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# High resolution palaeoecological records for climatic and environmental changes during the last 1350 years from Manzherok Lake, western foothills of the Altai Mountains, Russia

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## ABSTRACT

Compilation of spore-pollen, diatom and biochemical analyses of samples from the top 80-cm sediments of Manzherok Lake, located on the western foothills of the Altai Mountains (51°49'15.5"N, 85°48'35.7"E, 400 m a.s.l.), revealed influence of regional climate changes during the past 1350 years on the hydrological budget of the lake and the dynamics of the surrounding vegetation. Based on indicator species of diatom complexes in the lake sediments, the reconstructed lake level and pH can be deciphered as (1) shallow pond with relatively high pH prior to the Medieval Warm Period (MWP), (2) dramatic flooding with freshwater in the MWP, (3) lowering of the lake level during the Little Ice Age (LIA), and (4) contemporary rise of the lake level after the LIA. Increased concentrations of the detrital elements and severe degradation of diatom assemblages in the lake sediments took place during the dramatic flooding stage. The reconstructed lake level based on the diatom assemblages is in good agreement with the palynological data which indicate changes from birch forest-steppe to pine and cedar forests in the beginning of MWP, and then to birch-pine anthropogenically transformed forest-steppe in the LIA. Sharp maxima of non pollen palynomorphs *Anabaena* and *Bryales/Algae* at the 43–46 cm depth (~900 a BP) possibly mark ecological crises in lake's biotope. Cold and dry conditions during the LIA were clearly expressed in pollen diagram of Manzherok Lake by decline of maxima of Siberian pine pollen and increase of *Artemisia* pollen. This study provides evidence to support a dry episode in the 9th century, wet climatic conditions in the MWP and a dry LIA in the Russian Altai Mountains in contrast to the opposite pattern revealed for arid regions of Central Asia and NW China during the same periods (Chen et al., 2010; Eichler et al., 2011; Chen et al., 2015). Our study indicates that, as a small and shallow lake located in the forest-steppe western foothills of the Altai Mountains, Manzherok Lake is more sensitive to high-resolution (less than centennial scale) climatic and environmental variations, in comparison with the large and deep Teletskoye Lake located in the mountain taiga zone of the northern Altai.

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## 1. Introduction

Study of climatic dynamics and its impact on the natural ecological system in recent years is particularly relevant in

connection with the ongoing scientific debate about the role of the human factor in global warming both in overpopulated and in pristine areas. In this regard, particular attention is paid to paleoecological studies of the last two thousand years, the environmental conditions of which can often be recorded in the upper layers of lake sediments (Mason et al., 1994). Lake sediment records provide opportunities for an integrated approach to paleoenvironmental reconstructions, including palynological studies that reveal landscape characteristics at the regional level (e.g., Andreev

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et al., 2007; Blyakharchuk et al., 2004, 2007, 2008; Chernova et al., 1991; Rudaya et al., 2009, 2016; Schlütz and Lehmkuhl, 2007; Sun et al., 2013) and diatom and geochemical studies that characterize the local lake conditions (e.g., Mitrofanova, 2009; Mitrofanova and Sutchenkova, 2014; Westover et al., 2006) and changes in terrestrial environments (e.g., Babich et al., 2015; Kalugin et al., 2007; Rudaya and Li, 2013; Shelekhova et al., 2013).

Despite the growth in the abundance of paleoclimatic data, there is still a lack of reliable data for some inland areas, such as Siberia. Poorly investigated in this context are regions of the Altai-Sayan mountain area. As a huge mountain range in northern Central Asia, the Altai Mountains contain valuable information of paleovegetation types and paleoenvironmental variations under climatic influence. Ecologically, this region connects the semi-arid and arid steppe zone in Central Asia and the relatively humid forest-steppe zone and humid mountain taiga in North Asia (Shumilova, 1962). At the present, the moisture budget in this region strongly depends on the westerly circulation (Liubimtseva et al., 2005). Above the ridges of the Altai-Sayan mountain region, the air flows of the Atlantic cyclones meet with the Siberian High, Arctic cyclones and most north-western spurs of South-Eastern monsoon, providing the most precipitation.

Due to their large topographic relief from a few hundred meters in elevation to ~4500 m a.s.l., the Altai Mountains comprise different climatic and vegetation zones. Although several lakes in the region have been studied, including: Teletskoye (Andreev et al., 2007; Kalugin et al., 2007; Rudaya et al., 2016), Achit Nuur (Sun et al., 2013), Lake Uzun-Kol (Blyakharchuk et al., 2004), Lake Ak-Kol (Blyakharchuk et al., 2007), Lake Dzhangyskol (Blyakharchuk et al., 2008), and Hoton-Nur Lake (Rudaya et al., 2009), our knowledge of the regional climatic conditions during the past 2000 years are still limited. Chen et al. (2015) summarized the moisture conditions during the Medieval Warm Period (MWP) and the Little Ice Age (LIA). Only two records in the Altai region are available: Teletskoye and Achit Nuur lakes. Rudaya et al. (2016) compiled all Holocene pollen records published in recent decades of the Altai region and found that few records were able to decipher climatic conditions of the past 2000 years. Detailed examination of the only two published records: Achit Nuur (Sun et al., 2013) and Teletskoye Lake (Rudaya et al., 2016), shows that the resolution and chronology of pollen records of both lakes are inadequate to provide detailed climate variability during the past millennium. Sun et al. (2013) described the climatic condition of ~1600–~0 a BP (upper 62-cm record in the core) as a whole because of low sampling resolution (2–4 cm) and three  $^{14}\text{C}$  dates with a ~2000-year reservoir age. For the Teletskoye Lake record, the pollen composition and biomization mainly reflected temperature changes (Rudaya et al., 2016). Besides, Teletskoye Lake is a large and deep lake that may not be sensitive to annual-to-decadal climatic changes due to its relatively low sedimentation rate (0.45 mm/yr) and long residence time. Hence, high-resolution paleoclimate records with accurate chronology in the Altai region especially on the western foothills of Altai Mountains are needed. Such records may be retrieved from small lakes in the area.

Here, we report a high resolution (1-cm sampling interval), AMS  $^{14}\text{C}$  dated sediment record from Manzherok Lake located on the western foothills of the Altai Mountains. This 80-cm long core covers continuous deposition in the lake during the last 1350 years. Combining spore-pollen, diatom and biochemical analyses, we attempt to decipher changes in the lake level and local vegetation. The information to be obtained is essential for understanding the dynamics of vegetation and climate in this central area of Eurasia. The detailed palynological data may also allow us to evaluate human impact on the vegetation and agricultural history in this region.

## 2. Regional setting of the study area

An 80-cm long sediment core was collected in the summer of 2010 from the central part of Manzherok Lake (51°49'15.5"N, 85°48'35.7"E), which is located 18 km southwest of the city of Gorno-Altai in the Maiminsky district of the Altai Republic (Fig. 1). The lake is 1112 m in length and 400 m in maximum width, with an area of 0.4 km<sup>2</sup> (Seledtsov, 1963). Water depth at the coring site was 3 m. Manzherok Lake has an altitude of 423 m above sea level and is located on the high right bank of the ancient terraces (2.5 km from its modern channel) of Katun' River (Fig. 1). Geologically, Manzherok Lake lies within the tectonic unit of Bijsk-Katun' anticlinorium (projection) – surfacing more ancient geological structures of the Altai Early Caledonian fold system. Consequently, in the area of Manzherok Lake a positive element of relief is presented by ancient carbonate rocks of the **Baratalsk** series (R3 -V), formed in the Proterozoic marine environment (Geology of the USSR, 1997). The Manzherok Lake area, referring to the low mountains district with mountain chernozems (black earth) soils and mountain steppe and forest-steppe vegetation, is a right hand-bend of the valley of Katun' River (Fig. 1). It was formed by deposits of high and low terraces above the floodplain of the river. The mountain valley of Katun' River near the lake is expanded to 3 km and forms a sharp bend to the east. Although the lake level exceeds 88 m above the Katun' River level, Manzherok Lake is considered as a remnant on a high floodplain terrace along the ancient channel of the Katun' River (Tsimbaley, 2008).

Located in the western periphery of the mountains of Southern Siberia, the climate of this area is moist and has relatively mild temperature even though it is classified as the West Siberian continental type (Ogureeva, 1980). The precipitation is 500–700 mm/year. The average temperatures are +18 °C in July and –15 °C in January, with annual mean temperatures ranging from –4 to +2 °C.

According to geobotanical categories, the study area is located in the subtaiga forest-steppe altitude-belt complex of pine and birch forests (Smagin et al., 1980) or in the north Altai taiga-forest-steppe subprovince (Kuminova, 1969; Ogureeva, 1980). The combination of plant species creates a forest-steppe landscape of foothill, in which steppes exist only on the southern slopes. Northern slopes are covered by forests. Large areas are occupied by arable land. Forest-steppe fringed with wide strips on the western and north-western foothills in the Altai Mountains forms the forest-steppe zone within an absolute altitude range of 500–700 m above sea level. The lower boundary of this altitudinal zone is limited by the annual amount of precipitation of 600–800 mm. The combination of meadow steppes, stepped meadows with birch, and aspen groves on the northern slopes is the characteristics of the West Siberian forest-steppe. Pine herb-moss and shrub-sedge forests are spread on gray fresh and moist loamy soils, and pine fern-tall herb forests grow on dark gray forested soils. Local vegetation around Manzherok Lake is zoned as the following. The slopes of the mountains, to the east and north-east of the lake, are covered by birch (*Betula pendula* Roth.) and aspen (*Populus tremula* L.) forests with admixture of pine (*Pinus sylvestris* L.). On the tops of the mountains towering over the lake at 800–1000 m, among the trees mentioned above, grow fir (*Abies sibirica* Ledeb.), Siberian cedar (*Pinus sibirica* Du Tour) and larch (*Larix sibirica* Ledeb.). A narrow strip of the east coast of the lake is covered by lacustrine sediments that form a swampy land overgrown with shrubs and forest. The western side of the lake is represented by a flat surface sloping gently downward toward the lake, where it is plowed into a field with the width of up to 600 m. In this field, clearings of a pine forest with planting of birch and meadow took place during the first half of the 20th century. The forest was gradually cut down, and the area was plowed after 1945 CE. Around the plowed field, all terrace areas of

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