Fire-Induced Forest Transformations in the Zabaikalye Region

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Introduction

Southern regions of Siberia are the most vulnerable to climate change and fires (Malevsky-Malevich *et al.* 2008, Gustafson *et al.* 2010). Unusually high fire frequency and short fire return interval became characteristics for many regions recently (Kuprianov 2009, Buryak *et al.* 2011). The Zabaikalye region located in the south of Siberia is characterized by one of the highest fire activity in Russia (Kukavskaya *et al.* 2013). This region corresponds to the "hot spot areas" of land cover change due to increased fire frequency (Achard *et al.* 2006).

The objective of our research was to investigate the impact of fires on forest state in the Zabaikalye region, southern Siberia.

Study Area and Methods

Area burned was analyzed with the use of fire datasets from the Institute of Forest SB RAS available since 1996 (Sukhinin *et al.* 2004, Soaj *et al.* 2004). To obtain indices of live vegetation (Normalized Difference Vegetation Index, NDVI) and fire severity (Normalized Burn Ratio, NBR), MODIS Nadir BRDF Adjusted Reflectance data product (MCD43A4) was used. We used a time series of vegetation and burn index anomalies to identify when sites burned and to evaluate recovery post-disturbance. NDVI and NBR anomalies were averaged prior to disturbance, and this value was compared with average NDVI and NBR values five years after the disturbance.

Ground-based measurements were conducted on a number of sites, primarily in the central and southern part of the Zabaikalye region. We estimated in situ fire impacts on the overstory and subcanopy tree layers, young regeneration, and surface and ground biomass in Scots pine and larch forests dominated in the region. At each location both unburned and burned plots were examined. Carbon emissions from fires were estimated based on fuel consumption data that were obtained by subtracting fuel loads on burned sites from those on unburned sites.

Results and Discussion

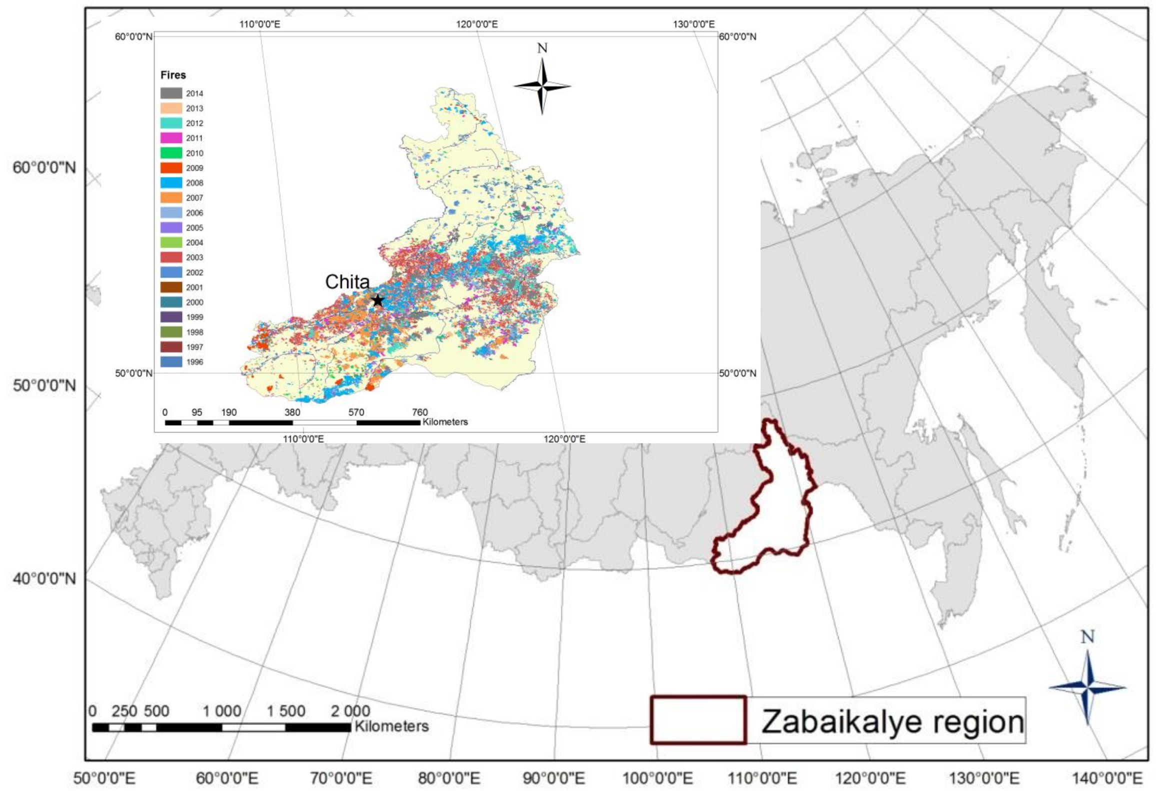

Figure 1. Location of the region of investigation. The inset represents the Zabaikalye region with area burned showed in different colors from 1996 to 2014

According to the satellite fire dataset from 1996 to 2014 annual area burned in the Zabaikalye region varied from 0.2 to 6.0 million hectares (figure 1, 5). Official Russian fire data that tended to underestimate area burned (Conard *et al.* 2002) for the same period varied from 0.02 to 0.9 million hectares.

The highest fire frequency is observed in the central and southern parts of the Zabaikalye region, mainly nearby the roads (figure 2). Due to the dry climate, low amount of winter and summer precipitation fire season lasts up to 7-8 months in the region (figure 3).

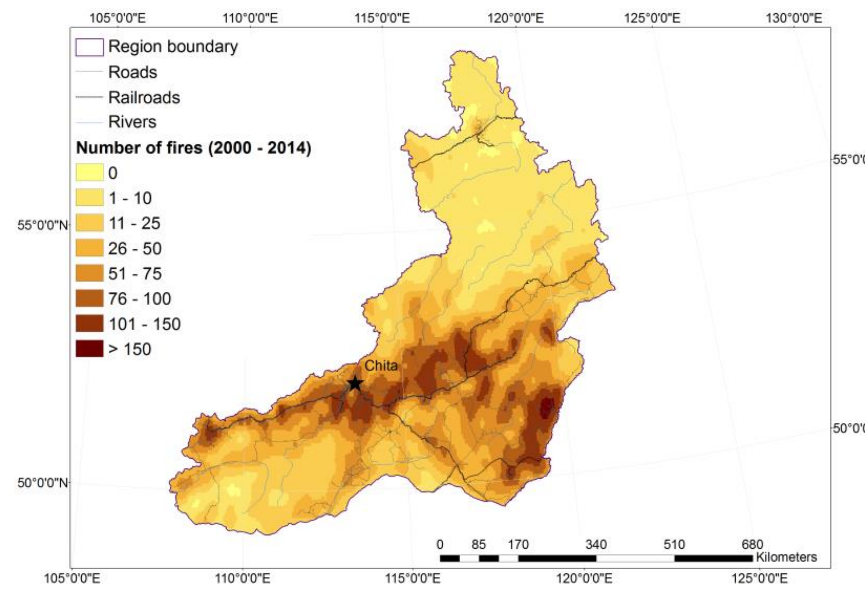

Figure 2. Number of fires in the Zabaikalye region by the 0.25º x 0.25º grid

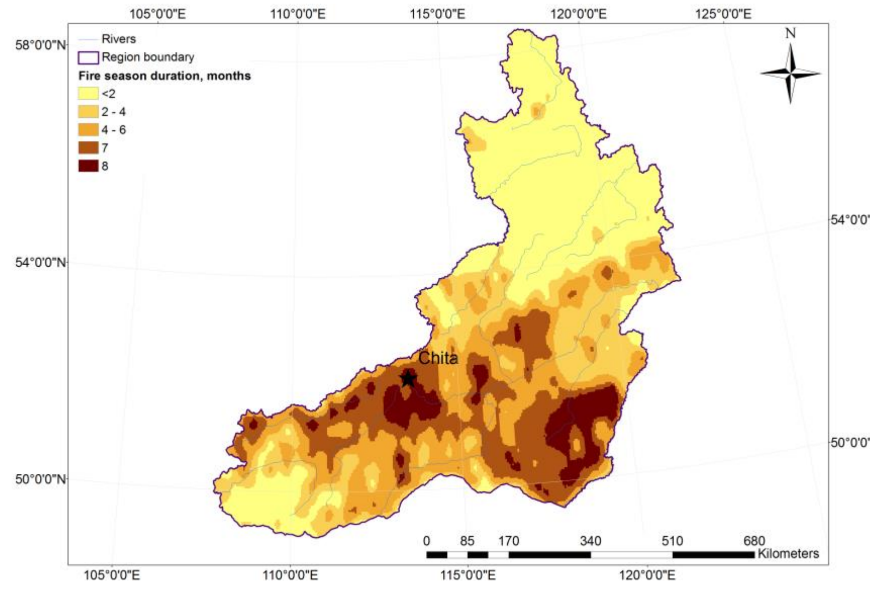

Figure 3. Fire season duration in the Zabaikalye region by the 0.25º x 0.25º grid

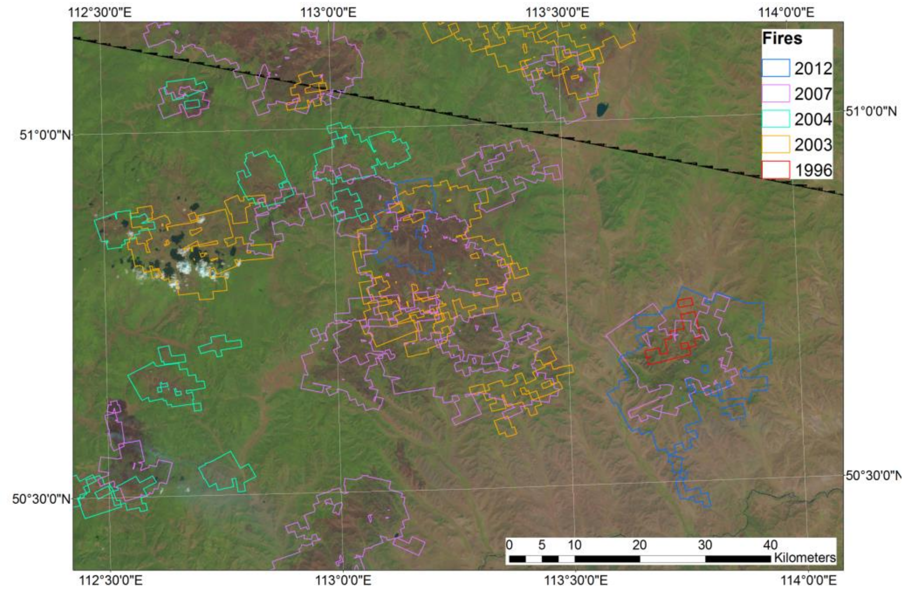

Figure 4. An example of the intersected fire polygons for a part of the Zabaikalye region

Fires often occur on the same territory of the Zabaikalye region. Fire return interval could be as low as 1-2 years for some forest areas (figure 4). Based on fire data from 1996 to 2014 (figure 5) we calculated the area burned repeatedly in the Zabaikalye region (figure 6). For the whole period repeatedly burned areas amounted 11.9 million hectares with fires spread across some areas more than twice (Figure 6).

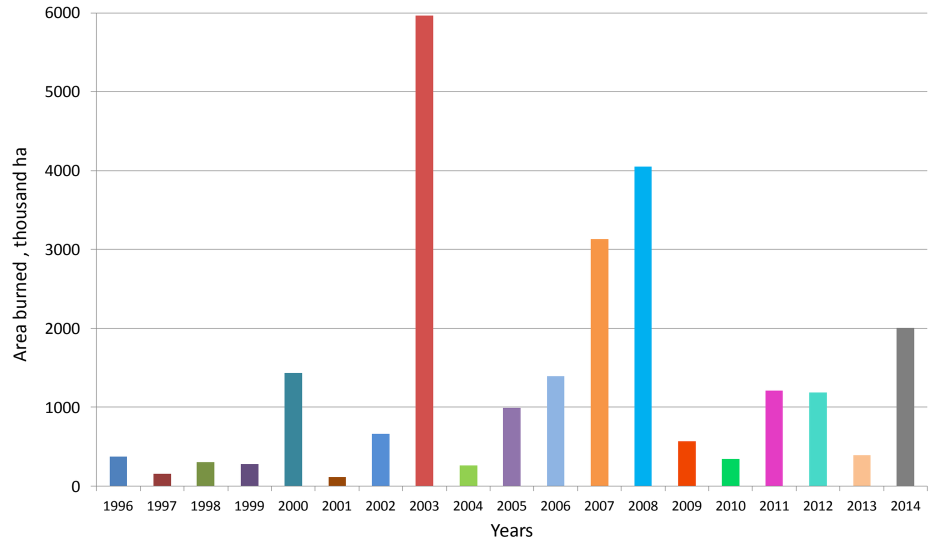

Figure 5. Annual area burned in the Zabaikalye region

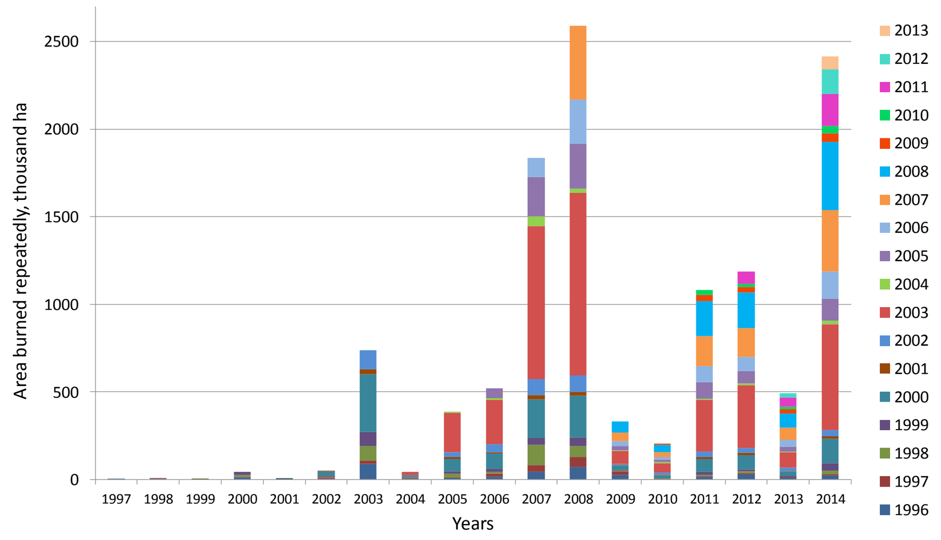

Figure 6. Repeatedly burned area in the Zabaikalye region for the period from 1996 to 2014

Wildfire effects in the forest ecosystems in great extent are determined by the characteristics of disturbances (low-severity fire vs. high-severity fire, one burning vs. repeated burnings, logging vs. absence of logging, legal vs. illegal logging). The worst consequences were observed on the sites undergone by multiple disturbances with fires characterized by high severity (figure 7).

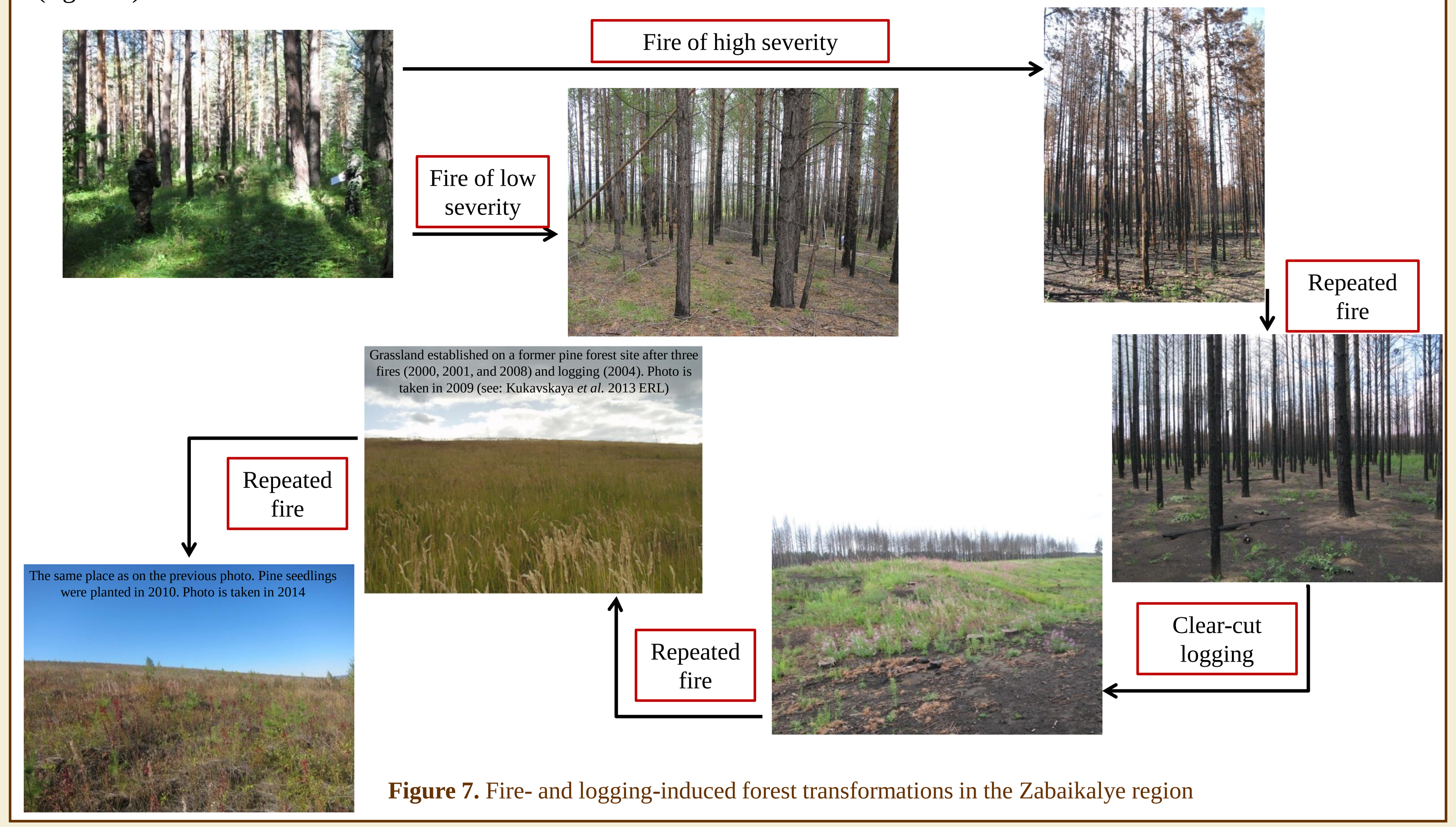

Figure 7. Fire- and logging-induced forest transformations in the Zabaikalye region

Surface and ground fuel structure and loading changed substantially after fire events. Low-severity fires decreased fuel loadings by 8-20%, high-severity fires – by 30-62 %, while after repeated fires fuel loads accounted not more than 5-10% of the prefire loads (figure 8) with mineral soil exposed (figure 9).

Carbon emissions varied from 2 to 12 tC/ha in the light-coniferous forests of the Zabaikalye region. At repeatedly burned sites the amount of carbon emitted to the atmosphere averaged 6.2 tC/ha while it was as much as 4 times higher at sites where first fire resulted in total tree mortality and trees were falling on the ground.

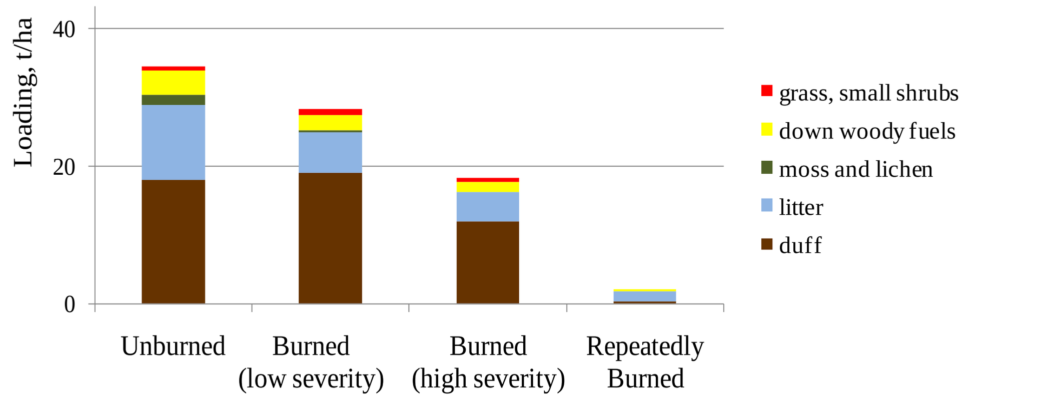

Figure 8. Postfire changes in surface and ground fuel loads

Figure 9. Mineral soil exposed by repeated fires

In the southern regions repeated fires 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 (figure 7). In addition, soil erosion is a quite often phenomenon in mountain forests of the Zabaikalye region after fires of high-severity or repeated fires (figure 10).

Table 1. Regeneration on different types of field sites

Density of healthy seedlings (thousand per ha ± standard error)			
Unburned	Burned (low severity)	Burned (high severity)	Repeatedly burned
6.1±1.5	9.0±1.4	5.4±1.1	0.1-0.3 or none

Figure 10. Postfire soil erosion

The analysis of the NDVI or NBR indices revealed that the sites that exhibited a normal recovery trajectory showed a sharp reduction in NDVI and NBR anomaly values in the year of fire event and gradual recovery of these values to pre-fire levels after approximately five years (figure 11a). The sites where recruitment failure was observed in the field exhibit a much slower recovery, and most do not appear to be approaching the pre-fire NDVI or NBR anomaly levels (figures 11b,c,d).

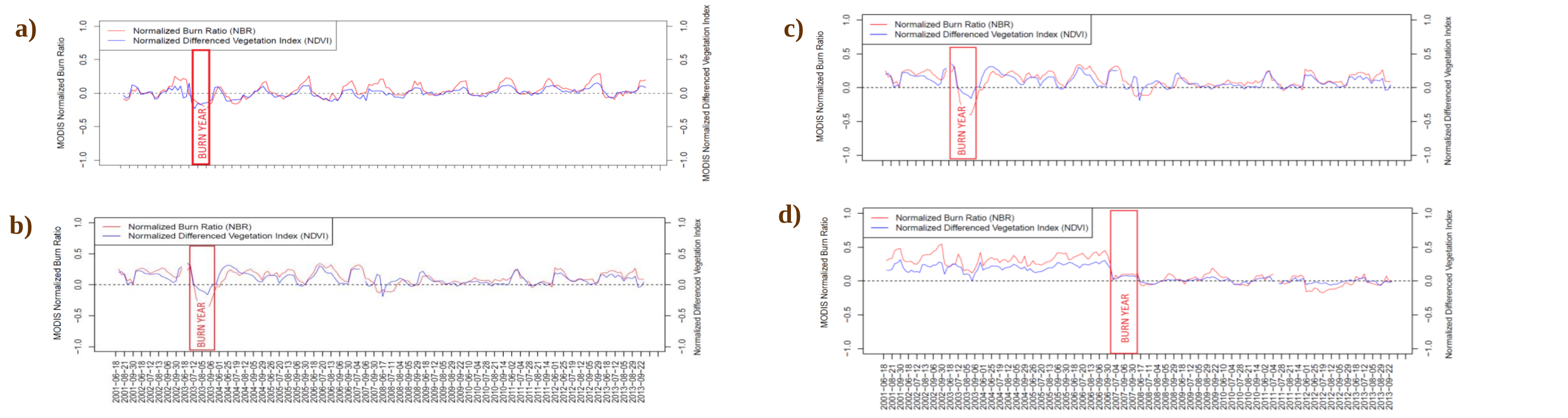

Figure 11. Normal recovery of vegetation index anomaly values (a) and recovery for sites where recruitment failure appears to have occurred (b,c,d)

Conclusions

Changing anthropogenic patterns and climate change increase ecosystem damage from wildfires and inhibit recovery of natural ecosystems. Repeated disturbances result in soil overheating, erosion, absence of seed sources, and proliferation of tall grasses as well as reduction of the amount of carbon that is stored in the terrestrial ecosystems. Detection and monitoring of changes in the areas of Siberia where wildfires have caused a major shift in ecosystem structure and function is required for the development of sustainable forest management strategies to mitigate climate change.

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