Mitigation and Adaptation Strategies for Global Change (2006) 11: 883–896
DOI: 10.1007/s11027-005-9017-2

AN EXPERIMENTAL BURN TO RESTORE A MOTH-KILLED BOREAL CONIFER FOREST, KRASNOYARSK REGION, RUSSIA

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Abstract. 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 favorable to the establishment and propagation 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 favorable for conifer regeneration. Our study was conducted in a mature fir dominated stand that died during an outbreak 6–8 years previously with most of the dead trees still standing. A bulldozer drove through the stand downing standing snags in late summer with 15–20 m between passes. Snags knocked down by the bulldozer and additional snag fall throughout the following winter increased downed dead wood 50–60% and large downed dead wood 80% compared to an adjacent untreated area. In June, a prescribed fire was set and fuel load consumption averaged 70%. Average soil temperatures during the burn ranged from 47 °C at a depth of 2 cm to 10 °C at 10 cm; hot enough to kill the grass. 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.

Keywords: *Abies sibirica*, coarse woody debris, dark coniferous forest, fuel load, *Picea obovata*, prescribed fire, Siberian moth, snag

1. Introduction

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. Lepidoptera: Lasiocampidae) over the past century (Kulikov 1971). In the southern taiga, mixed species stands of Siberian spruce (*Picea obovata* Ledeb.), Siberian fir (*Abies sibirica* Ledeb.), and Siberian pine (*Pinus sibirica* Du Tour) are most affected by the moth and mortality is often severe, not only to mature stands but also understory regeneration. Farther north, stands of Siberian larch (*Larix sibirica* Ledeb.) are

TABLE I
Fuel loading in forests with different defoliation extent

Defoliation extent (%)	Snags (m^3/ha)	Duff (t/ha)	Mosses (t/ha)	Grasses (t/ha)	Woody surface fuel by diameter class (cm)(t/ha)				Total surface fuel (t/ha)
					<0.7	0.7–2.5	2.5–7.5	>7.5	
0	0	3.4	3.6	0.5	2.2	2.4	6.5	28.7	47.3
0–25	30	3.5	2.9	0.6	2.8	3.1	8.2	35.4	56.5
25–50	80	4.2	3.2	0.8	4.3	3.8	11.3	39.2	66.8
50–75	120	4.8	3.1	1.0	5.8	6.0	12.6	40.6	73.9
75–100	170	6	3.1	1	6.6	7.3	14.1	46.8	84.9

similarly impacted. In some areas, regeneration of native conifers had yet to occur nearly 100 years after stands were killed by Siberian moth (Kulikov 1971). It is estimated that establishment of stands similar in composition to the pre-outbreak coniferous forest may take 150–200 years. Reducing the time between stand mortality and the initiation of forest regeneration in moth-killed landscapes is a major challenge for forest managers.

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).

Defoliated forests exhibit varying degrees of surface fuel loads and snag volumes, depending on the extent of defoliation (Table I). Forests defoliated >75% contain the maximum amount of surface fuels and volume of standing snags. As snags dry and branch and top breakage add down woody material to the forest floor, the potential for high intensity fires increases (Stocks 1987). Once fires become established in these conditions even the most aggressive fire suppression actions 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) (Table II).

Thus, reducing fire hazard in these forests requires removing dead woody material and accumulated ground fuels as a first step. Allowing these materials to burn in a wildfire would seem the most effective and economically justified solution to the problem, but it is not that simple. The random occurrence and nature of wildfire may not achieve sustainable forestry objectives. Our observations in moth-killed stands subjected to wildfire under moderate fire weather conditions

TABLE II

Number of fires and area burned before and 6–8 years after an outbreak of Siberian moth in the Usolsky Leskhoz

Relative to outbreak	Fires (number)	Area burned (ha)
Before (1994–1998)	23.5	174
After (1999–2003)	40.8	4,778

revealed that dead standing trees charred rather than burned and did not mitigate hazardous fuel conditions.

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 the lack of seed trees in the vicinity contribute to the delay of natural regeneration. Silvicultural treatments to break up the sod are almost impossible to achieve due to the structural impediments of the large amount of downed dead wood and number of standing snags. The salvage of moth-killed trees is rarely an option in many portions of Siberia because of limited access and the distance to timber markets.

In this paper we present results from a study that was designed to investigate how prescribed fire could be used to restore boreal conifer stands killed by Siberian Moth. This work expands on earlier experimental prescribed fires in slash fuels in Siberia 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).

2. Materials and Methods

2.1. Description of the Study Area

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) (Figure 1). The Siberian fir-dominated stand was on a level site with an elevation approximately 250 m above mean sea level. The most prevalent soils in the area are podzols with prolonged frost penetration, but without a permafrost layer. Soils at the site were remarkably shallow and stoney for the area. Humus content ranged from 3 to 7% and decreased rapidly with depth. These soils are characterized by high acidity

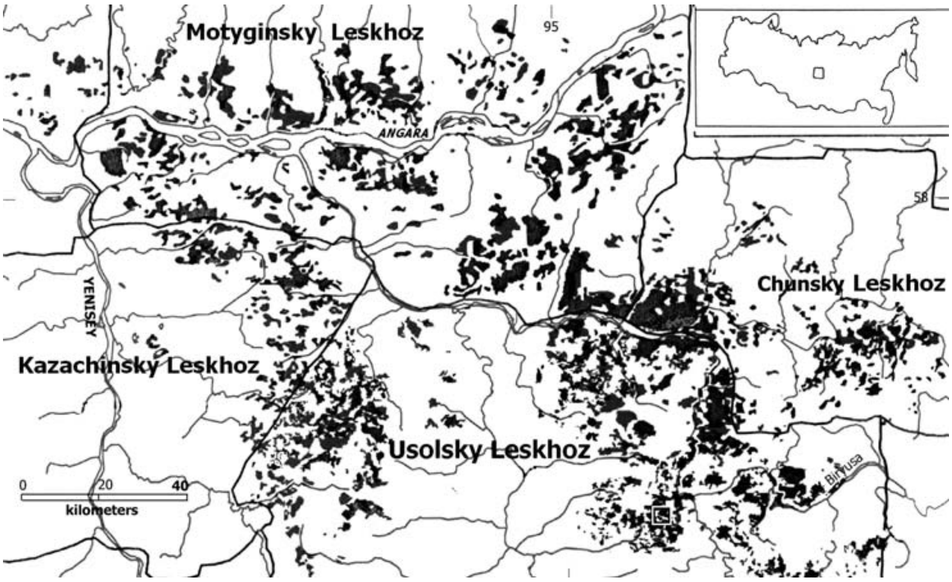

Figure 1. Location of experimental site.

especially in upper horizons and significant quantities of mobile aluminum and iron (Gorbachev and Popova 1992).

The study area has a continental climate with short warm summers (mean daily July temperature, 18 °C) and long cold winters (mean daily January temperature, −22.5 °C). Mean annual precipitation in the area is 387 mm. The growing season extends from mid-May to the end of September and has a mean annual length of 129 days. The fire season generally begins in early May following snowmelt and runs 5 months to the end of September. Continuous snow cover typically extends for six months, from 25 October to 23 April (Galakhov 1964). Prevailing winds are from the west and southwest with an annual average speed of 2–4 m/s. Maximum average wind speeds are in the spring (April–May) and late fall (October–November), while minimum average wind speeds are in the summer (July–August).

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 (late successional, mixed spruce, fir, and 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 (Anon 1996). By 2001 the defoliated area increased due to additional, secondary insect attacks (Grodnitsky et al. 2001) (Figure 1).

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. Compared to maximum potential stocking, the relative stand density was 0.9. 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 (Figure 2a and b). Most of the conifer snags still retained fine branches. The understory was dominated by small (up to 4 m tall) mountain ash (*Sorbus aucuparia*) in dense patches (up to 10,000 stems/ha), raspberry (*Rubus* spp.) clumps, occasional red elderberry (*Sambucus racemosa)*, meadowsweet (*Spiraea* spp.), and black currant (*Ribes nigrum*) shrubs. The ground cover was mainly sedges and grass (especially *Calamagrostis* spp.) with minor components of vetch (*Vicia* spp.), fireweed (*Epilobium augustifolium*), horsetail (*Equisetum* spp.), and bedstraw (*Galium* 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.

2.2. Site preparation for the experimental burn

In late August and early September 2001, firelines were established to separate a roughly rectangular experimental site (300 × 200 m) within an approximately

(a)

Figure 2. (a) Dark coniferous stand 100% defoliated. (b) In-stand view of fuels.

(*Continued on next page*)

(b)

Figure 2. (*Continued*)

1,000 ha block of dead conifer forest. The firelines were built using a large (40 ton) special-purpose APL-55 bulldozer, which was designed by the Department of Technical Forest Management Assistance (Kharinsky et al. 1991) and included a specialized blade 3 m wide (Figure 3). 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

Figure 3. Special-purpose bulldozer for knocking down snags and constructing firelines.

were stripped to bare soil by bulldozing 6 m wide firelines. The eastern side was bordered by an old harvest unit 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. In the process of driving the bulldozer across the site, some snags hit by the blade fell in the direction the bulldozer was going while others fall to the sides and into other standing snags. 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 (Figure 4).

2.3. Preburn fuel sampling

To better understand why standing snags tended to char rather than burn, we collected samples of wood with an increment borer at 1.5 m above the ground from standing snags and at the equivalent height from snags that had fallen but were not lying directly on the ground. Samples were subdivided into 3 parts depending on distances to the pith. Moisture content of the samples was determined after oven-drying at 104 °C for 24 h.

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

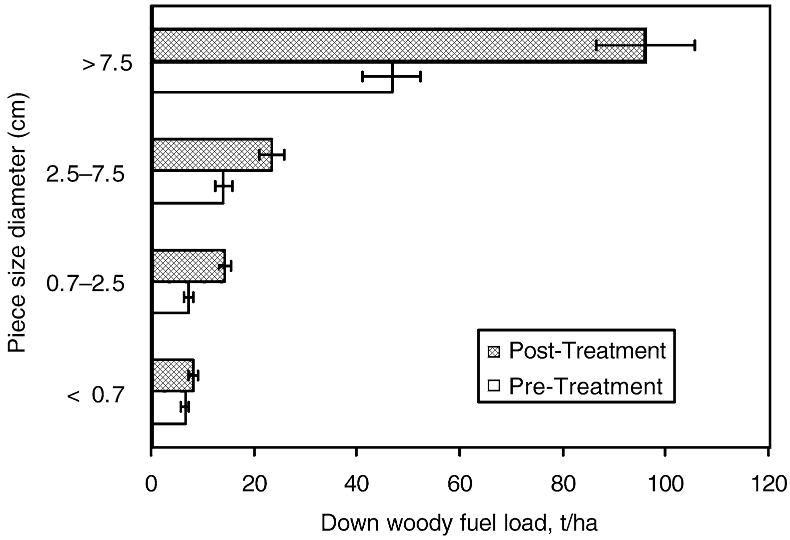

Figure 4. Effect of knocking down snags on the amount of downed wood.

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 × 25 cm subplots located at 5 and 10 m from the apexes along each side of the triangular sample plots (i.e., 12 subplots/plot). 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 × 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.

2.4. Fire weather danger measurements

Daily weather forecasts are available from the Krasnoyarsk Avialesookhrana (Aerial Forest Protection Service). On site weather data were collected using a firefighter's weather kit before the prescribed burn. The experimental burn prescription was developed based on plot arrangement and fuel conditions.

For fire danger estimation we used the Nesterov Index (NI) (Nesterov 1949) modified for local conditions. NI requires daily observations of dry-bulb temperature, dew point temperature, and precipitation. The difference between daily temperature and dew-point is multiplied by temperature and cumulatively summed over the number of days since 3 mm of precipitation to provide a general index of ignition potential. On the Usolsky Leskhoz, NI values for the spring fire season range from Class I (zero) to Class V (extreme) as follows: Class I, 0 to 550; Class II (low), 551 to 900; Class III (moderate), 901 to 1800; Class IV (high), 1801 to 3450; and Class V, $\geq$ 3451. A comparison between the Canadian Fire Weather Index and NI showed close correlation for estimating ignition potential (Stocks et al. 1996).

2.5. Burning procedure

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 NI 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, ignited snags and 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.

2.6. Postburn fuel sampling

After the experimental burn the surface fuel load was reinventoried on the triangular sample plots. Consumption of surface fuels was determined by preburn and postburn 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.

In May 2002 there was a wildfire near the experimental site when the NI was Class III or moderate with a value of 1500. Using the same sample protocols, we collected postburn samples from that area to compare with the experimental burn.

3. Results and Discussion

Low consumption of standing snags by fire was explained by the high moisture content of the wood. Layer-by-layer wood moisture content analysis showed a considerable difference between standing and downed snags, with moisture content increasing progressively toward the pith (Figure 5). At each layer, moisture content of standing snags was 2 to 3 times that of downed snags not lying directly on the ground. Clearly, downing more snags before the burn would increase consumption of woody debris by the fire achieving better overall results. Maximum dead wood consumption would require an all-snags-downed scenario, but that would be much more costly than the method we used.

On average, deadwood consumed by fire was 70%, with greater consumption in the experimental prescribed fire than in the nearby wildfire (Figure 6). Smaller pieces were consumed most fully, but the prescribed fire consumed a markedly higher percentage of large pieces than did the wildfire.

More of the forest floor and moss layers were consumed in the prescribed fire compared to the wildfire, while both wildfire and prescribed fire were effective at killing grasses (Figure 7). Generally less than 25% of the forest floor layer was consumed in the wildfire and, although greater, the reduction of the moss layer in the prescribed fire was only about two-thirds. Thus, even after wildfire, the forest

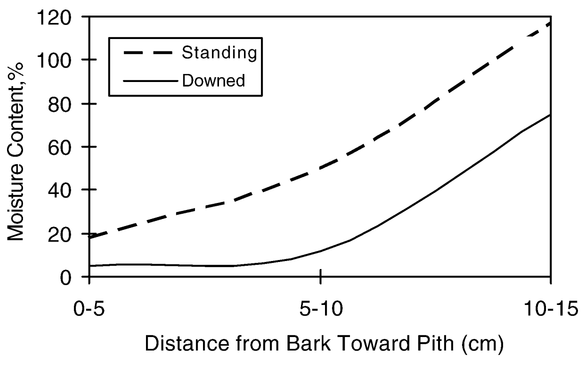

Figure 5. Moisture content at various depths in the wood of standing and downed snags 6–8 years after dying from defoliation by Siberian moth.

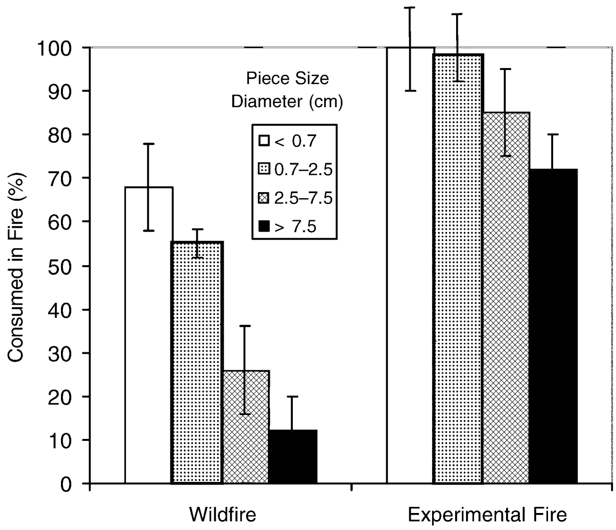

Figure 6. Comparison of consumption of dead wood by wildfire and experimental fire.

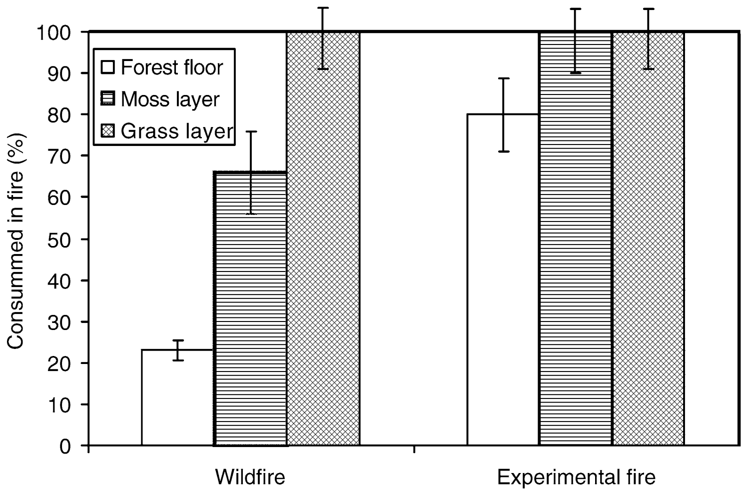

Figure 7. Comparison of consumption of forest floor, moss, and grass layers by wildfire and prescribed experimental fire.

floor and moss layers 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

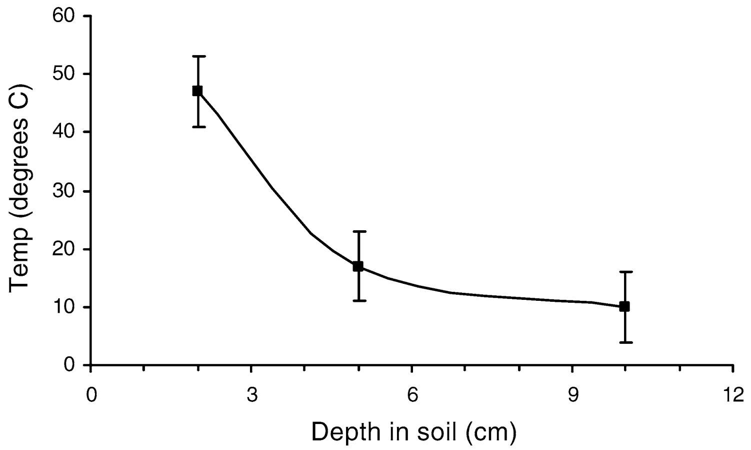

Figure 8. Soil temperature with depth during prescribed fire.

complete snag consumption and, thereby, more complete consumption of the forest floor, moss, and grass layers.

After the prescribed fire, large downed woody fuel loading did not exceed 30 tons/ha and the minimum unburned piece diameter was 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 (Figure 8). The surface soil horizons became hot enough to kill *Calamagrostis* while enhancing fireweed. Due to its rod-like root system, fireweed does not form sod so it does not hamper conifer seed germination. In fact, fireweed provides good shelter for germinating conifers and does not compete with the seedlings as they grow (Ivanova and Perevoznikova 1994).

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 with be monitored over the next several years and related to forest floor consumption and micro site conditions.

4. Conclusions

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 mitigating wildfire hazard. This combined method resulted in an area suitable for both natural conifer regeneration and planting without additional mechanical site preparation.

Acknowledgments

We thank International Programs of the USDA Forest Service for generous financial support for the program that included this study.

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