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Landscapes of the 'Yuka' mammoth habitat: A palaeobotanical approach

Natalia Rudaya [a,d,*], Albert Protopopov [b], Svetlana Trofimova [c], Valery Plotnikov [b], Snezhana Zhilich [a]

[a] *Centre of Cenozoic Geochronology, Institute of Archaeology & Ethnography, Novosibirsk 630090, Russia*
[b] *Division for Study of the Mammoth Fauna, Sakha Academy of Sciences (Yakutia), Yakutsk 677007, Russia*
[c] *Laboratory of Palaeoecology, Institute of Plant and Animal Ecology, Yekaterinburg 620144, Russia*
[d] *Novosibirsk State University, Novosibirsk 630090, Russia*

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ABSTRACT

In August 2010, a well-preserved *Mammuthus primigenius* carcass was found along the coast of Oyogos Yar in the region of the Laptev Sea and the mummy was nicknamed 'Yuka'. Frozen sediment samples from the area of skull condyles were collected for pollen and plant macrofossil analyses. The results from the palaeobotanical investigation confirmed that the Yuka mammoth lived during the optimum of the Kargin Interstadial (MIS3). The burial place of the mammoth could have been a small shallow freshwater pond with either stagnant or slowly moving water. The vegetation of the Oyogos Yar in MIS3 optimum was probably represented by zonal tundra-steppe combined with mesic-xeric meadows.

1. Introduction

In August 2010, a well-preserved woolly mammoth (*Mammuthus primigenius* Blumenbach, 1799) carcass was found along the Oyogos Yar coast near the Kondratievo River (72°40′49.44″ N, 142°50′38.35″ E; Fig. 1) in the region of the Laptev Sea.

The juvenile female mummy was nicknamed 'Yuka' after the name of the village of Yukagir, whose local people discovered it. The mammoth was found about 4 m above the beach level; the height of the shore did not exceed 5 m. Unfortunately, the first scientists P. Lazarev and S. Grigoriev from the Mammoth Museum (Sakha Academy of Sciences, Yakutsk) only reached the studied site 2 years later, when more than 100 m of the bluff had been washed away; therefore, a taphonomical description was not performed in detail. After its discovery, Yuka spent 2 years in the Yukagir's natural refrigerator ('lednik'). The mammoth carcass was found hanging over a melting ledge in the upper third of a north-facing slope composed of loess sediments from the rich Late Pleistocene fossil-bearing Yedoma (Maschenko et al., 2012; Fig. 2). The Siberian Yedoma consists of ice-rich silts and silty sand penetrated by large ice wedges, resulting from sedimentation and syngenetic freezing, and driven by certain climatic and environmental conditions during the late Pleistocene and is widespread in West Beringia (Schirrmeister et al., 2013 and references therein). The carcass was transported to the Sakha Academy of Sciences in Yakutsk (Fig. 3).

By analysing the teeth and tusks, Yuka was determined to be approximately 6–8 years old when it died (Maschenko et al., 2012). The mammoth had most likely been attacked by lions or other predators. However, there were no indications that the predators had killed the mammoth. A 40-cm incision was found in the lumbar region and appears to have been made by a sharp implement. Most of the internal organs were missing. The skull, pelvis, ribs and several other bones had also been removed and were placed alongside the carcass. Such injuries might be evidence of the activities of ancient humans. Evidence of the butchery of a mastodon (*Mammut americanum*) by Paleo-Indians was described in Fisher (1984) and Fisher et al. (1991). Moreover, Fisher et al. (1991) suggested that the carcass of the Burning Tree mastodon discovered in a small pond in Licking County, Ohio, might have been buried in a shallow lake by humans to keep the meat at a low temperature. However, the appearance of the first people in East Beringia is estimated at 27–28 kyr BP (Pitulko et al., 2004).

The woolly mammoth inhabited the huge area covering the most part of Eurasia and northern part of North America in the Late Pleistocene. The distribution of the Mammoth faunal complex was associated with the spread of a unique Pleistocene biome called the Mammoth Steppe (e.g., Guthrie, 2001) or tundra-steppe (e.g., Tugarinov, 1929; Hibbert, 1982; Yurtzev, 1981, 2001), which rapidly degraded at the Pleistocene/Holocene boundary (Sher et al.,2005). There are several hypotheses for

* Corresponding author. Tel.: +7 383 316 54 11; fax: +7 383 330 11 91.
E-mail addresses: nrudaya@gmail.com (N. Rudaya), a.protopopov@mail.ru (A. Protopopov), Svetlana.Trofimova@ipae.uran.ru (S. Trofimova), mammuthus@mail.ru (V. Plotnikov), snezhy@yandex.ru (S. Zhilich).

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Fig. 1. Map of the region studied with the location of the Yuka mammoth's burial place.

tundra-steppe extinction (see review in Zimov et al., 2012); however, the interactions between grazing animals, climate and vegetation are still unclear.

In recent years, because of the high interest of scientists in multiproxy researches of large Pleistocene mammals, local people have reported several frozen mammoth carcasses discovered in Arctic Siberia. Based on the investigations of Siberian mammoth intestines by paleobotanical, chemical and genetic methods, excellent complex studies have been published (Aptroot and van Geel, 2006; van Geel et al., 2008, 2011; Kosintsev et al., 2012a,b). The relationships between mammoths and the early humans of the Eastern Siberian Arctic have also been the focus of study in recent years (Pitulko et al., 2004; Nikolskiy et al., 2011; Nikolskiy and Pitulko, 2013). Nikolskiy and Pitulko (2013) have shown that Upper Paleolithic humans hunted mammoths sporadically to obtain mammoth ivory and consume mammoth meat. It is notable that humans hunted animals of a certain size that were adolescents, with tusks about 100–120 cm and also young adult female mammoths (Nikolskiy and Pitulko, 2013).

A fragment of Yuka's rib was AMS-dated to 34,300 + 260/− 240 ^{14}C (GrA-53289), which corresponds to the termination of the Marine Isotope Stage 3 (also called the Middle Weichselian, Kargin or Molotkov Interstadial). The interval of 44–32 kyr BP is noted for the largest proportion of radiocarbon-dated mammal bones collected from the Laptev Sea region (Kuznetsova et al., 2004; Sher et al., 2005).

Here, we describe the results of the paleobotanical analyses of the sediment samples from the area of the mammoth skull condyles, with the aim of reconstructing the living environment of the Yuka corresponding to the termination of the MIS3 climatic optimum, one of the most controversial periods of the Late Pleistocene in the Eastern Siberian Arctic.

2. Regional setting

The Oyogos Yar belongs to the coastline of the Laptev Sea in the Arctic Yakutia (NE Siberia). It is more than 100 km long and thus is the most extended Quaternary outcrop in North Yakutia, located between Cape Svyatoy Nos in the west and Kondratievo River mouth in the east (Velichko, 1973). The eastern part of the Siberian Arctic has been free of inland glaciations since at least the Late Saalian (ca 160–140 kyr BP; Svendsen et al., 2004). The ^{230}Th/U dating of frozen peat in the permafrost deposit at the southern cliff of Bol'shoy Lyakhovsky Island located 70 km to the north of the studied site has shown that permafrost has been preserved there for at least

Fig. 2. The location of the discovery of the Yuka mammoth carcass along the Oyogos Yar coast (photo by Vasily Gorokhov).

200 kyr, suggesting an absence of ice sheets over this entire period (Schirrmeister et al., 2002a). Prior to the early Holocene, during the Late Pleistocene regression, the Eastern Siberian Arctic marginal plain extended 400–700 km north to about 78°N and incorporated all the northern present-day islands (Sher et al., 2005).

The radiocarbon date from the fragment of Yuka's rib relates to the end of MIS3 Interstadial that lasted for about 50–25 kyr BP in NE Siberia (Andreev et al., 2002; Schirrmeister et al., 2002b; Kienast et al., 2005; Sher et al., 2005; Schirrmeister et al., 2008; Wetterich et al., 2008; Zanina et al., 2011; Wetterich et al., 2014). The onset, duration, and termination of the MIS3 Interstadial optimum based on paleoproxies vary in the Eastern Siberian Arctic in different records (see review in Wetterich et al., 2014); however, its limits can be identified as 44–32 kyr BP.

Pollen records related to the early part of MIS 3 (50–40 kyr BP) are characterised by the dominance of Cyperaceae and Poaceae pollen, with some *Artemisia* and *Salix*, reflecting the tundra-steppe environment (Andreev et al., 2011). Higher pollen concentrations and a high abundance of Cyperaceae, Poaceae, *Artemisia*, Caryophyllaceae and Ranunculaceae, as well as the permanent presence of *Salix* pollen characterise the MIS3 optimum (Andreev et al., 2011; Wetterich et al., 2014). It appears that vegetation became mosaic; open grass-sedge associations combined with willow shrubs spread into more protected and wet places. Warmer summer air temperatures and moister climatic conditions that suggest the existence of small ponds during the MIS3 optimum are also confirmed by plant macrofossil records (Kienast et al., 2005), and the finding of green algae remains (Andreev et al., 2011; Wetterich et al., 2014) and a high diversity and abundance of testate amoebae and ostracods (Bobrov et al., 2004; Wetterich et al., 2005).

The modern climate of the Oyogos Yar coast is characterised by mean temperatures during the warmest month of approximately 4 °C, whereas the mean temperature during the coldest month is approximately −30 °C (Rivas-Martinez, 1996–2009). The Oyogos Yar belongs to the southern arctic tundra province of Eastern Siberia, which is dominated by *Alopecurus alpinus*, *Salix polaris* and *Carex bigelowii* ssp. *arctisibirica* (Aleksandrova, 1980). The vegetation is also represented by *Salix pulchra*, *S. reptans*, *S. sphenophylla*, *Vaccinium vitis-idaea*, *Arctous alpine*, *Diapensia obovata*, *Ledum decumbens*, *Dryas punctata*, *Cassiope tetragona* and *Eriophorum vaginatum* (Egorova et al., 1991) and by the mosses *Aulacomnium turgidum*, *Dicranum elongatum*, *Tomethypnum nitens* and *Hylomium splendens* (Andreev et al., 1987). The boreal or subarctic shrubs (*Alnaster fruticosa* or *Betula nana*) that are found to the south are completely absent from the study site today (Kienast et al., 2011).

3. Materials and methods

Two frozen sediment samples from the area of the skull condyles were collected for pollen and plant macrofossil analyses. This was the only place to obtain the samples since the Yukagirs washed all the mammoth remains, including the gut, with water from a pump.

The intestinal contents were absent, and therefore, a sample for the analysis of microfossils and macroremains was collected from the skull. The sample was thawed, dried, and sieved through a 250-μm mesh to remove coarse organic matter, which was later used for plant macrofossil analysis. The sample was sequentially treated with 10% HCl and 10% KOH and washed with distilled water. A 7-μm mesh sieve was used to remove the fine-grained fraction. Pollen residues were mounted in glycerine and analysed using a Zeiss AxioImager D2 light microscope with 400× magnification. The identification of pollen and spores was performed using a reference pollen collection and pollen atlases (Kuprianova and Alyoshina, 1972; Beug, 2004). Non-pollen palynomorphs (NPPs) were identified using descriptions, pictures and photographs published by van Geel (2001). A total of 329 pollen grains and spores, which were taken as 100% for determining percentages of pollen taxa, were counted in the sample. The total number of palynomorphs, including the NPPs, was 481. The total number of NPPs was taken as 100% when calculating the percentages of individual NPPs.

Fig. 3. The Yuka Mammoth in the environs of Yakutsk, Russia (photo by Valery Plotnikov).

The plant macrofossil sample was washed through a 250-μm mesh sieve and then air-dried. A total of 40 mL dry matter was examined and subjected to analysis using a Carl Zeiss Stemi 2000-C stereomicroscope. Twigs, leaf remains, fruits, seeds, mosses and a variety of unidentified vegetative remains were identified from the sample, following Nikitin (1969).

4. Results

4.1. Pollen data

In total, 25 taxa of pollen and spores were identified in the sample. Herbaceous taxa (92%) dominated the pollen spectrum with 6% of the pollen originating from trees (Fig. 4). Among herbs, *Artemisia* pollen dominated (46%), together with indeterminable forb pollen (12.5%), and pollen from the Ranunculaceae, Poaceae, Caryophyllaceae, Asteraceae, and Brassicaceae. Indeterminable herbaceous pollen related to very small (about 6–7 μm) and probably not mature tricolpate forms. Arboreal pollen was represented primarily by *Salix* and *Betula* sect. *Nanae* and 2% of spores came from ferns and lycopods. The highest percentage of the NPPs was determined to be the remains of the green alga *Botryococcus* (up to 90%).

4.2. Plant macrofossils

The sample contained a mixture from the vegetative parts of the plants and the mineral fraction in a ratio of ca. 60:40 (before sieving). The vegetative parts of plants included small parts of herbaceous stalks

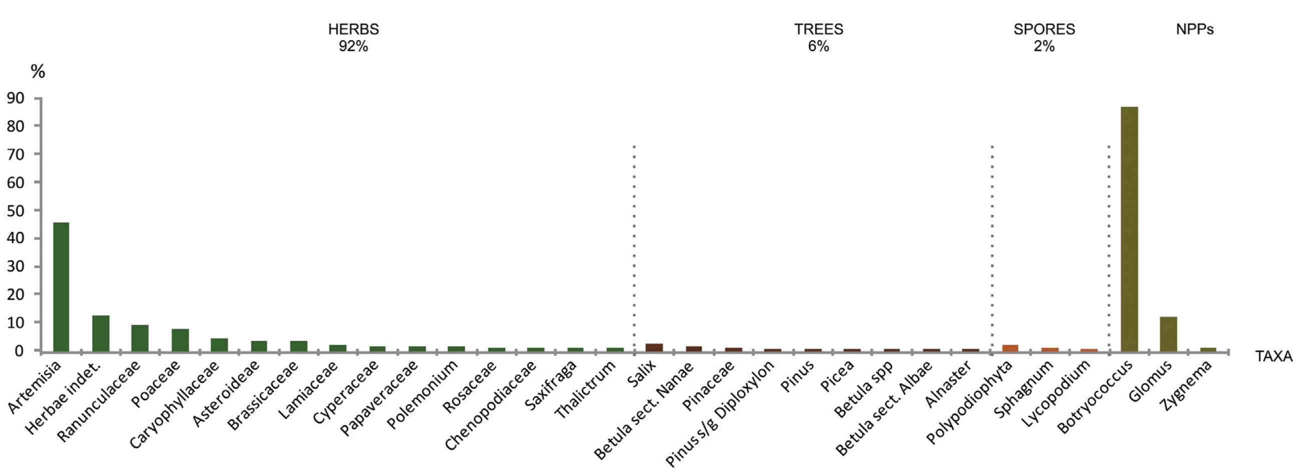

Fig. 4. The results of pollen analysis from the sediment sample taken from the Yuka mammoth cranium.

and leaves. Other remains were represented by leaves and twigs of Bryales, seeds of herbs, 20 mammoth hairs, 13 ephippia of *Daphnia*, five ostracod shells, seven chitin fragments of *Coleoptera*, two fragments of Oribatidae and a fragment of mammoth cranium. Plant macrofossils included 12 taxa (Fig. 5). Seeds belonged to the Potamogetonaceae—*Potamogeton vaginatus* (one endocarp); Poaceae—*Deschampsia* sp. (one caryopsis), *Hordeum* sp. (one caryopsis), Poaceae sp. (one caryopsis); Cyperaceae—*Carex* spp. (seven fragments of nutlets), Cyperaceae (*Carex*, *Scirpus*?) (one nutlet), Rosaceae—*Potentilla* sp. (three nutlets); Ranunculaceae—*Ranunculus* sp. (one fragment of nutlet), *Batrachium* sp. (one nutlet); Primulaceae—*Androsac*e sp. (one seed); Caryophyllaceae (one seed); Asteraceae—*Tephroseris* cf. *atropurpurea* (one achene).

Among the Cyperaceae macrofossils, the nutlet, which combines diagnostic features of *Carex* and *Sciprus*, was found. The absence of bristles at the base of the nutlet makes it similar to that of *Carex*; however, bristles are not often preserved in fossil nutlets of *Sciprus*, *Eriophorum* and *Eleocharis*. The walls of this nutlet are thick and shape of nutlet is hemispherical, which is more typical for *Sciprus* than for *Carex* (Fig. 5).

5. Interpretation and discussion

According to radiocarbon dating (34,300 + 260/− 240 yr BP), the Yuka mammoth lived during the termination of the Kargin Interstadial. The presumed climatic optimum for the Kargin Interstadial in the Laptev Sea region occurred between ca. 44–32 kyr BP (see review in Wetterich et al., 2014). As mentioned above, the vegetation of the MIS3 optimum became mosaic and the earlier-prevailing tundra-steppe was combined with willow shrubs or relatively mesophytic communities that were spread throughout protected and wet places (Andreev et al., 2011). Plant macrofossil data from palaeorecords dating between 48 and 33 kyr BP from the Bykovsky Peninsula indicate that remains from typical steppe and meadow plants, e.g., *Festuca*, *Kobresia*, *Hordeum*, *Linum*, *Silene* and *Potentilla*, were numerous. Such plant communities suggest relatively warm summers. Macrofossils of taxa from permanently wet habitats were also found in the Middle Weichselian Interstadial, dating between about 48 and 35 kyr BP (Kienast et al., 2005).

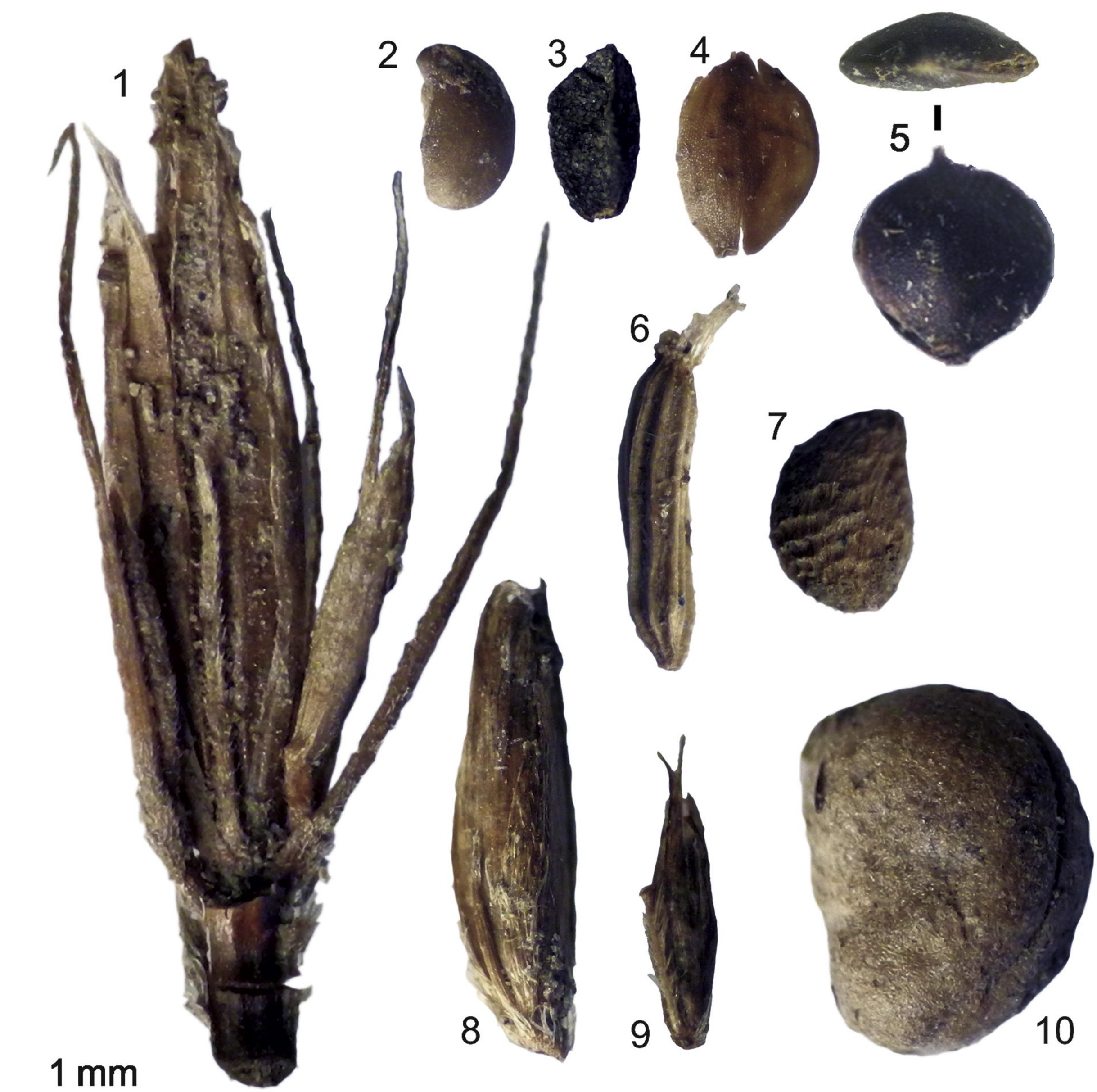

Fig. 5. Plant macrofossils of the plants of the sediment sample from the Yuka mammoth cranium: (1) *Hordeum* sp., caryopsis; (2) *Potentilla* sp., nutlet; (3) *Androsac*e sp., seed; (4) *Carex* sp., nutlet; (5) Cyperaceae (*Carex*, *Scirpus*?), nutlet; (6) *Tephroseris* cf. *atropurpurea*, achene; (7) *Batrachium* sp., nutlet; (8) Poaceae, caryopsis; (9) *Deschampsia* sp., caryopsis; (10) *Potamogeton vaginatus*, endocarp.

Paleobotanical data obtained in this study represent two sets of taxa (macro- and microfossils), whereas macrofossils more reflect the local vegetation in the burial place of the Yuka mammoth, the pollen spectrum mainly reflects the regional vegetation.

In general, macrofossil plant remains obtained from the sediment sample in the Yuka mammoth's skull are characteristic of the herbaceous taxa that are widespread on the modern Yakutian tundra (Table 1). However, seeds of *P. vaginatus* and *Batrachium* sp. as well as ostracod shells and ephippia of *Daphnia* reflect the existence of small freshwater ponds with stagnant or slowly moving water exactly at the site where the mammoth carcass was found. In addition, *P. vaginatus* requires warm summers and does not occur in modern vegetation north of the 12 °C mean July isotherm (Flora Sibiri, 1988a). One of the nutlets of Cyperaceae combines the characteristics of both *Carex* and *Scirpus* (Fig. 5). The genus *Scirpus* does not grow in the Eastern Siberian Arctic today. *Scirpus lacustris* and *S. orientalis* occur in the southern part of Central Yakutia and *S. maximowiczii* grows in the Yana-Indigirka lowland. *Scirpus* inhabits water meadows, the banks of ponds and landscape falls (Flora Sibiri, 1990). *Deshampsia* sp. and *Ranunculus* sp. are also indicators of wetland in the Yuka's burial place (Table 1). The high abundance of *Botryococcus* remnants in the pollen spectrum confirms the aquatic nature of the environment at the burial place of the Yuka mammoth. The finding of *Carex* nutlet fragments does not contradict the reconstruction of wetland in the studied sites; different species of *Carex* can be dominant in variety of steppe, tundra as well as wet intrazonal communities. Except for aquatic and wet-site plants, the macrofossil spectrum includes steppe elements such as Caryophyllaceae and *Potentilla* sp. The type of vegetation, including these macrofossils, resembles the plant community that is relic today, and persisted in various parts of Metaberingia (Yurtzev, 2001). It is called 'mesic-xeric meadows enriched with steppe elements', which are sometimes zoogenic and have a sparse canopy of shrubs. The dominants of this community are grasses, and shrubs are represented by *Rosa acicularis*, *Pentaphylloides (Potentilla) fruticosa*, *Salix glauca* and *Betula nana*. This conclusion is confirmed by pollen data. Despite the dominance in the pollen spectrum of *Artemisia*, the Ranunculaceae and Poaceae are highly abundant; the percentages of *Salix* and *Betula* sect. *Nanae* are also significant and are the most common arboreal taxa.

The pollen spectrum from the sample studied is generally typical of pollen spectra from the late Kargin records of the Eastern Siberian Arctic. Six leading taxa in the spectra are *Artemisia*, the Ranunculaceae, Poaceae, Caryophyllaceae, Asteraceae and Brassicaceae. Five taxa (excluding Ranunculaceae) might characterise steppe-like vegetation, and we suggest that it is a regional (zonal) feature. However, the percentage of *Artemisia* (46%) is significantly higher than in contemporary pollen records from North Yakutia (e.g., in Bol'shoy Lyakhovsky Island it is up

Table 1
Taxa of plant macrofossils of a sediment sample from the Yuka scull, their modern distribution, ecology and implications for paleoenvironmental reconstruction.

Taxa	Modern distribution in Eastern Siberian Arctic	Modern ecology	Implication for paleoenvironmental reconstruction
Potamogetonaceae			
Potamogeton vaginatus	Northern Eurasia and North America; the northern limit in the Eastern Siberian Arctic (ESA): Shamanovka River, the tributary of the Indigirka River (Flora Sibiri, 1988a).	Lakes, former river-bed	Indicator of wetland; its more northern distribution than today might indicate a relatively warm climate during the MIS3 optimum.
Poaceae			
Deschampsia sp.	The species *D. borealis* and *D. brevifolia* occur today in the ESA with circumarctic areas and a northern limit at the New Siberian Archipelago (Alexandrova, 1963; Arkticheskaya flora SSSR, 1964).	Wet places in the tundra, often in disturbed soils associated with riverbanks, wet slopes, near ponds.	Indicator of wet habitats.
Hordeum sp.	Only one species of *Hordeum*—*H. jubatum* occurs today in the Arctic Yakutia (Flora Sibiri, 1988b) with a limit of 70°N (http://www.agroatlas.ru).	*H. jubatum* grows in meadows in the river valleys, as a weed near roads, villages and disturbed places. Other Siberian species prefer salt marshes along the riverbanks and the banks of salt and brackish lakes (Flora Sibiri, 1988b).	*Hordeum* might indicate salt soils at the Yuka burial place.
Cyperaceae			
Carex spp.	The flora of the ESA includes 32 *Carex* species (Flora Sibiri, 1990), but only a few today on the Laptev sea coast and the New Siberian Archipelago, e.g., *Carex bigelowii* ssp. a*rctisibirica*, *C. aquatilis* ssp. *stans, C. subspathacea* ssp. *subspathacea* (Alexandrova, 1963; Egorova, 1999).	Arctic *Carex* spreads mostly in different types of arctic tundra, on riverbanks etc. The dominant of the modern Oyogos Yar vegetation is *Carex bigelowii* ssp. *Arctisibirica*, which inhabits sedge-moss swamps and shrub-moss tundra.	Indicator of tundra communities as well as wet habitats.
Rosaceae			
Potentilla sp.	28 species occur in the ESA today (Flora Sibiri, 1988c).	Arctic *Potentilla* mainly prefers rocks, stony tundra, pebbles (Flora Sibiri, 1988c).	Indicator of stony tundra or rocky sites. Non-arctic *Potentilla* is widespread in steppe communities and might indicate a steppe or tundra-steppe environment.
Ranunculaceae			
Ranunculus sp.	According to the Flora Sibiri (1993), 26 species of *Ranunculus* occur in the modern ESA.	Arctic *Ranunculus* inhabits mainly wet and aquatic sites.	Indicator of wet or aquatic habitats.
Batrachium sp.	Two species of *Batrachium* (*B. peltatum* and *B. divaricatum*) grow today in the ESA, but to the south of Oyogos Yar (Flora Sibiri, 1993).	Aquatic plants grow in ponds with still or slightly running water (Arkticheskaya flora SSSR, 1971; Flora Sibiri, 1993).	Indicator of aquatic habitats.
Primulaceae			
Androsace sp.	Only three species of *Androsace* (*A. bungeana, A. triflora, A. septentrionalis*) occur in the ESA (Flora Sibiri, 1997).	Rocks, stony sites.	Indicator of intrazonal habitats, e.g. rocks.
Asteraceae			
Tephroseris cf. *atropurpurea*	*Tephroseris atropurpurea* is widespread in Siberia and in the north of the Far East. The northern limit of its area is the New Siberian Archipelago (Flora Sibiri, 1997).	In the meadows, on sandy slopes, on banks of ponds, in bushes, in ernik's, in different types of tundra (Flora Sibiri, 1997).	The mesophytic ecology of *T. atropurpurea* can indicate a relatively humid climate in MIS3 comparable with that of today.

to 4% (Wetterich et al., 2014) and Kurungnakh Island and Bykovsky Peninsula it is up to 10% (Andreev et al., 2011). The overrepresentation of *Artemisia* might be explained by the existence of disturbed soils close to the studied site, where wormwoods grew as weeds. Indirect evidence of this is that a high abundance of *Glomus* chlamydospores, an indicator of soil erosion (van Geel et al., 2003 and pollen of the Chenopodiaceae, a very rare family in Arctic, mainly of ruderal origin (Arkticheskaya flora SSSR, 1966) was found.

6. Conclusions

The results of pollen and plant macrofossil analyses confirm that the Yuka mammoth lived during the optimum of the Kargin Interstadial. Paleobotanical data presented in this study suggest that the vegetation of the MIS3 optimum in the Eastern Siberian Arctic became mosaic; zonal tundra-steppe might have been combined with mesic-xeric meadows enriched with steppe elements. The burial place of the mammoth could have been a small shallow freshwater pond with stagnant or slowly moving water. An explanation for the overrepresentation of *Artemisia* in the pollen spectrum is the existence of disturbed soils close to the studied site, where wormwoods grew as weeds.

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