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Logging and Fire Effects in Siberian Boreal Forests

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Introduction

Wildfire is one of the main disturbances in the Russian boreal zone. Currently, several million hectares burn annually in Russia, most of which is in Siberia (Vivchar 2011). In addition to fires, logging is an important disturbance factor in many forest areas of Siberia (Achard *et al* 2006). Logged areas appear highly susceptible to fire due to a combination of high fuel loads and accessibility for human-caused ignition. In addition to legal cutting, illegal logging has become one of the most significant threats facing the forests of Siberia and the Russian Far East since the 1990's (Vandergert and Newell 2003). Both fire and logging result in significant forest cover loss in the boreal zone (Potapov *et al* 2008). Fire consequences on logged sites vary widely depending on site characteristics, fuel types, structure, and loads; time since timber harvest, logging methods, species composition of regeneration (coniferous vs. deciduous) and weather conditions before and during burning (Valendik *et al* 2011).

The objective of our research was to investigate the influence of logging on the effects of wildfires in the forests in Siberia. We analyzed and compared the impacts of fire and logging on fuel loads, carbon emissions, soil respiration and microbocenosis, and tree regeneration in different regions of Siberia.

Study Area and Methods

The investigations were carried out in three regions of Siberia (Angara, Shushenskoe/Minusinsk, and Zabaikal regions) that represent different ecozones and are characterized by different dominant types of logging activities (clear-cuts vs. partial logging, legal logging vs. illegal logging, etc.) (figure 1).

In 2009-2013 we measured fire impacts on the overstory and subcanopy tree layers, young regeneration, and surface and ground biomass at 23 study areas in Scots pine and larch forests of Siberia. Four 3-4 ha sites representing different histories of logging and fire were typically examined in each study area: (i) unlogged/unburned; (ii) logged/unburned; (iii) unlogged/burned; and (iv) logged/burned. Additionally, 8 field sites that had experienced repeat burns were investigated (overall 100 field sites).

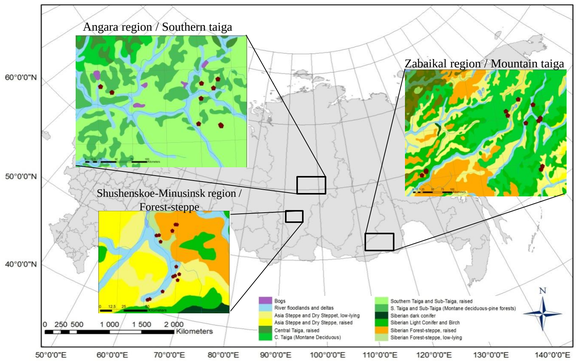


Figure 1. Regions of investigations. Dark dots represent the location of sample sites. The background in the insets is from the Digitized Ecosystem Map of the Former Soviet Union (Soja *et al* 2004) with ecosystem types shown in different colors

On each field site a set of nine sampling triangles 5-m on a side was established (figure 2). A base transect starting usually from the road was set up with three sample transects contained 9 sample triangles. We measured dead and down woody fuels on triangle sides using a line intercept method and collected ground fuels samples on 27 subplots on each field site. The diameter at stump height and at 1.35 m for tall regeneration and trees as well as height by species were estimated using a circular 9-m radius sample plot at each sample triangle to determine stand characteristics. On logged sites stand characteristics were reconstructed for each study area on the basis of relationships between the diameter at stump height and breast height in undisturbed forest sites. Regeneration shorter than breast height was characterized inside the triangle. Carbon emissions from fires on both logged and unlogged sites were estimated based on fuel consumption data that were obtained by subtracting fuel loads on burned sites from those on unburned sites.

Microbial biomass was determined by the method of substrate-induced respiration (Anderson and Domsh 1978). Basal respiration was found from the rate of CO_2 flux measured by a LHM80 modification of a Chrome-4 gas chromatograph.

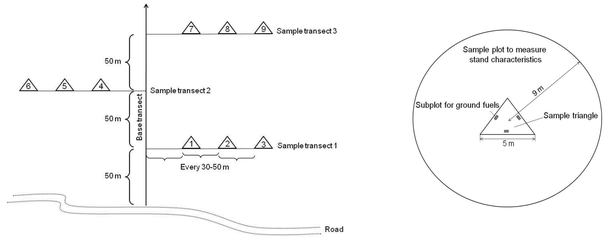


Figure 2. The diagram for basic sampling layout for each field site

Results

We found large variations of fire and logging effects among regions depending on growing conditions and type of logging activity. Logged areas in the Angara region had the highest surface and ground fuel loads (up to 135 t/ha), mainly due to logging debris (figure 3a). This resulted in high carbon emissions where fires occurred on logged sites (up to 41 tC/ha) (figure 4). The Shushenskoe/Minusinsk and Zabaikal regions are characterized by better slash removal (figure 3b,c) and a smaller amount of carbon emitted to the atmosphere during fires (figure 4). Illegal logging, which is widespread in the Zabaikal region (figure 3d), resulted in an increase in fire hazard and higher carbon emissions than legal logging (figure 4). The highest fuel loads (up to 70 t/ha) and carbon emissions (18-28 tC/ha) in the Zabaikal region are on repeatedly burned unlogged sites. Our carbon emission estimates on unlogged sites are in good correspondence with data obtained in the course of the experimental burnings conducted within the framework of FIRE BEAR project (figure 4).

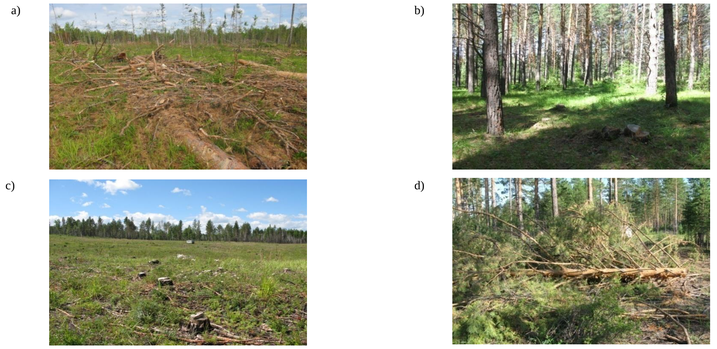
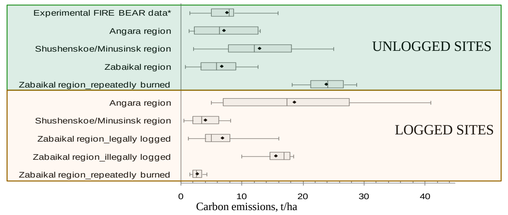


Figure 4. Logged sites after (a) clear-cut logging in the Angara region; (b) legal partial logging in the Shushenskoe/Minusinsk region; (c) legal clear-cut logging in the Zabaikal region; d) illegal partial logging in the Zabaikal region



* data from Mcrae *et al.* 2006, Kukavskaya and Ivanova 2006, Ivanova *et al.* 2011

Figure 6. Comparison of inter-site range of estimated carbon emissions from fire

Soil respiration was less on both burned and logged areas than in undisturbed forest (figure 4). The highest structural and functional disturbances of the soil microbocenosis were observed on logged burned sites (figure 5).

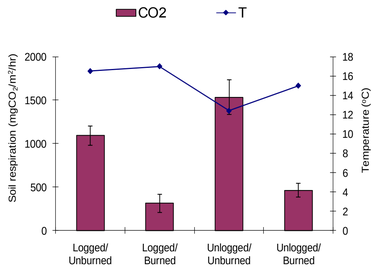


Figure 4. Changes in soil respiration after fire and logging

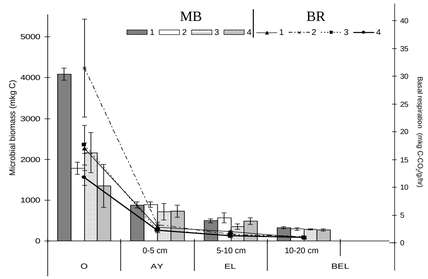


Figure 5. Changes in soil microbial biomass (MB) and basal respiration (BR) in different sites: 1 – unlogged/unburned; 2 – unlogged/burned; 3 – logged/unburned; and 4 – logged/burned

We observed an increase in the density of healthy regeneration after fire in unlogged forests. However, repeated fires together with logging activities resulted in insufficient regeneration, or even total lack of tree seedlings (Table 1). Without replanting on these sites postfire, we expect the forested area will decrease and large areas will transition to steppe ecosystems.

Table 1. Density of healthy seedlings in different types of field sites (thousand per ha ± standard error)

Region	Density of healthy seedlings (thousand per ha ± standard error)				
	Unlogged/ unburned	Unlogged/ burned	Logged/ unburned	Logged/ burned	Logged/ repeatedly burned
Angara	21.2 ±4.2	24.5±3.8	44.3±8.2	6.3±1.7	1.5±0.6
Shushenskoe/ Minusinsk	33.4±3.2	63.8±9.7	38.2±3.2	2.4±0.4	0.8±0.5 or none
Zabaikal	6.1±1.5	9.0±1.4	5.1±0.2	2.2±0.4	0.4±0.2 or none

Conclusions

Fire and logging effects are region and site specific and depend on forest types, type of logging activity, and weather conditions prior to and during burning. Understanding current interactions between fire and logging is important for modeling ecosystem processes and for managers to develop strategies of sustainable forest management. The negative impacts of fire and logging on air quality, the carbon cycle, and ecosystem sustainability in our study regions could be decreased by better slash removal in the Angara region, removal of trees killed by fire in the Zabaikal region, and tree planting after fires on drier sites where natural regeneration is hampered by soil overheating and grass proliferation. Changing patterns in the harvest of wood products can be expected to increase the emissions and ecosystem damage from wildfires, inhibit recovery of natural ecosystems, and exacerbate impacts of wildland fire on climate and air quality.

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