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GEOGRAPHY

Dynamics of Forest Fires and Climate in Ilmen Nature Reserve, 1948–2013

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Abstract—This paper considers the impact of climatic factors on the forest fire rate in Ilmen State Reserve based on 66 years of direct observation data for 1948–2013. This period was marked by a gradual annual increase in the number of recorded fires in the reserve. The higher fire rate is generally related to lengthening of the fire season and more frequent fires in the spring and summer–early autumn periods. We did not obtain sufficient evidence to verify a relation of the higher fire rate to climate changes. The average monthly and seasonal weather conditions can be involved to explain only some causes of the interannual fire rate variability. The observed changes in some climatic characteristics could have contributed to an increase in the fire rate, while others could have reduced it.

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Forest fires are an important factor in the formation of the forest cover. Knowledge of the forest dynamics and causes of fire is necessary for traditional forest management, forecasting, and regulation of the state of the forest under changes in the climate [1, 2]. The number of different models to forecast fire hazards and forest fires under climate change is increasing [3–8]. Since the causes of forest fires are very specific [1, 2, 6], it is necessary to develop regionally adapted forecast models. In this regard, it is relevant to conduct joint analysis of the fire rate and climatic changes in Ilmen State Reserve (ISR). The objective of this investigation is to estimate the impact of climate factors on the fire rate in ISR using 66 years worth of direct observation data for the period 1948–2013.

ISR (30 380 ha in area) is located in the Southern Urals (Chelyabinsk Region, Miass) in the southern taiga subzone near a zonal forest–wooded steppe ecotone that is in need of analysis of the dynamics and causes of forest fires [2, 9].

The dynamics of forest fires in ISR for ten-year periods has been reconstructed since 1890. We have the monthly forest fire distribution estimates since 1948. According to both recording methods, the number of fires has increased to the present. Based on the decadal recording for 1890–2013, the relation between the decade number and the fire rate is significant: $r_S = 0.62$ ($P = 0.0235$; $n = 13$; r_S is Spearman's correlation ratio). As follows from the data on the annual fire rate in ISR in 1948–2013, the correlation between the year and the fire rate is significant, but not very close: $r_S = 0.25$ ($P = 0.0434$; $n = 66$; Fig. 1), due to the high interannual variability of the fire rate. The correlation between the year and the moving average fire rate over five years is much closer: $r_S = 0.66$ ($P < 0.0001$; $n = 62$).

The seasonal fire distribution was analyzed in three rough 20-year intervals: 1948–1970, 1971–1990, and 1991–2013. Most fires in all years were characteristic

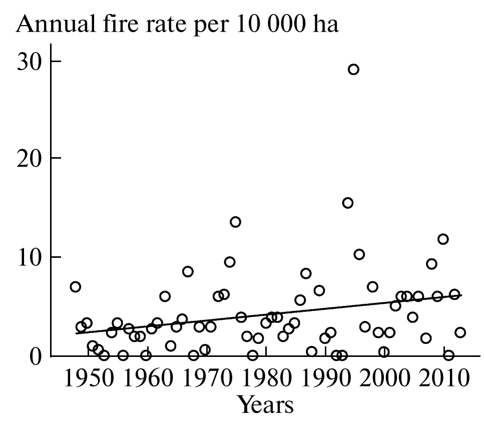

Fig. 1. Increase in the annual forest fire rate in Ilmen Reserve, 1948–2013.

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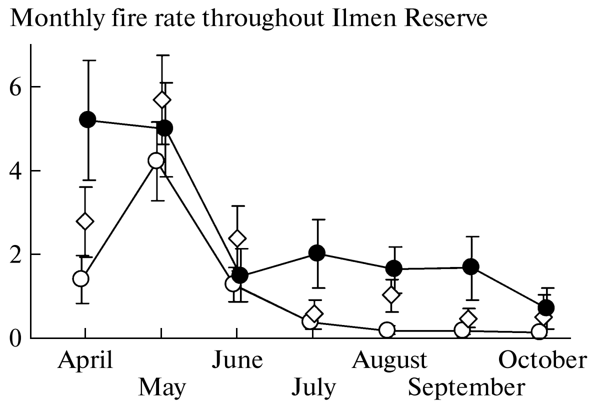

Fig. 2. Average fire rate per month (±SE) in Ilmen Reserve in the years (○) 1948–1970, (◇) 1971–1990, and (●) 1991–2013.

of the period from April to October with the peak in May (Fig. 2). Both regular increase in the number of fires from 1948–1970 to 1991–2013 and interannual variability are important under two-way ANOVA analysis of the moving average estimates of the number of fires for five years from April to October: $F_{\text{interval (2; 413)}} = 42.40$; $F_{\text{month (6; 413)}} = 77.08$; $F_{\text{interval × month (12; 413)}} = 4.71$; in all cases, $P < 0.0001$. As follows from active interaction of the factors, the general growth in the fire rate is due to the increase in their number in the spring and summer–early autumn periods. Thus, the higher fire rate in ISR forests is related to lengthening of the fire hazard period, which is the current trend in many regions [1, 6].

At the first stage of investigation, the average parameters of the calendar year were used to study the relationship between the weather characteristics and the fire rate (table). The correlation between the total annual precipitation and the fire rate is closer than the relationship between the average annual air temperature and the fire rate.

The second stage of investigation involved analysis of the relationship between the fire rate and the average weather characteristics in winter (including November of the previous year), spring, summer, and autumn (without November) (table). The seasonal fire rate is highly dependent on the specific features of the weather only in summer. A multiple linear regression was used to explain the variability in the total annual fire rate based on the average temperature and the sedimentation total per season. The following equation is optimum (standardized form):

Relation of weather conditions in different periods of the year with the fire rate in these periods (*r*) and variations in the average temperature and precipitation total at the Miass meteorological station in 1948–2013 (*B*) ($n = 66$)

Period	r^1		B^2	
	temperature	precipitation amount	temperature, °C/10 years	precipitation amount, mm/10 years
Year[3]	+0.19	–0.33**	+0.26***	+5.64
Winter[4]	–0.11	–0.10	+0.28**	–0.32
Spring	+0.22	–0.15	+0.32**	+6.10*
Summer	+0.33**	–0.44***	+0.18*	+2.71
Autumn[5]	+0.21	–0.24	+0.31**	–3.21
January	+0.07	–0.06	+0.20	+0.61
February	–0.20	–0.10	+0.40	–0.21
March	–0.01	–0.13	+0.61**	+1.02
April	+0.38**	–0.25*	+0.26	+1.48
May	+0.22	–0.19	+0.09	+2.06
June	+0.24	–0.26*	+0.20	–0.63
July	+0.34**	–0.38**	+0.18	+0.34
August	+0.26*	–0.27*	+0.16	+2.04
September	+0.09	–0.20	+0.16	–1.08
October	–0.08	–0.24*	+0.35**	–1.55
November	+0.17	+0.17	+0.42*	–1.56
December	+0.11	–0.07	+0.13	–0.76

[1] Pearson's correlation ratio between weather characteristics in the given period and the fire rate in this period; [2] absolute parameter variation for 10 years, regression coefficient of the straight-line approximation of the relationship between year, temperature, and amount of precipitation; [3] whole calendar year; [4] including November of the previous year; [5] September–October. Significance values of *r* and *B*: (*) $P < 0.05$; (**) $P < 0.01$; and (***) $P < 0.001$.

$$N = -0.157\,T_{\text{winter}} + 0.267\,T_{\text{spring}} - 0.254\,W_{\text{spring}} + 0.248\,T_{\text{summer}}, \quad (1)$$

where N is the annual fire rate; T and W are the average temperature and sedimentation total in the corresponding season; $R^2 = 0.23$. The annual number of fires increases in years characterized by elevated temperatures in spring and autumn, rather than in summer, and decreases in years with high rainfall in spring, rather than in summer. Only 23% of the interannual variability in the fire rate is due to specific features of the seasonal weather.

This conclusion clarifies the analysis data on the correlations between the fire rate in some months and their weather characteristics (table). A significant increase in the number of fires is characteristic of April and July–August at elevated temperatures in these months. Reduction in the number of fires under an increase in the monthly precipitation was noted for April, June–August, and October. Based on the average temperature and precipitation total in some months, the total fire rate variability per annum is described by the following equation:

$$N = 0.179\,T_4 - 0.208\,W_4 + 0.131\,T_5 - 0.151\,W_7 - 0.151\,W_9 + 0.135\,T_{10}, \quad (2)$$

where T_i and W_i are the average temperature and precipitation total of the corresponding month; i is number of the month starting from January; $R^2 = 0.18$. Variability in the annual fire rate is positively related to April–May and October temperatures and negatively to April, July, and September precipitation.

According to the Miass meteorological station data, the years 1948–2013 were marked by a trend toward an increase in the average air temperature by 0.26°C over 10 years (table). It is much higher than the average global warming trend [10, 11], but is lower than the average warming trend in the Russian Federation in the period 1976–2012, and is similar to the warming trend in Western Siberia and the Ural Federal District in the years 1976–2012 [11]. The warming trend in February–March and October–November is the most noticeable in ISR. The summer air temperature changed slightly. The amount of precipitation also increased slightly from 1948 to 2013, mainly in the spring months.

We need to decide on whether the observed climate changes could be the cause of the increase in the ISR fire rate. Two items of Eq. (1) (temperature of spring and autumn months) from 1948 to 2013 varied so that it could contribute to the increase in the forest fire rate. The long-term trend of two other items in the equation could have contributed to the reduction in the fire rate. Hence, the 1948–2013 seasonal weather characteristics varied so that these changes as likely causes of more frequent forest fires acted differently. In addition, we have failed to explain the observed increase in the fire rate using Eq. (2). Out of its six items, the long-term trend is significant only for the average temperature in October (when fires are rare). The weather characteristics in other months included in Eq. (2) remained almost unchanged in 1948–2013.

Hence, the analysis of 66 years of observations over the forest fire rate and climate changes in Ilmen Reserve provided no sufficient evidence for a relation of the observed increase in the number of fires and the current climate changes. This is due to the following facts. Firstly, the average monthly and seasonal weather conditions explain only some causes (18–23%) of the interannual fire rate variability. Secondly, the 1948–2013 seasonal weather characteristics varied so that these changes as likely causes of more frequent forest fires acted differently: the observed changes in different climatic characteristics could have contributed to an increase or decrease in the fire rate. The weather characteristics of April, May, June, and September related to the forest fire rate showed no significant changes from 1948 to 2013. The increase in the forest fire rate is related to high and constantly growing anthropogenic pressure due to intrusion of poachers, miners, and tourists to the reserve or adjacent areas and due to forest burnings. The anthropogenic component is discussed as the main reason for the growing fire rate in well-developed forest areas [1, 2, 9, 11, 12]. This assumption encourages a cautious optimism and is indicative of the fact that it is still possible to ensure a favorable fire situation in the forests by improving the forest protection system in the future despite the climate-caused fire hazard.

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