GC31B-0456

Effects of Repeated Fires in the Forest Ecosystems of the Zabaikalye Region, Southern Siberia

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Introduction

Fire is the main ecological disturbance controlling forest development in the Russian boreal forests and contributing substantially to the global carbon cycle. The warmer and dryer climate observed recently in the boreal forests is considered to be responsible for extreme fire weather, resulting in higher fire frequency, larger areas burned, and an increase of fire severity (Flannigan *et al.* 2009). Because of the increase of fire activity, boreal forests in some regions may not be able to reach maturity before they re-burn, which means less carbon will be stored in the ecosystem and more will remain in the atmosphere. Moreover, if one fire occurs within a few years of another, some stands will not re-grow at all, and even more carbon will accumulate in the atmosphere.

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). 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 repeated fires on carbon emissions and forest ecosystem components in the Zabaikalye region, southern Siberia.

Study Area and Methods

The investigations were carried out in the Zabaikalye region located in the south of Siberia (figure 1).

Area burned was analyzed for the whole Zabaikalye region with fire datasets from the Missoula Fire Sciences laboratory available from 2002 to 2012 (Petkov *et al.* 2013 IBFRA). To obtain indices of live vegetation (Normalized Differenced Vegetation Index, NDVI) and fire severity (Normalized Burn Ratio, NBR), MODIS Nadir BRDF Adjusted Reflectance data product (MCD43A4) was used. Vegetation and burn indices were compared with surrounding areas that did not burn to account for inter-annual variations in growing conditions unrelated to fire disturbance. 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 southern part of the Zabaikalye region (figure 1). 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. Moreover, areas that have multiple fire disturbances were chosen to be investigated. 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.

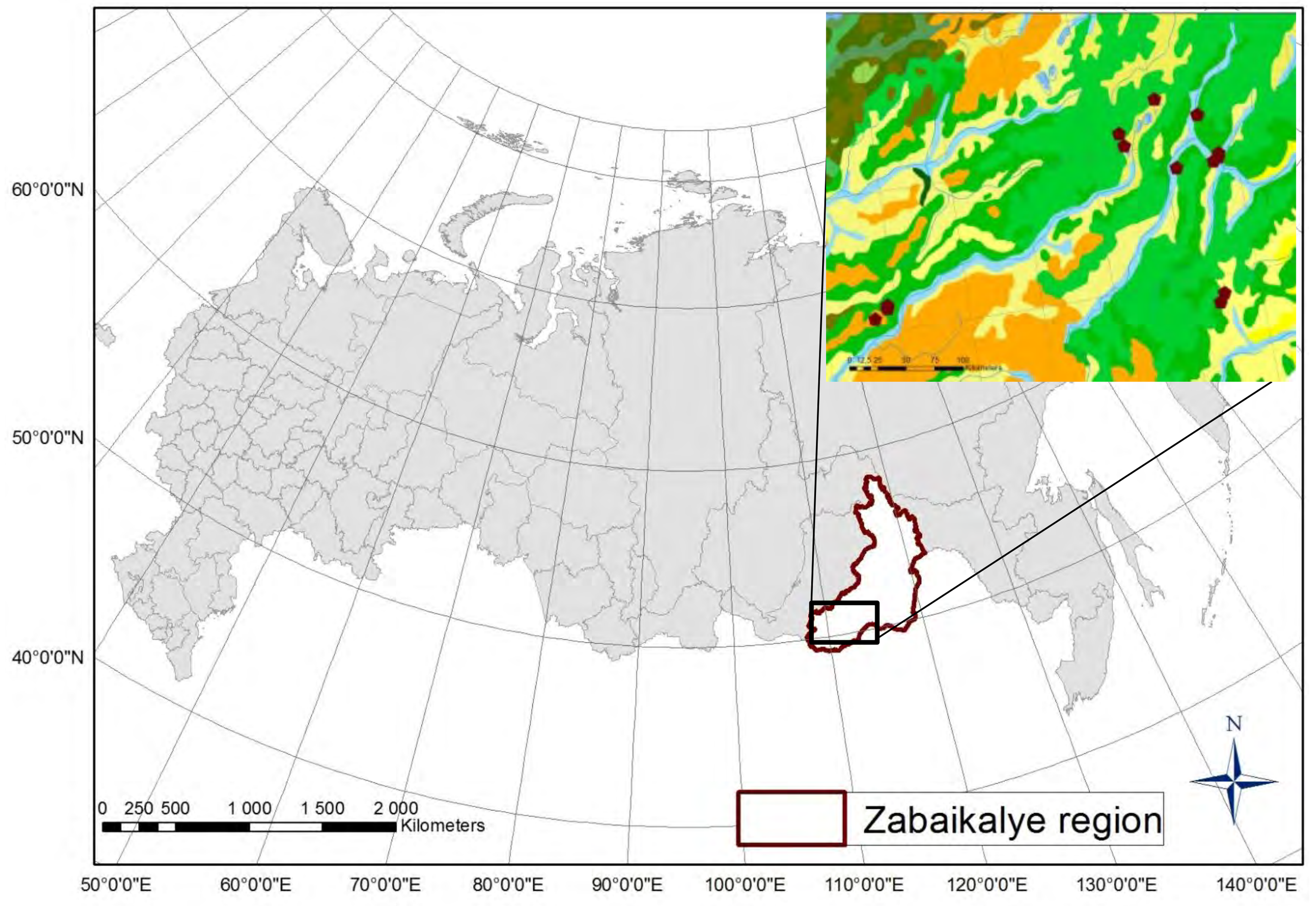


Figure 1. Region of investigation. Dark dots in the inset represent the location of ground sample sites and the background is from the Digitized Ecosystem Map of the Former Soviet Union (Soja *et al* 2004) with ecosystem types shown in different colors

Results and Discussion

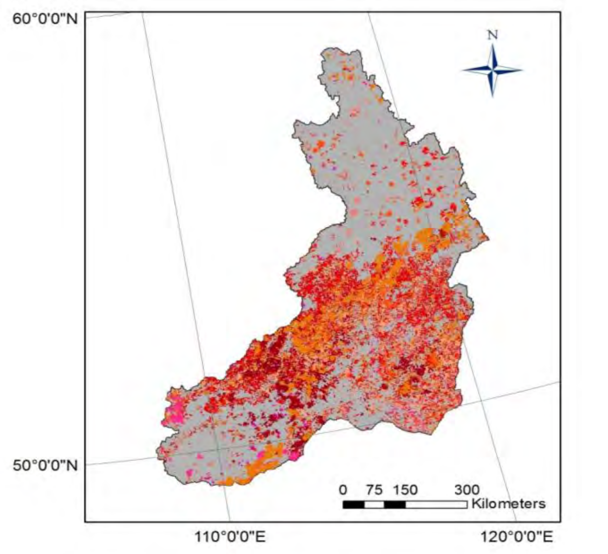


Figure 2. Area burned in the Zabaikalye region in the years 2002-2012

According to the satellite fire dataset from 2002 to 2012 annual area burned i Zabaikalye region varied from 0.3 to 7.1 million hectares (figure 2, 3). Of Russian fire data that tended to underestimate area burned (Conard *et al.* 200 the same period varied from 0.02 to 0.9 million hectares. Nonetheless, there significant correlation between annual area burned estimates from different sour Based on fire data from 2002 to 2012 we calculated the area burned repeatedly i Zabaikalye region (figure 4). For example in 2003, there were only abou thousand hectares burned on the same sites where fires occurred in 2002, wh 2008 areas burned repeatedly on the sites burned from 2002 to 2007 reached than 2 million hectares. For the whole period from 2002 to 2012 repeatedly bu areas amounted 7.3 million hectares (Figure 4).

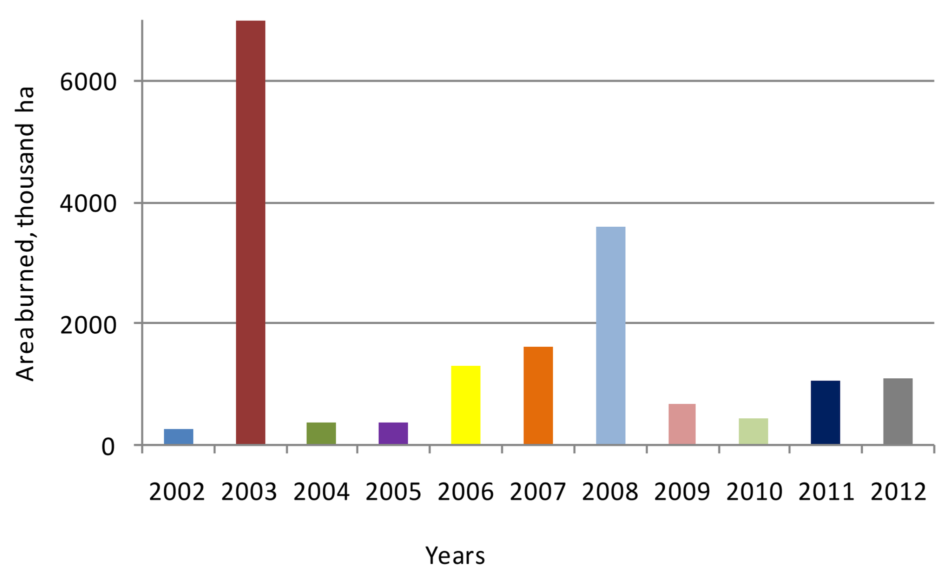


Figure 3. Annual area burned in the Zabaikalye region

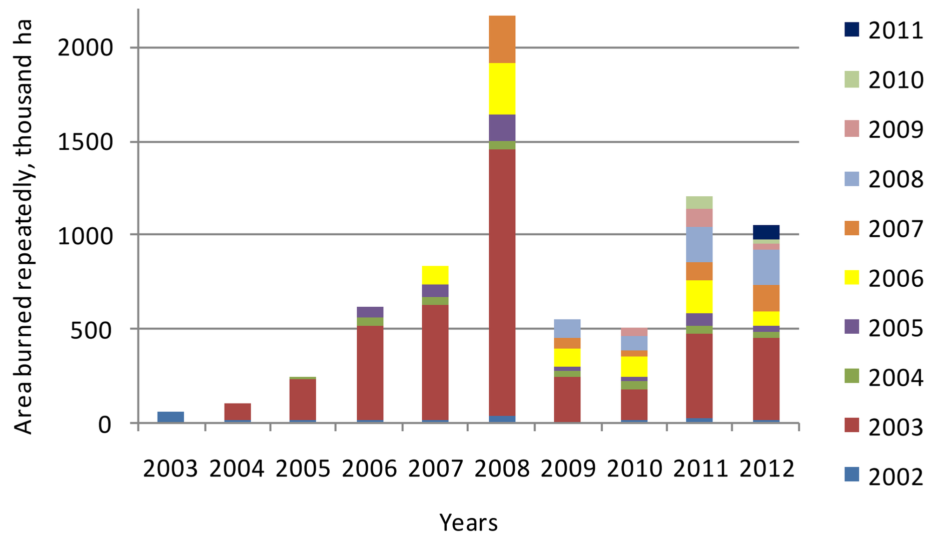


Figure 4. Repeatedly burned area in the Zabaikalye region for the period from 2002 to 2012

Fire 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. two or three burnings, logged vs. unlogged sites). The worst consequences were observed on the sites undergone by multiple disturbances with fires characterized by high severity (figure 5).

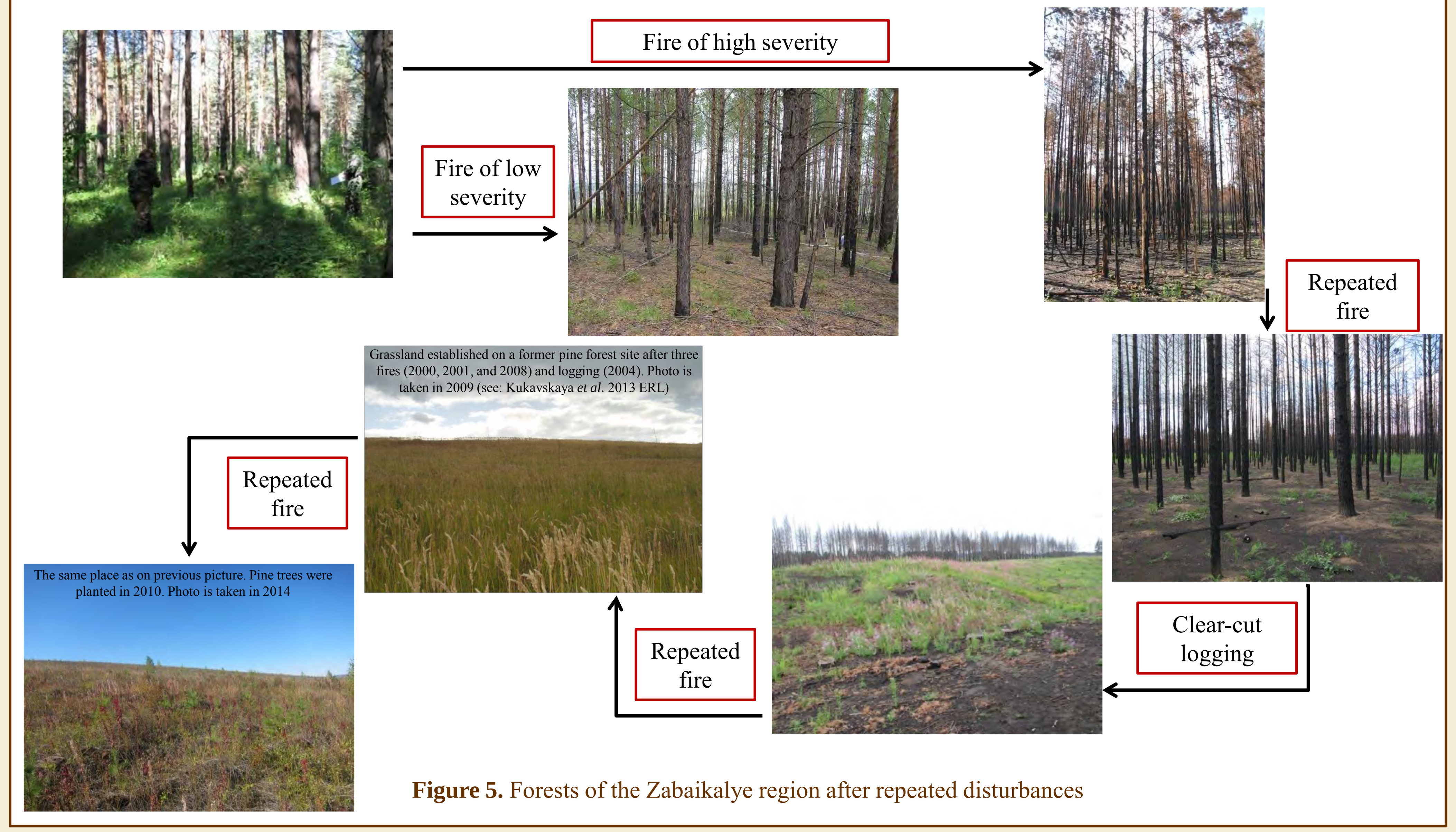
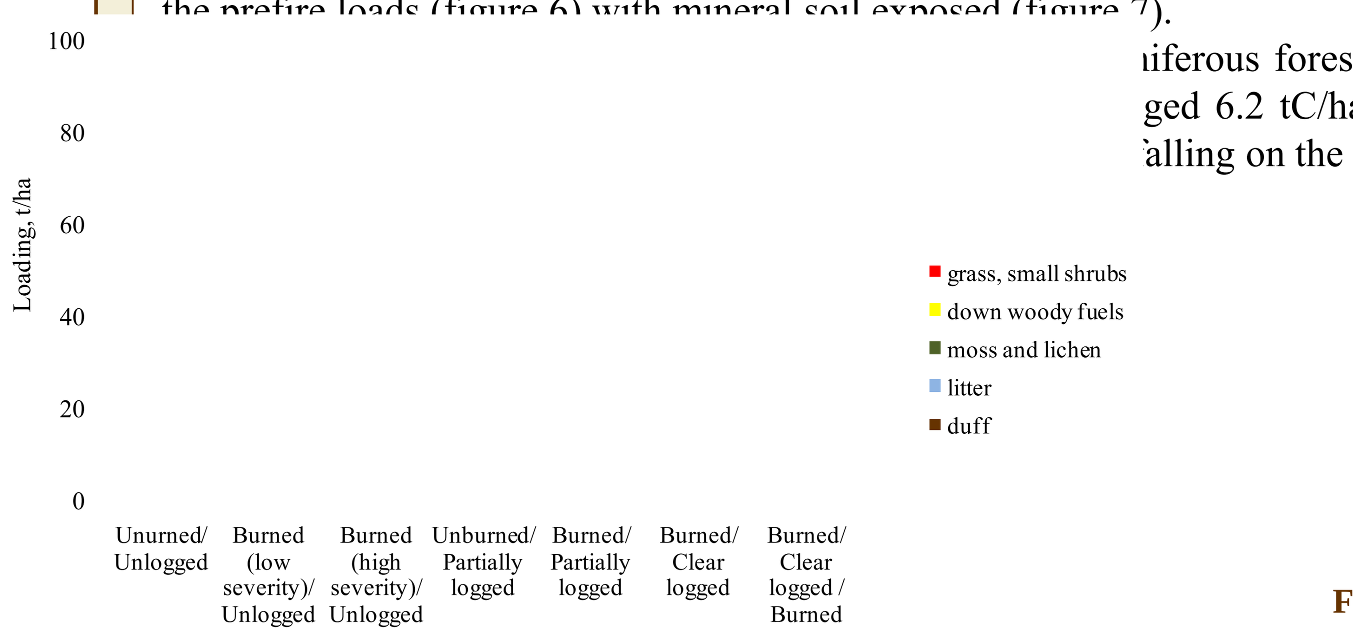


Figure 5. Forests of the Zabaikalye region after repeated disturbances

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 6) with mineral soil exposed (figure 7).



…iferous forests of the Zabaikalye region. At repeatedly burned …ged 6.2 tC/ha while it was as much as 4 times higher at sites …alling on the ground.

Figure 7. Mineral soil exposed by repeated fires

…eneration, 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 5). 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 8).

Table 1. Regeneration in 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 8. 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 9a). 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 9b,c,d).

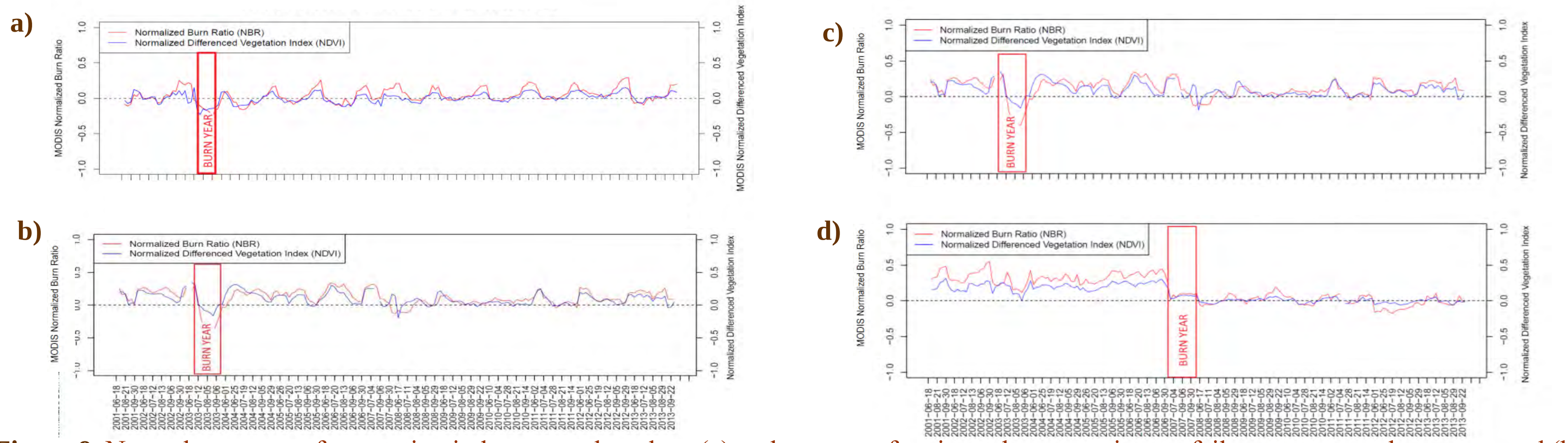


Figure 9. Normal recovery of vegetation index anomaly values (a) and recovery for sites where recruitment failure appears to have occurred (b,c,d)

Conclusions

Changing anthropogenic patterns and climate change can be expected to increase ecosystem damage from wildfires and inhibit recovery of natural ecosystems. Repeated fires 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 repeated fires 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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Acknowledgements

The authors gratefully acknowledge financial support for this research from the National Aeronautics and Space Administration (NASA), the Land Cover Land Use Change (LCLUC) Science Program.