Holocene vegetation and climate changes in the North-Eastern Caucasus (pollen data from mountains and plain peatlands)

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Abstract. Dagestan (North-Eastern part of the Caucasus) is characterized by a unique historical and environment development, however, there is little, if no, data on nature changes throughout the Holocene history of the region. In contrast to the much-studied neighboring Caucasus regions, Dagestan remains mostly unexplored from the standpoint of paleoecology. In 2017, we investigated a detailed radiocarbon-dated 185 cm peat sequence from the Shotota swamp located in the mountainous zone of Dagestan. Peat and soil deposits span most of the Holocene (about 9000 years), and they let us study vegetation history of the Eastern Caucasus for the first time. The results of the study show significant discrepancies in the timing and sequence of the expansion of tree species in the Holocene in comparison with Transcaucasia and the Western Caucasus. The second key study, an examination of a 270 cm peat sequence from Arkida swamp, formed in the second half of the Holocene, also provided new paleoenvironmental data on the south of the Caspian lowland. The vegetation of the flat parts of Dagestan, adjacent to the mountainous zone, has been dry and treeless for the last four thousand years, however, humidification fluctuations and vegetation changes were distinguished.

1. Introduction

Until recently, it was not possible to analyze the Holocene environmental changes of the North-Eastern Caucasus, since there was no paleoecological information from peat or lake archives in the mountainous and lowland parts of Dagestan. Gaps in our knowledge about the response of vegetation to climate changes in this part of the Caucasus are particularly noticeable when contrasted with the rather well explored neighboring regions: Transcaucasia and the Western and Central Caucasus [1-6]. Lack of essential data does not allow us to consider the range of issues related, for example, to the phases of tree species spread or the land use development in antiquity. Furthermore, such information would enable us to include the Eastern Caucasus area in a land-cover modeling program or cultural landscapes reconstructions over the Holocene.

One plausible reason for why reliable palynological reconstructions for the mountainous zone of the Eastern Caucasus are lacking in this region is an extremely small number of bogs; they do not even appear on Dagestan vegetation maps [7]. There are also no known lakes that can provide a promising
high-resolution recording of vegetation history and climate for a long period. To rectify this problem, we carried out field reconnaissance in various parts of the mountainous and plain areas of Dagestan from 2016 to 2018 [8; 9], identifying several promising swamps. The sediment analysis of two of these swamps is currently completed, and the pollen composition of the region's wetlands was investigated for the first time.

2. Key studies
We obtained the first data on the vegetation history and climate, both for the mountainous and lowland areas of Dagestan, after completing the stratigraphic, botanical and palynological analyses of sediments of two peatlands: Shotota and Arkida (figure 1) [10].

The Shotota swamp (42°59′N, 46°59′ E, 1860 m a.s.l.) is located in the mountainous zone of Dagestan on the Khunzakh plateau. This swamp is situated where a slope of the Arzhut Range transitions to the flat parts of the plateau and occupies its lower part between 1830 and 1870 m a.s.l.; it is the largest swamp massif in the Eastern Caucasus. However, the flora of this mountain zone is relatively poor, and it can be best characterized as a meadow-highland-xerophytic [11], with a large number of endemic species.

The Khunzakh plateau, containing the Shotota swamp, is almost treeless, with pine woodlands found only on the northern slopes. The main background vegetation consists of a motley combination of various subalpine meadow associations with grass steppes on the southern slopes. As can be seen on the vegetation map of Dagestan [12], the main forest areas are located in the foothills in the east of Dagestan at altitudes from 500 to 800–1000 m. These areas combine dry oak forests and moist deciduous forests.

Figure 1. Location of the study area and investigated swamps in Dagestan (a); a peat profile of the Shotota swamp and a sediment core of the Arkida swamp (b); landscapes around the Shotota (c) and the Arkida swamps (d).

The Arkida swamp (43°14′ N, 47°01′ E) is located in the south of the Caspian lowland, in the area where the mountain stream of the Sulak River passes to the plain area, and the groundwater influence in depressions creates conditions for the wetlands formation. Mostly open landscapes are widespread
in this area, with wormwood steppes, halophyte vegetation, and flat grassy swamps. Conditions for forests, usually dry oak woodlands with shrubs, are present only in the river valley.

The climatic conditions of the plains and mountains of Dagestan vary greatly. For the coastal lowland, warm winters are typical, and the summers are hot, with the average annual precipitation not exceeding 350–400 mm/year. Snow stays on the ground from 10 days to 1 month. The vegetation cover is a wormwood-grass steppe. For mountainous Dagestan in the area of the Khunzakh plateau, the average annual precipitation is 577 mm, the average annual temperature is 6.1°C, the average July temperature is 16.1°C, and the average temperature in January is −4.4 °C [12]. Notably, in the five cold months (November–March) only 55mm of precipitation falls, so a stable snow cover does not form in this area. Most precipitation comes as strong summer rainfalls.

3. Methods
Peat sequences and underlying sediments were taken without disturbing the peat structure. The radiocarbon dating (17 samples from the Shotota and 10 samples from the Arkida swamp) was conducted using liquid scintillation counters (LCS). An age-depth model was built in R [13] using the Bchron package [14]. The accumulation rate was calculated based on the results of the mean ages at every cm of the sediment. Loss on ignition (LOI) was carried out to estimate the ratio of the organic and mineral content of the sediment. The composition of peat-forming plants was studied in samples after washing the sampled peat over a 250 μm sieve, evaluation of the quantitative ratio of fossil plant remains was conducted using the point method. Altogether, 65 samples of the Shotota and 40 samples of the Arkida swamp were studied by the palynological method.

4. Results
The longest paleoecological record for the main part of the Holocene was obtained in the Shotota swamp in the inner mid-mountain zone of Dagestan. Soil deposits under the peat were formed in the boreal period of about 9000 cal yr BP; bogging of the site started ca. 7200 cal yr BP. The age of the Arkida swamp, located in the south of the Caspian lowland, does not exceed 4500 cal yr BP; beginning of bogging here is not directly related to climate but rather, it is connected with complete filling with alluvium the early Holocene fluvial downcutting of the Sulak River, which led to rising groundwater and the waterlogging in the relief depressions of the Khvalyn sea terraces.

During the Holocene, there were only sparse forests in the mid-mountain zone; open meadows or steppe landscapes predominated. The mid-mountain zone of Dagestan experienced a consistent change of dry steppes at the beginning of the Holocene (9200–7300 cal yr BP), an increase in moisture with the appearance of deciduous woodland at about 7300-6000 cal yr BP; a sharp dry interval at about 6000 cal yr BP, followed by cooling; several fluctuations in humidification against the background of the active resettlement of pine woodlands during the last 5000 years [10].

According to the pollen data, we found that the first appearance of deciduous forests and, later, the expansion of coniferous forests in Dagestan occurred with a significant delay, compared to other regions of the Caucasus. In Dagestan, elm-hornbeam forests with an admixture of lime, oak and maple appeared ca. 7300 cal yr BP and separately from conifers; the delay was about 2000 years in contrast to the nearest sequences of Transcaucasia [4]. An important feature is the absence of beech; its pollen appeared in a small amount later, not earlier than 2400 cal yr BP, while in Transcaucasia it was well represented already as early as 9000 years ago [4] and in the central part of the Northern Caucasus [15] probably from the Boreal period of the Holocene. The spread of coniferous forests was delayed by 4-3 millennia due to the absence of refugia in this part of the Caucasus. It is likely that the northeastern part of the Caucasus repeatedly fell under the more pronounced influence of the winter Siberian High and lacked moisture. This prevented slopes afforestation, and for that reason, the landscapes of the mid-mountain zone were formed by meadows and steppes with rare forests – broad-leaved composition in warmer and wetter periods, and with a dominance of birch and pine during a cooling in the second half of the Holocene. The vegetation history in the region is not consistent with
either Transcaucasia or the western and central parts of the North Caucasus and represents the unique development of ecosystems in the mountainous zone of Dagestan.

The pollen data obtained for the flat area adjacent to the Dagestan mountainous zone from the north-east showed the dominance of dry steppe during the second half of the Holocene [in press]. The dynamics of the pollen ratio between wormwood and pigweeds (Artemisia/Chenopodiaceae), episodes of the tree pollen appearance, fluctuations in the peat accumulation rate and pollen concentration, allowed us to identify periods of increased moisture at about 3400-3000 cal yr BP and after 1200 cal yr BP. They are accompanied by the appearance of a local, apparently riverine forest with oak, pine, birch, hornbeam, and even beech. An opposite trend towards climate aridization and the spread of semi-desert vegetation with only tamarix trees has been established for the intervals of 4200-3400 cal yr BP and 3000-1200 cal yr BP. The most pronounced dry period circa 2000-1500 cal yr BP led to a critical slowdown in the peat accumulation, desertification, and disappearance of riverine light forests.

Some trends in climate changes reconstructed for the Arkida swamp correspond to those of the Lower Volga area, identified by the pollen data from the delta sediments [16; 17]. For the southern part of the Caspian lowland, the Arkida peat record is the first natural archive with sequentially accumulated organogenic deposits. Unlike the Volga delta, the peat deposits of the Arkida are not complicated by the influence of a large river and therefore constitute a much more representative record of the paleoecological events of the Holocene.

5. Conclusion
In general, the research of the Shotota and the Arkida peatlands, as well as reconnaissance drilling in other swamps of Dagestan [8; 10] showed a perspective of the further search for new peat archives for a more detailed reconstruction of landscape and climate changes in this part of the Caucasus.

6. Acknowledgments
The studies were carried out with the financial support of the Russian Science Foundation (project 17-18-01406) and the Russian Foundation for Basic Research (project 19-29-05205 MK)

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