The influence of changing forestry practices on the effects of wildfire and on interactions between fire and changing climate in central Siberia

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ABSTRACT

The Russian boreal zone is a region of global significance in terms of climate change impacts and carbon storage, but it is also a tremendous, largely untapped, reservoir of wood products. currently, wildfires in the Russian boreal forests burn about 10 to 15 (20) million ha per year, and both the area burned and the severity of fires are expected to increase as climate changes. Both legal and illegal logging are also increasing rapidly in many forest areas of Siberia (Vandergert and Newell 2003). These logged areas often have extremely high fuel loads due to logging debris and typically experience higher severity fires than unlogged forests. Such fires may often occur close to communities, increasing the threat that homes and businesses will be burned. Changing patterns of land use, primarily 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 changing climate and on air quality. Most research to date on the effects of fire on carbon cycle, fire emissions, and ecosystem recovery has focused on relatively undisturbed forests. However, as the areas impacted by logging increase, it is becoming rapidly apparent that any accurate regional assessment of these interactions must include effects related to logged areas. We propose to estimate the relative effects of wildfire, under variable seasonal climate regimes, on logged and unlogged sites in central Siberia, including potential feedbacks to the atmosphere and climate. The project will integrate data and models derived from field sampling with analysis of Landsat and MODIS imagery to extrapolate fire effects and processes to a landscape level. The results will provide a basis for improved projections of impacts of climate change and land use patterns on burned area, fire severity and carbon cycle, with an emphasis on central Siberia.

KEYWORDS:

1. **Research Fields:** Land Use, Logging, Carbon Cycle, Forest Management
2. **Geographic Area/ Biome:** Boreal Forest, Siberia
3. **Remote Sensing**: MODIS, LANDSAT, AVHRR, others
4. **Methods/Scales**: In-situ data linked to remote sensing.

INTRODUCTION

This study is focusing on interactions between fire and logging in Scots pine (*Pinus sylvestris*), larch (*Larix* spp.) and dark conifer forests of central Siberia. The three primary study regions are the Angara, Chitah, and Shushenskoye Regions to enable us to cover a diversity of environmental conditions, fire season differences, terrain types, vegetation conditions, and logging impacts. Parts of the Angara and Chitah Regions were identified by Achard et al. (2005) as potential hotspots of land cover change due to logging activity. The Angara Region, on the north and south sides of the Angara River, is a hilly upland terrain with increasing and extensive logging activity that experiences frequent droughts and severe fire seasons. The fire season is typically from mid-June to mid-August. The Chitah Region,

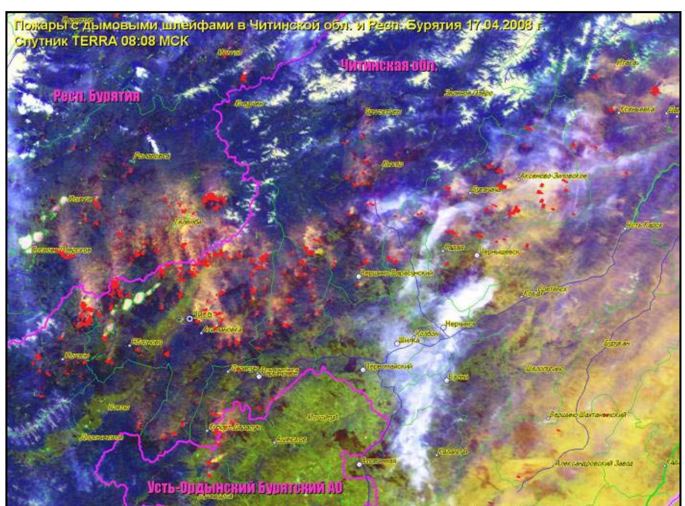

Figure 1. Extensive fires in the Chita and Buryatia regions in late April 2008, as observed from TERRA MODIS.

southeast of Lake Baikal, contains extensive larch and pine stands, as well as forest steppe. Fires in unlogged stands are typically surface fires that occur early in the season. Legal and illegal logging activities in this area are increasingly common and logged sites are subject to substantially higher fire severity (Buryak 2007). Logging is less frequent in the Shushenskoye Region, but the terrain is more complex. In all regions, fires starting in logged areas increasingly threaten communities and natural resources. We anticipate sampling a minimum of 5 logged and unlogged sites burned by wildfires in each region, as well as comparable unburned site (15 sites of each type in total) over the course of this study. Sites will be selected based on fire patterns, vegetation and fuel characteristics, and accessibility. We anticipate focusing field work in at least two regions each year of the study. The regional distribution of wildfire occurrence varies greatly from year to year across Siberia (Conard et al. 2002, Sukhinin 2008). Therefore the particular sites sampled in each year will be determined where there has been sufficient recent wildfire activity to accomplish our objectives.

Logging Fire	Unlogged	Logged
Unburned	X	X
Burned	X	X

Figure 2. General matrix of site types for sampling

To determine the relative impacts of fire on logged and unlogged areas, on emissions, carbon storage, ecosystem damage and recovery, and atmospheric chemistry, we propose a well-designed field campaign to quantify fire behavior and fuel consumption, estimate emissions, and evaluate ecosystem damage and recovery. Sampling methods will be similar to those used in our previous research in central Siberia. Fuels and fuel consumption will be evaluated by a combination of line transects for down and dead woody material, duff consumption pins, and small plots for evaluating consumption of duff and litter (McRae et al. 2006). We will use nested fixed area plots to map surface vegetation cover and to evaluate changes in herbaceous and woody vegetation and tree mortality. Specific methods and plot sizes will need to be adapted to the configuration and vegetation structure on individual sites, but standard vegetation sampling methods will be used. At least ten replicate plots will be distributed across each study area to achieve a representative sample. In unlogged areas, we will install sufficient plots to include 100 overstory trees for mortality evaluation. When possible, we will do prefire and postfire sampling of the burn area. Otherwise, we will obtain control samples from adjacent and comparable unburned areas. We will combine plot-based data on prefire (unburned) and postfire vegetation and fuels with weather data and remote-sensing data on active fires, fire perimeters, and burn severity (e.g., as measured by dNBR) to extend models and data developed in our current research on wildfires in Siberia to include logged sites (Figure 3) and to enable evaluation of impacts at landscape to broad regional scales. Based on data collected to evaluate burn severity in our previous study, Sukhinin (unpublished, 2008; Lentile et al. 2006) has observed strong relationships between both dNBR and NDVI and burn severity; we will improve quantification of these relationships and extend observations to logged sites.

Figure 3. Aerial view of a fire in a logged area in the Angara Region.

Relevance to NASA priorities:

The research proposed here will provide essential information for assessing the potential for changes in forestry practices to support adaptation to changing climatic conditions in the broad region of central Siberia by addressing *"the potential feedbacks of changes in land use and land cover to climate"*. It will focus on vulnerability of fire-impacted logged and unlogged forest systems to climate variability and change and on the resilience of logged and unlogged systems burned under different seasonal climate regimes. The proposed project addresses one of the NASA LCLUC key science questions, "*What are the impacts of climate variability and changes on LCLUC and what the potential feedback is*?" The proposal responds directly to the NASA LCLUC NEESPI Science Plan on "---*the role of anthropogenic impacts on producing the current status of the ecosystem, both through local land-use/land-cover modifications and through global gas and aerosol inputs?*" It is also relevant to characterizing and quantifying rates of change in wildfire impacts within the GOFC-GOLD framework; and to three societal benefits themes of GEOSS: Reducing loss of life and property from natural and human-induced disasters; Understanding, assessing, predicting, mitigating, and adapting to climate variability and change; and improving the management and protection of terrestrial, coastal and marine ecosystems. The proposed work will integrate data from multiple satellite systems (including MODIS, AVHRR and Landsat), ground observations, and models.

Year 2 Goals:

In Year 2 the PIs focused on the following major tasks:

- Evaluating and revising methods for field sampling of fuels and estimating fuel consumption on logged and unlogged sites that were unburned or recently burned, especially for illegal logging sites.
- Conducting 2nd year field sampling in three regions in the summer of 2010 (Figure 4).
- Evaluating results of initial field work and developing a plan of work for 2011.
- Continuing to coordinate methods and evaluate models for remote sensing analysis.

Figure 4 general regions of ground sampling for this project.

STATEMENT OF PROGRESS

Evaluation of methods for field sampling during the 2009 season led to the recognition that we needed specific sampling methods for exposed roots, which are often consumed in high severity surface fires. These were added to the sampling methodology for the 2010 season. We also added some flexibility to the sample design in terms of distribution and number of plots, minimum numbers of trees sampled and other factors. This was done both in recognition that it was very difficult to find sites with all combinations of fire and logging, and because of differences in spatial distribution of logging activity between illegal logging sites and forest-steppe sites and the typical closed forest sites in other locations.

Year 2 field sampling. Sampling areas for 2010 were identified using satellite remote sensing data on recent fires and logging activity to identify accessible sites that might be appropriate for field sampling. One field team (led by Ivanova) sampled sites in the Angara region, and a second team (led by Buryak) sampled sites in Chitah and the Shushenskoye region (Fig. 4). They worked primarily in Scots pine and larch-dominated forest types. Sampling sites ranged from forest-steppe and mountain forests in the south to southern and central taiga forests in the north. These teams obtained data from the four general types of sites originally planned (see Fig 5), but in Chitah, we are also sampling illegal as well as legal logging sites, which differ in logging methods, as well as sites that have been logged after fire. Over a dozen sites with different characteristics were sampled in 2009, and an additional 30 sites in 2010.

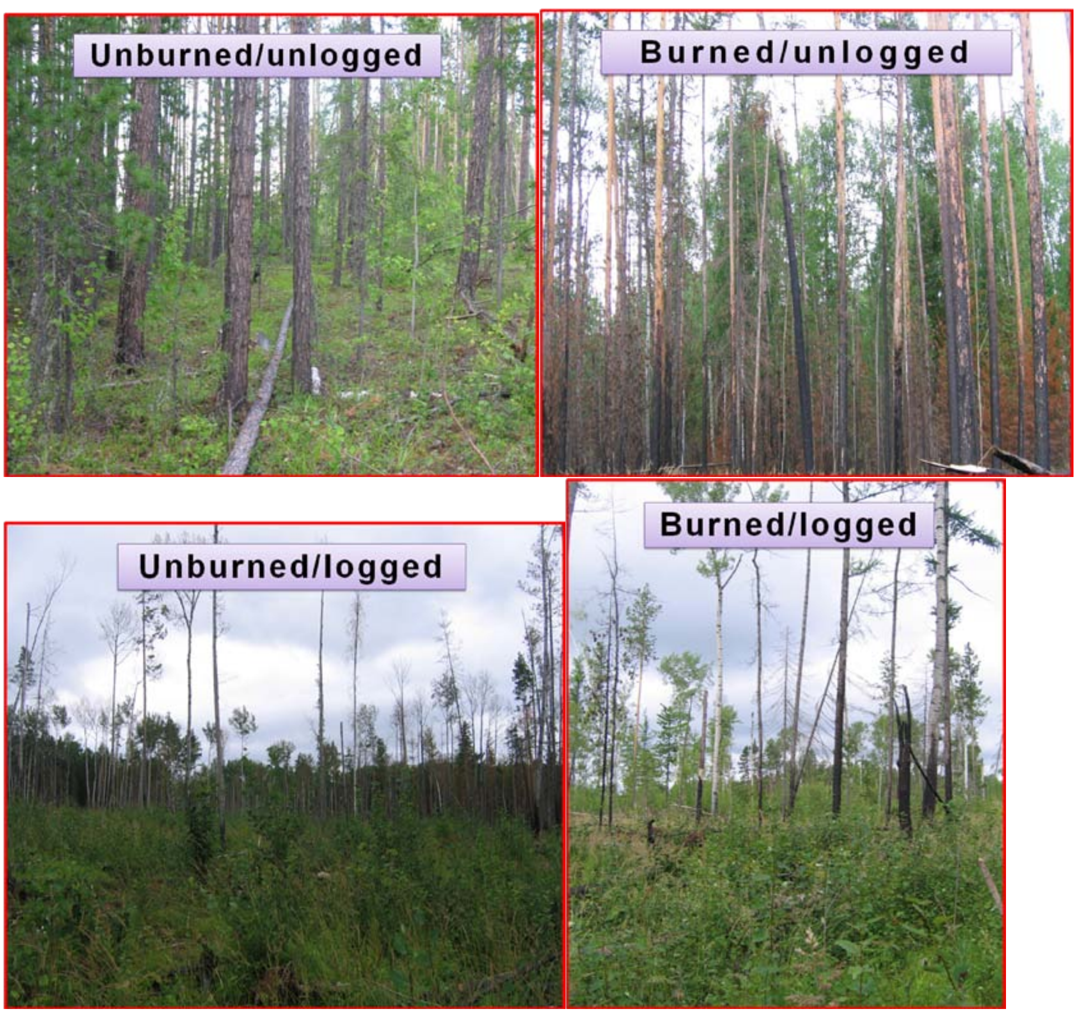

Figure 5. Examples of sites with different disturbance characteristics

Evaluating initial results and planning 2011 work. Russian, US, and Canadian collaborators met for 3 days in Belfast, Maine in late fall, 2010 to review progress, discuss methodological problems and coordination of data analysis for the two field teams and for the remote sensing component of the project, and planned work for year 3. Experience from sampling in 2009 and 2010 seasons has led to the recognition that potential patterns of logging and burning are much more complicated than previously recognized. In future sampling we will work to ensure adequate sampling of a wide range of logging treatments and logging/fire interactions as represented in Fig. 6. We will continue to sample burns and logged areas in the central Krasnoyarsk Region (pre-Angara), Shushenskoye/Minusinsk, and Chita, with a focus on filling major gaps in combinations of disturbance regimes that are important in these three subregions.

Our project review and planning meeting was held immediately before the December 2010 AGU meeting in San Francisco for efficiency in travel plans. At AGU, project scientists and collaborators presented 2 posters directly related to this project (Ivanova *et al*. 2010; Buryak *et al*. 2010), 2 posters related to past LCLUC work (Baker and Bogorodskaya 2010; Sukhinin *et al.* 2010), and an oral overview of our long-term work in Russia (Conard 2010). There are also a number of papers and presentations by Russian collaborators listed at the end of this report.

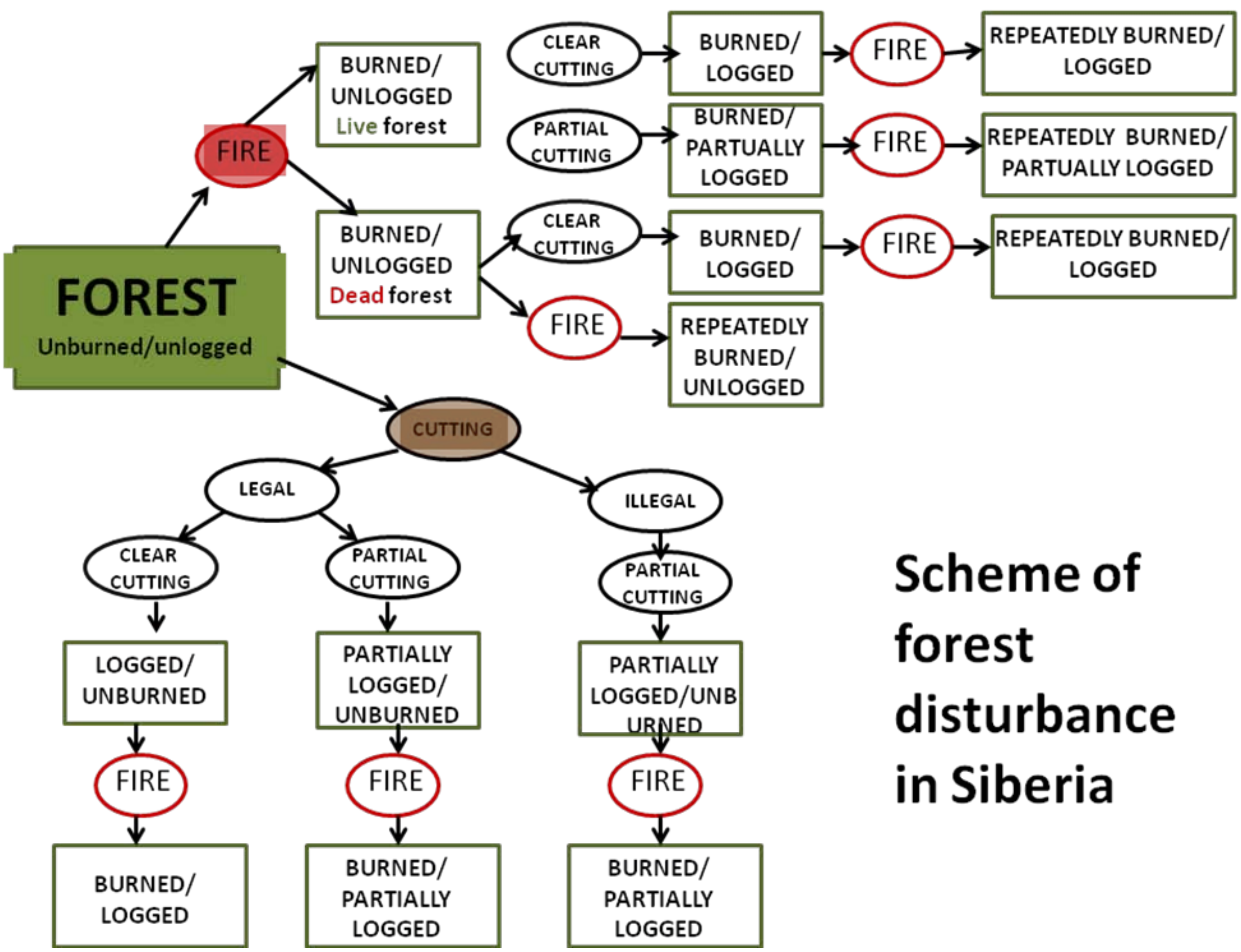

Figure. 6—Revised flow chart of potential fire/logging interactions in south and central Siberia

Remote sensing analysis. Sukhinin and Buryak have been working together to develop remote sensing-based models for mapping tree mortality, types of disturbance, and regeneration on logged and burned sites, using data from field sites in this project and our previous LCLUC project. Preliminary results of these efforts are quite promising (Table 1 and Figure 5) and were presented at AGU (Buryak et *al*. 2010).

The examples shown below illustrate the ability of various indices to discriminate between levels of tree mortality, amount of regeneration on harvested sites, and different major forest types (Table 1).

The graph in Figure 7 is an example of one of many regression analyses we have done between various remote sensing-based indices and the amount of postfire tree mortality. We are relating ground-based data from our sample plots with data from various satellite sources to try to identify sensors and indices that will enable us to make estimates of effects of fire and logging on carbon, fire emissions, and other ecosystem characteristics at a landscape to regional scale.

Site type	**Tree mortality**	**NDVI**	**Index 57**	**Index 47**	**Index 54**
Fire scars	20-40%	0,183	0,300	0,175	0,131
	40-60%	0,106	0,275	0,154	0,127
	60-80%	0,105	0,279	0,099	0,185
	80-100%	0,039	0,241	0,013	0,229
Harvested sites	**Category of regeneration**				
	Very bad	0,048	0,274	0,055	0,221
	Bad	0,118	0,292	0,123	0,172
	Satisfactory	0,233	0,323	0,253	0,076
	Good	0,344	0,370	0,413	-0,054
Undisturbed forests	**Forest type**				
	Coniferous	0,143	0,295	0,338	-0,049
	Deciduous	0,398	0,385	0,472	-0,107
	Mixedwood	0,299	0,352	0,428	-0,090

Table 1. Relationships of several RS-based chlorophyll indices with different types and levels of disturbance based on Landsat ETM data.

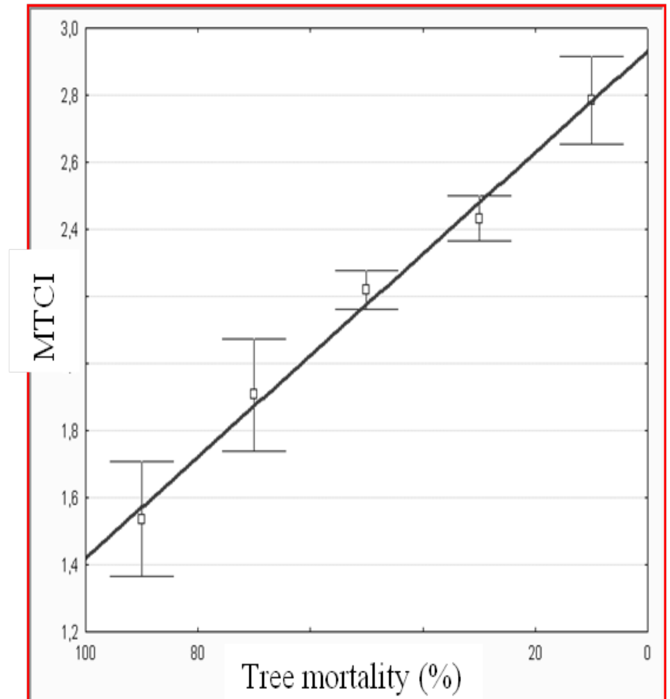

Figure 7. MTCI values for different tree mortality levels, using ENVISAT-MERIS data, where:

$$MTCI = \frac{R_{Band10} - R_{Band9}}{R_{Band9} - R_{Band8}} = \frac{R_{753.75} - R_{708.75}}{R_{708.75} - R_{681.25}}$$

Preliminary data on effects of logging and burning on fuels and carbon stocks.

- The modified field sampling methods for sampling stand structure and fuels generally worked well, although we have needed to make some additional adjustments for sampling on illegal logging sites.

- At the sites evaluated thus far, estimated surface fuel loads, fuel consumption, and fire emissions are substantially higher on logged sites than on unlogged sites. Because of high fuel loads and greater exposure of fuels to sunlight, burn severity is generally much higher on logged sites as well. The types of surface fuel available to burn and the total fuel loading (Figure 6) varied greatly between logged and unlogged sites. On unburned unlogged sites, for example, there were more needles and cones, while on unburned logged sites there was more bark and herbaceous vegetation. About 4% (less than 0.5 t/ha) of downed woody fuel was consumed by fire on the unlogged site, and about 16% (8 t/ha) was consumed on the logged site. Thus emissions from combustion of downed woody fuel would have been about 16 times as great on the logged site as on the unlogged site. Legend indicates size classes of downed woody fuels (which would include logging slash on logged sites.

- In the Angara and Shushenskoye regions most logging involves relatively large clearcut blocks. Because of high fuel loads these areas are susceptible to fire after logging. In Chitah, much of the logging is selective logging that occurs on already-burned sites, so different sampling strategies and analysis methods may be required.

- Dead down woody fuels are significantly less on unburned/logged area in Chita and Shushenskoe, Minusinsk sites (due to better slash removal after logging) compared to the Angara region;

- At the time of this report, analysis of field data for the 2010 field season is ongoing.

Effects of logging and burning on soil respiration

In our previous LCLUC projects, which focused on the effects of wildfire on essentially undisturbed Scots pine and larch forest in the central Krasnoyarsk region, we determined that soil respiration was reduced substantially after fires, and that this magnitude and duration of this effect increased with higher fire intensity and severity. After 4 to 5 years on most sites, the resulting cumulative decrease in soil CO_2 emissions was similar to the amount of CO_2 emitted in the fires, which has implications for the overall impact of fire on carbon flux (Baker and Bogorodskaya, 2010; Bogorodskaya, 2011)). We have been doing similar analysis of the interacting effects of fire and logging on soil respiration processes (Fig 8), and have found that soil respiration is on both burned and logged areas is about half that on undisturbed forest sites (unlogged/unburned). There are further reductions in respiration on burned sites due to the removal of surface litter layers by fire. There does not appear to be a direct relationship between these changes in soil respiration and soil temperature when we compare sites with different disturbance histories. We, therefore, conclude that at least some of these changes are due to changes in microbial populations in the soil, with possible contributions from changes in root respiration where large numbers of trees are removed or killed by fire.

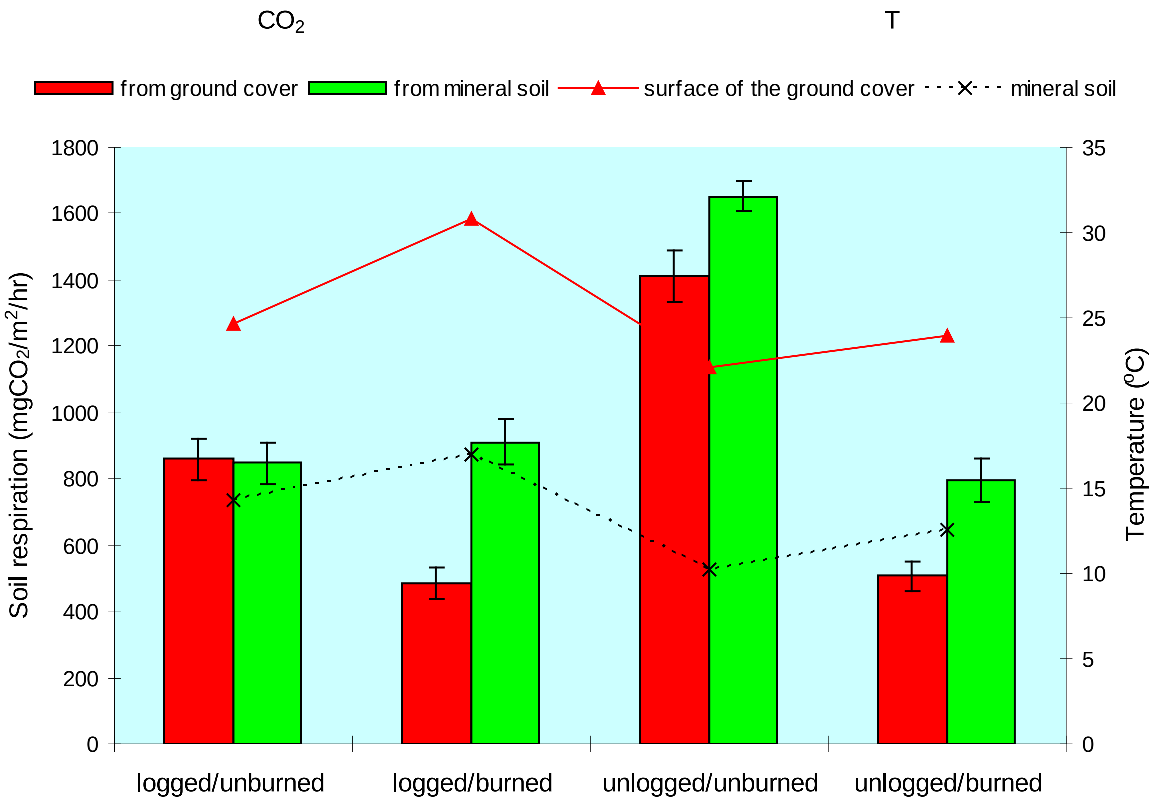

Figure 8. Postfire changes in soil respiration on logged and unlogged sites in Scots pine forests of the Angara Region.

Preliminary Conclusions

Based on the sites studied thus far, above-ground carbon stocks are higher on unlogged than on logged sites. However, both live and dead surface fuel loads are much higher on logged sites, as might be expected where logging slash is typically left onsite. This increase tends to be higher on legally-logged sites in the Angara Region, which are typically clearcut. Illegally logged sites in the more southern areas generally are selectively logged, or logged in small patch cuts. Because of the high loads of dead and downed materials fuel consumption and emissions are as much as 4 to 5 times higher on logged sites. The magnitude of these differences is such that quantifying them is clearly important for determining carbon stocks and fire emissions for forests in Siberia. As with burned sites studied previously, logged sites and logged/burned sites also see strong reductions in soil respiration (CO_2 emissions from soil) for several years after fire. We will sample additional sites over the next year to ensure a broad representation of the ranges in fuels, carbon, fuel consumption, and emissions on a diverse sample of logged and unlogged sites in central Siberia. We continue to make progress in developing remote-sensing based methods for evaluating the effects of fire and fire/logging interactions at a landscape scale.

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Vandergert, P., and J. Newell. 2003. Illegal logging in the Russian Far East and Siberia. International Forestry Review 5(3):303-306.

New publications (2010-2011) related to this project:

Oral and Poster Presentations:

Buriak, L.V., A.I. Sukhinin, S.G. Conard, G.A. Ivanova, D.J. McRae, A.J. Soja, and E.V. Okhotkina. (2010) Estimating Scots Pine Tree Mortality Using High Resolution Multispectral Images Abstract GC33A-0932 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec. (*Poster)*

Ivanova G.A., Kukavskaya E.A., Zhila S.V. (2010) Fire impact on carbon balance parameters and ecosystem components of light-coniferous forests of central Siberia. GEO-Siberia-2010: International exhibition and scientific congress, Novosibirsk: SSGA. (*In Russian*)

Ivanova, G.A., Conard, S.G., McRae, D.J., Kukavskaya, Y.A., Bogorodskaya, A.V., Kovaleva, N.M. (2010) Carbon Emission from Forest Fires on Scots Pine Logging Sites in the Angara Region of Central Siberia. **Abstract** GC33A-0938 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec. (*Poster)*

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Zhila S.V. (2010) Post-fire tree mortality at grass/moss larch stands of Angara region // Proceedings of Interregional theoretical and practical conference of students “Young scientists in solving actual problems of science” (May, 2010, Krasnoyarsk). P. 75-78 (In Russian)

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Skudin V.M., Sukhinin A.I., Buryak L.V., Kalenskaya O.P., Ponamarev E.I. (2010) Prediction of fire effects in forest ecosystems of Angara region on the basis of GIS-analysis. Forestry, 2010, №1, Moscow. P. 36-39. (In Russian)

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Awards in 2010-11:

Conard, S.G.:

2010: Elected a Fellow of the American Association for the Advancement of Science, in part on the basis of international reputation and accomplishments in fire research. Award presented at annual AAAS meeting, Feb 2011 in Washington, DC.

Ivanov V.A.:

2010: Letter of commendation and medal of Administration of Krasnoyarsk krai for fruitful work and to the 80-anniversary of foundation of Siberian State Technological University (Administration of Krasnoyarsk krai, Krasnoyarsk).

Kukavskaya E.A.:

2010: Fulbright fellowship from the 2010-2011 Russian Fulbright Visiting Scholar Program for the project entitled "Siberian Biomass Burning Emissions Estimates". Currently in the US working with Amber Soja.