Chronosequence of forest fire effects on the active layer, Central Yakutia, eastern Siberia

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Abstract

Forest fires are a recurrent disturbance in Eastern Siberia among other disturbances (clear-cutting, agriculture, construction). Despite the large area that fires cover and its ecological role in this boreal region it has been poorly studied or it has not been well understood. This study has been conducted in naturally burnt sites (five) with different post-fire periods; 4, 5, 15, 25 and 50 years and intact (*Larix cajanderi*) forest sites (three) that were considered as control sites. The sampled profiles included the active layer (layer of ground that freezes in winter and thaws in summer) and the upper permafrost (frozen ground for more than two consecutive years). The objective of this study is 1. To determine the effect of fire on the belowground and 2. To find the causes that determines forest regeneration or permafrost degradation. When degradation occurs the forest do not return to its original state because of soil salinization due to salt release formerly trapped in the permafrost. The results of this study show that the active layer of burnt sites older than 25 years does not differ significantly with the active layer of intact forests. On the other hand, the 'younger' burnt sites showed a deepening of the active layer. The degrading and aggrading processes of the permafrost are followed and promoted by hydro-geochemical processes. In the intact forests sites, the soil ion profile shows increasing concentration downwards, especially in the permafrost layer. During the years of permafrost thawing, ions moved upward into the upper soil layers. Once the water balance of the site is balanced by the appearance of birch (*Betula platyphilla*), soil moisture in the lower layers start accumulating and this movement downward brings the ions back to the lowers layers where due to high water content and lower soil temperatures become trapped again in permafrost (aggrading). This process takes approximately 20 years. In conclusion, fires, in Central Yakutia, are at present assimilated by the disturbed forest ecosystem and the changes it experiment initially are temporal. The conditions necessary for a permanent change in this boreal forest ecosystem is the increase in fires frequency which would not allow forest regeneration and in consequence active layer would not be able to recover. In conclusion, fires are part of the forest ecology but if global warming increases the frequency of fire occurrence, then the time needed for

forest recovery will be cut short and the process of degradation will be accelerated.

Keywords: Disturbance, Forest fires, Global warming, Permafrost Regions, Salinization.

1. Introduction

Forest fires in Central Yakutia are recurrent phenomena that determine regeneration, changes in land cover, changes in water and CO_2 balance and many other processes. The trigger for fire can be natural (lightings) or human caused (human activity) but the condition necessary for severe fire expansion is dry weather (long rainless periods), high temperatures and low relative humidity. Under especial circumstances, which can be linked to 10-13 years climatic cycles (Shender et al., 1999) burnt sites can developed into thermokarst depressions (Czudek and Demek, 1970; Brouchkov et al., 2004; Agafonov et al., 2004), known as Alas, which is the last stage of forest degradation in this region. Or as it is more general, forest can return to its former state (before the disturbance occured).

Forest fires in eastern Siberia are not crown fires, which are more devastating in their effect (Harden et al., 2000), but surface fires (Mouillot and Field, 2005), because of low tree density and because of the pyrophytic properties of larch trees (Nikolov and Helmisaari, 1993; Tvsetkov, 2004). Therefore, burning over millions of hectares does not necessarily mean that the forest disappears and turns into saline thermokarst depressions (Brouchkov et al., 2004). Changes in the aboveground can alter the movement of water and salts present in the lower part of the active layer and upper permafrost (Lopez et al., 2006). Forest fires in Siberia have been cited as a large scale disturbance that can contribute to permafrost degradation or to the release of carbon stock that is protected in the permafrost (Apps et al., 1993, Gower et al., 2001) by low temperatures and that can be released to the atmosphere if the soil thermal regime is altered by climatic change (Kasischke et al., 1995; Zimov et al., 1996). However, to our knowledge no study has focused on the actual effect of forest fires or global warming in eastern Siberia by considering soil texture, ice content and especially ion content present in the permafrost. Thus, the objective of this study is 1. to determine the effect of fire on the belowground and 2. To find the causes that determines forest regeneration or permafrost degradation. to determine the short-term (temporal) and long-term (permanent) physical and chemical changes in the soil profile caused by forest fires and the conditions that determine their development.

2. Materials and Methods

2.1 Site description

Neleger Experimental Station is located 30 km north-northwest from the city of Yakutsk (62º 05' N, 129º 45') and belongs to the Permafrost Institute. Mean annual air temperature is –10 to -11°C; amplitude of monthly temperatures is about 62°C. Snow cover is 30 - 40 cm, but reaches 60 cm. Icy deposits are located at depths from 1.5 m to about 3 m; they occur over more than half of the territory and have thicknesses of up to 20-25 m and are distributed in 18% or 76 thousand km^2 of the territory of central Yakutia (Fedorov et al.,1991). The area consists of a group of Lena River terraces with elevations of 200-220 m.a.s.l.; it is a region of continuous permafrost up to 400-500 m thick. Quaternary deposits are from a few meters to 200 m thick. The bedrock predominantly consists of limestones and argillites. Disturbances that occurred around 9000 years ago, and still continue, have changed the landscape of this area to grassland (alas). Precipitation during the snow-free growing season is 110 mm which is about half the annual precipitation, whereas the corresponding potential evaporation rate is 370 mm (Muller, 1982). Soils in this region are classified as Gelisols; they are predominantely silty-clay-loam (SiCL) to silty-clay (SiC) in 70 % of the territory and sandy-loam (SaL) in the remaining part.

2.2 Sampling

The sites selected were three intact forests (F1, F2 and F3) and five burnt forests (B1, 4 years; B2, 5 years; B3, 15 years; B4, 25 years and B5, 50 years). The soil texture at all sites was silty loam. Three 2m-long soil profiles were collected at each location, starting in May 2006. The sampling took place when the soil profile was still frozen and required a boring machine. The frozen layer (permafrost) was estimated by an increase in ground resistance to drilling and an appearance of visible ground-ice content. The core samples were sectioned in 10-cm intervals, logged, double-bagged, and returned to a laboratory. Soil texture was determined by observation and tact.

2.3 Soil moisture and chemical analysis

Soil moisture was determined gravimetrically by drying to a constant weight at 105°C for 24 hours. A different set of soil samples taken next to the samples used for soil moisture measurements, in each of the profiles, was air dried and then analyzed for pH in a supernatant suspension of 1:5 soil:deionized water mixture (pH meter HORIBA) and electric conductivity in a supernatant suspension of 1:5 soil:deionized water mixture (Page et al., 1982) (EC meter TOA CM-30V) for each sampling site. Electric conductivity of saturated paste (EC_e), used to evaluate saline and alkaline soils was estimated using soil water 1:5 suspension measurements and following the relation obtained by Slavich & Petterson (1993) for each soil texture found in the different profiles.

3. Results

Soil texture was silty loam at almost all locations down to 1.5 to 1.6 at all intact forest and burnt sites alike. In deeper layers the soil tend to be sandy loam instead. At one of the profiles in site F1, pure ice was found from 1.5 down to 2.00. The ice found in that particular sampling is part of ice wedges that can be 40 m long. It is this ice that if melted could form pools and the slumping of ground with the consequence of permanent forest disturbance. Pure ice was not found in burnt sites during sampling but layers with high ice content were found below the active layer. By principle ice wedges are distributed in areas were the soil is predominantly silty loam and they are absent in sandy loam soils. Ice wedges are found especially in the depressions of hummocks in the forest soil.

The long record of climatological data showed that especially in the last decades there has been an increase in air temperature but the higher increases in air temperature have been reported in winter rather than in summer, which might account for higher ground temperatures that in the future can bring instability to the layers with high ice content in the permafrost layer. Precipitation follows the same trends in winter, with higher snow precipitation in the last decades compared to more stable values in summer. It is also important to mention that snow depth itself is not the determing factor affecting ground temperatures but rather the time when the snow season begins since this will determine the rate at which the ground will freeze (Smith, 1975).

3.1. Soil moisture

Soil moisture in the active sampled at the forest sites depending on the time passed since the fire occurred. The values in the profile revealed conditions of water storage from the previous year, before they froze in October. The similarity found in all the intact sites made it clear to identify the soil moisture pattern with a drier soil moisture layer in the border between the active layer and the permafrost layer. Increases in ice content in the thawed permafrost layer after approximately 20 years (soil moisture measurements ranged from 0.4 to 0.6 $cm^3.cm^{-3}$ in F4 and F5). Soil moisture in the active layer at the 'younger' burnt sites ranged from 0.2 at the bottom to around 0.4 $cm^3.cm^{-3}$ at the surface of the mineral soil layer. At approximately 120 cm depth at all burnt sites soil moisture increased as in the intact forest sites, signalling the boundary zone or 'shielding layer' between active layer and the permafrost layer (Shur, 1988). In the burnt sites the active layer depth ranged from approximately 130 to 160 cm depending on the time elapsed after the fire event. Thus, the results shown for all the alas sites correspond to the active layer alone. In the burnt site the presence of organic matter at the soil surface differed from one another depending on the years passed after the fire event since the organic matter present at that time was strongly affected.

3.2. *Soil pH and EC_e(Electrical conductivity)*

Soil surface pH (0 to 15 cm) at the forest sites where the organic matter distributes ranges between 5.5 to 6.2 and then increased rapidly to more than 8 when the mineral soil layer was reached. Soil texture differences between F1, F2, F3, F4 and F5 where confirmed as no differences in pH were observed between the active layer and the permafrost. This is also observed in the soil profile of the burnt sites. Except for the 50 years burnt site, pH is on average 6.2 but the other more recently burnt sites (5 years and 15 years) are closer to 5.5 which is a value commonly observed in intact forests. At all sites, pH becomes stable from 50 cm down regardles of active layer depth, soil moisture conditions or surface vegetation.

Electrical conductivity of the soil profile showed lower values in the active layer (0.81±0.24) than in the permafrost layer (1.0 to 3.0 $mS.cm^{-1}$) for predominantely silty loam soils. In the burnt sites, the same pattern is observed except for the 5 years burnt site where values in the permafrost remained low (0.2 to 0.8 $mS.cm^{-1}$). At this particular site, soil texture in all the samples in the permafrost was sandy which explains the poor accumulation of ions that otherwise would have increased the EC_e as in the other sites. In general, the increase in salinity (using EC_e as a proxy) for the burnt sites in the active layer (1.03±0.19) is small.

4. Discussion

Contrary to what has been suggested in previous studies, forest fires do not cause physical or chemical changes that might bring changes in the landscape or specifically hinder the reestablishment of trees. Alas sites, where trees are not able to grow because of high salt content in the root zone (Lopez et al, 2006) were caused by global climate changes rather than forest fires, despite of the large areas that are recurrently affected by this phenomenon. Lost of transpiration from trees lost in a clear-cut site in the same area was the cause for immediate increase of soil moisture in the active layer (Iwahana et al., 2005). In this experiment the same was not observed in the site more recently burnt (5 years) or in the other sites, suggesting that vegetation that appeared after severe forest fires (*Chamerion angustifolium*) transpired highly (2.6 mm d^{-1}, unpublished data) as compared to the forest maximum transpiration of 3 mm d^{-1} found for the same region (Dolman et al., 2004, Ohta et al., 2001). Another reason for the lack of soil moisture increase in this site is the sandy texture of the soil in the deep active layer and upper permafrost where any excess water could filtrate down avoiding water accumulation. After fires, the active layer is known to deepen in the first years and later recover to its former depth (Mackay, 1995) following revegetation of the forest soil and thickening of the organic matter layer, factors that play an important role in keeping a thin active layer. It is important to mention that not only trees prevent active layer deepening but also some other kinds of grasses like *Carex spp*, for example. In the older burnt sites (25 years and 50 years) the depth of the active layer was found at around 110 cm depth which is similar to intact forest (Sawamoto et al., 2000) with silty loam soils. The 5 years burnt site have sandy composition in the upper permafrost so a sharp deepening of the active layer (160 cm) does not have serious repercussions because of the poor ice content in these layers.

In B3, B4 and B5 sites, birch (*betula platyphilla*) is predominant with higher tree density in the older sites. In the 50 years site, the pH (ranging from 6.1 to 7) at the surface is bigger than recently burnt sites. In a previous study, Lopez et al. (2006) found a belt of birch trees between larch forests and alas, where salt content was higher than in forest soils. Thus, the higher density of birch trees in comparison to larch trees in this region could be linked to a response in slight changes in the chemical composition of the upper mineral soil layer after fire. In time, which is a period of about 100 years, the larch forest becomes dominant again

The results of this study suggest that climate change rather than forest fires were responsible for the widespread formation of alases in Central Yakutia. At present, the same trends that were observed in the past are becoming a common feature of this permafrost underlain territory. Forest fires play a regeneration role that has been part of this boreal forest for centuries (Ivanova, 1996) and has scarcely triggered thermokarst formations (Brouchkov et al, 2004). If temperature and precipitation keep increasing in winter then the findings by Payette and Delwaide (2000) on the role played by snow on thermokarst formations can bring instability to the permafrost layer.

5. Conclusions

The effects of forest fires in the boreal forest of Central Yakutia are not permanent but are part of a regeneration cycle for the forest in this region. The steps leading to forest degradation (active layer continuous deepening, thawing of ice deposits, formation of pools on the forest soil, etc.) were not observed in the burnt sites in this study. On the contrary, forest fires appear as a temporal phenomenon that revitalizes the forest without affecting its stability.

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