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GRASSFIRE FORECAST AT AGRICULTURAL LANDS IN JEWISH AUTONOMOUS REGION

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The method proposed for prediction of the grass fire ignition and development during spring-autumn fire period is based on the author's probability model for prediction of wild fire ignition depending on natural and man-made conditions, and the Australian McArthur model for forecast of non-forest fire development. This method has been verified on fire data of 2015-2017 in the Jewish Autonomous Region. Calculations were done with the help of electronic maps of forest area quarters and the network of operational-territorial units (OTU) of the agricultural lands designed at 2.5 x 2.5 km cells. The Earth's remote sensing data on non-forest fires in 2010-2014 and information on Normalized Difference Vegetation Index (NDVI) during periods before and after growing season (April 23 – May 13, and September 24 – October 10) are used. The highest probability of the fire effect on agricultural land is found at a distance of 3 km from the roads and 3-6 km from the urban areas. The spatial coincidence of OTU with real and predicted grassfires and the validity of the forecast in spring before growing season are considered to be satisfactory. The suggested method of predicting grassfire ignition and development has a considerable practical importance and can be applied in the development of fire-incident management strategies and measures to mitigate a threat to human and environmental health.

Keywords: *grassfire, ignition and development, Jewish Autonomous Region.*

Introduction

Prognosis and control of grassfires at agricultural land close to the woody plot is important for mitigating its threat to human and environmental health. These fires often cause significant damage to plant ecosystems, being the reason of forest and turf burn. The complexity of their monitoring, prevention and elimination is explained additionally by the fact that these areas are not assigned to the organizations of the Russian State Fire Service, and firefighting is transferred to municipal and private organizations.

Domestic and foreign systems of prediction the ignition and development of fires are based on two approaches: they use mathematical models of analytical type and experimental-statistics. In Russia, presented models are mainly applied to predict the rate of forest fire development, its perimeter and area [1, 5, 9]. The model proposed by McArthur is based on special datasheets of natural conditions in the southeast of Australia, and is most-known model used to predict the development of non-forest fire in grassland [7]. The Ministry of Natural Resources of Canada uses the Fire M3 – Fire simulation and mapping system, which is designed to search active vegetation fires, estimate their area, and transfer data to the Canadian Wildland Fire Information System [6]. The construction and testing of system for predicting the spread of grassfire that cause fire transition onto the woody plot, has not yet been carried out in Russian Federation, and therefore becomes particularly important.

Herbaceous plant fuel depends on features of grass species, and its fire hazard characteristics are based on grass ecology (annual or perennial plant, vegetation period, density, degree of drying, ratio of dead and vegetating grass) as well as on weather conditions that play a decisive role in ignition and spatiotemporal development of fires. The period when grass is ready to burn depends first on the phenological phase of plant, and second, on its gross volume, density, and energy content, and on weather conditions. This is the main difference in predicting grass fire hazard when compare with risk of forest fire.

Germination, spring green up stage and tillering are grass vegetative phases which are very important for agriculture, and affect productivity of natural hayfields and pastures. Coloring and defoliation period (transition of vegetating plant to dry leaves and twigs), and period from leaf coloring stage to seeding time, are the most fire-dangerous phenological phases when highly flammable grass is the main conductor of burning. The fire has a high rate of distribution and can change direction, overcoming various barriers and spreading to a vast area. Weather conditions affect the degree of drying of vegetating grass and dead twigs. Grasses as a conductor of burning respond to changes in climatic, seasonal and daily weather conditions faster than other species.

All the above characteristics of the herbaceous plant fuel are critical for the assessment of the probability of grassfire ignition on natural and agricultural lands and its development onto the forest areas. In the Jewish Autonomous Region (JAR) the yield from natural grassland (18.7 kg ha^{-1}) is higher than the mean value for Russia (10.0 kg ha^{-1}). Successful progress of livestock farming here depends on the quality of natural hayfields and pastures. That is the reason why grassfire and its prediction in region is an important problem not only for forestry, but for agriculture as well. The current work focuses on design of method for grassfires forecasting in the transition seasons of spring and autumn, which is crucial for monsoon climates at boreal latitudes [4]. This method is based on the author's original model for prediction of forest fire ignition depending on natural and man-made conditions, and the Australian McArthur model of non-forest fire development.

Method and Materials

Our own method for grassfires forecasting includes the following stages: 1) to determine periods of agricultural grassfires; 2) to determine daily level of grass drying during those periods; 3) to calculate daily fire hazard depending on weather conditions that favors the generation of fire, with purpose to identify days when grassfire can ignite due to meteorological conditions; 4) to calculate the probability of grassfire ignition depending on natural and man-made factors; 5) to calculate the rate of grassfire development; 6) to calculate time of probable grassfire spread onto the nearest woody plot.

First, the degree of plant drying at the beginning of the pre-vegetative period and at the end of the post-vegetative period is defined. For this purpose it is assumed, that on a dry day grass is dry with an increased level of dry carbon. Dry day is determined as a period when daily precipitation falls in the range of 0 – less than 3 mm in previous, current and subsequent day. Literature review shows the content of non-forest dry grass (*C*) is maximum (100%) during the steady temperature transition from 0 to 5°C [3]. In other periods the content of dry grass is defined by Normalized Difference Vegetation Index (NDVI) [8, 10] as −0.5 for artificial materials (concrete, asphalt); −0.25 for water; −0.05 for snow and ice; 0 for clouds; 0.025 for open soil; 0.5–0.7 for sparse vegetation; 0.7–1.0 for dense vegetation. If pixilation of non-forest area is from 0.5 to 0.7, *C* is equal to 50%; from 0.7 to 1.0, *C* = 0%.

The prediction of grassfire probability is made on the basis of modified deterministic-probabilistic model by Filkov and Baranovsky [1, 6] (1):

$$F_{i,j}(B)=\begin{cases} F_{i,j}(C)\big[\ (F_{i,j}(N)F_{i,j}(B/N)+ \\ +F_{i,j}(M)F_{i,j}(B/M)\ \big]\quad at\quad R_N\le R_{k\,p} \\ F_{i,j}(C)\big[\ (F_{i,j}(D)F_{i,j}(B/D)+ \\ +F_{i,j}(M)F_{i,j}(B/M)\ \big]\quad at\quad R_N> R_{k\,p} \end{cases},\quad (1)$$

where *i* – forecast day; *j* – operational-territorial unit (OTU) as a pixel at the remote sensing (RS) image; $F_{i,j}(B)$ – probability of grassfire; $F_{i,j}(C)$ – probability of grass burning depending on complex meteorological index [10], determined by the degree of pyrophytic danger; $F_{i,j}(N)$, $F_{i,j}(D)$ – the probability of man-made origin of fire from the nearest settlement, railway or highway; $F_{i,j}(B/N)$, $F_{i,j}(B/D)$ – probability of burning due to man-made reasons; $F_{i,j}(M)$ – probability of natural reason of fire (lightning); $F_{i,j}(B/M)$ – probability of fire due to natural reason of fire (lightning); *RN* – distance from OTU to the nearest settlement. *N*, *D* and *M* form a complete group of incompatible events, which are calculated as frequency characteristics [2].

The McArthur method (mk4) for meadow areas was used [7] to calculate the rate of grassfire development (2):

$$v=0.2\,6e^{5.0\,1\lg(c+0.001)-2\,3.6+0.028t-0.226\sqrt{r\,h}+0.633\sqrt{v}},\quad (2)$$

where *w* is rate of grassfire (m s^{-1}), *rh* – air relative humidity (%); *c* – dry grass content (%), *v* – wind speed (m s^{-1}).

The calculation of the time for grassfire speeding up to the nearest woody plot is determined by the rate of burning and distance to the forest.

The area of non-forested land in the JAR covers 1382 thousand ha, that is 38% of its total square. 2010 to 2014 year period was taken as a base period for a model; 2015 to 2017 year non-forest fire data were used to verify the model. Calculations were made using specially constructed electronic map of forest area quarters and the network of OTU at the agricultural land designed as 2.5 x 2.5 km cells (Figure 1); total number of cells was 2623. Each cell contained 100 pixels of the Moderate Resolution Imaging Spectroradiometer (MODIS) image with a special resolution of 250 m. MODIS is a sensor onboard the Terra satellite launched by National Aeronautics and Space Administration (NASA) (public access on NASA

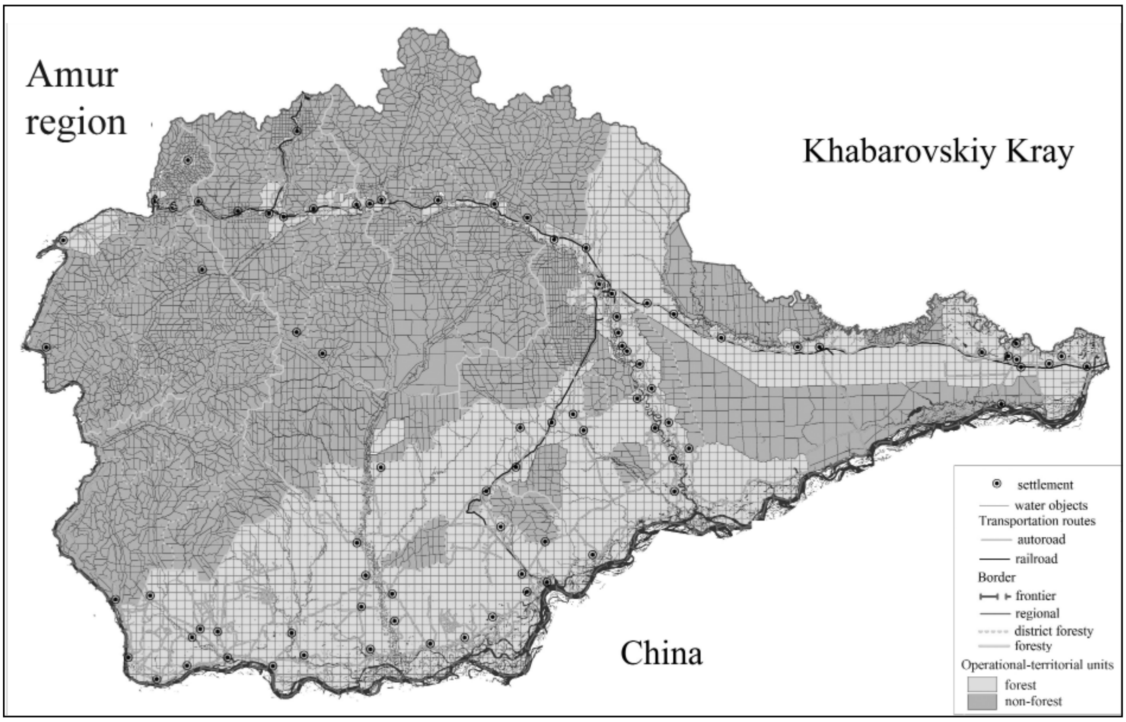

Figure. 1. Electronic map of operational-territorial units, Jewish Autonomous Region

website http://rapidfire.sci.gsfc.nasa.gov). RS data on non-forest fires in 2010–2014 and information on NDVI index before (after) growing season (April 23 – May 13 and September 24 – October 10) were used.

Information on grassfires for period 2010–2014 is based on MODIS data in 36 spectral channels with a spatial resolution 250, 500, 1000 m per pixel. Since land with non-forest fire is only recorded by RS data, the rule of 70–100% non-forest area to the woody area ratio should be applied to classify the land as non-forest area.

For spatial prediction of grassfire and calculation of spreading rate, RS images obtained in red (620–670 nm) and near infrared (841–876 nm) channels (product MOD09GQK) were selected and utilized.

The Student *t*-test with a probability threshold of 0.5–0.6 at level of 0.05 was used to decide the difference or similarity between spatial distribution of OTU with actual and predicted grassfires.

Results and Discussion

NDVI index was calculated pixel by pixel for 12 days out of 30 in spring and autumn; images were not considered in days when clouds covered near 90%. For each OTU of non-forest land, the mean vegetation index was determined by sampling the corresponding values of nested pixels at the satellite image.

Figure 2 presents information on NDVI index for April 27, when 3 fires were detected, and for April 28, with fires spreading to woody plots. Figure 2 shows the probability of grassfire in non-forest area on April 27 and the speed at which these fires run to the woody plots. In most cases, the running time is more than 12 hours depending on wind speed and other weather conditions. On April 27 and during the previous days NDVI was not recorded for clouded areas, which were colored white on the map.

According to *t*-test statistics, there is no significant difference between spatial distribution of the OTU with actual and predicted grassfires in spring, which means that grassfire forecast is considered to be satisfactory. The validity of the forecast in the spring pre-vegetating period is more than 60%; the autumn forecast was not validated due to the small number of fires.

The probability of man-made origin of fire from the nearest settlements or railways and highways was determined for the base period from 2010 to 2014, maximum of grass fires being observed at a distance of 3 km from the roads (2,714 cases) and 3–6 km from the urban areas (918 cases). The results show the grass- and pasture lands in the southern and south-eastern part of the study area are mostly exposed to burning (Figure 3).

As a whole, the consequence of the pyrophytic factor influence depends on the degree of exposure to burning. In areas with frequent fire load they contribute to a reduction of the total number of species of

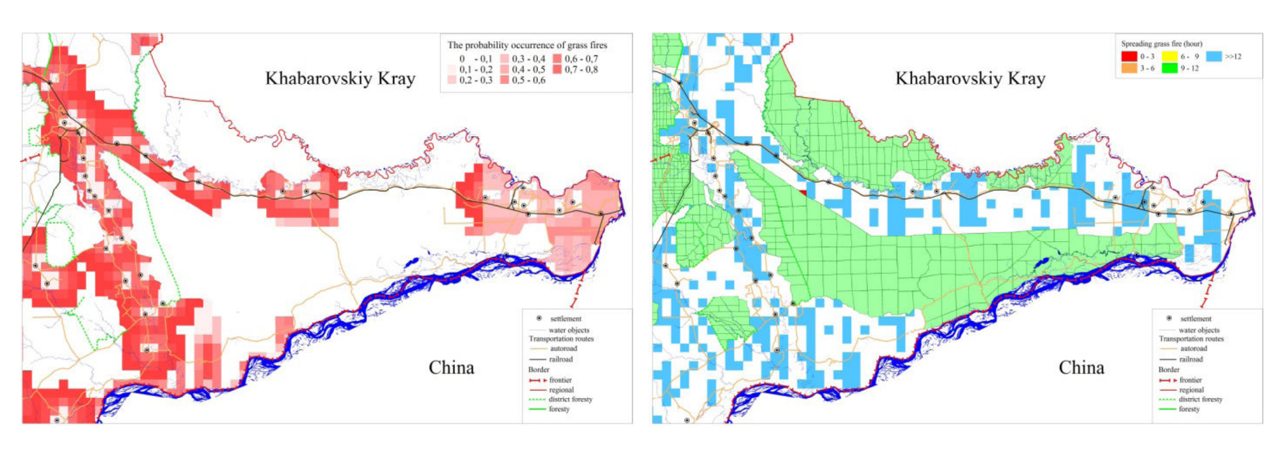

Figure 2. Forecast of grassfires ignition and time to spread onto the woody plots, April 27, 2015, Birobidzhanskoe Forestry in the Jewish Autonomous Region

vascular plants and complete burning of litter layer. On the contrary, non-frequent low fires do not affect underground biomass, the grass community does not deteriorate, species richness does not change, which may strengthen shrub growth. Fire does not cause any serious disturbances and acts as a natural renewal factor for this type of vegetation, playing beneficial role in its permanence.

Conclusion

A method of forecasting the ignition and development of grassfires depending on natural and man-made conditions is proposed. This method is verified on grassfire data from the Jewish Autonomous Region in 2015–2017. The results for spring are found to be satisfactory; verification for autumn is planned as the next step of the research project. In summary, it was found that the high probability of the fire affecting agricultural land is observed at a distance of 3 km from the road network and 3–6 km from the settlement. These areas are mainly concentrated in the southern and south-eastern part of the Jewish Autonomous Region, where the main hayfields and pastures are located. The suggested method is of great practical importance and can be applied for fire-prevention measures and recommendations.

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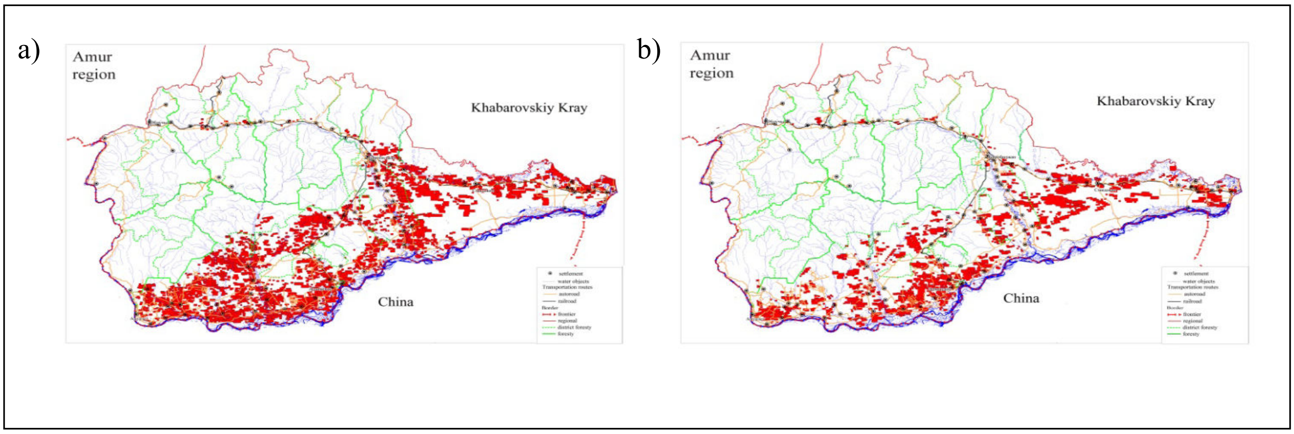

Figure 3. Grassfires in the Jewish Autonomous Region, 2010–2014: a) spring, b) autumn

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