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Last straw versus Blitzkrieg overkill: Climate-driven changes in the Arctic Siberian mammoth population and the Late Pleistocene extinction problem

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A B S T R A C T

A set of radiocarbon dates on woolly mammoth were obtained from several regions of Arctic Siberia: the New Siberian Islands ($n = 68$), north of the Yana-Indigirka Lowland ($n = 43$), and the Taimyr Peninsula ($n = 18$). Based on these and earlier published dates ($n = 201$) from the East Arctic, a comparative analysis of the time-related density distribution of ^{14}C dates was conducted. It was shown that the frequencies of ^{14}C dates under certain conditions reflect temporal fluctuations in mammoth numbers. At the end of the Pleistocene the number of mammoths in the East Arctic changed in a cyclic manner in keeping with a general “Milankovitch-like” trend. The fluctuations in numbers at the end of the Pleistocene occurred synchronously with paleoenvironmental changes controlled by global climatic change. There were three minima of relative mammoth numbers during the last 50 000 years: 22 000, 14 500–19 000, and 9500 radiocarbon years ago, or around 26 000, 16–20 000, and 10 500 calendar years respectively. The last mammoths lived on the New Siberian Islands, which were connected to the continent at that time, 9470 ± 40 radiocarbon years ago (10 700 ± 70 calendar years BP). This new youngest date approximates the extinction time of mammoths in the last continental refugium of the Holarctic. The adverse combination of environmental parameters was apparently a major factor in the critical reduction in mammoth numbers. The dispersal of humans into the Arctic areas of Siberia no later than 28 000 radiocarbon years ago did not overtly influence animal numbers. Humans were not responsible for the destruction of a sustainable mammoth population. The expanding human population could have become fatal to mammoths during strong the minima of their numbers, one of which occurred at the very beginning of the Holocene.

1. Introduction

The last non-compensated extinctions among large terrestrial mammals started roughly 40 000 years ago, becoming more pronounced towards the end of the Pleistocene. Possible causes of the extinction have been a topic of discussion for more than 150 years. Nearly all of the known hypotheses concerning the disappearance of certain taxa or entire faunas were put forward in the 19th century (Pavlova, 1924; Grayson, 1984). At present, there are two frequently mentioned causes of this extinction (see Barnosky et al., 2004; Koch and Barnosky, 2006 for a review):

1. Transformation of the environment caused by global climatic changes, appearing as fluctuations of temperature, humidity, depth of snow cover, wind, change of composition and decrease in productivity of vegetation, changes in landscapes, soil geochemistry, interspecies and intraspecies competition, disease, and other natural factors. We attribute the astronomical impact hypothesis for Pleistocene extinction to this group of factors, as the impact event (if it ever took place) would have operated indirectly, triggering the mentioned environmental factors.

2. Extermination by humans. There are many extinction models in which some of the named factors operate jointly. Different authors have varying ideas regarding the principal model (see for example: Martin and Steadman, 1999; Barnosky et al., 2004; Whitney-Smith, 2004; Wroe et al., 2004; Guthrie, 2006; Wroe et al., 2006).

For a long time, testing these hypotheses has been severely hampered by a lack of direct evidence for dependence of animal population sizes upon any particular factor (natural or anthropogenic). The recent widespread use of different dating techniques, especially radiocarbon age measurement, has begun to supply the necessary data.

Each direct radiocarbon date on a bone, even if not found *in situ*, uniquely corresponds to three parameters:

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1. The animal species (if known).
2. The bone location (if known).
3. The radiocarbon date of the animal's death.

If the taphonomic biases are low, a sufficient number of dates allows for reconstruction of the spatio-temporal dynamics of animal ranges and abundance. Furthermore, the radiocarbon method allows for precise dating of some natural and anthropogenic processes. A joint comparative analysis of densely-dated sequences is one of the most promising methods to search for cause-effect relationships of the Late Pleistocene extinction (Martin, 1984; Guthrie, 1990, 2006; Sulerzhitsky, 1995; Graham et al., 1996; Sulerzhitsky and Romanenko 1997; Vasil'chuk et al., 1997; Sher, 1997; Bocquet-Appel et al., 2005; Orlova et al., 2001; MacPhee et al., 2002; Stuart et al., 2002; Kuzmin et al., 2003; Barnosky et al., 2004; Gamble et al., 2004; Kuzmin and Orlova, 2004; Orlova et al., 2004; Stuart et al., 2004; Sher et al., 2005; Stuart, 2005; Ugan and Bayers, 2007; and many other authors).

By the late 1980s, numerous fossil localities of northeastern Asia had yielded a large series of ^{14}C dates on mammoth bone collagen (Orlova, 1979; Lavrov and Sulerzhitsky, 1992; Sulerzhitsky, 1995; Sulerzhitsky, 1997; Sulerzhitsky and Romanenko, 1997). The analysis of these data revealed a distribution of dates over time resembling in shape the well-known climatic trend of the terminal Pleistocene. Most dates are concentrated within the 45–24 ka interval (all dates quoted uncalibrated), which preceded the beginning of the last glacial maximum (LGM). Within the LGM (23–15 ka), the number of dates strongly decreases, followed by a short-term increase. In the interval corresponding to the early Holocene, the number of dates sharply decreases to zero, indicating the time of mammoth extinction (in Wrangel [Vartanyan et al., 1993, 1995, 2008; Vartanyan, 2007] and Pribilof Islands (Guthrie, 2004; Veltre et al., 2008) woolly mammoths survived somewhat longer).

The subsequent considerable increase in the number of radiocarbon dates suggests that the general trend remains unchanged (compare Sulerzhitsky, 1997; Sher et al., 2005); and general trends (but not details) of date distribution from different areas of Arctic Siberia and northern North America are much alike (compare Matheus et al. (2003), Guthrie (2004), and Sher et al. (2005)). It was suggested that this stability in the temporal distribution of dates and its spatial consistency is not coincidental and is indicative of fluctuations in actual numbers at the end of the Pleistocene. At the same time, it was noticed that major fluctuations in the frequency of dates broadly correspond to the paleoclimatic pattern and, hence, the paleoclimatic changes may be their cause. According to this approach, the number of dates is *a priori* regarded as a function of animal numbers. Although a few authors (Sulerzhitsky, 1997; Matheus et al., 2003; Sher et al., 2005; Surovell et al., 2009) have paid special attention to the possible influence of taphonomic, geological, and other postmortal factors on date frequency, it is clear that dependence of date numbers on animal numbers, climate, and taphonomy are relevant to the extinction problem and are require special evaluation. We have had the opportunity to conduct such research on abundant material obtained in the New Siberian Islands and the adjacent lowland, through the framework of the Russian-American project "Zhokhov-Yana".

The northern portion of Eastern Siberia has proved to be an ideal region to recover high-quality continuous series of radiocarbon dates on mammalian remains. At the end of the Pleistocene, this area did not experience the destructive action of continental glaciation. Permafrost conditions, persisting here for a million years, have allowed the preservation of buried bones and even soft tissues of animals. During the colder periods of the Pleistocene, this area was a part of the extensive Beringian land that incorporated vast emerging shelf areas due to sea level falls. At the same time, colder climatic conditions would have led to expansion of steppe-like landscapes, favorable for abundant and diverse Pleistocene fauna (Guthrie, 1990; Sher, 1997; Yurtsev, 2001). During interglacial periods, this region served as a refugium for the Pleistocene fauna (Boeskorov, 2006; Lister and Stuart, 2008) because it preserved the conditions of the colder periods of the Pleistocene. Therefore, this region is one of the world's largest sources of Late Pleistocene mammal remains.

We selected mammoths, *Mammuthus primigenius* (Blumenbach), as the subject of study because their remains are well represented in the material collected by the "Zhokhov-Yana" project and are the most suitable for conventional radiocarbon dating, which requires large samples. In addition, the dates on mammoth available from the literature, which we included in the analysis, are most abundant. Finally, the mammoth was one of the dominant members of the Late Pleistocene ("Mammoth") Fauna of the Holarctic and it definitely played a role in the human economy, as mammoth remains occur in many Paleolithic sites. The significant number of new reliable dates with accurate sampling, and careful analysis of the dating results, enable a study of short-period fluctuations in frequencies of radiocarbon dates. This makes possible a detailed comparison between the dynamics of mammoth numbers, environmental fluctuations and human impact.

Contrary to other regions of Eurasia where the "Mammoth Fauna" coexisted with people for a longer time, the northern region of the Eastern Arctic was not populated by humans until a relatively late period. This provides an important opportunity to evaluate the "Blitzkrieg overkill" hypothesis for northernmost Asia. The Blitzkrieg overkill hypothesis assumes that people destroyed a sustainable megamammal population shortly after first contact. The alternative "Last straw" hypothesis assumes a low influence of humans on the sustainable mammal population, but a human-induced extinction of megamammal populations stressed by adverse environmental conditions.

2. Methods and material

There are two hypotheses requiring evaluation prior to the analysis of human vs. naturally-induced causation of mammoth extinction in Arctic Siberia:

1. The distribution of date numbers through time represents actual trends in the mammoth population, and is not significantly affected by taphonomic biases.
2. Mammoth numbers depend on climate-driven environmental conditions (although this statement is broadly accepted, it remains insufficiently demonstrated).

To test the first assumption, we have compared the density distribution of mammoth-based ^{14}C dates from five regions of the Arctic Siberia remote from each other (Fig. 1). Any marked agreement of these patterns would indicate an effect of some uniform parameter, such as the abundance of mammoths and/or taphonomy. To reveal actual changes in mammoth populations it is very important to estimate the influence of the taphonomy on the distribution of the dates. Taphonomic biases could be introduced by large-scale climate-driven factors, such as regional or global cycles in deposition and exposure of fossil-bearing layers. These could be similar across the whole region. In this case taphonomic biases could contribute significantly to date distribution trends.

The evidence suggests a low effect of taphonomy on the frequency of dates (at least for Beringia):

1. Individual frequency distributions of dates are not equal for different mammal taxa (mammoth, bison, horse, caribou,

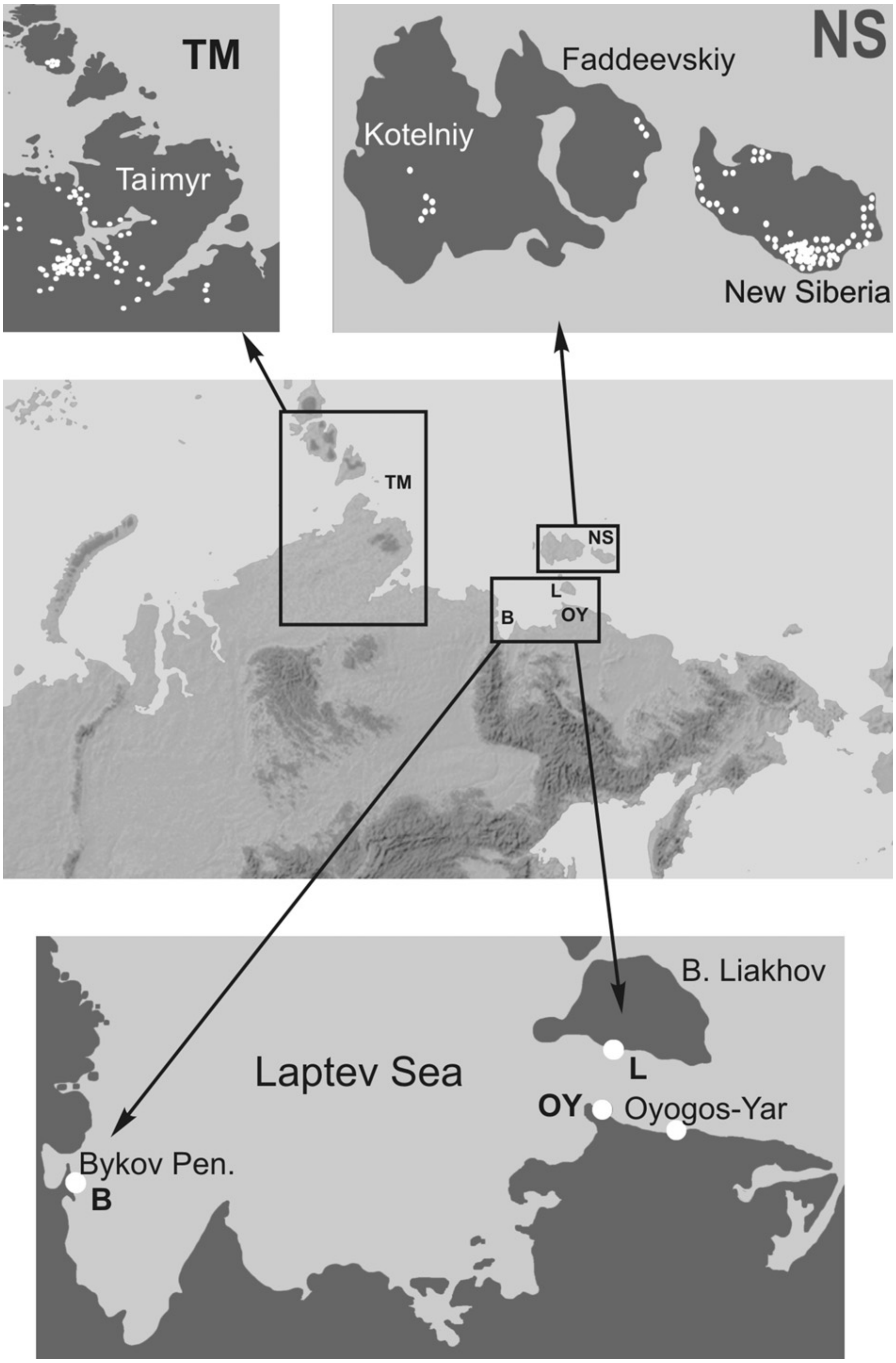

Fig. 1. Geographic locations of the areas and individual sites that yielded ^{14}C-dated mammoths discussed in the text. Points designate sampling sites. NS and TM are areas that produced ^{14}C date samples of the "areal" type. OY, B, L, are individual sites yielding series of ^{14}C dates of the "spot" type. NS, New Siberian islands (including New Siberia, Faddeevsky, and Kotelny Islands); TM, Taimyr region (including Taimyr Peninsula, lower reaches of the Khatanga River area, and Severnaya Zemlya Archipelago); OY, Oyogos-Yar; B, Bykovsky Peninsula; L, southern coast of Bolshoi Lyakhovsky Island.

muskox) sampled in the New Siberian Islands (Nikolskiy et al., in preparation), Taimyr Peninsula (MacPhee et al., 2002), and Northern Alaska (Matheus et al., 2003). If taphonomy was a significant effect, the frequency distributions of dates of different taxa would be similar.

2. ^{14}C frequency distributions, and mtDNA data, suggest similar trends in the demographic history of Beringian bison (Shapiro et al., 2004). Since we can detect the population changes (independently confirmed by mtDNA) through ^{14}C frequency distributions, it is quite probable that the influence of taphonomy is low.[1]
3. One of the largest ^{14}C samples discussed in this report was collected at the Mamontova Hayata site, Bykovsky peninsular (Schirrmeister et al., 2002; Sher et al., 2005) (Fig. 1B). This is

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[1] mtDNA study of mammoths suggests no demographic changes before and during the LGM. But only 25 samples were analyzed, probably insufficient to demonstrate trends (Barnes et al., 2007).

a very well-documented section of Late Pleistocene deposits. The precise ages of units in the 50-m high section were defined by about one hundred radiocarbon determinations. The distribution of dates over the section suggests roughly equal rates of deposition (Schirrmeister et al., 2002, p. 101). But mammoth ^{14}C date frequencies are not equally distributed (Fig 5B). This most probably suggests some other, not taphonomic biases on mammoth bone distribution.[2]

Although we believe that taphonomic biases did not contribute significantly to date distribution trends, we applied strict quality-control criteria to the material to minimize bias in the distribution of dates not reflecting fluctuations of animal numbers, but related to features of taphonomy, sedimentation, postsedimentary concentration of bones, and overrepresentation in the sample of bones of a certain age. These criteria include:

- Material that is sufficiently abundant (hundreds of specimens) to produce a representative, unbiased series of samples for ^{14}C dating (many tens of samples). Smaller collections favor incidental enrichment or depletion of certain age intervals.
- Samples have to originate as far as possible from areas with similar environmental conditions. Marked differences in local conditions can influence the number of mammoths, causing a shift in date distribution.
- Bone remains for dating should be collected from extensive areas in order to balance out the influence of local taphonomic and other selective factors.
- Samples should not be overloaded with materials from uniquely rich localities (sections). Even if such a site (section) has sufficient stratigraphic range, it is unlikely to yield an even distribution of dated material throughout this range.
- Samples should not include specimens from archeological sites and natural mass accumulations of animal remains. It is obvious that both cases will produce artificial peaks within the distribution curves corresponding to the age of an archeological site or the formation time of the mass accumulation.
- The collecting should favor a uniform sampling of materials of different age. In general, this is possible when most bones are sufficiently exposed from sediments.
- Duplication of dates (dating of bones from the same skeleton) should be excluded.

The first hypothesis (the distribution of date numbers through time represents actual trends in the mammoth population, and is not significantly affected by taphonomic biases) would be additionally indirectly confirmed by dissimilarity between (a) series of dates that conform to the above criteria, and (b) those that do not, i.e. that are biased by the factors not related to animal numbers. Therefore, we compared dates based on two different types of samples: "areal", and "spot". Areal samples (Fig. 1 NS, TM) comprise mammoth bones collected over a vast area, assuming that small effects of local taphonomy would be reduced by mutual compensation. Spot samples (Fig 2 B, L, OY) consist of material collected over a limited space, usually along an individual outcrops up to several kilometers long. The influence of taphonomy would here be more apparent, as unequal bone accumulation and subsequent exposure would be more probable at a local site than across the sum of many sites spread over a large area. At the same time we should not mix material from several areal samples, because in different regions the population dynamics could vary due to different environments. It is important to take into account that combining samples from too-vast areas may result in the loss of weak signals.

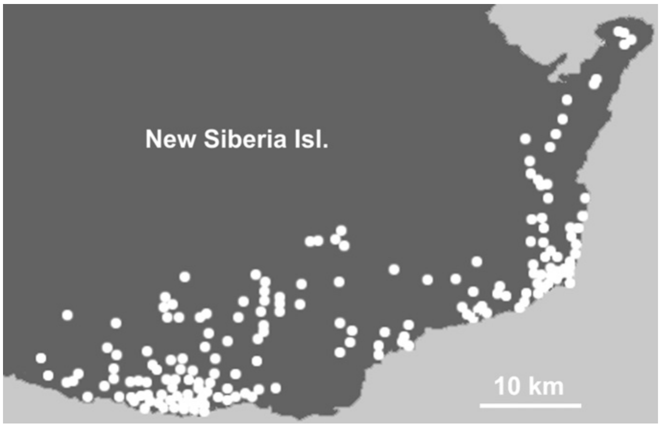

Fig. 2. Map showing localities where Quaternary mammal remains have been collected over the New Siberia Island. This island is one of the biggest among the New Siberian Islands, and most of the bones for dating have been collected here. Bones are uniformly distributed across the area, do not form marked concentrations, and are not specifically confined to certain local geological bodies. Linear and point concentrations are controlled only by the density of field routes.

We have selected 330 ^{14}C dates on mammoth bone collagen. Of these, 192 dates have been obtained directly by us in the Laboratory of Geochemistry of Isotopes and Geochronology of the Geological Institute of the Russian Academy of Sciences by the scintillation (conventional) method (87 dates reported here for the first time).[3] One-hundred and thirty eight additional dates are taken from the literature. The list of dates with their basic descriptions is given in Table 1.

Two sets of ^{14}C dates of mammoth bones represent areal samples. They closely met the quality criteria listed above and were used for the evaluation of the first hypothesis (the frequency of radiocarbon dates of mammoth corresponds to the time-related abundance of this species). The first set of dates comes from the New Siberian Islands, including New Siberia, Faddeevsky, and Kotelny Islands (Fig. 1, NS). The second set comes from the Taimyr region, which comprises the Taimyr peninsula, the lower reaches of the Khatanga River, and the Severnaya Zemlya Archipelago (Fig. 1, TM).

The NS set includes 86 finite dates from many tens of small localities scattered throughout the vast, 35 000 km^2, area (Fig. 2). The majority of bones were collected on gentle slopes of small rivers and creeks shaped by thermoerosion, in creek channels, and on the coast.

The TM sample consists of 125 finite dates on mammoth remains collected from an area covering 250 000 km^2 (Severnaya Zemlia is not included in this area count). The sampling protocols were the same as in the NS sample (personal observations of Sulerzhitsky; see also MacPhee et al., 2002).

The settings of bone occurrence in both collection areas are similar to each other and differ from conditions in many other Arctic Siberian regions. These distinctive features include the scattered areal occurrence of bones, the lack of major bone concentrations, the absence of an evident connection with specific stratigraphic or lithogical settings, and a nearly homogeneous distribution of bones throughout the sequence of Late Pleistocene Ice Complexes if found *in situ* (Fig. 2). This type of occurrence and distribution of bones implies limited or no transportation of the

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[2] We strongly suspect that postmortem elimination of bones from the record, if any, was very low, due to the conserving action of permafrost.

[3] The method used for the treatment of bone collagen was established by Arslanov and Svezhentsev (1993) and modified by Sulerzhitsky (1997).

Table 1
Radiocarbon age on collagen from mammoth bones in Arctic Siberia New Siberian Islands (without B. Liakhovsky Island).

No.	Lab. number	Date ^{14}C yr BP	Dated bone/tissue	Position on the map	Locality	Source and remarks
1	GIN-11874	9470 ± 40	Tusk	Fig. 1 (NS)	New Siberia Island	This report
2	GIN-11245	9650 ± 60	Tooth	Fig. 1 (NS)	New Siberia Island	Anisimov et al. (2005)
3	GIN-11255	10 200 ± 100	Tooth	Fig. 1 (NS)	New Siberia Island	This report[a]
4	GIN-11271v	10 260 ± 120	Tooth	Fig. 1 (NS)	New Siberia Island	This report[a]
5	GIN-11088	10 580 ± 50	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
6	GIN-11087	10 950 ± 50	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
7	GIN-11263	11 060 ± 40	Limb bone	Fig. 1 (NS)	New Siberia Island	This report[a]
8	GIN-11258	12 250 ± 50	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
9	LU-2096	12 590 ± 60	Tusk	Fig. 1 (NS)	Bennett Island	Verkulich et al. (1989)
10	GIN-11244	13 050 ± 150	Tooth	Fig. 1 (NS)	New Siberia Island	This report[a]
11	GIN-11880	13 230 ± 70	Tusk	Fig. 1 (NS)	New Siberia Island	This report
12	GIN-11875	13 250 ± 60	Tusk	Fig. 1 (NS)	New Siberia Island	This report
13	GIN-8230	13 700 ± 100	Bone	Fig. 1 (NS)	Kotelniy Island	Sulerzhitsky and Romanenko (1997)
14	LU-1671	15 420 ± 110	Tusk	Fig. 1 (NS)	Kotelniy Island	Makeyev et al. (1989)
15	GIN-11256	17 500 ± 300	Tooth	Fig. 1 (NS)	New Siberia Island	This report[a]
16	GIN-8229	18 500 ± 120	Bone	Fig. 1 (NS)	Faddeevsky Island	Sulerzhitsky and Romanenko (1997)
17	GIN-11823	18 850 ± 70	Tusk	Fig. 1 (NS)	New Siberia Island	This report
18	GIN-10645	19 400 ± 90	Tibia	Fig. 1 (NS)	Faddeevsky Island	This report[b]
19	LU-1790	19 990 ± 110	Tusk	Fig. 1 (NS)	Kotelniy Island	Makeyev et al. (1989)
20	GIN-11271v	20 150 ± 250	Tooth	Fig. 1 (NS)	New Siberia Island	This report[a]
21	GIN-10644	20 340 ± 80	Tibia	Fig. 1 (NS)	Faddeevsky Island	This report[b]
22	GIN-11878	20 800 ± 70	Tusk	Fig. 1 (NS)	New Siberia Island	This report
23	GIN-5760	20 900 ± 100	Tusk	Fig. 1 (NS)	Faddeevsky Island	Sulerzhitsky (1995)
24	GIN-11254	23 350 ± 500	Tooth	Fig. 1 (NS)	New Siberia Island	This report[a]
25	GIN-11253	23 510 ± 120	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
26	GIN-8244	23 940 ± 150	Tusk	Fig. 1 (NS)	Faddeevsky Island	Sulerzhitsky and Romanenko (1997)
27	GIN-11257b	24 800 ± 300	Tooth	Fig. 1 (NS)	New Siberia Island	This report[a]
28	GIN-8227	25 180 ± 150	Tusk	Fig. 1 (NS)	Faddeevsky Island	Sulerzhitsky and Romanenko (1997)
29	GIN-8246	25 200 ± 180	Bone	Fig. 1 (NS)	Faddeevsky Island	Sulerzhitsky and Romanenko (1997)
30	GIN-8532	25 540 ± 170	Bone	Fig. 1 (NS)	Faddeevsky Island	Sulerzhitsky and Romanenko (1997)
31	GIN-4710b	25 800 ± 200	Tusk	Fig. 1 (NS)	Faddeevsky Island	Stuart (1991)
32	GIN-8224	27 100 ± 300	Bone	Fig. 1 (NS)	Faddeevsky Island	Sulerzhitsky and Romanenko (1997)
33	GIN-11268	27 300 ± 200	Humerus?	Fig. 1 (NS)	New Siberia Island	This report[a]
34	GIN-4710	28 000 ± 200	Tusk	Fig. 1 (NS)	Faddeevsky Island	Stuart (1991)
35	GIN-8225	28 650 ± 350	Bone	Fig. 1 (NS)	Faddeevsky Island	Sulerzhitsky and Romanenko (1997)
36	GIN-11257a	29 000 ± 1000	Tooth	Fig. 1 (NS)	New Siberia Island	This report[a]
37	LU-1791	29 020 ± 190	Tusk	Fig. 1 (NS)	Kotelniy Island	Makeyev et al. (1989)
38	GIN-4711	29 100 ± 1000	Rib	Fig. 1 (NS)	Faddeevsky Island	Stuart (1991)
39	GIN-4330	29 100 ± 400	Radius	Fig. 1 (NS)	Faddeevsky Island	Lavrov and Sulerzhitsky (1992)
40	GIN-11252	29 500 ± 300	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
41	GIN-8260	29 700 ± 250	Bone	Fig. 1 (NS)	Faddeevsky Island	Sulerzhitsky and Romanenko (1997)
42	GIN-11897	29 850 ± 600	Tusk	Fig. 1 (NS)	New Siberia Island	This report
43	GIN-8236	29 900 ± 300	Bone	Fig. 1 (NS)	Lopatka Peninsula	Sulerzhitsky and Romanenko (1997)
44	GIN-11251	30 400 ± 600	Tooth	Fig. 1 (NS)	New Siberia Island	This report[a]
45	GIN-11791	31 100 ± 350	Scapula	Fig. 1 (NS)	New Siberia Island	This report
46	GIN-11271	31 300 ± 700	Tooth	Fig. 1 (NS)	New Siberia Island	This report[a]
47	GIN-8226	31 400 ± 300	Tusk	Fig. 1 (NS)	Faddeevsky Island	Sulerzhitsky and Romanenko (1997)
48	GIN-11259	31 600 ± 700	Tooth	Fig. 1 (NS)	New Siberia Island	This report[a]
49	GIN-11789	31 900 ± 300	Femur	Fig. 1 (NS)	New Siberia Island	This report
50	GIN-11265	33 000 ± 700	Limb bone	Fig. 1 (NS)	New Siberia Island	This report[a]
51	GIN-8233	33 600 ± 500	Bone	Fig. 1 (NS)	Lopatka Peninsula	Sulerzhitsky and Romanenko (1997)
52	GIN-11877	33 950 ± 260	Tusk	Fig. 1 (NS)	New Siberia Island	This report
53	GIN-11270	34 200 ± 700	Scapula	Fig. 1 (NS)	New Siberia Island	This report[a]
54	GIN-11899	34 400 ± 400	Tusk	Fig. 1 (NS)	New Siberia Island	This report
55	GIN-8254	34 400 ± 400	Bone	Fig. 1 (NS)	Kotelniy Island	Sulerzhitsky and Romanenko (1997)
56	GIN-8247	34 500 ± 500	Bone	Fig. 1 (NS)	Faddeevsky Island	Sulerzhitsky and Romanenko (1997)
57	GIN-11247	34 560 ± 400	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]

(*continued on next page*)

Table 1 (*continued*)

No.	Lab. number	Date ^{14}C yr BP	Dated bone/tissue	Position on the map	Locality	Source and remarks
58	GIN-8243	35 210 ± 500	Tusk	Fig. 1 (NS)	Faddeevsky Island	Sulerzhitsky and Romanenko (1997)
59	GIN-11264	35 400 ± 400	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
60	GIN-11900	35 500 ± 300	Tusk	Fig. 1 (NS)	New Siberia Island	This report
61	GIN-11876	35 600 ± 400	Tusk	Fig. 1 (NS)	New Siberia Island	This report
62	GIN-11028	35 600 ± 400	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
63	GIN-11691	35 700 ± 600	Mandible	Fig. 1 (NS)	New Siberia Island	This report
64	GIN-8223	35 800 ± 700	Bone	Fig. 1 (NS)	Bel'kovskiy Island	Sulerzhitsky and Romanenko (1997)
65	GIN-8238	36 000 ± 500	Bone	Fig. 1 (NS)	Faddeevsky Island	Sulerzhitsky and Romanenko (1997)
66	GIN-11822	36 100 ± 350	Tusk	Fig. 1 (NS)	New Siberia Island	This report
67	GIN-11248	36 600 ± 500	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
68	GIN-8243a	36 700 ± 500	Tusk	Fig. 1 (NS)	Faddeevsky Island	Sulerzhitsky and Romanenko (1997)
69	GIN-11879	37 150 ± 700	Tusk	Fig. 1 (NS)	New Siberia Island	This report
70	GIN-112672b	38 250 ± 600	Scapula	Fig. 1 (NS)	New Siberia Island	This report[a]
71	GIN-11267zh (the same specimen as GIN-112672b)	38 450 ± 600	Scapula	Fig. 1 (NS)	New Siberia Island	This report[a]
72	GIN-11250	38 900 ± 500	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
73	GIN-11820	40 260 ± 500	Tusk	Fig. 1 (NS)	New Siberia Island	This report
74	GIN-11266	40 300 ± 1000	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
75	GIN-11246	40 500 ± 600	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
76	GIN-11693	40 900 ± 1000	Tooth	Fig. 1 (NS)	New Siberia Island	This report
77	GIN-11824	40 900 ± 700	Tusk	Fig. 1 (NS)	New Siberia Island	This report
78	GIN-11029	41 000 ± 600	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
79	GIN-11788	41 350 ± 600	Tusk	Fig. 1 (NS)	New Siberia Island	This report
80	GIN-11031	44 100 ± 1000	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
81	GIN-11821	44 400 ± 1100	Tusk	Fig. 1 (NS)	New Siberia Island	This report
82	GIN-11030	44 400 ± 1400	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
83	GIN-11694	45 000 ± 1000	Tusk	Fig. 1 (NS)	New Siberia Island	This report
84	GIN-11787	45 500 ± 1300	Tusk	Fig. 1 (NS)	New Siberia Island	This report
85	GIN-11817	47 100 ± 1500	Tusk	Fig. 1 (NS)	New Siberia Island	This report
86	GIN-11818	48 600 ± 1500	Tusk	Fig. 1 (NS)	New Siberia Island	This report
87	GIN-11262	>33 500	Femur	Fig. 1 (NS)	New Siberia Island	This report[a]
88	GIN-11790	>36 900	Tusk	Fig. 1 (NS)	New Siberia Island	This report
89	GIN-11692	>40 000	Limb bone	Fig. 1 (NS)	New Siberia Island	This report
90	GIN-11261	>45 000	Limb bone	Fig. 1 (NS)	New Siberia Island	This report[a]
91	GIN-11695	>47 000	Rib and humerus	Fig. 1 (NS)	New Siberia Island	This report
92	GIN-11271a	>47 900	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
93	GIN-11086	>48 000	Tusk	Fig. 1 (NS)	New Siberia Island	This report[a]
94	GIN-11260	>48 000	Limb bone	Fig. 1 (NS)	New Siberia Island	This report[a]
95	GIN-11819	>50 000	Tusk	Fig. 1 (NS)	New Siberia Island	This report
Oyogos-Yar						
1	GIN-11898	16 200 ± 400	Limb bone	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
2	GIN-9556	17 100 ± 300	Tooth	Fig. 1 (OY)	Kondrat'eva	This report[c]
3	GIN-10651	19 800 ± 130	Radius	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
4	GIN-10560	22 700 ± 700	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
5	GIN-10561	23 000 ± 600	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
6	GIN-9045	25 200 ± 300	Limb bone	Fig. 1 (OY)	Svyatoy Nos Cape	This report[d]
7	GIN-9563	26 100 ± 600	Tusk	Fig. 1 (OY)	Kondrat'eva	This report[c]
8	GIN-10594	27 000 ± 600	Tooth	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
9	GIN-10600	29 100 ± 300	Tooth	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
10	GIN-10652	34 400 ± 400	Ulna	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
11	GIN-10564	34 500 ± 800	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
12	GIN-9558	36 400 ± 400	Tusk	Fig. 1 (OY)	Kondrat'eva	This report
13	GIN-9565	37 200 ± 400	Tusk	Fig. 1 (OY)	Kondrat'eva	This report[e]
14	GIN-10657	40 500 ± 900	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
15	GIN-10555	40 800 ± 1500	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
16	GIN-9566	40 900 ± 1200	Tusk	Fig. 1 (OY)	Ulakhan-Taala	This report[c]
17	GIN-9552	42 900 ± 900	Limb bone	Fig. 1 (OY)	Ulakhan-Taala	This report[c]
18	GIN-9568	43 100 ± 1000	Tusk	Fig. 1 (OY)	Kondrat'eva	This report[c]
19	GIN-9557	47 400 ± 1200	Tusk	Fig. 1 (OY)	Kondrat'eva	This report[c]
20	GIN-9044	48 800 ± 140	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[d]
21	GIN-9555	>16 000	Limb bone	Fig. 1 (OY)	Kondrat'eva	This report[c]
22	GIN-10655	>16 700	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
23	GIN-9564	>31 600	Tusk	Fig. 1 (OY)	Ulakhan-Taala	This report[e]
24	GIN-10596	>34 700	Tooth	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
25	GIN-10602	>34 700	Tooth	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
26	GIN-9559	>36 900	Tusk	Fig. 1 (OY)	Kondrat'eva	This report[c]
27	GIN-10563	>38 200	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
28	GIN-10601	>38 600	Tooth	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
29	GIN-11901	>40 900	Tooth	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]

Table 1 (*continued*)

No.	Lab. number	Date ^{14}C yr BP	Dated bone/tissue	Position on the map	Locality	Source and remarks
30	GIN-10559	>44 200	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
31	GIN-10565	>44 200	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
32	GIN-10557	>44 900	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
33	GIN-9567	>46 000	Tusk	Fig. 1 (OY)	Kondrat'eva	This report[e]
34	GIN-10556	>46 400	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
35	GIN-10597	>48 400	Tusk	Fig. 1 (OY)	Aebeliakh Bay	This report[e]
36	GIN-10598	>48 900	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
37	GIN-9560	>49 000	Tusk	Fig. 1 (OY)	Ulakhan-Taala	This report[e]
38	GIN-9569	>49 000	Tusk	Fig. 1 (OY)	Kondrat'eva	This report[e]
39	GIN-9562	>50 000	Tusk	Fig. 1 (OY)	Kondrat'eva	This report[e]
40	GIN-10653	>50 000	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
41	GIN-10558	>50 200	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
42	GIN-10595	>50 200	Tusk	Fig. 1 (OY)	Svyatoy Nos Cape	This report[e]
43	GIN-9561	>51 000	Tusk	Fig. 1 (OY)	Ulakhan-Taala	This report[e]
Taimyr Peninsula region						
1	GIN-1828	9670 ± 60	Tusk	Fig. 1 (TM)	Taimyr – Nizhnyaya Taimyra R	Stuart (1991)
2	GIN-8256	9780 ± 40	Tusk	Fig. 1 (TM)	Taimyr, north-east coast	Sulerzhitsky and Romanenko (1997)
3	GIN-1495	9860 ± 50	Tooth	Fig. 1 (TM)	Taimyr – Nizhnyaya Taimyra R	Lavrov and Sulerzhitsky (1992)
4	GrA-17350	9920 ± 60	Mandible	Fig. 1 (TM)	Taimyr – Bikada R	MacPhee et al. (2002)
5	GIN-10508	10 070 ± 60	Tusk	Fig. 1 (TM)	Taimyr – Nyen'gatiatari R	MacPhee et al. (2002)
6	GIN-1489	10 100 ± 100	Tooth	Fig. 1 (TM)	Taimyr – Engelhardt L	Lavrov and Sulerzhitsky (1992)
7	GIN-11138a	10 200 ± 40	Tooth	Fig. 1 (TM)	Taimyr – Kupchiktakh L	MacPhee et al. (2002)
8	GIN-10507	10 270 ± 120	Tibia	Fig. 1 (TM)	Taimyr – Nyun'karakutari R	MacPhee et al. (2002)
9	Beta-148640	10 270 ± 40	Tusk	Fig. 1 (TM)	Taimyr – Gol'tsovaya R	MacPhee et al. (2002)
10	GIN-1828k	10 300 ± 100	Radius	Fig. 1 (TM)	Taimyr – Nizhnyaya Taimyra R	Stuart (1991)
11	LuA-4820	10 450 ± 110	Tusk	Fig. 1 (TM)	Severnaya Z, October Revolution Is.	Möller et al. (2006)
12	GIN-3768	10 680 ± 70	Limb bone	Fig. 1 (TM)	Taimyr – Taimyr L, Nganasanskaya R	Stuart (1991)
13	GIN-10552	10 790 ± 100	Tooth	Fig. 1 (TM)	Taimyr – Krasnaya R	MacPhee et al. (2002)
14	GIN-11529	10 950 ± 70	Atlas	Fig. 1 (TM)	Taimyr	This report[g]
15	GIN-3067	11 140 ± 180	Tooth	Fig. 1 (TM)	Taimyr – Taimyr L, Baikura Neru B	Stuart (1991)
16	T-297	11 450 ± 250	Soft tissues	Fig. 1 (TM)	Taimyr – Mamonta R	Heintz and Garutt (1964)
17	LU-610	11 500 ± 60	Tusk	Fig. 1 (TM)	Severnaya Z – October Revolution Is.	Makeev et al. (1979)
18	GIN-8881	11 870 ± 180	Bone	Fig. 1 (TM)	Taimyr – Taimyr L, Cape Sabler	Dereviagin et al. (1999)
19	Beta-148663	11 940 ± 40	Ulna	Fig. 1 (TM)	Taimyr – Arylakh L	MacPhee et al. (2002)
20	GIN-10506	12 050 ± 100	Pelvis?	Fig. 1 (TM)	Taimyr	This report[f]
21	GIN-10506	12 050 ± 100	Tibia	Fig. 1 (TM)	Taimyr – Bikada R	MacPhee et al. (2002)
22	GIN-1783	12 100 ± 80	Limb bone	Fig. 1 (TM)	Taimyr – Taimyr L, Baskura Peninsula	Stuart (1991)
23	GIN-2943r	12 260 ± 120	Limb bone	Fig. 1 (TM)	Taimyr – Severnaya R	Lavrov and Sulerzhitsky (1992)
24	GIN-3242	12 450 ± 120	Limb bone	Fig. 1 (TM)	Taimyr – Severnaya R	Lavrov and Sulerzhitsky (1992)
25	GIN-2677	12 780 ± 80	Limb bone	Fig. 1 (TM)	Taimyr – Bikada R	Stuart (1991)
26	LU-3827	13 200 ± 130	Tusk	Fig. 1 (TM)	Taimyr – Taimyr L, Cape Sabler	Möller et al. (1999)
27	GIN-2758a	13 340 ± 240	Limb bone	Fig. 1 (TM)	Taimyr – Bolshaya Balakhnya R	Lavrov and Sulerzhitsky (1992)
28	Beta-148636	13 560 ± 40		Fig. 1 (TM)	Khatanga R. basin	MacPhee et al. (2002)
29	GIN-8883	13 620 ± 70	Bone	Fig. 1 (TM)	Taimyr – Taimyr L.	Dereviagin et al. (1999)
30	GIN-3518	14 800 ± 50	Bone	Fig. 1 (TM)	Khatanga – Khatanga R basin, Ulakhan-Yuryakh R	Sulerzhitsky et al. (1986)
31	Beta-148642	15 390 ± 50	Femur	Fig. 1 (TM)	Taimyr – Taimyr L, Cape Sabler	MacPhee et al. (2002)
32	GIN-3130	16 330 ± 100	Mandibula	Fig. 1 (TM)	Taimyr – Bolshaya Balakhnya R	Stuart (1991)
33	Beta-148646	18 190 ± 60	Molar	Fig. 1 (TM)	Taimyr – Bolshaya Balakhnya R	MacPhee et al. (2002)
34	LU-654A	19 640 ± 330	Tusk	Fig. 1 (TM)	Severnaya Z – October Revolution Is.	Makeev et al. (1979)
35	LU-688	19 970 ± 110	Tooth	Fig. 1 (TM)	Severnaya Z – October Revolution Is., Ushakova R	Makeev et al. (1979)
36	UtC-8138	20 380 ± 140	Hair	Fig. 1 (TM)	Taimyr – Bolshaya Balachnya River	Buigues and Mol (1999)
37	GIN-3952	20 400 ± 100	Tusk	Fig. 1 (TM)	Taimyr – Dudypta R	Sulerzhitsky et al. (1987)
38	Beta-148647	20 620 ± 70	Limb bone	Fig. 1 (TM)	Taimyr – Verkhnaya Taimyra River	Mol et al. (2001a, b)
39	Beta-148633	20 800 ± 70	Mandible	Fig. 1 (TM)	Taimyr	MacPhee et al. (2002)
40	GrA-17604	20 950 ± 190	Calcaneus	Fig. 1 (TM)	Taimyr – Taimyr L, Baskura Peninsula	MacPhee et al. (2002)

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Table 1 (*continued*)

No.	Lab. number	Date ^{14}C yr BP	Dated bone/tissue	Position on the map	Locality	Source and remarks
41	GIN-5574	22 000 ± 200	Tooth	Fig. 1 (TM)	Khatanga Bay area – Popigay R basin	Stuart (1991)
42	GIN-3089	22 750 ± 150	Bone	Fig. 1 (TM)	Taimyr – Taimyr L, Baskura Peninsula	Sulerzhitsky (1995)
43	GIN-2763a	23 500 ± 300	Tusk	Fig. 1 (TM)	Taimyr – Bederbo-Tarida R	Stuart (1991)
44	GIN-11530	23 600 ± 300	Tusk	Fig. 1 (TM)	Taimyr	This report[b]
45	GIN-1296B	23 800 ± 400	Limb bone	Fig. 1 (TM)	Taimyr – Taimyr L, Sabler Cape	Stuart (1991)
46	Beta-148639	24 170 ± 110	Skull	Fig. 1 (TM)	Taimyr – Trautfetter R	MacPhee et al. (2002)
47	Beta-148651	24 250 ± 110	Skull	Fig. 1 (TM)	Khatanga – Munchirdakh L	MacPhee et al. (2002)
48	GIN-8737	24 760 ± 110	Scapula	Fig. 1 (TM)	Taimyr – Labaz L	Sher et al. (2005)
49	GIN-2160	24 900 ± 500	Pelvis	Fig. 1 (TM)	Taimyr – Taimyr L, Baskura Peninsula	Lavrov and Sulerzhitsky (1992)
50	GIN-8884	24 990 ± 260	Bone	Fig. 1 (TM)	Taimyr – Taimyr L, Sabler Cape	Dereviagin et al. (1999)
51	LU-749B	25 030 ± 210	Tibia	Fig. 1 (TM)	Severnaya Z – October Revolution Is., Knizhnaya R	Makeev et al. (1979)
52	LE-612	25 100 ± 550	Soft tissues	Fig. 1 (TM)	Taimyr – Pyasina R	Zubakov and Kind (1974)
53	Beta-148634	25 800 ± 130		Fig. 1 (TM)	Khatanga R. basin	MacPhee et al. (2002)
54	Beta-148665	26 100 ± 170	Humerus	Fig. 1 (TM)	Taimyr – Taimyr L, Baskura Peninsula	MacPhee et al. (2002)
55	GIN-11127	26 200 ± 150	Tusk	Fig. 1 (TM)	Taimyr – Bolshaya Balakhnya R	MacPhee et al. (2002)
56	GIN-1216	26 700 ± 700	Tusk	Fig. 1 (TM)	Khatanga – Putorana Plt., Maymecha R basin	Stuart (1991)
57	GIN-11510	26 900 ± 250	Humerus	Fig. 1 (TM)	Taimyr	This report[f]
58	GIN-3836	27 300 ± 200	Rib	Fig. 1 (TM)	Taimyr – Logata R	Stuart (1991)
59	GIN-3929	27 500 ± 300	Tusk	Fig. 1 (TM)	Taimyr – Kubalakh R	Sulerzhitsky et al. (1987)
60	Beta-210777	27 740 ± 220	Mandible	Fig. 1 (TM)	Taimyr – Baikura-Turku Bay, Lake Taimyr	Poinar et al. (2006)
61	Beta-148662	28 270 ± 210	Ulna	Fig. 1 (TM)	Taimyr	MacPhee et al. (2002)
62	Beta-148643	28 310 ± 170	Molar	Fig. 1 (TM)	Taimyr – Taimyr L, coast opposite Kupffer Is.	MacPhee et al. (2002)
63	GIN-952	28 800 ± 600	Tusk	Fig. 1 (TM)	Taimyr – Shrenk R	Kind et al. (1978)
64	GIN-5073	28 900 ± 300	Tusk	Fig. 1 (TM)	Khatanga R. basin – Anabarka R	Lavrov and Sulerzhitsky (1992)
65	GIN-8882	29 250 ± 450	Bone	Fig. 1 (TM)	Taimyr – Taimyr L, Sabler Cape	Dereviagin et al. (1999)
66	GIN-2155	29 500 ± 300	Tusk	Fig. 1 (TM)	Taimyr – Taimyr L, Matuda P	Stuart (1991)
67	GIN-2154	29 500 ± 350	Tooth	Fig. 1 (TM)	Taimyr	This report
68	Beta-148635	29 990 ± 280	Humerus	Fig. 1 (TM)	Khatanga – Talalakh L	MacPhee et al. (2002)
69	GIN-11130a	30 850 ± 200	Mandible	Fig. 1 (TM)	Taimyr – Bolshaya Balakhnya R	MacPhee et al. (2002)
70	Beta-148637	30 890 ± 290	Tooth	Fig. 1 (TM)	Khatanga – Talalakh L	MacPhee et al. (2002)
71	GIN-11504	31 300 ± 200	Tusk	Fig. 1 (TM)	Taimyr	This report[f]
72	Beta-148631	31 580 ± 330	Tibia	Fig. 1 (TM)	Taimyr – Baikuraturku L	MacPhee et al. (2002)
73	GIN-3240a	31 800 ± 500	Skull	Fig. 1 (TM)	Taimyr – Severnaya River	
74	GIN-3117	32 000 ± 200	Femur	Fig. 1 (TM)	Taimyr – Bolshaya Balakhnya R	Stuart (1991)
75	GIN-2151	32 000 ± 500	Limb bone	Fig. 1 (TM)	Taimyr – Taimyr L, Matuda P	Stuart (1991)
76	GIN-11137	32 200 ± 800	Tooth	Fig. 1 (TM)	Taimyr – Kupchiktakh L	MacPhee et al. (2002)
77	GIN-5074	32 300 ± 400	Tusk	Fig. 1 (TM)	Khatanga basin area – Popigay R	Lavrov and Sulerzhitsky (1992)
78	Beta-148667	32 530 ± 270	Skull	Fig. 1 (TM)	Taimyr – Taimyr L, Sabler Cape	MacPhee et al. (2002)
79	GIN-8261	32 600 ± 700	Bone	Fig. 1 (TM)	Taimyr – Pyasina R, Farvaterniy Is	Sulerzhitsky and Romanenko (1997)
80	Beta-148632	32 750 ± 280	Tibia	Fig. 1 (TM)	Taimyr	MacPhee et al. (2002)
81	Beta-148641	32 840 ± 290	Femur	Fig. 1 (TM)	Taimyr – Arylakh L	MacPhee et al. (2002)
82	GIN-3821	35 000 ± 500	Femur w/ marrow	Fig. 1 (TM)	Taimyr – Logata R	Lavrov and Sulerzhitsky (1992)
83	GIN-3822	36 200 ± 500	Tusk	Fig. 1 (TM)	Taimyr – Logata R	Lavrov and Sulerzhitsky (1992)
84	GIN-5751	36 600 ± 500		Fig. 1 (TM)	Khatanga R basin, – Anabarka R	Lavrov and Sulerzhitsky (1992)
85	GIN-3122	36 800 ± 500	Tusk	Fig. 1 (TM)	Taimyr – Bolshaya Balakhnya R	Lavrov and Sulerzhitsky (1992)
86	Beta-148630	36 950 ± 450	Mandible	Fig. 1 (TM)	Taimyr – Arylakh L	MacPhee et al. (2002)
87	GIN-11137a	37 000 ± 400	Tusk	Fig. 1 (TM)	Taimyr	This report[f]
88	GIN-5750	37 000 ± 500	Tooth	Fig. 1 (TM)	Khatanga – Semieriskyay R	Lavrov and Sulerzhitsky (1992)
89	Beta-148666	37 080 ± 460		Fig. 1 (TM)	Khatanga – Popygai R	MacPhee et al. (2002)
90	GIN-11533	37 200 ± 400	Limb bone	Fig. 1 (TM)	Taimyr	This report[g]
91	GIN-942	38 000 ± 1500	Tusk	Fig. 1 (TM)	Khatanga R, Krestovskiy Mys	Kind et al. (1978)
92	GIN-3817	38 300 ± 600	Bone	Fig. 1 (TM)	Taimyr – Logata R	Sulerzhitsky (1995)
93	GIN-11513	38 300 ± 700	Humerus	Fig. 1 (TM)	Taimyr	This report[f]
94	GIN-3118	38 400 ± 700	Radius	Fig. 1 (TM)	Taimyr – Bolshaya Balakhnya R	Lavrov and Sulerzhitsky (1992)
95	GIN-27636	38 500 ± 500	Tooth	Fig. 1 (TM)	Taimyr – Bederbo-Tarida R	Lavrov and Sulerzhitsky (1992)
96	GIN-3136	38 500 ± 600	Femur	Fig. 1 (TM)	Taimyr – Bederbo-Tarida R	Lavrov and Sulerzhitsky (1992)
97	GIN-1491	38 800 ± 1300	Tusk	Fig. 1 (TM)	Taimyr – Trautfetter R	Lavrov and Sulerzhitsky (1992)
98	GIN-3476	38 800 ± 400	Tusk	Fig. 1 (TM)	Taimyr – Nemu-Dika-Tarida River	Sulerzhitsky et al. (1986)
99	GIN-3831	38 900 ± 600	Tusk	Fig. 1 (TM)	Taimyr – Logata R	Lavrov and Sulerzhitsky (1992)
100	Beta-148664	39 050 ± 580	Pelvis	Fig. 1 (TM)	Taimyr – Arylakh L	MacPhee et al. (2002);
101	GIN-3120/II	39 100 ± 1000	Ulna	Fig. 1 (TM)	Taimyr – Bolshaya Balakhnya R	Lavrov and Sulerzhitsky (1992)
102	GIN-3121/II	39 200 ± 700	Limb bone	Fig. 1 (TM)	Taimyr – Bolshaya Balakhnya R	Lavrov and Sulerzhitsky (1992)
103	GIN-3071	39 300 ± 500	Femur w/ marrow	Fig. 1 (TM)	Taimyr – Taimyr L, Baikura Neru B	Lavrov and Sulerzhitsky (1992)
104	GIN-11127a	39 300 ± 600	Tusk	Fig. 1 (TM)	Taimyr – Bolshaya Balakhnya R	MacPhee et al. (2002)
105	Beta-148638	39 560 ± 910	Mandible	Fig. 1 (TM)	Taimyr – Trautfetter R	MacPhee et al. (2002)
106	GIN-3135	39 800 ± 600	Skull	Fig. 1 (TM)	Taimyr – Bederbo-Tarida R	Lavrov and Sulerzhitsky (1992)

Table 1 (*continued*)

No.	Lab. number	Date ^{14}C yr BP	Dated bone/tissue	Position on the map	Locality	Source and remarks
107	GIN-11134	40 200 ± 600	Sacrum	Fig. 1 (TM)	Taimyr – Bolshaya Balakhnya R	MacPhee et al. (2002)
108	GIN-3804	40 200 ± 600	Tusk	Fig. 1 (TM)	Taimyr – Logata R	Lavrov and Sulerzhitsky (1992)
109	GIN-5025	40 300 ± 400	Tooth	Fig. 1 (TM)	Khatanga R. basin – Anabarka R	Lavrov and Sulerzhitsky (1992)
110	GIN-12710	40 300 ± 600	Limb bone	Fig. 1 (TM)	Taimyr	This report[f]
111	GIN-1818/II	40 500 ± 800	Limb bone	Fig. 1 (TM)	Taimyr – Engelgardt L	Lavrov and Sulerzhitsky (1992)
112	Beta-148645	40 560 ± 700	Pelvis	Fig. 1 (TM)	Taimyr – Taimyr L, Sabler Cape	MacPhee et al. (2002)
113	GIN-3100	40 600 ± 600	Limb bone	Fig. 1 (TM)	Taimyr – Bolshaya Balakhnya R	Lavrov and Sulerzhitsky (1992)
114	GIN-2744B	41 200 ± 1000	Limb bone	Fig. 1 (TM)	Taimyr – Bederbo-Tarida R	Lavrov and Sulerzhitsky (1992)
115	GIN-5224	41 900 ± 800	Tusk	Fig. 1 (TM)	Khatanga R. basin – Anabarka R	Lavrov and Sulerzhitsky (1992)
116	Beta-148648	42 420 ± 500	Tibia	Fig. 1 (TM)	Taimyr – Arylakh L.	MacPhee et al. (2002)
117	GIN-3946	42 800 ± 800	Bone	Fig. 1 (TM)	Khatanga R. basin – Massonov R	Sulerzhitsky et al. (1987)
118	GIN-3072	43 500 ± 1000	Humerus	Fig. 1 (TM)	Taimyr – Taimyr L, Baikura Neru B	Lavrov and Sulerzhitsky (1992)
119	GIN-766	45 000 ± 1000	Limb bone	Fig. 1 (TM)	Taimyr – Kheta R	Lavrov and Sulerzhitsky (1992)
120	GIN-3073	46 100 ± 1200	Scapula	Fig. 1 (TM)	Taimyr – Taimyr L, Baikura Neru B	Lavrov and Sulerzhitsky (1992)
121	GIN-11512	46 400 ± 1500	Limb bone	Fig. 1 (TM)	Taimyr	This report[f]
122	GIN-11514	47 200 ± 1400	Tusk	Fig. 1 (TM)	Taimyr	This report[f]
123	Beta-148669	47 660 ± 1650	Tooth	Fig. 1 (TM)	Khatanga – Popygai R	MacPhee et al. (2002)
124	GIN-3118a	47 900 ± 1600	Tusk	Fig. 1 (TM)	Taimyr – Bolshaya Balakhnya R	Lavrov and Sulerzhitsky (1992)
125	GIN-689	49 700 ± 1100	Tusk	Fig. 1 (TM)	Khatanga – Putorana Plt., Maymecha R	Lavrov and Sulerzhitsky (1992)
126	GIN-11508	>38 500	Limb bone	Fig. 1 (TM)	Taimyr	This report[f]
127	GIN-11128	>38 600	Rib	Fig. 1 (TM)	Taimyr	This report[f]
128	GIN-11502	>45 000	Limb bone	Fig. 1 (TM)	Taimyr	This report[f]
129	GIN-11509	>45 000	Humerus	Fig. 1 (TM)	Taimyr	This report[f]
130	GIN-11505	>49 100	Tusk	Fig. 1 (TM)	Taimyr	This report[f]
131	GIN-12160	>49 300	Limb bone	Fig. 1 (TM)	Taimyr	This report[f]
Bolshoy Lyakhovsky Island						
1	GIN-10713	12 030 ± 60	Ulna	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Kuznetsova et al. (2003), Sher et al. (2005)
2	GIN-10716	12 500 ± 50	Tusk	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Kuznetsova et al. (2003), Sher et al. (2005)
3	GIN-11084	20 800 ± 100	Bone	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Andreev et al. (2004)
4	GIN-10707	22 100 ± 1000	Pelvis	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Kuznetsova et al. (2003), Sher et al. (2005)
5	GIN-10708	25 900 ± 600	Pelvis	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Kuznetsova et al. (2003), Sher et al. (2005)
6	GIN-10706	28 000 ± 180	Ulna	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Kuznetsova et al. (2003), Sher et al. (2005)
7	MAG-316	32 100 ± 900	Skin	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Lozhkin (1977)
8	GIN-10659	32 500 ± 500	Vertebrae	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Kuznetsova et al. (2003), Sher et al. (2005)
9	GIN-8739	32 500 ± 1000	Bone	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Kuznetsova et al. (2003), Sher et al. (2005)
10	GIN-11085	33 000 ± 320	Bone	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Andreev et al. (2004)
11	GIN-8740	34 800 ± 1000	Bone	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Kuznetsova et al. (2003)
12	GIN-8741	35 100 ± 1800	Bone	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Kuznetsova et al. (2003)
13	GIN-8738	36 500 ± 1600	Bone	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Kuznetsova et al. (2003)
14	GIN-10660	37 800 ± 900	Vertebrae	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Kuznetsova et al. (2003), Sher et al. (2005)
15	GIN-11705	38 700 ± 500	Bone	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Andreev et al. (2004)
16	GIN-10714	39 600 ± 1000	Femur	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Kuznetsova et al. (2003), Sher et al. (2005)
17	GIN-10703	40 200 ± 900	Humerus	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Kuznetsova et al. (2003), Sher et al. (2005)
18	GIN-8813	42 700 ± 1300	Bone	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Kuznetsova et al. (2003), Sher et al. (2005)
19	GIN-10717	43 600 ± 1000	Scapula	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Kuznetsova et al. (2003), Sher et al. (2005)
20	OxA-17111	50 200 ± 900	Hair	Fig. 1 (L)	Bolshoy Lyakhovsky Island, southern coast	Gilbert et al. (2007)
Bykovsky Peninsula						
1	GIN-10267	12 770 ± 170	Carpale	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
2	GIN-10242	13 100 ± 500	Pelvis	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)

(*continued on next page*)

Table 1 (*continued*)

No.	Lab. number	Date ^{14}C yr BP	Dated bone/tissue	Position on the map	Locality	Source and remarks
3	KIA-10679	14 220 ± 80	Skull	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
4	KIA-10680	14 320 ± 60	Rib	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
5	GIN-9881	14 340 ± 280	Metacarpale	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
6	GIN-10239	14 500 ± 110	Scapula	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
7	GIN-10240	14 500 ± 140	Pelvis	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
8	GIN-10234	14 600 ± 100	Rib	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
9	GIN-9907	14 730 ± 60	Pelvis	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
10	GIN-10236	20 200 ± 100	Scapula	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
11	GIN-10248	20 800 ± 600	Metacarpale	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
12	LU-1328	21 630 ± 240	Carpale	Fig. 1 (B)	Bykovsky Peninsula	Tomirdiaro et al. (1984)
13	GIN-9893	23 050 ± 120	Mandible	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
14	GIN-9908	23 100 ± 1200	Metacarpale	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
15	GIN-10264	24 300 ± 200	Vertebra	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
16	GIN-9887	24 800 ± 90	Femur	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
17	GIN-9880	25 000 ± 300	Carpale	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
18	GIN-9882	26 500 ± 230	Femur	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
19	GIN-9896	26 700 ± 900	Pelvis	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
20	GIN-10262	27 400 ± 800	Limb bone	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
21	GIN-10238	28 200 ± 900	Epistropheum	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
22	GIN-9906	28 700 ± 800	Ulna	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
23	GIN-9904	28 800 ± 180	Tusk	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
24	GIN-10247	28 900 ± 200	Pelvis	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
25	GIN-10245	29 400 ± 600	Rib	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
26	GIN-10244	30 300 ± 600	Ulna	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
27	GIN-10260	30 600 ± 900	Ulna	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
28	GIN-10249	31 500 ± 650	Metatarsale	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
29	GIN-9901	32 500 ± 300	Tibia	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
30	GIN-10266	32 800 ± 800	Femur	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
31	GIN-9884	33 000 ± 450	Tibia	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
32	GIN-9890	33 610 ± 300	Tusk	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
33	GIN-10263	33 800 ± 260	Tibia	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
34	GIN-10261	34 000 ± 500	Limb bone	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
35	GIN-9895	34 300 ± 320	Tusk	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
36	GIN-9897	34 900 ± 400	Pelvis	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
37	GIN-9898	35 500 ± 500	Tusk	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
38	GIN-9892	35 700 ± 700	Humerus	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
39	T-171(2)	35 800 ± 1200	Soft tissue	Fig. 1 (B)	Bykovsky Peninsula	Heintz and Garutt (1964)
40	GIN-9900	44 500 ± 1000	Atlas	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)
41	GIN-9891	44 500 ± 1100	Tibia	Fig. 1 (B)	Bykovsky Peninsula	Schirrmeister et al. (2002)

[a] Material collected by Anisimov and Tumskoy.
[b] Material collected by Romanenko.
[c] Originally published in Nikolaev et al. (2000).
[d] Originally published in Nikolskiy et al. (1999).
[e] Originally published in Nikolskiy and Basilyan (2003).
[f] Material collected by Koriagin.
[g] Material collected by Orlov.

remains from the sites of death. A considerable quantity of bones was preserved due to permafrost conditions. Active thermoerosion in Arctic islands and peninsulas then exposed a significant number of bones. These conditions of taphonomy, preservation, and exposure of bones are optimal for investigating time-related animal number fluctuations.

In order to evaluate the influence of local taphonomic and geological conditions on the time-distribution of dates, we have compared the areal samples (NS, TM) with three spot samples. The latter material came from the following sites: Oyogos-Yar, south side of Dmitri Laptev Strait – Fig. 1 OY, original data; Mamontova Khayata, Bykovsky Peninsula, Laptev Sea coast – Fig. 1B (Heintz and Garutt, 1964; Tomirdiaro et al., 1984; Schirrmeister et al., 2002); and Maloe Zimovye, Bolshoi Lyakhovsky Island, northern side of Dmitri Laptev Strait (Fig. 1 L) (Kuznetsova et al., 2003; Sher et al., 2005).

For the analysis we used both uncalibrated and calibrated dates when appropriate. To calibrate dates we have applied the CalPal_2007 software developed by Weninger et al. (2009).

We used a density trace and a frequency histogram techniques for showing the variation in frequency (concentration) of data points through time. The density trace plots were constructed by recording the number of observations within an interval of 10% of the horizontal axis as it is moved along the *x*-axis, and weighting them using the cosine function.

For plotting frequency histograms, samples were empirically divided into classes of 1200 years, which on the one hand would preserve important peaks of density distributions, and on the other hand minimizes noise. In addition, it is worth noting that the selected histogram interval exceeds the instrumental error of radiocarbon age measurements which in the oldest dates can amount to thousand years and more.

We use Pearson correlation coefficients (r) for statistical comparisons between samples. For each 1200-year bin we take the number of dates in one of the comparative samples and the number of dates in the other, and these are the paired x, y values. We examine the probability value (p) to test if the correlation is significant. For all cases we additionally use visual matching of diagrams for comparisons between samples.

The validity of the first hypothesis (number of dates reflects the number of animals) makes it possible to evaluate the second hypothesis (number of animals is climate-related). For this we have compared the observed distributions of radiocarbon dates with a series of high-resolution climatic proxies, as follows:

2.1. Record of changes in insect faunas from Late Pleistocene deposits of the Lena River delta

The recently published record of changes in insect faunas, from about 50 ka to the beginning of the Holocene, is based on materials from the section of Late Quaternary deposits at the Mamontova Hayata site, Bykovsky Peninsula, the Lena River delta, Arctic Siberia (Fig. 1B) (Sher et al., 2005). Fossil entomofaunas are very sensitive indicators of environmental changes (vegetation, annual temperature, humidity) in the Pleistocene (Berman and Alfimov, 1993; Elias, 1999; Kuzmina, 2001; Alfimov et al., 2003; Kuzmina, 2003). All studied insect species are extant. Data on modern ranges and environmental conditions allow us to reconstruct the relative changes of environment during the specified time interval. The analysis of insects from the Bykovsky section is aided by a parallel study of palynology and plant remains. A sufficient number of dates (about 100) and their mutual control help validate the accuracy of the correlation between age and climatic indicators. The record of fossil insects is sufficiently detailed and contains only a few gaps. The Bykovsky Peninsula (Fig. 1) is located just between the New Siberian Islands and Taimyr Peninsula, which makes the place ideal for studying regional past climatic changes to compare with mammoth number fluctuations.

2.2. Pollen and insect record in lower Yana River, Arctic Siberia

A high-resolution paleoclimatic archive comes from Lower Yana Paleolithic site at 70°43′N, 135 °25′E, Yana River, Arctic Siberia (Pitulko et al., 2004). This well radiocarbon-dated pollen and insect record spanning 34 000 years was another climatic proxy we used to compare with mammoth date distributions. Based on the environment encompassing the current distribution of plant taxa (the environmental envelope), Pitulko et al. (2007) and Pavlova et al. (2009) reconstructed the average temperatures of the warmest month and mean precipitation. Floristic data were controlled by paleoentomological proxies. This reconstruction of the paleoenvironmental conditions in terms of absolute temperature and moisture is important as it make it possible to estimate the response of mammoth population to these climatic factors.

2.2.1. Lake El'gygytgyn (Chukotka, Russian Far East) climatic proxy records

El'gygytgyn meteorite impact lake (67°30′N, 172°05′E, Russian Far East) is the largest and oldest unglaciated lake basin in the Arctic. Its sediments represent a 3.6 million-year-long, mostly time-continuous record of late Cenozoic Arctic climate evolution. We have used for comparison the magnetic susceptibility record during the last glacial cycle as a proxy for changes in past temperature (Asikainen et al., 2007; Brigham-Grette et al., 2007). Magnetic susceptibility is a proxy for changes in anoxia driven by changes in seasonal lake ice cover, in turn a function of temperature and insolation (Asikainen et al., 2007).

2.2.2. Lake Baikal (South eastern Siberia) climatic proxy record

Core data from Lake Baikal form one of the most promising sources of information on the paleoenvironments of northern Asia. The continuity of the paleoclimatic record, its sensitivity to orbital forcing, and its high resolution make it a candidate for a "paleoclimatic stratotype" section for continental Asia (Prokopenko et al., 2000). Climatic cycles are recorded in Lake Baikal as changes of productivity seen in diatom abundance, organic carbon accumulation, changes in biogenic silica concentrations, sponge spicule concentration, lithology, and some geophysical and isotope parameters. We have chosen the sponge spicule concentration record (Weinberg et al., 1999) as a very sensitive, high-resolution and continuous climatic proxy.

2.2.3. Greenland ice-core data

Greenland ice-core data have proven to be one of the most important sources of information on past climate. Ice-core isotope record sensitively responded to temperature fluctuations during the last glacial cycle (Dansgaard et al., 1993; Bender et al., 1994; Meese et al., 1994a,b). Strong similarities in oxygen isotope record in six Greenland ice-cores (Camp Century, Dye-3, GRIP, GISP2, Renland and NorthGRIP) have recently been revealed (Johnsen et al., 2001). This suggests that the dominant influence on oxygen isotope variations reflected in the ice-sheet records was climatic change. We have chosen the GISP2 d^{18}O values record (Grootes et al., 1993; Meese et al., 1994a,b; Stuiver and Grootes, 2000) with age model tuned to Hulu cave data (Weninger and Joöris, 2008).

2.2.4. Mg/Ca ratio in marine ostracod shells from the North Atlantic

Dwyer et al. (2002) reconstructed time-series of last-glacial cycle deep-sea temperature from water sediment cores from the western North Atlantic using Mg/Ca ratios of benthic ostracod shells. Mg/Ca analysis suggests that multiple-shell average Mg/Ca ratios provide reliable estimates of bottom-water temperature history. The water temperature records show glacial-to-interglacial variations, and changes during the deglaciation and the Holocene. The ostracod Mg/Ca ratio study provides evidence that deep-ocean circulation is closely linked to climate change over a range of timescales regardless of the mean climate state. Thus, benthic Mg/Ca ratios are a good proxy for high-resolution reconstruction of past climate conditions.

Agreement between these very differently originating climatic records and mammoth ^{14}C date frequencies would strongly suggest the dependence of past animal numbers on climate.

3. Results

3.1. Comparison between frequency distributions of ^{14}C dates on mammoths from different regions of Arctic Siberia

3.1.1. New Siberian Islands versus Taimyr region

The frequency distributions of ^{14}C dates of the NS and TM series are shown in Fig. 3. Most parts of the distributions are clearly in close agreement: correlation coefficient is 0.89, $p < 0.05$ at two scale segments 13 000–29 000 and 46 000–48 000 ^{14}C years BP, which covers 45% of the curve; correlation coefficient is 0.79, $p < 0.05$ if we exclude the segment between 31 700 and 41 000 ybp which reduces the overall correlation because of the weak negative correlation seen in this short fragment. The coefficient correlation of frequencies without any removals is 0.21, $p < 0.05$.

We interpret this correlation as an effect resulting from the same influence, i.e. uniform fluctuation of animal numbers in two extensive regions of Arctic Siberia during the last millennia of the Pleistocene.

3.1.2. New Siberian Islands and Taimyr region versus spot-sample-based frequency distributions

We assume that the comparison of *areal* and *spot* samples should reflect the degree of local taphonomic influences on the distribution patterns. All three spot series (B, OY, L) show marked differences from the areal, NS and TM, series (Fig. 4A, 5B, C).

Considering different segments across the six pairwise comparisons (Fig. 4), the correlation coefficients vary from −0.22 to 0.52; moreover, that fraction of the correlation coefficients which are relatively high (0.4–0.5) never reaches more than 20%. Thus, it is obvious that the local sites (OY, B, and L), even if they

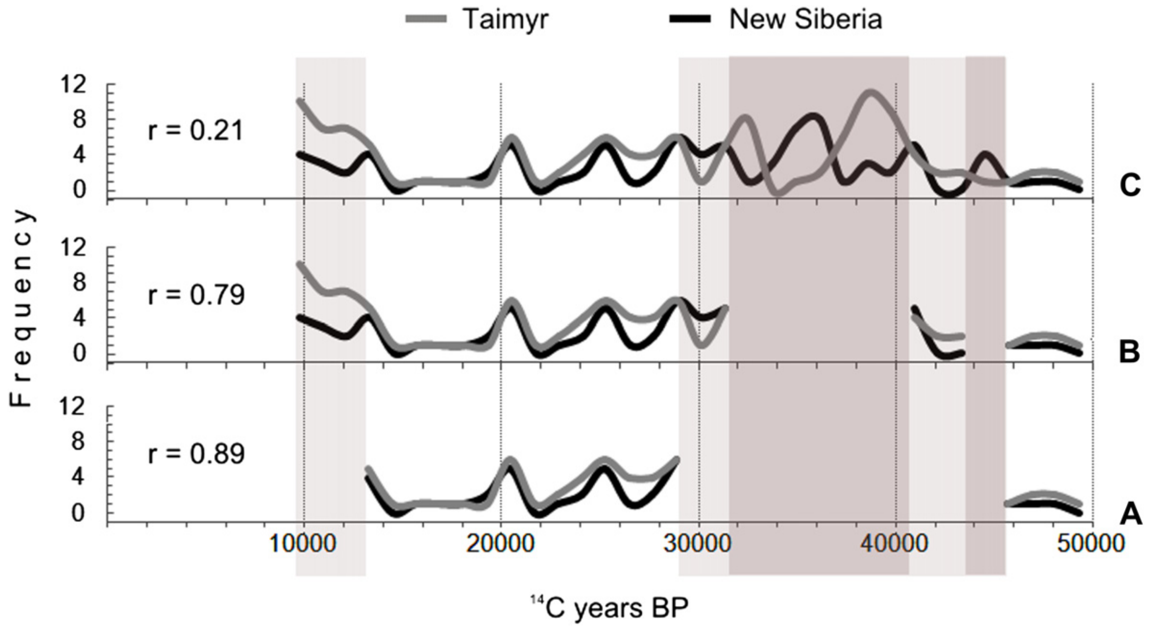

Fig. 3. Comparison of time-related densities of mammoth-based ^{14}C dates from the New Siberian Islands and the Taimyr region. (A) Fragments of curves with maximal correlation coefficient ($r = 0.89$, $p < 0.05$). (B) Fragment of curves where correlation coefficient is lower, but still is very considerable ($r = 0.79$, $p < 0.05$). (C) The total curve length correlated: correlation coefficient is weak ($r = 0.21$, $p < 0.05$) because of the negative correlation in the interval 31 700–41 000 radiocarbon years BP.

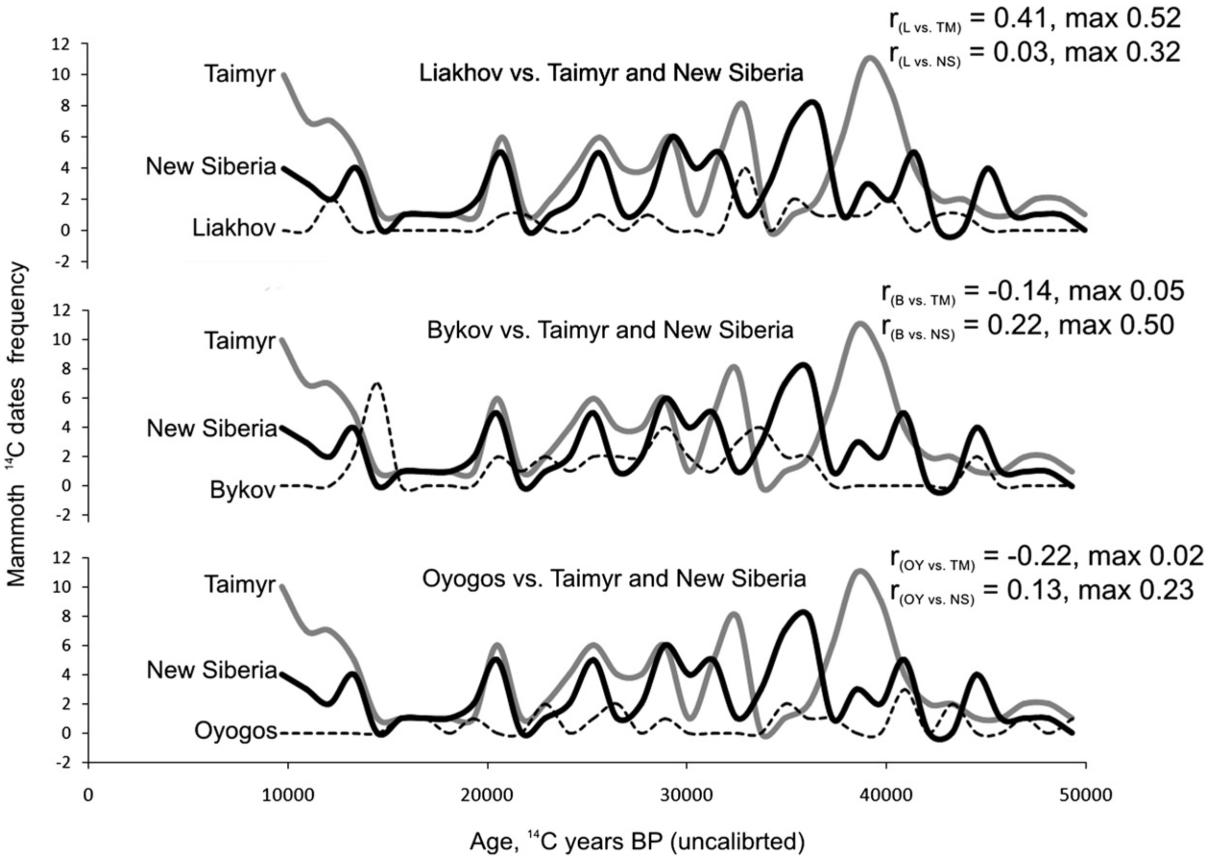

Fig. 4. Comparison of time-related density distributions of mammoth-based ^{14}C dates of "areal" type (New Siberia and Taimyr), and "spot" type: Bykovsky Peninsula, Oyogos-Yar, and Bolshoi Lyakhovsky Island. Indexes after each of the correlation coefficient symbols "r" indicate the pair of samples that have been compared (e.g. "$r_{(\text{L vs. TM})}$" means the comparison of the Bolshoi Lyakhov Island sample and the Taimyr sample). The first value of the correlation coefficient shows the correlation coefficient of the total curve length, the second value of the correlation coefficient shows the maximal correlation coefficient if we consider different portions of the curves.

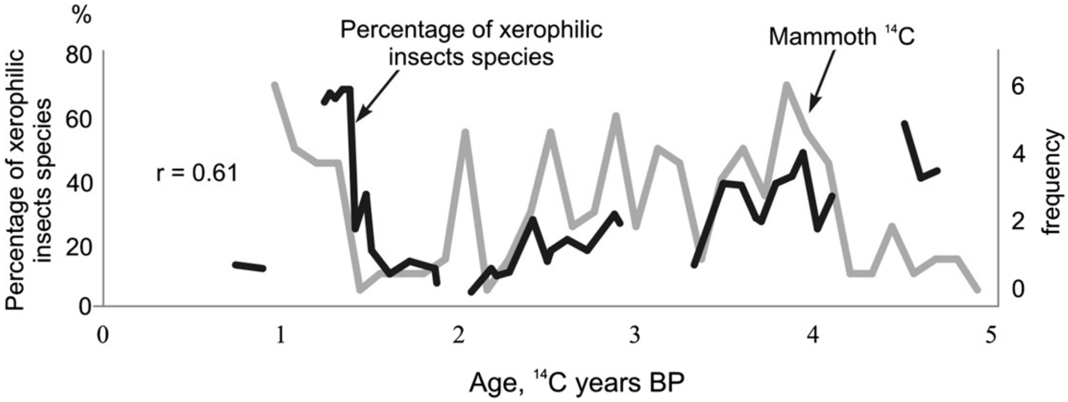

Fig. 5. Comparison of mammoth ^{14}C date frequencies and insect paleoenvironmental proxy record. The black line shows the percentage of xerophilic insect species. The gray line denotes frequencies of ^{14}C mammoth dates from New Siberian Islands and Taimyr Peninsula (combined).

were very productive, do not yield a representative sequence that adequately reflects the changing abundance of animals during the interval. Possible reasons include intermittency and irregularity of the terrestrial sedimentation, the low probability of uniform burial, and exposure rates on a strip of land that is a few kilometers long. The probability of taphonomic biases decreases when the studied material comes from a wider area and from multiple sites.

It is evident that a fluctuating trend over a period of tens of thousand years is present in all five distributions. This does not contradict the above conclusions. The effect of the largest fluctuations in animal numbers apparently overrides the effect of most local geological biases. The precise evaluation of the impact of local taphonomic factors on the distribution of dates, however, remains a difficult task. This is why we regard the results of studies based on all available dates, without applying the quality constraints outlined above, as debatable (see for example: Kuzmin, 2007, 2010).

3.2. *Changes in numbers of mammoths in Arctic Siberia in the Late Pleistocene and early Holocene based on time-related density distributions of ^{14}C dates*

We assume that the clear similarity of the samples originating from two Arctic regions (NS and TM), situated more than 1000 km from each other, provides ample evidence to support the first hypothesis: “Under certain sampling conditions the frequency of radiocarbon dates of mammoth corresponds with the time-related numbers of this animal.” It is evident, that the number of dates can only give an idea about relative, not absolute, animal numbers.

The distribution of dates shows that woolly mammoths populated vast areas, including the New Siberian Islands and the Taimyr region, from some 49 000 until 9470 radiocarbon years BP, or from about 55 000 to 10 700 calendar years BP. There were three minima of relative mammoth numbers during the last 49 000 years: 22 000, 14 500–19 000, and 9500 radiocarbon years ago, or around 26 000, 16–20 000, and 10 500 calendar years respectively. Significant peaks are observed at about 35 000–39 000 radiocarbon years (40 000–45 000 calendar years), and 10 000–14 000 ^{14}C years BP (11 000–15 500 calendar years BP).

The collection of youngest radiocarbon dates suggests explosive growth of mammoth numbers both in the New Siberian Islands (New Siberian Islands were connected to the continent), and in the Taimyr Peninsula, just before the Pleistocene-Holocene transition (PHT). A new ^{14}C date (GIN-11874) of 9470 ± 40 (10 700 ± 70 calendar years BP) indicates the last (known so far) occurrence of mammoth in the mainland of the Holarctic.[4] Along with many other new PHT dates (Table 1) this material suggests a broad expansion of the last mainland mammoth refugium to the east, up to the 150 E. The details of mammoth extinction will be discussed later.

3.3. *Comparison of the time-distribution of ^{14}C dates on mammoths and climatic proxy data*

Similar density distribution patterns of mammoth-based radiocarbon dates from two far-apart regions of the eastern Arctic demonstrate that the observed fluctuations mostly reflect changes in animal numbers and are only faintly affected by geological, taphonomic, and erosional factors. This conclusion permits us to search for the causes of fluctuations in numbers of Arctic Siberian mammoths through the Late Pleistocene and early Holocene.

3.3.1. *Record of changes in insect faunas from the Late Pleistocene deposits of the Lena River delta*

The comparison of fluctuations in mammoth numbers and the percentage record of xerophilic insects shows a striking covariation of the curves (Fig. 6). The correlation coefficient of 0.62, $p < 0.05$, suggests significant dependence of both processes on a third factor. It is likely that climatic temperature and moisture changes resulted in this effect.

These observations also corroborate the broadly accepted concept that mammoths strongly depended on a steppe-like landscape (the xerophilic insect percentage positively depends on the amount of steppe vegetation). Note that the mammoth record terminates at exactly the moment when the percentage of xerophilic insects dramatically drops to a very low value (9700 ^{14}C ybp). Although there is a short hiatus in the insect record during this transition, the insect composition immediately after the event suggests covariation of both factors.

3.3.2. *Pollen and insect record of the last 34 ka in the lower Yana River, Arctic Siberia*

The Yana River record provides fairly detailed and well-dated proxy data of absolute temperature and moisture spanning 9500–34 000 ybp. Although the Yana River site is somewhat to the south of the study area, data suggest that it supplies a rather realistic general picture of past climates across the entire region, because during the cold phases of the Pleistocene the latitudinal

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[4] In Wrangel (Vartanyan et al., 1993, 1995, 2008; Vartanyan, 2007) and Pribilof Islands (Guthrie, 2004; Veltre et al., 2008) woolly mammoths survived longer.

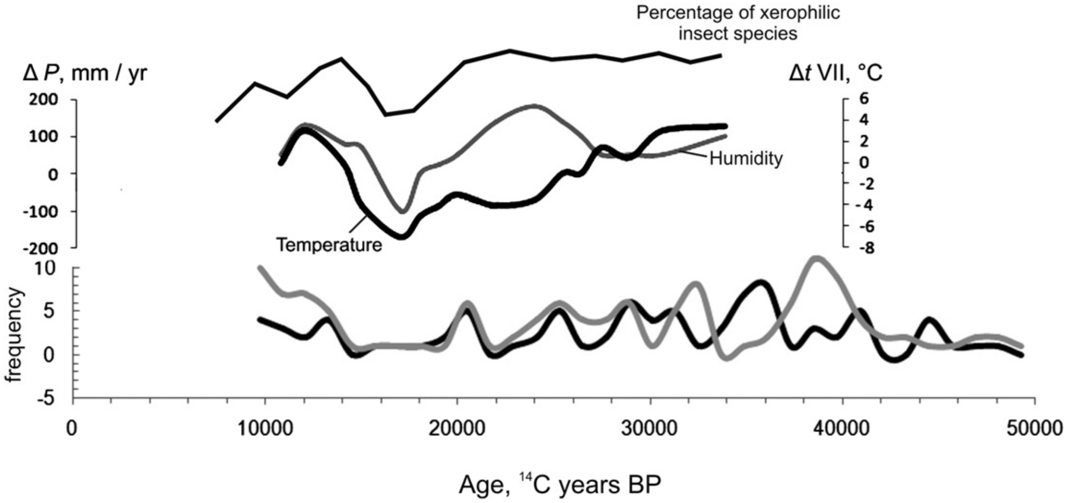

Fig. 6. Comparison of mammoth numbers and the Yana River site climatic proxy record. Upper curve, the percentage of xerophilic insect species; middle black curve, the average temperatures of the warmest month; middle gray curve, annual mean precipitation (based on the “environmental envelope” – the environment encompassing the current distribution of a plant taxa (Pitulko et al., 2007, Pavlova et al., 2009)), all parameters presented as deviations from their present-day values. Lower black curve, frequency of mammoth dates from the New Siberian Islands, lower gray curve, frequency of mammoth dates from the Taimyr peninsula.

climatic gradient was low. We can infer that general trends in mammoth numbers are similar to those of the humidity and summer temperature (Fig. 6).

The correlation coefficient between ^{14}C numbers and maximal summer temperature is 0.58, $p < 0.05$. For radiocarbon date numbers and humidity the value is 0.54, $p < 0.05$. That suggests a positive dependence between mammoth numbers and both summer temperature and annual moisture during the colder phase of the Late Pleistocene.

3.3.3. *El’gygytgyn Lake paleoenvironments record: change of magnetic susceptibility during the last glacial cycle*

Comparison of mammoth ^{14}C frequencies and the Lake El’gygytgyn (E-Lake) magnetic susceptibility – a proxy for temperature and insolation – demonstrates a positive correlation. The correlation coefficient is 0.61, $p < 0.05$ (Fig. 7). Millennial-scale anomalies of the E-Lake record do not fit so closely those of mammoth ^{14}C frequencies. This can be interpreted either as a real difference between small-scale climatic changes in the studied regions, or by imprecision in the age model applied to the E-Lake record – two age models proposed by Lozkhin et al. (2007) and Nowaczyk et al. (2007) provide scales which differ considerably one from another.

3.3.4. *Lake Baikal core record: concentrations of sponge spicules over time*

The comparison of the Lake Baikal climatic proxy record (based on sponge spicules) and mammoth date frequencies suggests a clear agreement between these differently scaled cycles (Fig. 8). The correlation coefficient reaches 0.73, $p < 0.05$.

3.3.5. *Greenland ice-core data: GISP2 d^{18}O values*

The smaller-scale fluctuations of GISP2 d^{18}O record do not conform the mammoth date frequencies – the correlation coefficient is 0.014 (Fig. 9). However if the GISP2 curve is shifted backward by 1100 years (Fig. 9) the conformity in the 13 000–36 000 ybp time span is pronounced ($r = 0.56$, $p < 0.05$). Atleast four different explanations for this phenomenon can be suggested:

1. There is a natural lag between the response of local environments and the global climatic changes.
2. The age model of the GISP2 d^{18}O record is not sufficiently precise.
3. The calibration of the mammoth ^{14}C dates is not correct.
4. There is no dependence between mammoth abundance and climate.

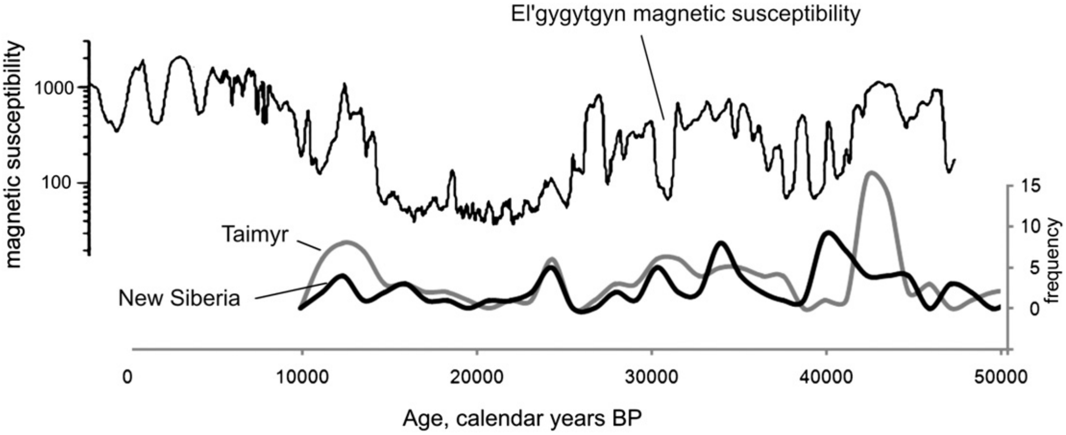

Fig. 7. Comparison between mammoth ^{14}C frequencies and Lake El’gygytgyn magnetic susceptibility, which is believed to be a proxy for temperature and insolation.

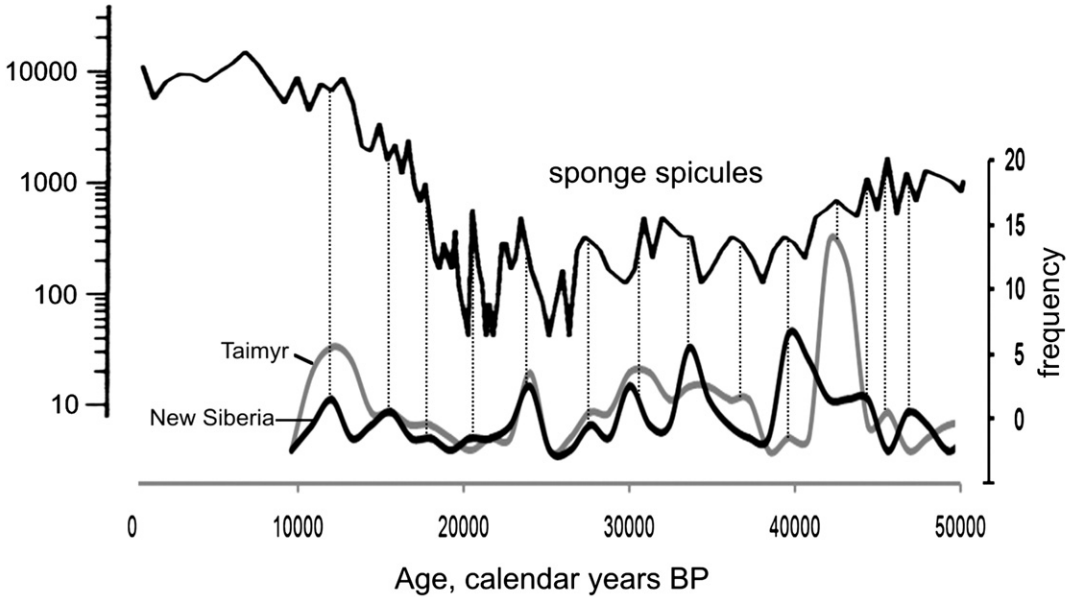

Fig. 8. Comparison of the Lake Baikal climatic proxy record (sponge spicules) and mammoth date frequencies.

We probably can reject the hypotheses 3 and 4, because some of the studied climatic proxies fit mammoth ^{14}C frequency distributions quite well. Hypotheses 1 and 2 appear to be more credible. In any case, cycles tens of thousands of years long (Milankovitch-scale) are visible both in the GISP2 d^{18}O record and the Siberian mammoth date frequencies.

3.3.6. *Mg/Ca ratio in marine ostracod shells from the North Atlantic*

Comparison of the mammoth date frequency record and the Mg/Ca ratio in marine ostracod shells from the North Atlantic reveals surprisingly high covariation: $r = 0.65$, $p < 0.05$ (Fig. 10). This probably reflects a similar response of West Beringian environments and the environments in certain parts of North Atlantic, to global climatic changes.

Not all the studied climatic proxies fit mammoth ^{14}C frequency distributions perfectly. This is to be expected as the different proxies do not all agree with one another, but least the general, tens of thousands of years-long cycles, are clear in all datasets. Smaller-scale fluctuations sometimes excellently fit the mammoth curve, sometimes not. New research is needed to evaluate the observed millennial-scale variations in mammoth date distributions. Thus, the comparison of mammoth ^{14}C frequencies (a reflection of mammoth numbers) and different climatic proxy data from northern Asia, Greenland and the North Atlantic suggests a positive dependence between mammoth numbers and climatic temperature spanning 49 000 to roughly 10 000 calendar years BP.

4. Discussion

The remarkable agreement between the patterns of fluctuation in mammoth numbers in the Taimyr area and the New Siberian Islands (Fig. 3) indicates a common external cause. The strong correlation of mammoth numbers with many climatic proxies

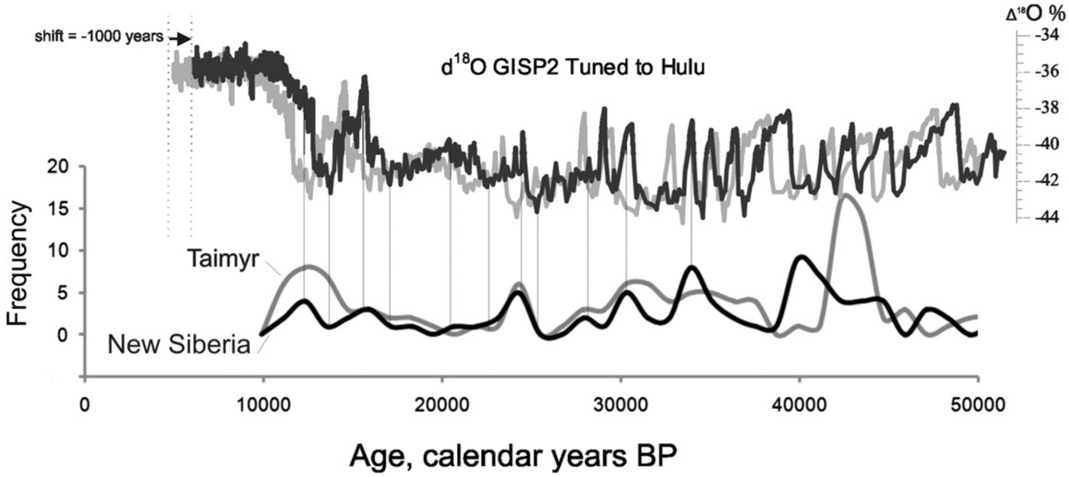

Fig. 9. d^{18}O GISP2 Tuned to Hulu (Grootes et al., 1993; Stuiver and Reimer, 1993; Meese et al., 1994a,b) versus mammoth radiocarbon date frequencies. The maximal conformity is reached when GISP2 curve is shifted on 1000 years back position (original position, gray line, shifted, black line).

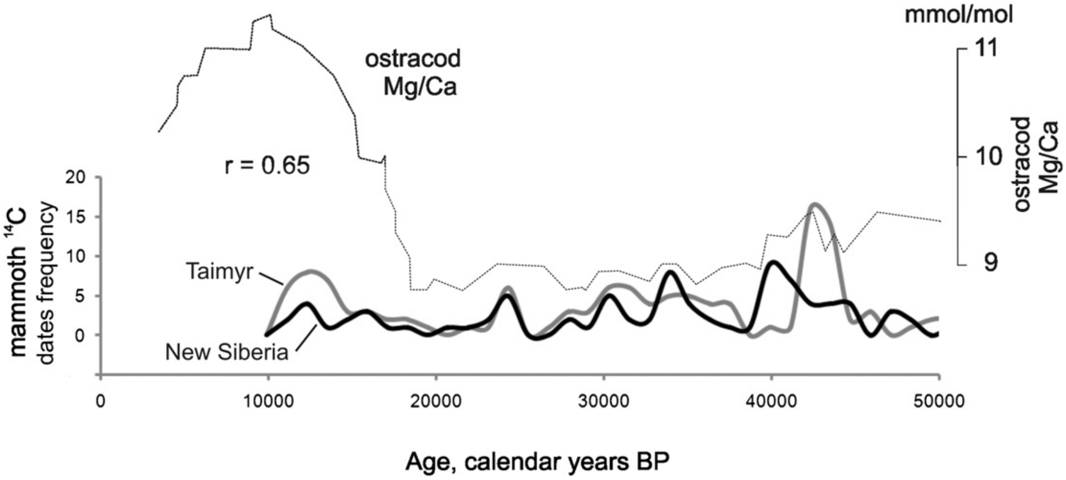

Fig. 10. Comparison of the mammoth date frequency record and the Mg/Ca ratio in marine ostracod shells from the North Atlantic.

stresses the dominant role of climatic factors. However, the response of mammoth populations to the climatic changes was not always the same. During the cold and moderately cold phases of the Late Pleistocene, mammoth numbers correlate positively with Milankovitch-scale and also most of the smaller, millennial-scale temperature changes (Figs. 5–10). Between 10 000 and 9000 ^{14}C ybp the trend is reversed – the global increase of temperature which caused rise in numbers of mammoth previously, this time,

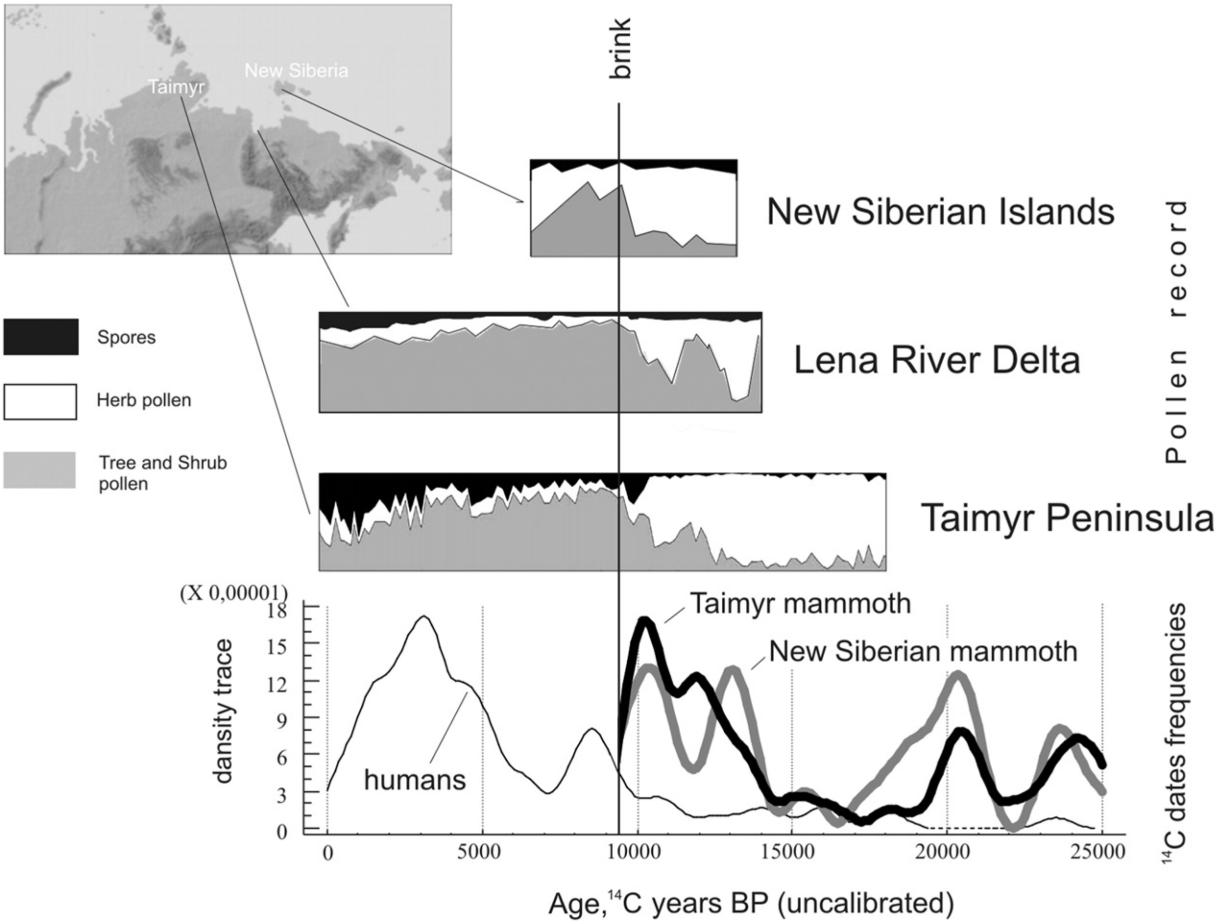

Fig. 11. Comparison between Arctic Siberia mammoth numbers, North-East Siberia human ^{14}C date frequencies, and the climatic proxy record of Arctic Siberian pollen. Pollen data: Taimyr Peninsula (Andreev et al., 2004); Lena River Delta (Pisaric et al., 2001); New Siberian Islands (Makeyev et al., 2003) demonstrate the most important moment of “slamming shut” of steppe-like landscapes, which occurred 9500 ^{14}C ybp all around the studied area. Note that most dated archeological sites occur to the south and to the east of the terminal mammoth population area.

with higher absolute temperatures reached, resulted in a reduction in numbers (Fig. 11). This evidently results from the ecology of the mammoth. The insect communities and plant fossil data from the Bykovsky Peninsula (Kienast et al., 2005; Sher et al., 2005), the lower Yana River (Pitulko et al., 2007; Pavlova et al., 2009), and Taimyr peninsula (Andreev et al., 2003, 2004) provide data on environments and climate spanning up to 55 ka. During the moderately cold stage preceding the LGM, arctic plant species coexisted with steppe, meadow aquatic and littoral taxa. Xerophilic species played an important role in the insect communities. The floristic and insect compositions reflect a continental, semi-arid climate with cold low-snow winters, and summers noticeably warmer than at present (Guthrie, 1990; Sher, 1997; Yurtsev, 2001). Productive steppe and meadow communities were very favorable for Late Pleistocene herbivores including mammoth. Mammoths existed in their largest numbers. Further cooling, slightly before and especially during the LGM, brought stronger climatic contrasts, with cool, dry summers and extremely cold winters. These unfavorable conditions decreased the number of animals, but the population quickly recovered when it became even slightly warmer in summer. A relative warming, which started 14 500 radiocarbon years bp, briefly restored the optimal conditions for mammoths. However, further very intensive warming sharply deteriorated the mammoth's environment. Plant macrofossil, pollen and insect assemblages dated to about 9500 radiocarbon ybp indicate a sharp paludification possibly caused by atmospheric humidity due to marine transgression increasing oceanic influence (Fig. 11).

Many steppe-adapted plant and insect taxa vanished from the area. Productive grass biomes were replaced by low-productivity taiga and tundra communities. Grazing areas were also shrinking due to greater watering of landscapes, dissection of relief (due to the thermoabrasion of the permafrost ground), and extensive transgression of the Arctic Ocean. Furthermore, the increased winter temperatures and moisture led to higher snow cover. This hampered winter foraging and increased the probability of spring floods, which were sometimes catastrophic (Nikolskiy et al., 2010). This combination of unfavorable conditions caused the great reversal in the response of mammoth populations to the climatic change. This time, the increase in annual temperature reduced mammoth numbers (this paper) and areal size (Stuart et al., 2002; Orlova et al., 2004). The extreme decrease in the mammoth populations pushed the species to the brink of extinction.

Thus, we consider climatic oscillations as the most important factor in controlling changes in the mammoth population. Climate had a direct and indirect influence over the mammoths and drove them to a critically small population size at the very beginning of the Holocene. Were these factors decisive in the ultimate extinction of *Mammuthus primigenius* in the Holocene? Extremely low numbers were very probably experienced by the species at various times in the past (Nogués-Bravo et al., 2008). At any rate, large-scale warming events, the interglacial periods similar to the Holocene, occurred many times in the Pleistocene, yet no extinction happened.

Archeological data need to be taken into consideration. The appearance of humans in Arctic Siberia at about 28 000 radiocarbon years (Pitulko et al., 2004), documented by the Yana Paleolithic Site, evidently did not visibly affect the mammoth (Fig. 3). Although Arctic coastal lowlands were most likely already inhabited, the mammoth population in the north of Siberia would not have experienced any serious human pressure because humans were still very rare in these regions. Moreover, it is not clear if significant mammoth mortality occurred due to hunting. The archaeozoological record of the Yana Site shows that mammoths did not play an important role as hunted prey. The number of its bones is much lower than the number of remains of other large herbivores, particularly horses.

The archaeological evidence of active human dispersal in northern and eastern Siberia becomes clearer with the spread of the Dyuktai Culture, roughly correlative to the LGM (Pitulko, 2006). In Northeast Asia, a number of sites – represented by the Dyuktai, Ezhantsy, Verkhnetroitskaya (with reservations), Khaiyrgas, Avdeikha and, probably, Berelyokh and Ushki I (bed VI) cultures – have been radiocarbon dated between 18–20 and 11–12 ka (Dikov, 1979; Mochanov, 1977; Mochanov and Fedoseeva, 1975; Kostukevich et al., 1980; Stepanov et al., 2003; Goebel et al., 2003). Notwithstanding relatively few known sites and poor knowledge of the vast Arctic region, the existence of a significant human population density by the end of the Pleistocene seems probable. People are believed to have populated the valleys of all the major rivers in the north and east of Siberia (Pitulko, 2001). Did the growing density of humans affect the population of mammoths? It is clear that the effect (if any) was quite limited. The number of dates on mammoths corresponding to the interval from 15 000 ^{14}C ybp to the beginning of the Holocene forms a significant peak and then shows an abrupt decline to zero (Fig. 11). The population of mammoths expands in parallel to the growing number of terminal Paleolithic sites, i.e. increasing number of mammoths with an increasing density of human population. This phenomenon has recently been independently described by Ugan and Bayers (2007). Thus, the sustainable population of Asian woolly mammoths was not observably affected by the presence of humans. This allows us to reject the "Blitzkrieg overkill" hypothesis of the mammoth extinction in Asia (extermination of mammoth by humans shortly after the first contact).

The global restructuring of environments in Arctic Siberia at the Pleistocene–Holocene boundary resulted in shrinkage of the formerly extensive range of mammoth. The youngest dates on mammoths have been shown to concentrate in the northernmost areas, including Yamal, northern Taimyr and Wrangel Island (Vartanyan et al., 1993, Vartanyan et al., 1995; Sulerzhitsky, 1997; Stuart et al., 2002). This trend is supported by new data from the New Siberian Islands and the adjacent mainland (this paper). The northern range shift and decrease in body size (see for example Vartanyan et al., 1993; Mol et al., 2006) could have secured survival for the mammoths, but it did not. It seems plausible that the final extinction of mammoths occurred due to interactions with humans. Although recent chronological data on the first appearance of humans on the Taimyr Peninsula, islands of the Arctic (New Siberian Islands, Wrangel Island), and Pacific (Pribilof Islands) do not strictly support this view – in all cases there is a minor gap between the last dates on mammoths and the first dates on humans (Table 2) – it is very probable that the contact of "first people" and "last mammoths" occurred in these areas. Both the last mammoths and the first humans were there so scanty, that their remains are so far paleontologically and archeologically invisible. At least data from further south suggest that the human population increased at the same time as the mammoth's demise further north, 9500 ^{14}C ybp (Fig. 11).

Thus, humans appear not to have been responsible for the destruction of a sustainable mammoth population. The presence of humans could, however, have been fatal to mammoths during strong minima in their range and numbers, which occurred at the very beginning of the Holocene on the mainland and in the middle Holocene on Wrangel Island. Humans may have acted as an additional stress factor, the "last straw", which destroyed the remaining restricted populations of mammoths living in very limited areas.

Table 2
Comparison of mammoth last occurrence and human first appearance in West Beringia and north Pacific islands.

Area	The last occurrence of mammoths (^{14}C BP)	The first occurrence of humans (^{14}C BP)
Wrangel Island, Bering Sea	3685 ± 60 (Ua-13366), Wrangel Island (Vartanyan, 2007)	3345 ± 70 (Ua-18086), Tchertov Ovrag archeological site, south of Wrangel Island (Gerasimov et al., 2002)[a]
Pribilof Islands, Pacific ocean	5630 ± 40 (Beta 190141B) St. Paul Island (Veltre et al., 2008)	Late eighteenth century, St. Paul Island (Veltre et al., 2008) + polar bear dated to 4430 ± 40 (Beta-182978)
New Siberian Islands	9470 ± 40 (GIN-11874), south of New Siberia Island (this report)	8000–7800, 22 dates, Zhokhov archeological site, Zhokhov Island, (Pitulko, 2003)
Taimyr peninsular	9670 ± 60 (GIN-1828), Nizhnyaya Taimyra R. (Stuart, 1991)	6030 ± 100 (Le-884), Tagenar VI archeological site, Central Taimyr (Khlobystin, 1989)
Lena-Indigirka coastal lowlands	11 900 ± 50 (GIN-12974), Berelyokh site, Lower Indigirka River (Nikolskiy et al., 2010) 12 770 ± 170 (GIN-10267), Bykovsky Peninsular, Lena River Delta (Schirrmeister et al., 2002)	28 250 ± 170 (Beta 173064), Yana archeological site, Lower Yana River (Pitulko et al., 2004)

[a] Should be slightly younger due to the basin effect.

5. Conclusions

The analysis of a large series of new, reliable radiocarbon dates on mammoths from Arctic Siberia, in combination with previously known archives, shows that the frequencies of radiocarbon dates of randomly-selected mammoth remains can, under certain conditions, reflect time-related changes in the numbers of these animals. The demonstrated validity of this hypothesis further supports the second hypothesis of the dependence of mammoth numbers on paleoclimatic conditions. The human dispersal to Arctic Siberia at the end of the Pleistocene, not later than 28 000 ^{14}C ybp, did not visibly influence the number of mammoths. The data allow us to reject the hypothesis of direct extermination of a sustainable mammoth population by humans. The presence of people could, however, have become fatal to mammoths during significant stresses on their numbers, one of which is recorded at the very beginning of the Holocene, which occurred at the same time as the human population started to grow. As the mammoth had survived a number of similar environmental stresses previous to those that coincident with its demise, human pressure was the only new factor that could have caused the extinction of the species.

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