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Dynamics of paleo-fires in the forest-steppe zone of the Western Siberia

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ABSTRACT. In this work we present the results of reconstruction of the dynamics of paleo-fires over the last 3300 cal. yr BP in the Barabinsk forest-steppe of the Western Siberia based on macrocharcoal analysis and radiocarbon dating of peat deposits of the Nikolaevsky ryam. The authors identified 18 local fire episodes using the CharAnalysis program. At the end of the Subboreal period, 6 local fires occurred, probably caused by dry and cold conditions. In the subAtlantic period of the Holocene, 12 fires were recorded with a peak of pyrogenic activity at 1200-1000 cal. yr BP. This peak of fires is probably associated with the warm and dry conditions of the Medieval Climate Optimum. As a result of the study, it was concluded that the intensity and frequency of paleo-fires in the area of Nikolaevsky ryam were influenced by climatic changes: in dry climatic periods, an increase in fire activity was observed.

Keywords: Western Siberia, paleo-fires, Holocene, macrocharcoal analysis, climate change

1. Introduction

Throughout the Holocene, there was a change in natural and climatic conditions, which led to the restructuring and evolution of ecosystems. Some of these changes can cause fires. But what is the scale and intensity of the fires in the past? How important is the role of climate in the occurrence of paleo-fire activity? To answer these questions, it is necessary to restore the local pyrogenic dynamics of the past. So we study swamp deposits using the method of macrocharcoal analysis (Mooney and Tinner, 2011). Peat sediments of mires are a reliable archive of paleoecological data. They store information in peat layers in the form of plant organics, palynomorphs, as well as macroscopic charcoal particles (size >100 microns) – direct witnesses of paleo-fires. The method of macrocharcoal analysis allows reconstructing the dynamics of paleo-fires on a local scale (1-3 km from the fire source). As an object of research, we chose extra zonal raised bog – "ryam", located in the Barabinsk forest-steppe of the West Siberian Plain. The published paleoecological studies in the Barabinsk forest-steppe zone (Naumov et al., 2009; Zhilich et al., 2017; Stepanova and Volkova, 2017; Koronatova and Mironycheva-Tokareva, 2019) are mainly related to the reconstruction of vegetation dynamics and climate change during the Holocene (Zhilich et al., 2017), the study of the formation of peat deposits (Stepanova and Volkova, 2017), and also with the study of modern climate (Koronatova and Mironycheva-Tokareva, 2019) and vegetation (Naumov et al., 2009). But no studies related to the dynamics of paleo-fires have been carried out thus for. Therefore, the aim of this work is to reconstruct the dynamics of paleo-fire activity in the Holocene on the example of the Nikolaevsky ryam of the Barabinsk forest-steppe.

2. Materials and methods

Nikolaevsky ryam (55˚09 N, 79˚03 E) is located within the Barabinsk forest-steppe (Ubinsky district, Novosibirsk region) in central part of the Ob-Irtysh interfluve of the Western Siberia. Modern vegetation of mire is represented by pine-birch-shrub-sphagnum formations in the center of the ryam, and on the periphery – a hummocky-sedge-reed swamp with an abundant growth of *Betula pubescens.*

The expedition works were carried out in September 2021. Samples of peat deposits of the Nikolaevsky ryam were selected for macrocharcoal analysis (the thickness of the deposits was 320 cm) from a peat section. Since the peat of the mire is dense and waterlogged, a hollow was dug to a depth of 170 cm, from which a peat monoliths were taken for further processing in the laboratory. The heavenly watered lower layers of the profile made further sampling difficult. From a depth of 170 cm to 320 cm, a core of a peat deposit was extracted using a Russian corer

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sampler. According to previously published studies (Stepanova and Volkova, 2017), the thickness of peat deposits of the Nikolaevsky ryam is more than 4 meters. In our case more deep peat was very dense and impossible for coring.

The standard method of sample processing by macrocharcoal analysis was used to reconstruct the local history of paleo-fires (Mooney and Tinner, 2011). Samples were taken with a volume of 2 cm^3 with an interval of 1-2 cm in each collected peat monolith. All 170 samples of peat deposits were washed with distilled water and sifted through a 125 microns sieve. After chemical treatment of samples by $Na_4P_2O_7$ and H_2O_2 (Mooney and Tinner, 2011), charcoal particles in each sample were counted in the Bogorov chamber under a binocular microscope at 45x magnification.

In the radiocarbon laboratory of IMCES SB RAS (Tomsk, Russia), 5 radiocarbon UMS dates were obtained (Table). Based on radiocarbon dates calibrated in the Bacon program (Blaauw and Christen, 2011) in R 4.0.4 (R Core Team, 2020) in system "from the present time" (for zero the reference point was adopted in 1950 yr.), a depth-age model of peat deposits of the Nikolaevsky ryam was constructed and the calendar age of each sample was calculated. All further paleo-reconstructions for this peat section are based on the calibrated (calendar) age.

Statistical processing of the obtained numerical data on the number of charcoal macroparticles in the peat deposits of the Nikolaevsky ryam was carried out using the CharAnalysis software package (Higuera, 2009) adapted for the R program. This program made it possible to calculate the rate of accumulation of charcoal particles (CHAR-index), to determine background and threshold values for separating local fires (within a radius of 1-3 km from the source of ignition) from regional fires (at a distance of up to 20 km), as well as to identify local fire episodes. The data of the depth-age model of the deposits of the Nikolaevsky ryam were used as a chronological basis.

3. Results and discussion

The age of peat deposits of the Nikolaevsky ryam was 3300 cal. yr BP according to radiocarbon dating. The study thickness of peat started to form at the end of the Subboreal period in a cold and dry climate (Arkhipov and Volkova, 1994). At this time, 6 local fire episodes were identified (from 3200 to 2500 cal. yr BP) using the CharAnalysis program. The peak of pyrogenic activity occurred at 2900-2800 cal. yr BP with a charcoal accumulation rate of ~400 particles per cm^2/year. These data indicate large local fires in the swamp, probably caused by increased aridity of the climate during this period.

In the Subatlantic period of the Holocene, 12 local fire episodes were identified. In the first half of the Subatlantic period (2600-1800 cal. yr BP), 3 local fires occurred with a peak pyrogenic activity at 2500 cal. yr BP and a charcoal accumulation rate of ~ 200 particles per cm^2/year. Dry and warm conditions of this period (Arkhipov and Volkova, 1994) could affect the occurrence of fires. In the second half of the Subatlantic period (1800-1000 cal. yr BP) 5 local fire episodes happened. At the same time, maximal peak of fire activity occurred at 1200-1000 cal. yr BP with the highest accumulation rate of charcoal ~600 particles per cm^2/year reflecting, possibly, spreading of fire on the surface of mire. These data indicate large local fires at this time. The revealed peak of fire activity coincides with a sharp increase in temperature and a decrease in precipitation of the Medieval Climate Optimum, which probably influenced the increase in fires in the swamp area. In the Late Holocene (1000 cal. yr BP – to the present day), 4 local fire episodes happened. But the activity of paleo-fires is quite low compared to previous periods, and the rate of accumulation of macrocharcoal particles reaches ~150 particles per cm^2/year. Probably, the dry climate at the beginning of the Little Ice Age influenced the occurrence of 3 small local fires (600-400 cal. yr BP). The subsequent warming of the climate led to another fire episode ~ 100 cal. yr BP. Fires that occurred in the late Subatlantic period could also occur as a result of anthropogenic influence, since there are localities.

Table. Radiocarbon dates from Nikolaevsky ryam.

Laboratory Code	Sample Depth (cm)	Radiocarbon Date (^{14}C yr BP)
IMCES-14C2271	48-50	450 ± 100
IMCES-14C2267	100-102	1150 ± 110
IMCES-14C2266	118-120	1600 ± 105
IMCES-14C2270	150-152	1745 ± 120
IMCES-14C2269	168-170	1805 ± 150

Conclusions

The results obtained indicate a direct influence of climate change on the intensity and scale of fire activity. New paleoecological data showed that fires in this area occurred repeatedly and of varying intensity during 3300 cal. yr BP. The main course of their occurrence was probably dry climatic conditions.

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Conflict of interest

The authors declare no conflict of interest.

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