Topical Scientific and Practical Issues of Wildland Fire Problem [1]

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Abstract

This paper considers the basic causes of wildfire problems and suggests the main objectives to resolve them in Russia. The main focus is on creation of the Russian wildfire behavior and fire effects prediction on the basis of vegetation fuel classification and methods of fuel mapping.

Introduction

At present our planet annually experiences over 200 thousand wildfires or vegetation fires (i.e. forest, bush, steppe, etc. fires) with their number increasing from year to year. Besides, disastrous fire outbreaks become more frequent on all continents. Damage that wildfires do to mankind is huge, especially taking into account indirect as well as direct damage.

Problem of wildfires has not been resolved anywhere in the world. Mere increase of technical power does not lead to desirable results. Forests of developed countries (e.g. in the US, Canada, Spain, Portugal, etc.) burn as actively as those in Africa or in Russia (Siberia and the Far East).

The main reasons of wildfire problem are as follows:

- Constant wandering of dry seasons over the planet causing outbreaks of wildfires; this is impossible to predict so far.
- Unpredicted self-development of ordinary wildfires into awful fire disasters.
- Difficulties in delivery and use of heavy machines on hardly accessible territories.
- Absence of a perfect method for economic evaluation of how effectively the wildfire control system works.
- Absence of the system of payments encouraging wildfire fighters.

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Ways to Resolve Wildfire Problem in Russia

According to Avialesookhrana, annual wildfire number and burnt area tend to increase for the last decade in Russia. For instance, the average number of fires increased from 11 thousand up to 18 thousand fire events, and burnt areas – from 600 thousand ha up to 1.5 mln ha (Davidenko 2005).

Lately the idea to obligatory suppress all wildfires (being the leading one in Russia for a long time) gave place to the idea to selectively suppress each wildfire depending on economic value of the forest subject to fire. Forest fire prevention, early fire detection, and effective respond to fire occurrence take priority among other preventive measures. However, the structure of fire fighting activities includes "wildfire development estimation and prediction" in the section "forest fire suppression", but nothing is said about how practically implement this prediction nowadays or in the future.

In some countries there are already wildfire behavior prediction systems which are constantly revised and improved. For example, in the USA – BEHAVE (Burgan and Rothermel 1984), in Canada – Fire Behavior Prediction (Forestry Canada 1992). A similar system is in the process of creation in Russia with special attention to natural conditions of the country (Volokitina and others 2006).

By "fire behavior" we imply the following: 1) fire spread over the territory; 2) dynamics of fire spread rate and intensity; 3) fire progress (e.g. development of surface fire into crown fire); 4) assessment of fire effects (e.g. damage of a tree stand).

Wildfire behavior prediction is necessary for successful fire management. It is used to help calculate optimum manpower and facilities for fire suppression. By predicting behavior of a large fire it is possible to foresee dangerous tendencies and situations of its spread and development (probable danger to inhabited areas or valuable objects, etc.) and make an optimum fire management plan. Scenarios of fire spread and fire effects on a defined area under different weather conditions are necessary to choose the optimum time and method of prescribed burning.

So, to solve the problem of wildfires in Russia it is necessary, above all, to create the Russian wildfire behaviour and fire effects prediction system. Other objectives worth mentioning are as follows:

- Elaborate a technique of proper wildfire monitoring including estimation of vegetation damage. The factors disturbing accuracy of estimations are: geographical features of the vegetation cover, phenological dynamics of vegetation, shielding of the surface by cloudiness, smoke, forest canopy, etc.
- Improve daily rating of regional fire danger, which depends upon many factors.
- Improve fire-preventive arrangement of the territory covered by vegetation, the main goal being creation of favourable conditions for active fire management.
- Choose the main direction in elaboration of fire-fighting means and methods taking into account their universality, simplicity, reliability, transportability, and economy.

- Elaborate an improved technique for estimation of economic effectiveness of the wildfire control system.
- Develop international cooperation of scientists and professionals in fire management; at present language barrier (absence of coordinated terminology) as well as financial factor interferes with it.

Russian Wildfire Behavior and Fire Effects Prediction System

We have developed a principle scheme for the Russian fire behavior prediction system *(fig. 1)* (Sofronov and others 2005). The key elements are an information database and a model of fire behavior prediction. The most important is surface fire behavior prediction since over 90 percent of all fires are surface fires resulting in more than 80 percent of burnt area (Volokitina and Sofronov 2002). Besides, crown and ground fires usually develop from surface fires.

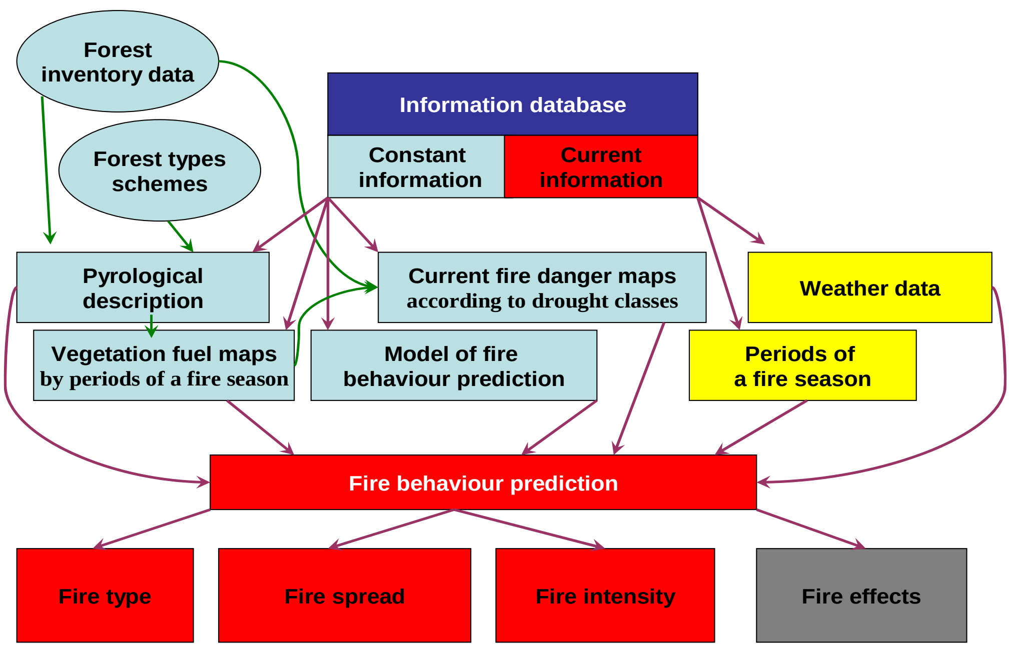

Figure 1— Principle scheme of fire behavior prediction.

The information database should contain a pyrological description of each homogeneous vegetation site including information about vegetation fuel complexes, their properties, state, and information about their moisture and burning conditions.

Pyrological descriptions of vegetation sites can be based on a standard description, or individual site specific descriptions. Standard "fuel models" and "fuel types" are used in the American and Canadian systems. In the American system BEHAVE (Burgan and Rothermel 1984) there are only three fuel models to represent all forests, which is not sufficient for application to Russia. The Canadian Fire Behaviour Prediction (FBP) system has 16 fuel types, 12 of which are forest. These types are pyrologically well studied, however, they do not reflect the whole variety of Canadian forests.

To predict fire behavior, pyrological descriptions of all kinds of sites is needed, otherwise, the vegetation fuel map will not be complete. Russia also used a standard approach for pyrological descriptions for many years. Different forest types were studied for this purpose, however, there are hundreds of forest types in each region of Russia and still there is not a single region with full information about all forest types.

Individual pyrological descriptions made up of standard elements are more accurate for representing the pyrology of a site, provide a more complete vegetation fuel map, which is why we are developing this approach for Russia. The availability of a vegetation fuel classification that contains types of prime conductors of burning and their properties (Volokitina and Sofronov 2002) makes this approach feasible *(tables 1, 2)*.

At present we are developing a variant of a system with individual characteristic of vegetation sites in the mode of large-scale vegetation fuel maps (VF maps) with an enclosed pyrological description of all forest inventory units. In the Sukachev Institute of Forest, Siberian Branch of the Russian Academy of Science, a simple and inexpensive method of creating large-scale vegetation fuel maps was developed. This method makes maximum utilization of available forest inventory information for making maps using a specially developed computer program (Volokitina and others 1995; Volokitina 1996; Volokitina and Sofronov 2002) *(fig.2)*.

VF mapping is based on fuel classification, i.e. division of fuels into groups and types. Classification of the group of prime conductors of burning (PCB) from the surface cover is of great significance. PCB is a layer of moss, lichen, and fine vegetation remnants. This layer affects fire occurrence and spread. Classification of PCB is based on the analysis and pooling of both published data with data we collected on drying rates of the PCB in various regions of Russia. This classification takes into account seasonal and weather dynamics of PCB, as well as soil moisture impact on their drying rate. In this group, we distinguish 8 types, for which there are detailed characteristics (Volokitina and Sofronov 2002).

We have developed and tested the identifier of PCB types as well as the technology for creating large-scale vegetation fuel maps in GIS using forest inventory data, a process that was done in collaboration with a GIS group of scientists and remote sensing specialists in the Sukachev Institute of Forest. There is a structural and functional GIS scheme. We developed a program for making VF maps *(fig. 2)*.

In the map *(fig. 3)*, different colors stand for types of PCB. Pyrological descriptions of inventory units shown on the map are enclosed with a large-scale VF map. The pyrological description indicates dominant tree species, age, relative basal area of a tree stand, slope exposure, and slope steepness. Pyrological descriptions are usually made for two most differing phenological periods in a season, namely:

- for “leafless spring”, when foliage is absent in the tree canopy and green grasses are absent on the soil, and
- for “full summer”, when vegetation reaches its full development.

Table 1— *Classification of Vegetation Fuels (VF).*

VF group	VF subgroup	VF type (and subtype)	Character of burning[1]
I. Cover of moss or lichen, fine litter (PCB)[2]	Mosses	Lichen (Lc)	Fl
		Dry moss (Dm)	Fl
		Moist moss (Mm)	Fl and Sm
		Bog moss (Bm)	
		subtype Bm (1)	Fl
		subtype Bm (2)	Wn
	Litter	Cured grass (Cg)	Fl
		Loose litter (Ll)	Fl
		Compact litter (Cl)	Fl and Sm
		«Non- conductor» (Nc)	
		subtype Nc (1)	Sm
		subtype Nc (2)	Wn
II. Duff, humus and peat layers of soil	Duff	Rough humus	Sm
		Mull	Sm
		Turf	Sm
	Peat and humus	Peat horizon	Sm
III. Layer of herbs and low brush (at coverage ratio 0.5 m or more)	Low brush	*Vaccinium vitis-idaea* (Vv)	Fl
		Arctostaphylos uva-ursi (Au)	Pd
		Swamp-shrub (Bs)	Fl and Pd
		And other types	
	Herb (green)	Grass (Gr)	Pd
		Sedge (Se)	Pd
		«Winter» sedge (Ss)	Fl
		Mixed herb (Mh)	Pd
		And other types	
IV. Large wood remnants (dead branches, snags, limbwood, slash)	Dead-standing and downed trees	Dead-standing trees	Sc, Sm
		Hanging limbwood	Sc
		Downed limbwood	Sc
	Slash	Coniferous foliage-covered slash	Fl
		Foliageless slash	Pd
V. Layer of young growth and shrubs	Coniferous	-	Fl
	Broad-leaved		Pd and Fl
VI. Green foliage, foliage-covered twigs, and dead limbs of live trees.	Coniferous	Crowns of young tree stands and dwarf Siberian pine thickets	Fl
		Crowns of spruce and fir stands	Fl
		Crowns of pine and larch stands	Fl
	Broad-leaved	Crowns of broadleaves stands	Pd
VII. Trunks of live trees, branches thicker than 7 mm		Healthy trunks	Sc
		Resinous trunks	Fl, Sc
		Rotten or hollow trunks	Sc, Sm

[1] Character of burning: Fl - burning with flame, Sm - smoldering, Sc - surface charring, Pd – passive thermal decomposition, Wn - would not burn.

[2] The first group of VF (PCB) plays the leading role in fire incidence and spread.

Table 2— *Types of prime conductors of burning (PCB).*

PCB types (and subtypes)	Typical areas, their attributes	Non-typical areas, their attributes	CCD[1]
1	2	3	4
Mossy PCB Subgroup			
Lichen (Lc)	1. Lichens predominate in the forest floor 2. Lichens are present in the forest floor on dry soil	Very dry, including rock outcrops, with litter of pine needles	I
Dry moss (Dm)	Forest floor is predominated by green mosses, somewhere with lichens, on drained soil in boreal and northern forests (green-moss and red whortleberry - green-moss forest types)		II
Moist moss (Mm)	Forest floor is predominated by green mosses usually with *Sphagnum* and *Polytrichum*, on insufficiently drained soil (forest types - mossy, *Aulacomnium*, moist billberry and similar)	In southern taiga on drained soil, the forest floor may be predominated by green mosses. Thin cover (up to 3 cm) of compact moss	III
Bog-moss (Bm) Subtype Bm1	Ground cover is predominated by *Sphagnum* and *Hypnum* moss species, on boggy and bog soils (without notable presence of sedge or grass) Boggy forests and small bogs amidst drained plains, with peat layer up to 0.7 m thick	 Ground cover is predominated by *Polytrichum*	 IV
Subtype Bm2	Large bogs and bog systems		cannot burn
Litter PCB Subgroup[2]			
Cured grass (Cg)	Forest floor is predominated by dry grass or sedge (i.e. naturally cured plants), usually in fall and spring. Not included are sedge forest types with ground cover of evergreen sedge	Bogs and swamps of sedge-sphagnum and sedge-hypnum types, with well-developed cover of sedge in spring and fall (in summer - Bm)	I
Loose litter (Ll)	1. Forest floor is predominated by herbs - in spring and fall. 2. Forest floor is predominated by litter of birch and aspen fallen leaves 3. Forest floor is predominated by litter of pine and cedar fallen needles	1.Forest floor is predominated by evergreen sedge - in spring and fall 2.Matted litter of dry sedge or grass	II
Compact litter (Cl)	1. Forest floor is predominated by compact litter of fallen needles of fir, spruce or larch – in all seasons 2. Forest floor is predominated by compact litter of fallen leaves of birch or aspen, and by matted dry herbs in summer		III

1	2	3	4
Non-conductor (Nc)	Surface fuel cover too scarce for fire to spread		
Subtype Nc1	Fuels not providing spread of surface fire: duff, humus, turf; usually in summer. Ground fires are possible.	Live grass load exceeds PCB load in summer, so spread of surface fire is impossible	IV
Subtype Nc2	Absence or very scarce presence of any PCB; sands, pebble, rock outcrops, plowed fields, roads, etc.		cannot burn

[1] Critical drought class (CDC) is a class of drought when burning of a specific PCB becomes possible under "standard" environment conditions. Drought class is rated according to the fire drought index (or Nesterov's index, or the LenNIILH PV-1 index), conventional units: I DC - up to 300 units, II DC - 301-1.000 units, III DC – 1.001-3.000 units, IV DC – 3.001-10.000 units, V DC - over 10.000 units of the fire drought index.

[2] PCB for the litter subgroup is determined separately for summer and separately for spring and autumn.

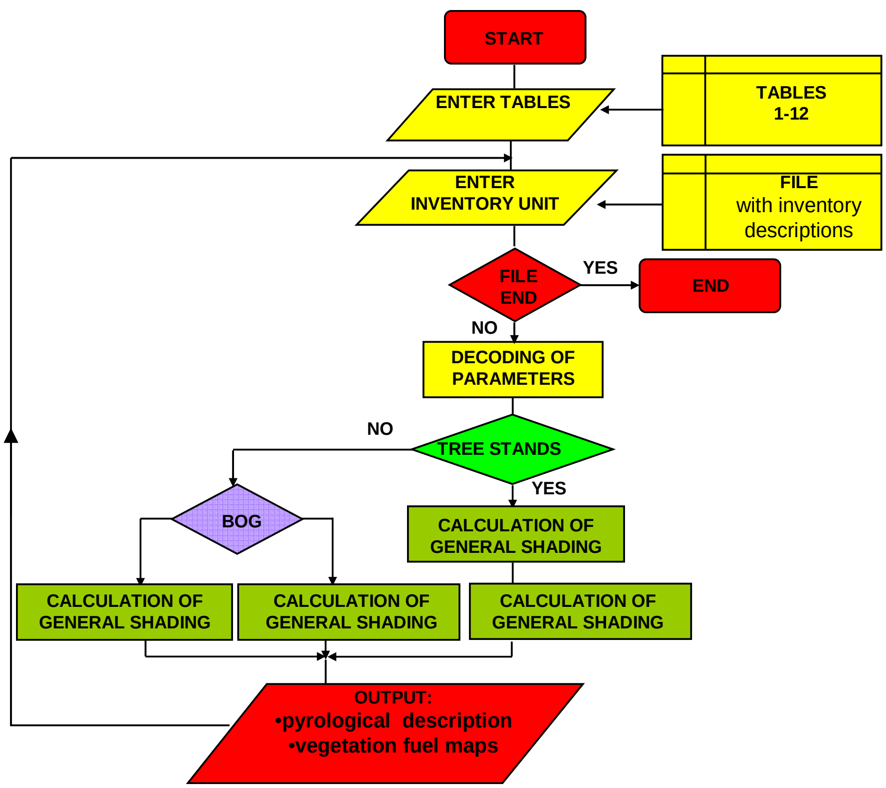

Figure 2— Program flowchart for VF maps creation.

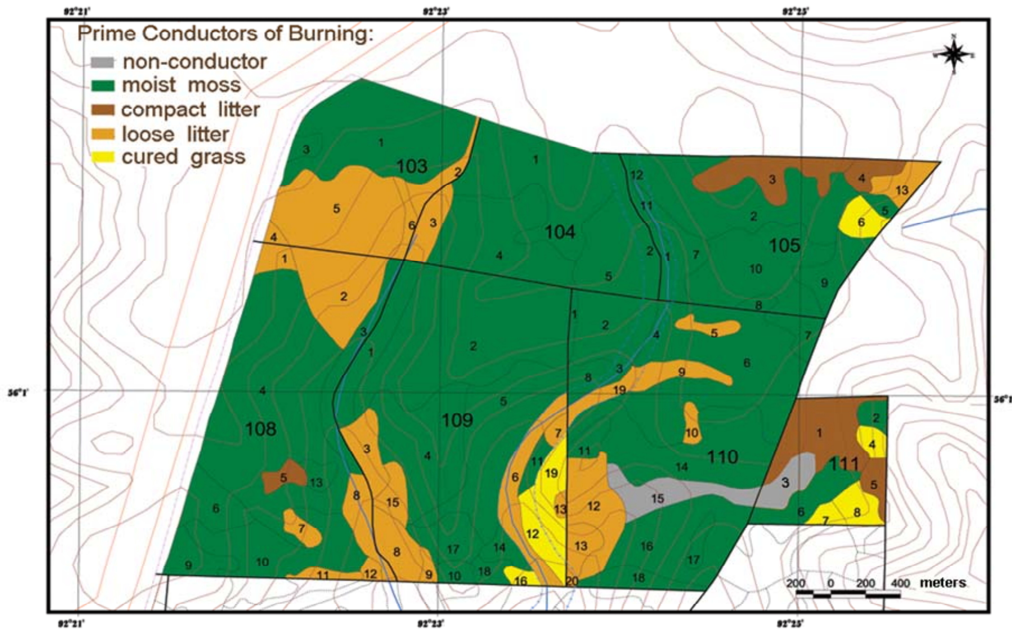

Figure 3— Large-scale vegetation fuel map

Critical drought class (i.e. such a drought class when a given vegetation plot becomes ready to burn) is required in the pyrological description of each inventory unit depending on the PCB type, canopy closure of a stand, and phenological period. Our observations of solar energy under the forest canopy allowed us to make tables for determination of critical classes of drought in each forest inventory unit, as well as a table that can be used to account for exposure and slope.

Then on the basis of the VF map, a map of current fire danger is made *(fig. 4)*.

To predict the rate of surface fire spread, a model is needed. There are a lot of different models describing process of burning under surface fires**,** however, currently, only Sofronov's model has got information dataware owing to improved by us vegetation fuel classification and developed practical methods of vegetation fuel mapping (Sofronov 1967; Sofronov and Volokitina 1990; Volokitina and others 2006). The principle of this model is very simple: rate of fire spread under no wind typical for a given PCB type is multiplied by variable coefficients of wind, relative air humidity, and slope.

Fire behavior prediction includes several stages. At first, it is estimated whether vegetation sites around an existing fire are ready to burn under the current fire weather index. Then fire spread rate and intensity on these sites are predicted according to weather forecast, in the process of modeling fire contour spread. When predicting fire contour spread, both unburnable areas and linear breaks are taken into account. Then fire intensity on each part of the fire edge is calculated. When planning fire suppression, the optimum amount of resources (human and other) is determined depending on the length of the fire perimeter, its spread rate and intensity. For fire suppression and fire effects prediction there are simple formulas and sets of tables (Volokitina and others 2005).

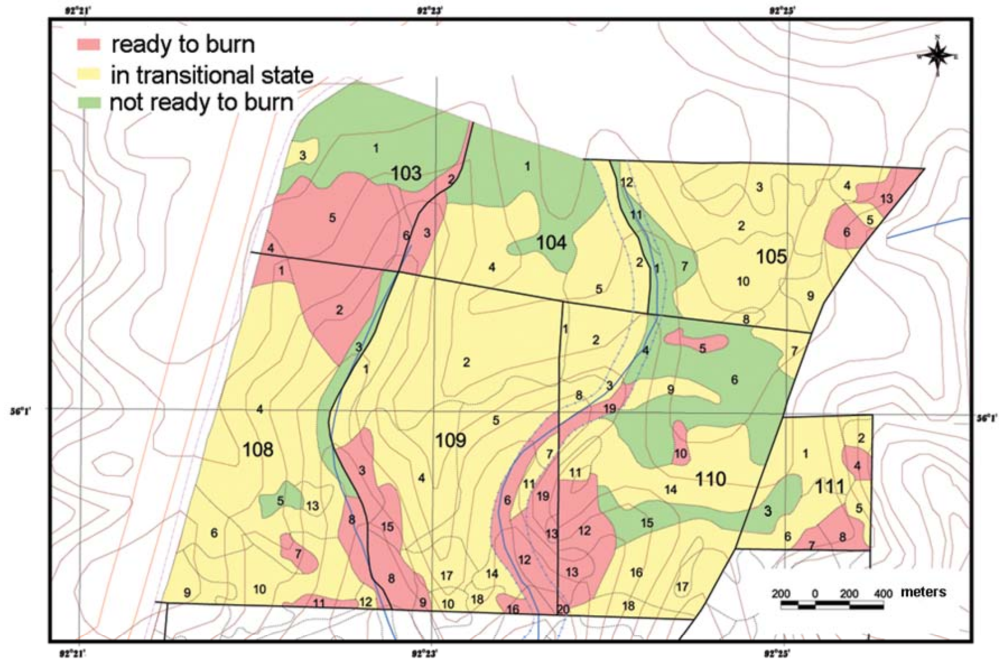

Figure 4— Current fire danger map (drought class III, for spring).

Other Objectives to Resolve Wildfire Problem in Russia

Other important objectives to resolve wildfire problems in Russia will be mentioned briefly.

It is necessary to elaborate a technique of proper wildfire monitoring including estimation of vegetation damage.

Damage of vegetation plots (including forest ones) should be estimated according to three gradations: 1) slight damage; 2) considerable damage; 3) heavy damage with lethal effects for trees. Space images should be used for this estimation immediately after a fire, i.e. estimation should be predictive.

The factors disturbing accuracy of estimations are: 1) geographical features of the vegetation cover; 2) phenological dynamics of vegetation; 3) different weather conditions; 4) shielding of the surface by forest canopy; 5) latent damage of trunks and roots, etc. To develop a proper estimation method ground observations of large fresh burnt areas should be carried out in combination with airborne and space survey in each natural region

It is essential to improve daily rating of regional fire danger, which depends upon many factors.

Factors interfering with it are as follows: 1) daily fire danger is expressed in conventional, not absolute values; 2) daily fire danger rating does not take into account all factors.

Daily fire danger depends not only upon weather but also upon other factors (ignition sources, vegetation features, phenological period, etc.). Effeciency of daily fire danger rating methods can be improved by indirect account of all fire danger factors with the help of individual local daily fire danger scales with comparable fire danger classes. The latter should be related to an absolute criterion – with probable daily number of *active* wildfires per mln ha (*fires/ mln ha*) (Sofronov and others 1998; Sofronova 2006).

There is need to improve fire-preventive arrangement of the territory covered by vegetation, the main goal being creation of favourable conditions for active fire management.

For this essential is creation of an information database containing different maps including special maps: 1) a map of vegetation fuels of 1:100,000 – 1:200,000 scale (Volokitina and Sofronov 2002); 2) an improved map of natural (typical long-term) fire danger rating (Sofronov and Volokitina 2002); 3) maps of fire distribution over the territory in spring, summer, and autumn; 4) maps of transport network and water sources with their description; 5) a map of available network of supporting lines for active fire suppression (including roads, paths, rivers, brooks, wet depressions, wetlands, etc.).

It is necessary to choose the main direction in elaboration of fire-fighting means and methods taking into account their universality, simplicity, reliability, transportability, and economy.

Wildfire control is not production of goods, therefore choice of means and methods of fire suppression cannot be determined by economic efficiency and profit. An optimum way of fire suppression is as follows: effective creation of a narrow fire line (0.2 – 0.5 m wide) around a fire together with backfiring from this line. To make this mineralized line there is no need in high-powered machines. Therefore, fires of any intensity can be suppressed this way.

There is need to elaborate an improved method for estimation of economic effectiveness of the wildfire control system.

Estimation and comparison of trends related to annual wildfire detriment and annual expenses for forest fire protection should be an essential part of this method. However, methods of economic fire effects assessment are poorly elaborated so far.

It is essential to develop international cooperation of scientists and professionals in fire management; at present language barrier (absence of coordinated terminology) as well as financial factor interferes with it.

It is next to impossible to resolve wildfire issue without exchange of information among scientists and professionals of different countries. Lack of terminological coordination and harmonization, polysemy of notions and terms, their constant transformation is a grave obstacle.

Proper terms contribute to science development, improper terms interfere with development of scientific knowledge. Coordination and harmonisation of terms contributes to coordinated and harmonised development of a respective field of science. Therefore, bilingual ideographic glossaries are of great importance for this since they can help to both coordinate our mother-tongue terminology and harmonize it with a foreign one in case of joint coordinated work of both scientific experts and translators who obtained an additional specialization both in Linguistics and in the respective scientific field.

Conclusion

Realization of the objectives considered in this paper will contribute to resolving wildfire problem in Russia. Development of cooperation among scientists of different countries is necessary to exchange advanced experience in the field of wildfire behavior and fire effects prediction

Acknowledgments

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