USING LARGE SCALE VEGETATION FUEL MAPS FOR FOREST FIRE CONTROL

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The main prerequisite to the existence of forest fire is its propagation over territory covered with vegetation fuel (VF), i.e. plants and plant residues. Diversity of species of the VF, dynamics of their weights and moisture content vary greatly both in space and time, pre-determining diverse character of natural fire danger, i.e. possibility and nature of burning of vegetation covered sites, as well as fire consequences.

It is intensive and large fires that are responsible for the main portion of burnt forests and fire damage. Control over such fires requires more manpower and facilities than are usually available. Therefore, to make that control effective, current fire danger in areas adjacent to the fire should be taken into account, and various barriers have to be used. It can be realised only if large-scale VF maps are available (1:10,000 - 1:50,000). Methods for drafting such maps based on forest inventory data is developed in the Institute of Forest, Siberian Branch, Russian Academy of Sciences (Volokitina, 1988; Volokitina, Tartakovskaya, Shevchuk, 1989).

For mapping, VF classification i.e. divisioning of VF under groups and types is used. Classification of the group of prime conductors of burning (PCB) is also developed. That group includes moss, lichens, cured grass and small plant residues.

Eight types of PCB is distinguished, by which fire behavior experts can appraise the readiness of vegetation plots adjacent to the fire for burning (Sofronov, Volokitina, 1985).

Large-scale VF map is developed based on the relevant colourless forest map. The latter id accompanied by the pyrological description of the plots available in the map. That description contains properties of PCB for two phenological periods: "leafless spring" and "full summer", as well as characteristics of other VF groups: litter, duff, snags, grass, shrubs, trees, and conditions of drying of the PSB. For each phenological period there is an indication for a forest fire drought class, at which those vegetation-covered sites become ready to burn. Pyrological descriptions of the sites, and sketches showing the sites' boundaries and numbers, and rivers, brooks, lakes and roads, form the data bank for prompt preparation of large-scale VF maps and maps of current fire hazard in each site of the region where forest fires are burning or can burn.

To elaborate optimum plans for forest fire control, predictions of fire behaviour must be at hand. To draft such predictions, the following data are used:

1) sketch of perimeter of the fire; reference points (compartment grid, rivers, lakes, etc.) should be also marked in the sketch;

2) data bank for prompt preparation of the VF map;

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3) fire weather data for any given day (air temperature, and relative humidity, wind speed and direction, fire weather drought index and class) and a forecast of those data for the next 24 hours;

4) tables of characteristics of burning for PCB types available;

5) tables of coefficients of influence of stand canopy closure on wind speed under that forest canopy;

6) tables presenting relative effect of main influencing factors (wind, slope, humidity) on the spread rate of surface fire (Sofronov, Volokitina, 1990).

Essential clarifications:

1. Pyrology is the science for vegetation fires (from the Greek word "pyros" meaning "fire"). Forest pyrology means the forest fire science.

2. For pyrological sites we use inventory taxons, that is why the topographic basis of the VF map is a colourless forest map as a set of large-scale plotting boards; such plotting boards are available in every forestry enterprise.

3. Pyrological description means the pyrological characteristics describing the inventory taxons. It is drafted based on their inventory descriptions by a special program.

4. The drought class (DC) is determined by value of fire weather drought index (FWDI). These days, two FWDIs are used in Russia: the Nesterov's index and humidity index of LenNIILKh (HI-1). We have improved those indexes by their integration and inserting corrections accounting for hygroscopicity of fuel, and by symplifying the accounting of precipitation effect. We have named the index "HHI":

$$HHI_n = [HHI_{(n-1)} + (t+10^\circ)_n] \cdot (t-t_d-5^\circ)_n] \cdot (C_r)_n,$$

where t is the air temperature at 13:00-15:00, °C;
t_d is the dew point at that temperature, °C;
n is the number of the day for which this index is being estimated;
$n-1$ is the number of the preceeding day;
C_r is the coefficient of precipitation, determined by total daily precipitation (R, mm) or by daily duration of precipitation (T, hr);

$$C_r = 1.8/(R+1) \text{ or } C_r = 1.8/(1,3T + 1)$$

Notes: 1) If R=0-0,5 mm or T = 0-0,4 hr, then $C_r = 1$.
2) In terms of pyrology, the period of 24 hours should be counted from a morning hour rather than from midnight. Therefore the index for each day is to be calculated twice: in the morning it is estimated based on the weather forecast, and in the next morning it should be recalculated taking into account the factual data.

Table 1. Pyrological characteristics of types of prime conductors of burning (PCB)

Pyrological characteristics	Fire weather drought index FWDI (Nesterov's or HI-1 or HHI), units										
	100	200	300	400	500	700	1000	2000	3000	4000	5000
Lichen type of PCB (Lc)											
E, MJ/sq.m	4.0	5.0	6.5	7.5	8.5	9.0	9.5	10.0	10.0	10.0	10.0
V_o,m/s	0.003	0.004	0.005	0.007	0.008	0.009	0.010	0.011	0.011	0.011	0.011
Dry moss type (Dm)											
E, MJ/sq.m	-	-	-	-	3.5	5.3	10.0	16.0	20.0	22.0	24.0
V_o,m/s	-	-	-	-	0.002	0.002	0.003	0.004	0.004	0.005	0.005
Moist moss type (Mm)											
E, MJ/sq.m	-	-	-	-	-	-	2.3	8.8	12.0	13.2	14.4
V_o,m/s	-	-	-	-	-	-	0.003	0.004	0.004	0.005	0.006
Loose litter type (Ll)											
E, MJ/sq.m	-	-	-	-	-	4.0	7.5	10.0	11.0	11.5	12.0
V_o,m/s	-	-	-	-	-	0.002	0.003	0.005	0.00	0.007	0.008
Compact litter type (Cl)											
E, MJ/sq.m	-	-	-	-	-	-	3.0	9.0	12.0	13.5	15.0
V_o,m/s	-	-	-	-	-	-	0.003	0.004	0.004	0.005	0.005
Cured grass type (Cg)											
V_o,m/s	-	-	0.005	0.005	0.006	0.006	0.007	0,007	0.007	0.007	0.007

Note: Bog-moss (Bm) and Non-conductor (Nc) types never burn. E - heat discharge intensity; V_o - base rate of spread.

The three above mentioned FWDIs are presented in abstract units (u). Fire weather drought classes (DC) are determined by the following FWDI scale: DC 1 - up to 300 u, DC 2 - 301-1,000 u, DC 3 - 1,001-3,000 u, DC 4 - 3,001-10,000 u, DC 5 - 10,000-30,000 u, DC 6 - more than 30,000 u.

5. Pyrological characteristics of PCB types (Table 1) shows that possibility of their burning appears at different values of FWDI and heat discharge intensity (E, MJ/sq.m). It also determines the basis rate of fire spread (V_o, m/s) at the following standard conditions: zero wind speed, horizontal fuel bed, ambient temperature 20 °C, air relative humidity 40%. (E and V_o in Table 1 were measured directly in the course of field experiments.)

6. To estimate wind speed under forest canopy at height of 2 m, value of wind speed at the relevant weather station should be multiplied by the coefficient K_{cc} depending on canopy closure (C). The closure is indicated in the pyrological description of the relevant taxon.

If	C =	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7
then	K_{cc} =	0,77	0,70	0,60	0,48	0,38	0,30	0,23	0,16

and if C =	0,8	0,9	1,0
then K_{cc} =	0,11	0,07	0,05

7. Relative contribution of the above mentioned main factors to the rate of spread of surface fire (Table 2) is assumed here independent and the same for each type of PCB, though, actually, this contribution is somewhat different for layers of various structures and, also, for different types of surface fire.

The developed method for prediction of fire spread consists of the following steps:

1) Data related to the taxon where the fire will burn (or is burning) are selected from the data bank; borders of the territory for which the map is to be drafted are defined more accurately in the sketch, a copy of the map of that territory is prepared based on the plotting board, and the pyrological description of the taxons in that territory is copied, and then a colorless VF map is drafted.

2) Then the VF map is colored to be converted into a map of current fire danger. To perform this, the drought class of the current day calculated based on the relevant weather data is compared with critical drought classes given for each taxon in the pyrological description. Taxons which critical drought classes are lower than the drought class of the current day are regarded ready to burn; they are colored red. Taxons which critical drought classes are higher than the drought class of the current day are considered not ready to burn for a while, and they are colored green. Taxons which critical drought classes are the same as the current drought class are considered to be in uncertain burning state; they are colored yellow.

Table 2. Coefficients of influence of wind, slope and relative humidity on the rate of fire spread

1. Effect of wind

Wind speed, m/s (height 2m)	0.0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0	5.0
K_w, head fire	1.0	1.2	1.4	1.7	2.1	2.6	3.2	4.0	5.0	6.0	7.0	10.0
K_w, back fire, flank	1.0	1.0	1.0	1.1	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.8
K_w, high-intensity flank (by Konev, 1984)	1.0	1.1	1.2	1.4	1.6	1.8	2.0	2.2	2.5	3.0	3.5	4.5

2. Effect of slope

Slope, degrees	-40	-30	-20	-10	0	10	15	20	25	30	35	40
K_s	0.7	0.7	0.7	0.9	1.0	1.2	1.5	2.0	2.5	4.0	6.0	12.2

3. Effect of humidity

Humidity, %	20	25	30	35	40	45	50	55	60	70	80	90
K_h	1.7	1.5	1.3	1.1	1.0	0.9	0.8	0.7	0.7	0.6	0.5	0.3

3) Perimeter of fire is copied from its sketch to the map prepared, recording the time when this perimeter was drawn. Arrow will show wind direction, and wind speed also should be indicated.

4) The time for which the prediction of fire spread is to be drafted is determined and ordered.

In case of large fire, some more directions probably will be needed to be drawn from its perimeter, each direction normal to the fireline; their angles to the wind direction should be indicated.

5) Four directions in which fire is anticipated to propagate are marked in the map by straight lines, usually from the centre of fire: 1) heading, downwind; 2) backing, upwind; 3) flanking, right flank, and 4) flanking, left flank, both are normal to the wind direction.

6) Those lines may cross various taxons available in the map. To estimate what time (T, s) it will take fire to propagate along those directions through each taxon, length of the line (L, m) crossing the taxon is divided by the estimated rate of fire spread in this taxon (V_x, m/s):

$$T = L/V_x$$

The estimated rate of spread is determined by the formula:

$$V_x = V_o \cdot K_s \cdot K_h \cdot K_w,$$

where K_s - coefficient of contribution of slope to the spread rate;

K_h - coefficient of contribution of relative humidity to fire spread rate;

K_w - coefficient of contribution of wind speed to fire spread rate.

V_o is taken from Table 1, in accordance with the relevant PCB type indicated in the pyrological description of the taxon, and the FWDI value. The coefficients are shown in Table 2. Wind speed should be corrected for canopy closure.

7) If there is a "yellow" taxon in the direction of fire propagation, i.e. the possibility of burning is uncertain there at present, two versions of fireline propagation in that place are to be estimated: 1) regarding the taxon is ready to burn, and 2) regarding it is not ready to burn.

8) If the taxon in the direction of fire spread is not ready to burn ("green"), the fire will stop propagating in this direction if the barrier is wider than the width of the burning strip of fire edge. In the other case the fire will propagate along the barrier to either one or two directions. To estimate the width of the burning fire edge in the direction of the barrier, fire spread rates along neighbouring directions should be predicted first.

If propagating fire encounters a barrier (a road, a brook, a river, etc.), its backfire and flanks are usually stopped while the head fireline, particularly a long one (over 100 m) or that of high-intensity, can overcome such barriers except rivers of 50 and more meters wide. In summer, river's floodlands should be added to the width of the river since they are usually are not ready to burn.

9) In result, fire perimeter is drafted for the given time, taking into account: 1) time-term for which the perimeter of the fire has been drafted; 2) period of fire propagating across each taxon in the given direction; 3) the final ordered time-term for which the fire perimeter should be predicted.

10) Estimation of the perimeter length (i.e. length of the fireline). The predicted perimeter is drawn in the map through the points, which the fireline would reach in the ordered time in each direction; length of this perimeter is measured (taking into account the scale), and multiplied by the twist coefficient which average value is 1.5.

11) The rate of perimeter increase (V_p) is determined by the rate of spread of fire head (V_{fh}) in the last taxon, i.e. closer to the ordered time:

V_{fh}, m/s	0.005	0.01	0.02	0.03	0.05
V_p , m/s	0.035	0.06	0.11	0.16	0.20

12) Power of surface fire is determined and qualitatively classified by the intensity of heat discharge from a unit of length of its head fire edge (I_{fh}):

Power of surface fire	Intensity (I_{fh}, kW/m)
low	up to 35
moderate	35-120
high	over 120

$$I_{fh} = E\, V_{fh}$$

E is taken from Table 1 in accordance with PCB type in the last taxon in the fire head direction, and the FWDI.

13) Data on the locality of fire perimeter, its intensity and the rate of perimeter increase for the given time, as well as characteristics of taxons adjoining the fire, being outlined in the map, facilitate drafting optimum plans to control forest fire.