POTENTIAL FIRE HAZARD EVALUATED FROM SITE CLIMATES AND FOREST TYPES IN THE TRANSBAIKALIAN MOUNTAINS

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ABSTRACT

We describe an approach of mapping potential fire hazard across a mountain terrain. Fire hazard was assessed from influencing factors like topography, climate, and climax forest type. The resulting map may serve for fire managers to identify areas at risk of fire and develop a priority list of activities as diverse as fire suppression and prescribed fire.

Keywords: fire hazard, climate, forest type, mapping

INTRODUCTION

Topography, climate, and vegetation (forest types) are considered to be the key factors accounting for fuel load and its flammability and for evaluating fire potential in the forest (Melekhov, I. 1939; Kurbatsky, N. 1963; 1975; Countryman, C. 1972; Andrews, P. and Williams J. 1998). These factors slowly change over decades or even centuries creating an environment for fire potential.

Topography, climate, and vegetation are closely related. In mountains, topography determines both vertical (zonal) climatic changes as elevation changes and a great variety of site climates as slopes change. Zonal and site climates in turn cause corresponding vertical vegetation zones and forest types.

Fuel load is determined by vegetation structure (forest type) and climate. Fuel flammability is evaluated from weather indices like the Nesterov index widely used in Russia (Kurbatsky, N. 1963; Baranov, N. 1976) or the Keetch-Byram Index incorporated into the 1988 National Fire Danger Rating System in the USA (Burgan, R. 1993). In the absence of current weather records in a given locality, the local climate can be used for evaluating potential fire hazard. Long-term weather patterns form by definition a local climate. In mountains, some parameters of a local climate like radiation balance and Budyko dryness index (the proportion of annual evapotranspiration to precipitation) can be calculated from the climatology of tilted surfaces.

Moreover, aspects and slopes themselves are also of great importance in spreading fires across a mountain terrain. Fire speed on steep (greater than 20^{o}) slopes is found to be 5 fold greater (Sofronov, M. 1967) than on the plain. Fires ignite more often on south- and west-facing slopes (80% of occurrence) than on north- and east-facing slopes (20% of occurrence) (Sofronov, M. 1967).

The forests of Transbaikalia have been under intensive study of the V. N. Sukachev Forest Institute, Krasnoyarsk, for four decades. From the view point of forest fire geography, three large forest regions have been identified with respect to potential fire hazard based on latitudinal variations of the climate (Furyaev, V. 1963; Yevdokimenko, M. 1975).

Our main goal is to demonstrate how potential fire hazard can be evaluated and mapped at a site level based on combination of topography, climate, and a forest type. To our knowledge, no maps of potential fire hazard for this region are available at the fine scales better applicable to fire management needs. The most hazardous sites in these maps should stay under intense monitoring from the very beginning of annual fire danger periods.

METHODS

The Ulan-Burgasy Range (Figure 1) in Central Transbaikalia has been chosen as a case study area that represents a great variety of forest types along an elevation gradient: from pine forests in dry forest-steppe foothills to cedar forests in wet uplands.

We developed a Digital Elevation Model (DEM) of this area with a pixel size of 100 m based on digitized elevation isolines from a 1:200, 000 map.

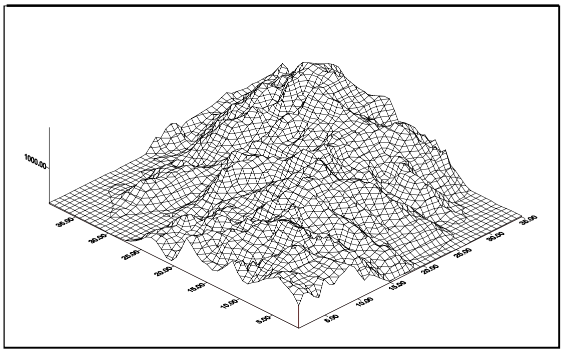


Figure 1. Topography of the Ulan-Burgasy Range. We used packages Surfer 6 and Idrisi for Windows 2.0 for producing our DEM. Elevation, aspect, and slope layers are shown in Fig. 2a, b, and c.

Along a transect (35 km by 38 km), 509 elementary forest inventory sites (EFIS) characterized by mature stands were selected across the range. Clear cuts, burned areas, and young growth were excluded from database. Each site was characterized by topographic features (elevation, slope, and aspect) and forest stand features (a dominant species and a forest type) derived from inventory data. Additionally, each site was characterized by climatic parameters (precipitation, radiation balance, and dryness index) calculated using lapse rates of monthly temperature, precipitation, air humidity, and cloudiness. Long-term records of 14 local weather stations were used to approximate site climates.

Annual precipitation (P, mm) was calculated based on elevational lapse rates determined separately for windward (P_w) and leeward (P_l) slopes ($R^2_{adj.}$ = 0.83).

$$P_w = 346 + 0.333 \text{ Elev.} \quad (1)$$

$$P_l = 275 + 0.452 \text{ Elev.} \quad (2)$$

In our previous studies, we showed that radiation balance and dryness index control vegetation distribution and productivity at global and regional levels (Tchebakova, N et al. 1994; Monserud, R. and Tchebakova, N. 1996). To apply these indices at a local level, we calculated them with respect to topography. Radiation balance and dryness index are calculated based on climatic submodels we modified for mountains (Tchebakova, N. 1983). Radiation balance on a slope (B_s) is calculated from:

$$B_s = B_f * K, \quad (3)$$

where Bf is radiation balance on a flat surface, K - a coefficient depending on aspect and slope. K is equal

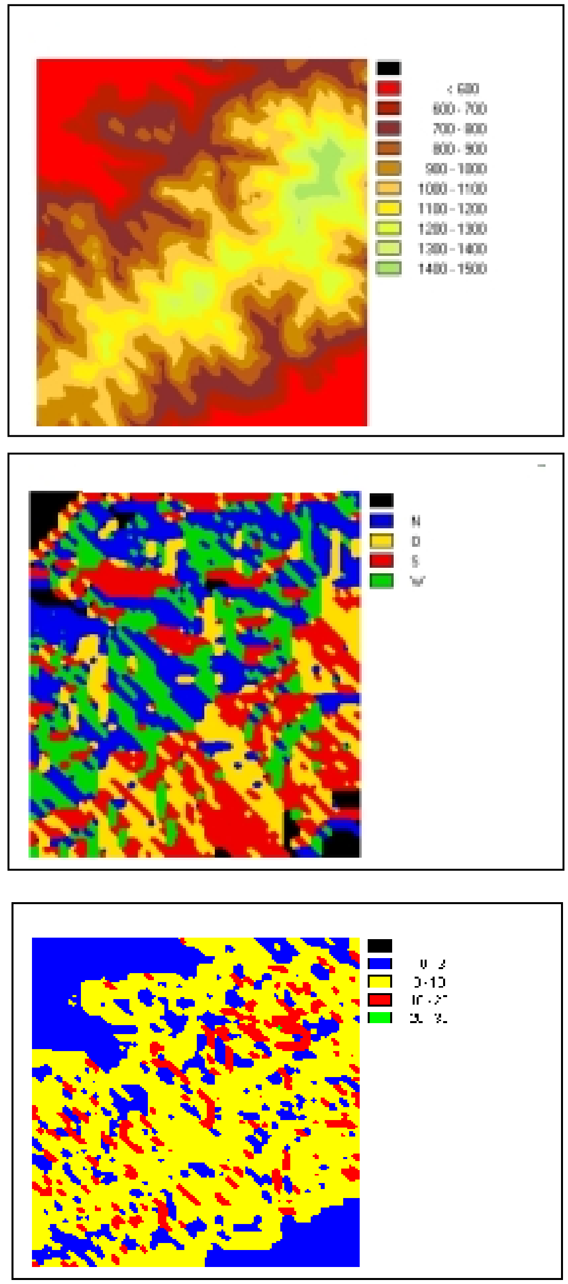


Figure 2. Digital Elevation Model (DEM) of the Ulan-Burgasy Range. Elevation (a), aspect (b), and slope (c) layers across the range.

to 1 for western and eastern aspects, is greater than 1 for southern aspects and less than 1 for northern aspects. K depends on latitude rather than on elevation. In this study, we used K calculated for the latitude 52N (Tchebakova, N. 1983) where the area of interest is located.

B_f is calculated for 14 weather station with record of monthly temperature, humidity, cloudiness, and precipitation as:

$$B_f = Q(1 - a) - E \qquad (4)$$

where Q(1-a) is absorbed short-wave radiation which is a function of global radiation under clear sky, albedo, and cloudiness; E is net longwave radiation which is a function of air humidity and temperature, and cloudiness (see Tchebakova, N. et al. 1993 and 1994 for more explanations).

Annual radiation balance on a flat site (RB, MJ/m^2) was calculated based on a lapse rate ($R^2_{adj.}$ = 0.8):

$$RB = 2000 - 420*Elev. \qquad (5)$$

Dryness index (DI) is calculated as:

$$DI = B_s / L* \text{ annual precipitation} \qquad (6)$$

where L is a latent heat of vaporization.

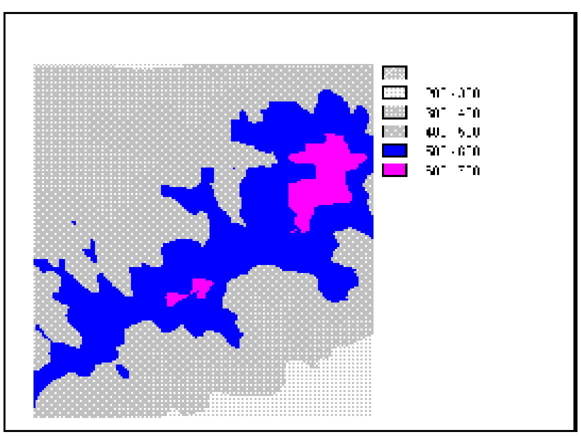
Coupling the DEM with climatic submodels (Eqs. 1-6), we obtained climatic layers (Figure 3 a, b, and c).

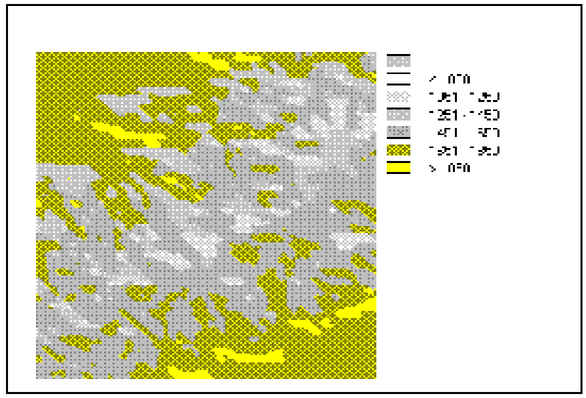
To relate forest types to site climates, we calculated RB and DI for each EFIS and ordinated them in RB-DI space. In the area under study, forest typologists differentiate 5 pine forest types, 3 larch forest types, and 3 cedar forest types like follows (Smagin, V. et al. 1980).

Pine (*Pinus sylvestris*) forest types are:

1. Grass-forb; 2. Vaccinium vitis idaea; 3. Rhododendron; 4. Ledum, and 5. Alnus;

Larch (*Larix sibirica*) forest types are:





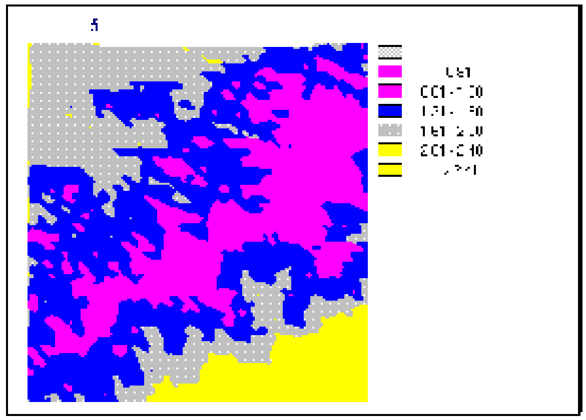


Figure 3. Precipitation, mm (a), radiation balance, MJ/m²*yr (b), and dryness index (c) layers across the range.

1. Grass-forb; 2. Vaccinium vitis idaea; 3. Rhododendron;

Cedar (*Pinus sibirica*) forest types are:

1. Green moss-Vaccinium vitis idaea; 2. Bergenia; 3. Ledum.

These forest types were arranged with respect to each other according to a fire hazard level. This compilation is based mainly on a classification by Melekhov (1939) with improvements by scientists of V. N. Sukachev Forest Institute (Kurbatsky, N. 1963; Furyaev, V. 1963; 1996; Sofronov, M. 1967; Yevdokimenko, M. 1975; Baranov, N. 1976; Kurbatsky, N. and Ivanova, G. 1987).

Based on this classification, local forest types can be conventionally arranged as fire danger decreases as follows:

1. Pine-Grass-Forb and Larch-Grass-Forb forest types;

2. Pine-Vaccinium vitis idaea and Larch Vaccinium vitis idaea;

3. Pine-*rhododendron* and Larch *rhododendron* forest types;

4. Pine-*Ledum*, Pine-*Alnus*, Larch-*Alnus*, Cedar Green moss-*Vaccinium vitis idaea*;

5. Cedar-*Bergenia*, and Cedar-*Ledum* forest types.

To characterize these forest types by climatic parameters, we ordinated dominant species and forest types in B_s-DI space (Figure 4 a, b). A species dominates in a stand if its proportion in a tree species composition formula is greater than 5 out of 10 units. The proportion 10 means “a pure stand;” the proportion 0 means “not available.”

As follows from Figure 4, both dominant species and forest types are well defined by DI. One can see that all forest types of cedar forests (“darkneedled” according to the Russian geobotanical terminology) are separated on average by a DI-value of 1.1 from pine and larch forests (“lightneedled”). Only the Pine-Alnus and Larch-Alnus forest types of lightneedled forests are characterized by DI-values less than 1.1 (Figure 4b). All other forest types are widely spread and characterized by DI greater than 1.1.

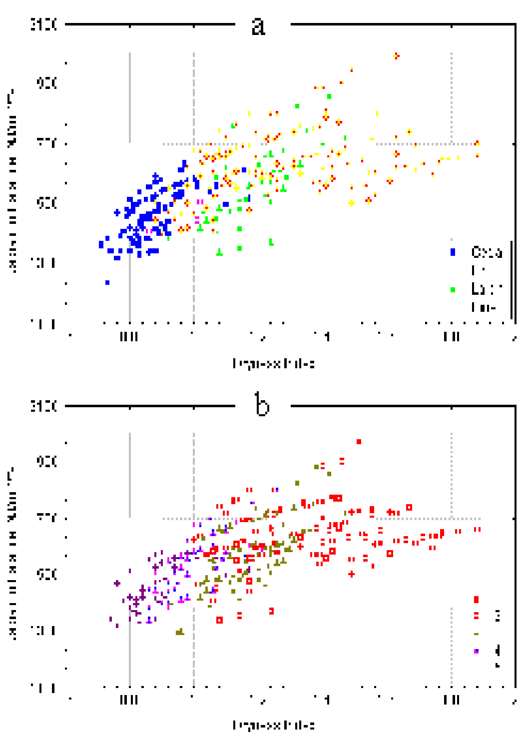


Figure 4. Dominant species (a) and forest types (b) ordinated in RB-DI space.

The wettest forest types (Cedar-*Bergenia*, and Cedar-*Ledum*, 5th grouping) are separated from wet forest types (Pine-*Ledum*, Pine-*Alnus*, Larch-*Alnus*, and Cedar Green moss-*Vaccinium vitis idaea*, 4th grouping) by DI equal 0.9 which is separated from the Pine-*rhododendron* and Larch *rhododendron* (3rd grouping) moist forest types by DI equal 1.1. So, the low fire hazard category can be definitely determined by DI less than 1.1.

Pine-Grass-Forb, Larch-Grass-Forb, Pine-*Vaccinium vitis idaea* and *Larch Vaccinium vitis idaea* (1st and 2nd groupings) are widely spread but their driest portion with high fire hazard can be approximately characterized by DI greater than 1.4. The moderately moist portion of these forest types combined with Pine-*rhododendron* and Larch *rhododendron* forest types (3rd groupnig) lay between DI-values greater than 1.1 and less than 1.4 and can be characterized as of medium fire hazard.

Because aspects and slopes influence fire spread speed, we adjusted fire hazard categories defined on a site climate basis to account for higher fire hazard for steep (greater than 20°) and south slopes. We left a category the same for gentle and north slopes. The resulting map of three fire hazard categories (high, medium, and low) based on both site climates and topography is given in the Figure 5.

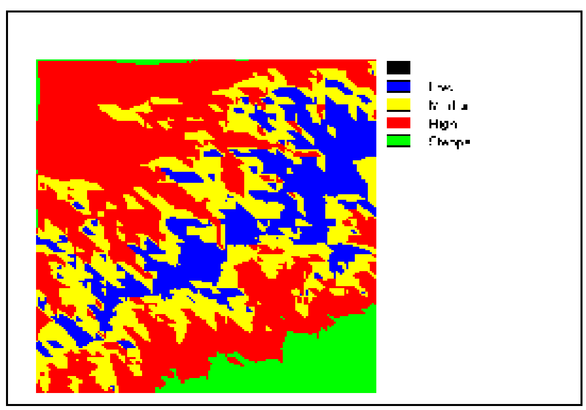


Figure 5. Fire hazard map based on site climates and topography.

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