ignition
- Combined ignition







After ignition and achieving quasi-stationary state of fire edge such characteristics as spread rate, flame length, flame depth have been defined using markers on photo and video images. In some cases where we used combined methods of ignition it was possible also define fire characteristics for short periods of time.

Fire characteristics among with weather data have been used to optimize prescribed fire timing. In prescribed fire planning it is necessary to forecast fire behaviour in definite forest sites and its main parameters as fire intensity, flame length, rate of spread etc. The achievement of goals defined before using of prescribed fire will depend upon precisely keeping of these fire parameters. Fire behaviour simulation on computer substantially simplifies prescribed fire planning.

Fire behaviour predicting and fuel modelling system BEHAVE developed at Intermountain Fire Science Lab., USA (Burgan and Rothermel, 1984; Andrews, 1986; Andrews, Chase, 1989; Andrews, Bradshaw, 1990) was used for experimental prescribed fires planning in slash fuels of clearcuts. Custom fuel models were developed for these slash fuels and used as inputs to RXWINDOW program for the determination of an optimal range of weather and fuel moisture conditions.

Using initial data and experimental results it has been defined prescriptions for prescribed burning for different periods of fire season in study area.´

Table 5. Optimal conditions for prescribed burning (tdp = ten-days period)

Period of fire season	**III tdp of May – I tdp of June**	**II tdp of June – I tdp of July**	**II-III tdp of July– I tdf of August**	**II-III tdp of August – I tdp of September**
Fire danger class	II-III	III	III-IV	III-IV
Nesterov Index	600-1600	1700-2000	2100-3000	3100-4000
Wind velocity (m/s)	< 2	< 3	< 4	< 5
Relative humidity (%)	> 60	> 40	> 30	> 30
Dry bulb temperature (˚C)	15-18	19-22	20-24	18-20

After prescribed fire experiments it was found that

- Technologies envisages possibility to use prescribed fire during all forest fire season.
- Most favourable period for prescribed burns on dark coniferous forests logged areas of Central Siberia starts from third ten-days period (tdp) of May by III tdp of June. During this period weather is suitable for forest fuels drying and small amount of vegetating plants favour to fire spread.
- Prescribed fires on fresh autumn and winter logged areas have good results. Slash fuels on these logged areas dry very fast and burn very intensively. Arrangement of slash fuels not close to soil allows its heating to temperatures not higher than lethal temperatures for soil microorganisms.
- Prescribed fires should be started when Nesterov Index (Nesterov, 1949, Valendik et al., 2006) has III and IV classes of fire danger index when completeness of slash fuels is in maximum.
- Day time 3-4 p.m is favourable to start prescribed burning. This time wind velocity and its direction are more stable and peak of prescribed fire comes in evening when it is easier to control its spread.

It was found that on fresh winter clearcuts prescribed burns

- Slash fuels with diameters up to 7 cm were utilized by 70-90%, pieces larger than 7 cm – 40-50% in prescribed burning of fresh logged sites.
- Duff depth is decreased up to 1-2 cm.
- Ash content after prescribed burning was up to 2 t/ha which enriched soil.
- Upper soil temperatures in 1-5 cm layer were not higher than 45-50°C that don’t destroy soils properties.
- 2/3 of site was suitable for seeds and seedlings growing.
- After prescribed burn live surface cover formed by fireweed creates microclimate suitable for seeds and seedlings growth.

- Due to forest management enterprises (leskhoz) data soil treatment using prescribed burn 8-10 times cheaper than usual mechanical treatment for planting.

It was stated that minimal costs of prescribed burns could be achieved when logged area is surrounded by dark coniferous forest with low fire hazard, i.e. forest fuels still in wet state to carry fire spread. In this case prescribed fire would it escape can't spread in surrounding forests and so heavy fire fighting equipment could not be used for fire mop up. Optimal conditions for prescribed fire depend on type of forest before logging. Completeness of slash removal is increased when increased fire intensity using different firing technique.

Natural regeneration from seeds is successful on distances 50-100 apart from forest stand. Logged areas after prescribed fires have been planted using seeds and seedlings of coniferous species without additional mechanical treatment of soil.

Removal of natural forest and slash fuels using broadcast burning on logged areas starting from 1996 by 2001 in area summed more than 900 ha in Krasnoyarsk Region (Central Siberia) allow to solve three main issues

- The use of the prescribed fire technologies on clearcuts allow to decrease slash fuels loading by 60%, in particular forest fire carriers by 80% significantly decreasing fire hazard.
- The completeness of duff layer burn depends on its moisture content and combustion rate and is equal to 60%. And 2/3 of the logged area is suitable for planting and seeding without preliminary mechanical soil treatment.
- Prescribed burns allow to eliminate *Calamagrostis* sp. and turn the process to fireweed formation promoting seeds and seedlings growth in first steps of succession.

Prescribed fires in forests damaged by Siberian Moth

Forest pests cause great annual wood loss and are a major economic problem in forest management (McCullough et al., 1998). In Russia, 13 million ha of boreal forest between the Ural Mountains and the Pacific Ocean have been damaged in outbreaks of Siberian moth (*Dendrolimus superans sibiricus* Tschetw.) over the past century (Kulikov, 1971). In the southern taiga, mixed species stands of Siberian spruce, Siberian fir, and Siberian pine are most affected by the moth and mortality is often severe, killing even regeneration. Farther north, stands of Siberian larch are similarly impacted. In some areas, regeneration of native conifers was not observed nearly 100 years after stands were killed by Siberian moth (Kulikov, 1971). It is estimated that establishment of stands similar in composition to the initial coniferous forest may take 150 to 200 years.

Defoliated forests represent two major problems for resource managers: they have high potential for forest fires and they may become unproductive wastelands (McRae, 1986). Because the volume of standing and down dead wood is high, moth-killed areas attain high flammability in early spring and fires can occur throughout the fire season (Stocks, 1987).

As snags become drier and branch and top breakage add down woody material further increasing the potential for high intensity fires (Stocks, 1987). Under such conditions, even heavy machinery may fail to contain the fires, allowing them to spread into surrounding living stands. Consequently, the average area burned per fire can increase dramatically. For example, in the Usolsky Leskhoz (forest management area), the number of fires 6-8 years after the most recent outbreak of Siberian moth doubled compared to before the outbreak but the total area burned increased many fold (Valendik et al., 2004).

Thus, reducing fire hazard in these forests requires removing dead woody material and accumulated ground fuels as a first step.

Mechanical site preparation for natural or artificial seeding or planting under such conditions is complicated because *Calamagrostis*, a thick sod forming grass, often becomes established soon after the trees have died and the forest floor becomes exposed to greater sunlight. The sod hampers tree seed germination and together with the lack of seed trees in the vicinity are major reasons for the delay of natural regeneration. Silvicultural treatments to break up the sod are almost impossible because there is typically a lot of downed dead wood and a large number of standing snags.

The experimental burning site was in the southern Angara-Kan part of the Yenisey Ridge of the Central Siberian Plateau near the Biryusa River basin, approximately 300 km northwest of Krasnoyarsk, Russia (57°18′ N, 95°19′ E). The Siberian fir-dominated stand was on a level site with an elevation of approximately 250 m above mean sea level.

The most recent Siberian moth outbreak in the area was in the mid-1990s, and it destroyed about 480,000 ha of dark coniferous forest (mixed spruce, fir, Siberian pine) in the Angara-Yenisey Region. Of the total, 50,000 ha were heavily damaged (50-75% mortality) and 240,000 ha suffered complete mortality (Grodnitsky et al., 2001). The affected area of the Usolsky Leskhoz, where our study took place, was 170,000 ha, or more than 22% of the entire leskhoz. Seventy thousand ha of the leskhoz had 75% or greater mortality following the outbreak (Anonymous, 1996). By 2001 the defoliated area increased due to additional, secondary insect attacks (Grodnitsky et al., 2001).

The experimental stand was in dark coniferous forest dominated by a Siberian fir overstory with approximately 10% birch and scattered individual stems of Siberian spruce and Siberian pine. Height of the fir trees averaged 20 m and average diameter at breast height (DBH) was 16 cm. The forest floor was composed of green mosses and low grasses. By 2001 all the conifers were dead and the only living trees in the overstory were birch. Most of the conifer snags still had fine branches. The ground cover was mainly sedges and grass (especially *Calamagrostis* spp.). Generally the grasses, which grow to about 40 cm tall, develop nearly complete cover resulting in thick sod. The litter layer and forest floor layer were typically 5-10 cm and 5 cm deep, respectively.

In late August and early September 2001, firelines were established to separate a roughly rectangular experimental site (300 x 200 m) within an approximately 1,000 ha block of dead conifer forest. The firelines were built using a large (40 ton) special-purpose APL-55 bulldozer) and included a specialized blade 3 m wide. A 10 m wide gravel road served as the fireline along the southern side (300 m) of the area. The western (200 m) and northern sides were stripped to bare soil by bulldozing 6 m wide firelines. The eastern side was bordered by an old cut and also was separated from the experimental site with a 6 m wide fireline. Snags on the experimental plot were knocked down with the bulldozer shuttling back and forth across the plot at a speed of 5-6 km/h with pass spacing of 15-20 m. More than 60% of the snags were knocked down in that manner. Autumn and winter winds downed additional snags. As a result, total downed dead wood increased 90% and woody debris 7.5 cm diameter and larger more than doubled compared with conditions before the treatment.

Surface fuel loads (downed woody material, litter, understory shrubs and herbaceous vegetation) on the experimental plot and an adjacent untreated portion of dead forest were inventoried to estimate their structure and distribution before and after knocking down snags. In the treated and untreated areas sample plots consisting of equilateral triangles with sides 15 m were installed (McRae et al., 1979). The apexes were marked with iron stakes to facilitate post-burn inventories. Dead and down woody material was measured using the line intersect technique (Van Wagner, 1968; McRae et al., 1979; Brown, 1974; Brown et al., 1981). All down and dead woody material was tallied by diameter classes (<0.7 cm, 0.7 – 2.5 cm, 2.5 – 7.5 cm) along the sides of the triangular sample plots. Diameters of larger materials were measured with calipers and their condition noted. Woody surface fuel loads were calculated using formulas by Brown (1974). There were no living understory conifers in the stand. Crown fuel loadings were not measured.

Litter and duff layer samples were collected from two 20 x 25 cm subplots located at 5 and 10 m from the apexes along each side of the triangular sample plots. Moss layer sampling used the same protocol on an equal number of nearby subplots (Valendik et al., 2000, 2001). Herbaceous vegetation was sampled on two 50 x 50 cm subplots arranged near the litter and moss subplots. The litter and duff, moss, and herbaceous vegetation samples were oven-dried for 24 h at 104°C to determine their respective fuel loads. Following the protocol of McRae et al. (1979), we installed two depth-of-burn pins on both sides of, and perpendicular to, each leg of the triangular sample plots at 0, 5, 10, and 15 m.

The prescribed burn was conducted on 20 June 2002. Weather conditions before the burn were as follows: dry bulb temperature, 18°C; air humidity, 40%; and wind velocity at 2 m, 0-2 m/s from the northeast. The Nesterov Index was 1900, corresponding Class IV or high ignition potential. Ignition time was 8:00 p.m.

The sequence of ignition was important for controlling the experimental fire and minimizing the potential for escape. Ignition was started using drip torches from the northeast corner of the experimental site along the northern fireline. Then ignition continued along the eastern side of the site. When the fire front has moved 20-30 m, ignition was undertaken along the fireline across the center of the site. When the fire front moved toward the western and southern portion of the site, ignition was made along those firelines. That ignition sequence ensured that the fire intensity increased, resulting in a convection column in the center of the experimental area. Intensive burning in the middle of the stand with flame heights up to 5 m and torching trees induced a strong indraft from the sides toward the center, thereby reducing potential for spotting outside the target stand. Nevertheless, the wind at 2 m was about 4 m/s, tilting the convection column 40-50 degrees and firebrands started spot fires up to 500 m southwest of the experimental site. Usolsky Leskhoz personnel with a special-purpose bulldozer and hand tools successfully suppressed the spot fires.

During the experimental burn, temperature of the mineral soil was monitored at depths of 2, 5, and 10 cm, using maximum-minimum mercury thermometers, electric thermometers, and melting elements.

After the experimental burn the surface fuel load was re-inventoried on the triangular sample plots. Consumption of surface fuels was determined by pre-burn and post-burn fuels loads. Depth-of-burn pins were measured after the burn and the depth of remaining organic matter was measured. Litter and duff, moss, and herbaceous vegetation samples were collected and oven-dried for 24 h at 104 °C in order to determine remaining forest litter loading. On average, deadwood consumed by fire was 70%.

More of the forest floor and moss layers were consumed in the prescribed fire and prescribed fire were effective at killing grasses. After wildfire, the forest floor and moss layers usually can inhibit forest regeneration from seeds on moth-killed sites (Furyaev, 1966; Kulikov, 1971).

Post fire forest fuel depth ranged 0 to 1.5 cm (1.1 cm average). That depth does not inhibit seed germination or seedling establishment. Therefore, to increase the effectiveness of fire for restoring sites for conifer regeneration, a large portion of the snags in a stand should be downed before the site burns. This will result in more complete snag consumption and, thereby, more complete consumption of the forest floor, moss, and grass layers.

After such controlled fires, large downed woody fuel loading does not exceed 30 tons/ha and the minimum unburned piece diameter is about 7 cm. Thus, large downed woody element consumption was sufficient to prepare the site for regeneration when the percentage of downed snags pre-fire was, on average, about 60%.

This intensive burn did not destroy agrochemical soil properties or induce soil coagulation. Soil temperature during the experimental burn reached up to 60°C at 2 cm below the surface. However, in general, the maximum soil temperature did not exceed 50°C, and was much cooler with depth in the soil. The surface soil horizons became hot enough to kill *Calamagrostis* while enhancing fireweed.

In spring of 2003, the year following the experimental burn, the site was planted with Siberian pine seedlings, without any mechanical site preparation. Seedling survival and growth will be monitored over the several years and related to forest floor consumption and micro site conditions.

Our test of mechanically knocking down snags followed by controlled burning was effective for reducing dead wood and killing *Calamagrostis* grass on moth-killed sites, thus enhancing forest regeneration and restoration. This combined method resulted in an area suitable for both natural conifer regeneration and planting without additional mechanical site preparation.

Prescribed understory burning

Another issue related to fire and forest management is forest fires in wildland-urban interface. People can be injured in fire and homes and properties could be destroyed not only in small-populated areas but small cities. The suppression of any fire in the forest surrounding villages all over the country led an unnatural increase of fuel loads, resulting in high-intensity crown fires that threaten settlements. These kind of catastrophic fires occur not only in Eurasian boreal forests but also in other forests of our planet.

To develop methodologies of fuel reduction in these forest areas, experimental understory prescribed burnings have been conducted to decrease surface fuel loads and to remove regeneration thickets having high potential for crown fires. It was recommended that the creation of park like stand without regrowth and understory with minimal surface fuel load near populated areas will exclude catastrophic forest fires (Valendik et al., 2002). As a result of these studies understory spring prescribed burnings in the light coniferous stands around the villages and along the roads have been introduced into the practice of forest management.

Conclusions

- Special rules and guidelines for prescribed burning have been developed and published in cooperation with regional forest management enterprises.
- Crews of foresters and firefighters have been trained during these experiments.
- A range of demonstration plots of prescribed burning was established to serve for long-term monitoring of post-fire succession.
- These plots will be integrated into the Eurasian Fire in Nature Conservation Network as well as in the Fire Paradox demonstration plot network.
- The cooperation with these networks will allow further studies of both prescribed burnings (fire danger, fire behaviour, fire effects) and long-term fire successions in Siberian forests.
- The results will be important to extend to other regions of the Russian Federation.

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