Future perspectives of forest management in a Siberian permafrost area

Kunihide Takahashi

Graduate School of Agriculture, Hokkaido University, Sapporo 060-8589, Japan

Corresponding author: kun23@for.agr.hokudai.ac.jp

1. INTRODUCTION

Permafrost areas in Russia cover about 1 billion ha, or about 60% of Russian territory (IIASA 2002). The Sakha Republic is an area of permafrost in which continuous and deep underground ice exists. The forest area of Russia covers about 900 million ha, 22% of global forest area; 52% is boreal forest. The boreal forest of Russia habitually experiences forest fires, and more than 40 million ha of forest have burned during the last decade. Major factors that affect the fire regimes of Russian forests are the tree species composition, climate (continentality and aridity), seasonal weather course (temperature, distribution of precipitation), population density, intensity of anthropogenic effects like burning a field.

Generally, fire generates specific features of ecological regimes at the landscape scale. There is no doubt that fires have also had a significant negative effect on biodiversity in the boreal zone. Wildfires from natural causes (lightning) constitute a very important ecological factor in the formation and sustainability of boreal forests. However, over 70% of fires in Russia are caused by humans. The official statistics show that 20,000–400,000 fires occur annually, and 2 or 3 million ha of forest and other lands are burned (Goldammer et al. 2003). Wildfire regimes are characterized by various fire return intervals and severities. There are several reasons why fire is a major natural disturbance in Russian forests (Shvidenko and Goldammer 2001). First, about 95% of the forests are boreal, much of which is dominated by coniferous stands that pose a high fire hazard. Second, a significant part of the forested territory is practically unmanaged and unprotected, and large fires (>200 ha) play an important role in this region. Third, because of the slow decomposition of plant material, these forests contain a large amount of accumulated organic matter, and a major part of the boreal forest is situated in regions with limited amounts of precipitation and/or frequent long periods of drought during the fire season. Fourth, in interactions with the climate and local growing conditions, fire controls the age structure, species composition, landscape diversity, and vegetation mosaic, as well as energy flows and biogeochemical cycles, and it particularly affects the global carbon cycle.

The purpose of this study was to clarify ecophysiological indices to estimate fire severity and to evaluate forest dynamics after fire. We discuss reforestation methods and the perspective of forest management in Siberian permafrost areas.

2. PRESENT STATE OF WILD FIRES AND FORESTS IN SIBERIAN PERMAFROST AREAS

The area burned by large fires in Russia covered 11 million ha in 1998, 11.7 million ha in 2002, and 19.3 million ha in 2003 based on satellite-derived data (Goldammer 2003, Goldammer et al. 2003, FAO 2004). In the Far East, forest fires were concentrated in the Sakha Republic and Khabarovsk Kray, part of which is a seasonal permafrost area (Newell 2004). Smoke from fires that occur in Khabarovsk Kray sometimes reaches Hokkaido, northern Japan. From 1991 to 2002,

Symptom of Environmental Change in Siberian Permafrost Region,
Eds. Hatano R and Guggenberger G, p 163-170, Hokkaido University Press, Sapporo, 2006

the annual average number of fires was 628 in Sakha and 548 in Khabarovsk, and the burned areas covered 274,500 ha in Sakha and 288,500 ha in Kabarovsk (Figs. 1, 2). Russian forest censuses conducted in 1993 and 2003 indicated that the area of land without trees increased by 1.2 million ha in Sakha and decreased by 1 million ha in Khabarovsk (FSFMRF 2004). During this 10-year period, the forest area and growing stock of conifers decreased by 5.8 million ha and 385 million m^3, respectively, in Sakha and increased by 3.2 million ha and 26.7 million m^3 in Kabarovsk. In contrast, the area and growing stock of birch remained stable in Sakha and increased in Khabarovsk. These facts indicate that the ability for natural reforestation is low in Sakha and high in Khabarovsk.

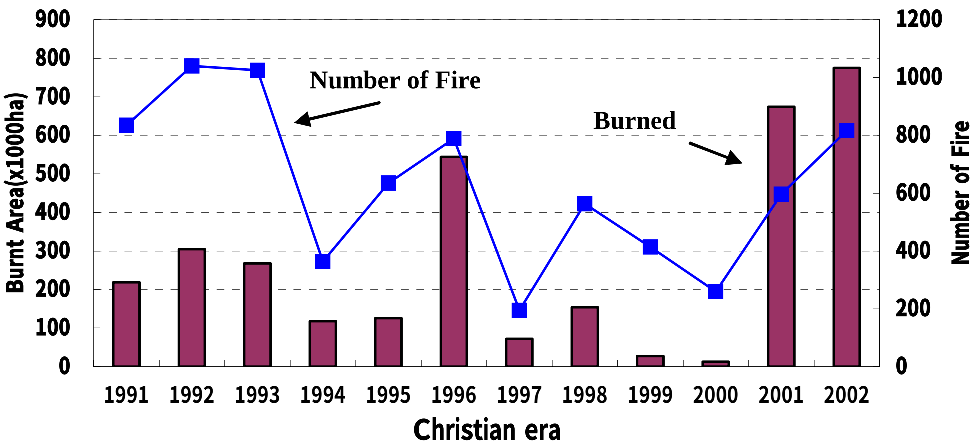

Fig. 1. Number of fires and burned area in Sakha.

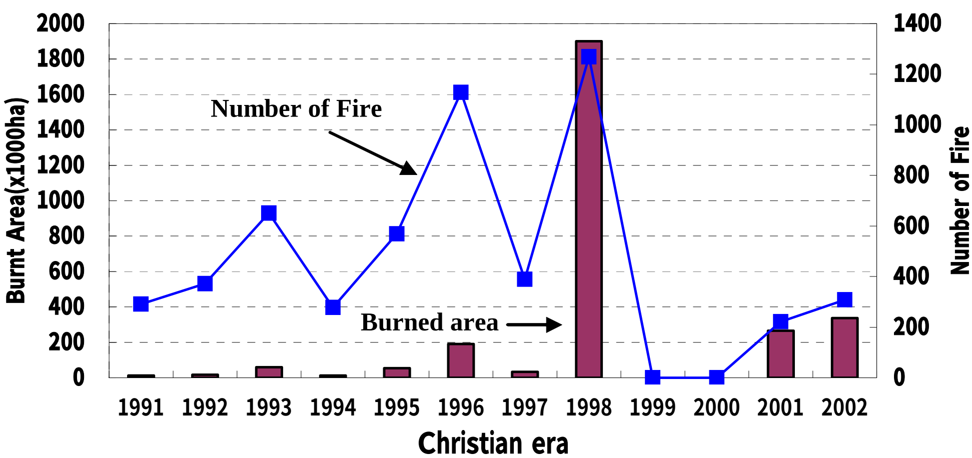

Fig. 2. Number of fires and burned area in Khabarovsk.

3. EFFECT OF FOREST FIRES ON SIBERIAN FORESTS

The total area affected by fires in Russia was more than 100 million ha in the period from 1990 to 1999. The average fire and post-fire dieback is estimated to be about 80 m^3/ha of forested area. This means that the expected losses of wood could reach 400–500 million m^3. Outbreaks of forest pests and diseases are also expected during the next few years, as well as a significant increase in the fire hazard because of the accumulation of large amounts of deadwood (Shvidenko and Goldammer 2001).

The total burned area of Sakha during the same period was 1.6 million ha. Almost all fires that occurred in Sakha were surface fires; for example, only one of 86 fires around Yakutsk that occurred between 1999 and 2001 was an underground fire. However, a severe surface fire destroyed a mature larch forest that had a maximum tree height of 20 m and diameter at breast height (DBH) of >30 cm. Surface fires create fire scars on the stems, and the height of these scars reflects the severity of the fire (Fig. 3).

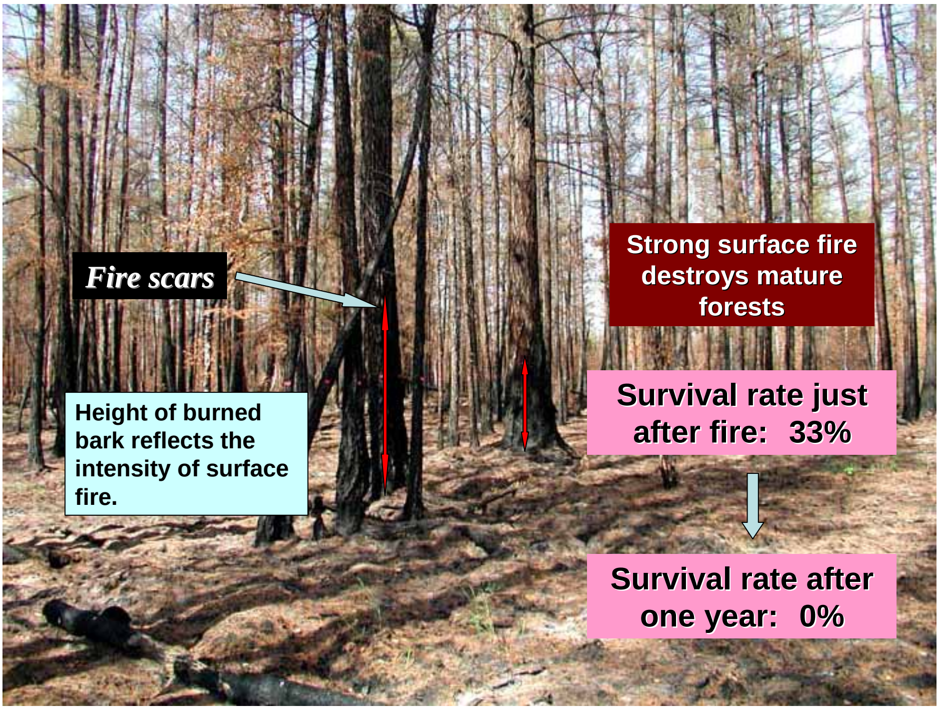

Fig. 3. A sever surface fire destroyed mature forests and height of the burned bark reflected the severity of surface fire.

The height of scorched bark in a forest damaged by a surface fire in 2002 was above 6 m. Sixty-seven percent of the trees died shortly after the fire, and the remainder died in the following year. The extent of the post-fire mortality was related to tree species, diameter, and the height of the scorched bark (Sherbakov 1979).

From the relationship between the height of fire scars and mortality, larch is considered more tolerant to surface fires than other conifers, although stand density and root system conditions are also important (Sherbakov 1979, Shvidenko and Nilsson 2000). Fire frequency, i.e., the fire return interval, is also an indicator of fire severity. We investigated stump discs of larch and found that the growth rings clearly recorded past fire events; our results showed that the average fire interval at our study sites was 15 years, ranging from 4 to 43 years (Takahashi 2002; Fig. 4). These results show a similar fire rotation period to that of larch stands in Central Yakutia (Ivanova 1996). Tree-ring analysis indicates that more than 50 years are required to conserve the next generation in these forests.

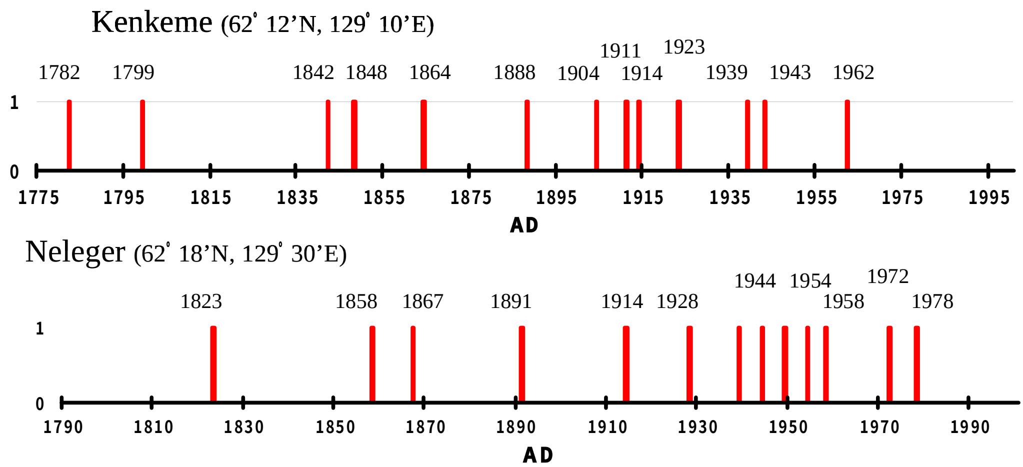

Fig. 4. Fire-return intervals in two mature larch forest (Takahashi et al. 2002).

4. POST-FIRE VEGETATION AND REGENERATION

Post-fire natural reforestation relies on a number of factors (Shividenko and Goldammer 2001). The process of post-fire regeneration strongly depends on the bio-climatic zone and geographic and site conditions. Shividenko and Goldammer (2001) concluded the following. The ability of boreal forests to restore themselves is very high. As a rule, post-fire reforestation in the extreme north (forest tundra, northern and sparse taiga) is slow and requires a long time, up to 30–35 years, because of insufficient availability and quality of seeds. The productivity of the first post-fire forest on permafrost is 2- to 3-fold higher than in undisturbed areas. In practically all bio-climatic zones, excluding larch stands in the extreme north, stand replacement basically causes succession with a change in the dominant species; for example, a typical progression is dark conifers (spruce, fir, cedar) to soft deciduous (birch, aspen) to mixed dark conifer–deciduous forests. Recurrent fires often lead to the impoverishment of forests and the generation of grassy glades, development of paludification, and finally, to indefinitely long periods of deforestation and "green desertification." Regeneration under the canopy layer of parent stands after non-stand-replacing fires is dependent on the frequency of recurrent fires; this is the major reason for the development of uneven-aged forests of different types.

Seed germination and vegetation dynamics are affected by soil moisture conditions in the residual organic layer or bare soil after fire. Two young dense larch stands (Viluy-52, Viluy-62) that died in a severe surface and crown fire showed that the vegetation may reflect soil moisture after fire. The dominant species of the forest floor vegetation in both stands before the fire was *Vaccinium vitis-idaea*. After the fire, the species composition of the dominant species differed between the two stands. *Chamerion angustifolium* and hygrophytes like *Calamagrostis langsdorffii*, *Corydalis sibirica*, *Marschantia polymorpha*, and *Funaria hygrometrica* were dominant in Viluy-52, suggesting that it became a wet site, and the species composition was unstable for 3 years. In Viluy-62, the dominant species after the fire were mesophytes, such as

Chamerion angustifolium, Rosa acicularis, and *Vaccinium vitis-idaea*, and the flora was stable for 3 years (unpublished data). Larch seedlings occurred in proportion to the number of seeds found in seed traps. Birch seedlings showed a noticeable trend of occurrence in the wet site.

5. EFFECT ON THE CARBON BALANCE OF SIBERIAN FORESTS

Many studies have attempted to quantify the emissions to the atmosphere from vegetation fires that occur in the boreal zone, including the Russian Federation (Goldammer and Furyaev 1996, Kasischke and Stocks 2000). Dense smoke significantly decreases photosynthetic activity and reduces visibility to 100 m or less. A recent example of a study on fire emission in the Russian Federation is a report by Kajii et al. (2002). These researchers used NOAA-AVHRR satellite data to quantify forest fires in boreal Siberia and northern Mongolia from April to October 1998, a year of extremely dry weather, particularly in the Russian Far East. The total area burned was estimated as 11 million ha, with 350 million tons of biomass consumed and 176 million tons of carbon released into the atmosphere. In our study sites, which were burned in 2002, the direct emission of carbon by consumed biomass was estimated at about 19 tons/ha (unpublished data).

About 15–20 million ha of burned forest will release 375–500 million tons of carbon by fire and 750 million to 1 billion tons of carbon by the decay of forest biomass after the fire (Goldammer 2003). Post-fire mortality is an important part of fuel accumulation and effects total post-fire emissions. The net primary production (carbon) of Siberian forests in permafrost areas is less than 2.8 kg m^{-2} y^{-1} (IIASA 2002). If we assume that the net primary production of Russian forested land (763 million ha) is 2 tons ha^{-1} y^{-1} based on IIASA's map, Russian forested land can't absorb the total amount of direct and post-fire emissions of carbon from 20 million ha in 1 year.

We used artificial surface fires at Spaskaya Pad in 2004 to investigate the effect of surface fires on the photosynthesis of larch crowns. Crown photosynthesis was not affected by the artificial surface fires after 1 year. The maximum average temperatures at the surface and at a depth of 5 cm were 307ºC and 67ºC, respectively. The temperature at a depth of 5 cm remained above 50ºC for 100 min. The maximum temperature at a depth of 10 cm was only 35ºC(unpublished data). The lack of an immediate effect of the surface fire on photosynthesis may have been because of low root temperatures; the main root system developed below a depth of 10 cm and the soil remained humid. However, it is necessary to continue to measure the photosynthetic ability of the crown because the bases of the stems received intense heat. The number of dead trees increased for several years after the surface fires (Shervakov 1979, Shvidenko and Goldammer 2001).

6. FUTURE PERSPECTIVES OF FOREST MANAGEMENT

Surface fires in the fire-adapted coniferous forests of Siberia constitute a regularly occurring phenomenon that is considered important in maintaining the stability, productivity, and carbon sequestration potential of these ecosystems. Early detection of fires and early fire-fighting measures are most important for preventing catastrophic fires. Observations conducted by aircraft and satellite are useful for the detection of fires. The Global Fire Monitoring Center (GFMC) monitored forest fires in Russian Asia over 1 year using satellite data and published the observations (Goldammer et al. 2003). According to the opinion of wildfire specialists and fire scientists in Russia and other countries, the main reasons for the growing number of large wildfires and burned areas is the poor detection of wildfires, a weak monitoring system, weakening of the Aerial Forest Fire Protection Service *Avialesookhrana*, and the lack of appropriate finances (Goldammer et al. 2003). Classification and weighing of protection objectives are necessary to fight fires efficiently (Table 1; FAO 2002). Because fire behavior is affected by fuel loads and fuel moisture, fuel inventories including atmospheric data are important (Volokitina 1996, Woodall et al. 2005), and prescribed fires may be necessary for fire suppression.

Not only the fire cycle and post-fire mortality control vegetation dynamics and reforestation. Studies of the fireless period required to maintain the next generation and of larch seed production are necessary for permafrost areas of Russia. Planting is an unrealistic measure for remote and unprotected areas in Russia, whereas sowing seeds from aircraft may be more useful in these areas.

Fig. 5 shows a basic pattern of larch forest dynamics after surface fires from our studies and other observations. It is important to predict the direction of vegetation dynamics after fires, especially the initial symptoms of degradation. Not all land requires protection at the same level. Classification and weighing of protection objectives are required to fight fires efficiently.

Table 1. Classification of protection objectives, areas and level of significance.

Protection Objectives Example	
Level	Description
Critical	Fire in any form is not desired at all. Fire has never played a role in the ecosystem or - because of human developments - can no longer be tolerated without significant economic loss. Virtually all fires would be actively suppressed.
Full Protection	Fire plays a natural role in the function of the ecosystem but - because of resource concerns and potentially high economic impacts from fire - considerable constraints exist. Fire suppression is usually aggressive.
Limited Protection	Fire is a desirable component of the ecosystem. Certain ecological/resource constrains may be applied. These constraints - along with health and safety, etc. - are used in determining the appropriate suppression tactic on a case-by-case basis.
Fire Use Area	Fire is desired to achieve the resource condition, sought for designated areas with no constraints. Prescribed fire is used to obtain the desired resource/ecological condition.

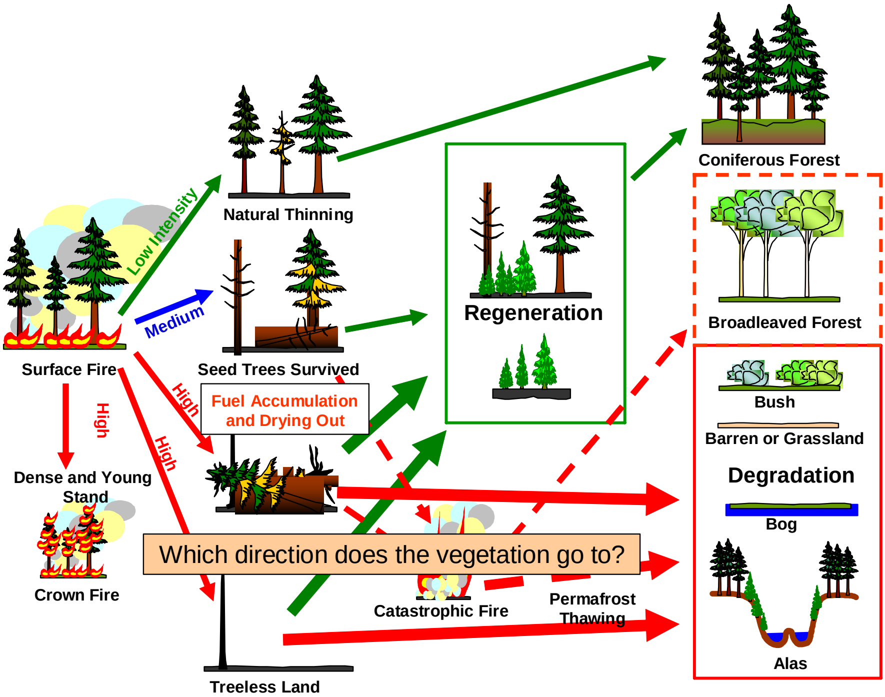

Fig. 5. A basic forest dynamics pattern of permafrost area after surface fire.

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