SCOTS PINE TREE MORTALITY ESTIMATION USING HIGH RESOLUTION MULTISPECTRAL IMAGES

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SUMMARY

Scots pine (*Pinus sylvestris*) forest stands of central Siberia are characterized by a mixed-severity fire regime dominated by low-to-high-severity surface fires, with occasional crown fires. In this study we linked field measurements of postburn mortality with air-borne and satellite observations of active wildfires and older fire scars to develop procedures for estimating tree mortality remotely. Tree mortality can be estimated from NDVI and other chlorophyll indices by relating them to field observations. We are comparing field data with intermediate-resolution satellite data (Landsat7-ETM) to estimate fire severity, emissions, and carbon balance, and to monitor immediate ecosystem fire effects (e.g., tree mortality) and long-term postfire vegetation recovery. We are also using these data to validate AVHRR, MODIS, and MERIS estimates of burned area. Estimating fireline intensity accurately appeared to be virtually impossible without the use of infrared imagery. We studied fire scars in the Angara Region of central Siberia (northeast of Lake Baikal) for which ENVISAT-MERIS, Spot4, Landsat5, Landsat7-ETM images and ground validation data were available for the 2003 - 2004 and 2006 – 2008 periods. We sampled severity field plots on burned sites differing in age, stand structure and composition. Images were obtained for these sampling locations for developing relationships of remote sensing parameters to tree mortality (%) at the time of observation. We calculated values of NDVI, dNBR, REP, and MTCI for each field test plot and developed regressions relating each index to tree mortality. Further development and testing of these relationships will facilitate accurate, broad-scale mapping of postfire tree mortality, along with the extent of wildland fires in Central Siberia.

BACKGROUND

We conducted this study in the Lower Angara Region in central Siberia because ecosystems disturbed by logging, fire, and biotic factors account for a significant part of the regional forestland (Fig.1). The area of sites disturbed by logging, insects, and other factors has been increasing in recent years, which results higher fire danger, and increasing fire frequency and area burned. Large amounts of debris common in disturbed areas aggravate negative fire effects. Fires can repeat annually or every two years on open disturbed sites. As a result, a number of the regional ecosystems are considered unstable and, hence need continuous ecological monitoring. The Angara Region borders the watershed between Podkamenaya Tunguska and Angara Rivers in the north, West Sayan foothills in the south, Yenisey Mountain chain in the west, and fore-Baikal Mountains in the east. The fire season here lasts from about mid May until September. While cyclones coming from south and southeast dominate in summer, anticyclones prevail in June and July. This is when droughts are usually brought by dry air masses from Mongolia and North-East China. Relatively high humidity common in the western part of the region is attributable to the north-south orientation of the Yenisei mountain chain. Climate becomes more continental as one moves from the west to the east. The regional climatic and vegetation conditions, particularly in intensive-logging areas, generally favor high fire activity. Field studies carried out in this region in 2002 – 2008 showed that the extent of forest fire effects is controlled by vegetation conditions, fire type, severity and recurrence.

METHODS

Field studies

- Disturbed and undisturbed sites of different types were identified in satellite images prior to the field work.
- Disturbance types included single-fire sites, logging sites, repeatedly burned sites, and burned logging sites with various intensities of disturbance
- Sample plots represented the diversity of disturbance and vegetation types across the region.
- 5 to 8 circular sample plots of 0.1 or 0.2 ha (radius of 17.84 and 25.23m, respectively) at each site were laid out 150 m apart along transects.
  - ✓ Ground plot data included: tree species, DBH, tree height, maximum and minimum stem char heights, percentages of dead and disturbed crown
  - ✓ We determined whether standing and fallen dead trees died before or after fire based on cause of death and degree of decomposition.
  - ✓ Fuel consumption data included average ground fuel depth of burn as well as the percentage consumption of each fuel type.
- On each plot, we photographed the overall vegetation, as well as individual vegetation layers and crown condition and closure.
- Time since last fire and fire intervals were determined from dated fire scars or age and condition of regeneration.

Remote sensing

We used Landsat ETM+ images to delineate burned sites, calculate NDVI values, and to characterize vegetation disturbance classes within each burned site. We identified thirty sites burned in 2006, totaling 3133 km², using Landsat ETM+ from after the fire season in 2006. The 2006 fire season lasted from June 5 to August 16 in the area of interest. Fires varied in severity. The presence of active fires was confirmed by hot spots identified by NOAA/AVHRR thermal channels.

We evaluated relationships between field-based mortality data and six different remote-sensing-based indices:

$$NDVI = \frac{R_{0.82} - R_{0.66}}{R_{0.82} + R_{0.66}}$$ From Landsat-ETM imagery

$$INDEX\ 57 = \frac{R_{1.65} - R_{2.22}}{R_{1.65} + R_{2.22}}$$

$$INDEX\ 47 = \frac{R_{0.82} - R_{2.22}}{R_{0.82} + R_{2.22}}$$

$$INDEX\ 54 = \frac{R_{1.65} - R_{0.82}}{R_{1.65} + R_{0.82}}$$

$$REP(MERIS) = 708.75 + 45 \frac{(R_i(MERIS) - R_{Band9})}{(R_{Band10} - R_{Band9})} = 708.75 + 45 \frac{(R_i(MERIS) - R_{708.75})}{(R_{753.75} - R_{708.75})}$$

where $R_i(MERIS) = \frac{(R_{Band7} + R_{Band12})}{2} = \frac{(R_{665} + R_{778.75})}{2}$

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

NDVI, INDEX 47, INDEX 57, and INDEX 54 are all chlorophyll indices based on data from Landsat ETM. REP and MCTI indices are based on data from the MERIS satellite. ETM and MERIS images for each site were from the same date.

Fig.1. Landsat7-ETM Spectral signatures for forest (maximum reflectance in the 0.75-0.90 µm spectral band) differ from those for burned area and clear cuts (maximum reflectance in the 1.55-1.75 µm spectral band).

Fig. 2. Test plot distribution for fire severity ground sampling in the Angara Region showing distribution of disturbed areas, as observed from Landsat7-ETM (Channel 4, 5, and 7).

RESULTS

A portion of the forest stands under study, represented mainly by middle-aged conifer stands dominated by Scots pine (*Pinus sylvestris*) and mature dark-needled stands with dense young conifer regeneration, experienced crown fire that resulted in 100% tree mortality (disturbance class I). This was clearly visible from the remote-sensing images. Surface fires of varying shape and mixed severity appeared to be more common. Tree mortality is 70-90% after a high-severity smoldering surface fire. Fires of this type, shape, and severity are characteristic of moderately stocked stands on wet soils. Most of the trees killed by fire had fallen down by the autumn of 2007 (1 year after fire). Tree mortality was less than 40% in mixed mature conifer stands after low- to moderate-severity fires. Such fires are common in mature and overmature well-stocked stands with feather moss-dominated surface vegetation. Post-fire tree mortality was 40-60% in low density stands. Tree mortality was less than 20% on these sites where surface fire was spotty.

Table 1. Percent tree mortality for different soil types depending on fire type and severity. Top row of each severity class is data for fast-moving surface fires; the bottom row is for smoldering fires.

Soil type		Dry sandy		Dry loamy sand		Mesic loam and loamy sand			Heavy wet loam		
Stand age		Middle-aged	Mature	Middle-aged	Mature	Middle-aged	Mature	Overmature	Middle-aged	Mature	Overmature
Fire severity	Low	45 1,3	3 0,4	25 1,5	8 0,9	19 1,2	13 0,7	17 2,4	**	**	**
		*				66 0,9	30 2,0	35 4,2	88 7,2	33 4,2	39 2,1
	Moderate	67 2,4	5 0,6	44 2,7	19 2,1	62 5,4	30 3,1	35 3,8	**	**	**
		*				86 2,6	71 6,4	86 0,7	96 3,7	73 3,7	83 3,3
	High	100	75 6,9	87 8,3	42 3,3	100	72 3,5	79 7,2	**	**	**
		*				100	73 1,9	96 1,5	100	100	100

* – fire did not transform to smoldering fire because of insufficient ground fuel;
** – smoldering fires at high fire danger classes.

Fig. 3. Tree mortality for fast-moving surface fire, moderate severity

Fig. 4. Tree mortality for fast-moving surface fire, high severity

Fig. 5. Tree mortality for smoldering fires, mesic loam and loamy sand

Fig. 6. Tree mortality for smoldering fires, heavy wet loam

We found strong relationships between all the remote-sensing based indices we tested and tree mortality measured on the field sites (Fig. 7 and 8; Tables 2 and 3). The levels of various indices were also strongly related to tree mortality, on burned sites, to regeneration on logged sites, and to forest type (Table 3).
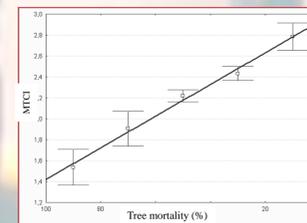

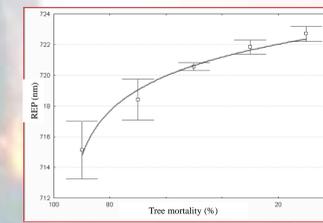Figure 7. MTCI relationship with tree mortality.

Figure 8. REP relationship to tree mortality.

Table 2. Observed MTCI and REP values for different tree mortality levels, using ENVISAT-MERIS information.

Tree mortality (%)	MTCI	REP (nm)
0 – 20	2.66 – 3.00	722.46 – 723.81
20 – 40	2.31 – 2.65	721.25 – 722.45
40 – 60	2.01 – 2.30	719.78 – 721.24
60 – 80	1.70 – 2.00	718.08 – 719.77
80 – 100	1.20 – 1.69	712.00 – 718.07

Table 3. NDVI and other Chlorophyll indexes obtained for different disturbance levels using Landsat7-ETM data

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
	Satisfy	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

CONCLUSIONS

- Estimating the effects of fire on ecosystems requires developing ecosystem-specific relationships between field data and remote sensing data. In forest systems, tree mortality depends on fire intensity, residence time, and the physiological effects of fire on the cambium, foliage and roots.
- We estimated tree mortality from several remote-sensing-based indexes through regression analysis, by relating field data obtained to wildfires to intermediate-resolution satellite data (Landsat7-ETM and ENVIROSAT/MERIS). All indices tested appeared to be useful remote-sensing indices for estimating fire severity.
- Further development and testing of these relationships will enable accurate, broad-scale mapping of fire intensity, severity, along with the extent of wildland fires in Central Siberia. This approach also has potential to help estimate fire emissions, long-term vegetation recovery, and fire effects on carbon balance.

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