

HUMAN AND DOG CONSUMPTION OF FISH ON THE LOWER OB RIVER OF SIBERIA: EVIDENCE FOR A MAJOR FRESHWATER RESERVOIR EFFECT AT THE UST'-POLUI SITE

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ABSTRACT. Ust'-Polui is one of the most extensively studied archaeological sites in the western Siberian Arctic. New radiocarbon (¹⁴C) dates for charcoal, faunal remains, bark, hide, and human bone from this site are presented. When modeled, the charcoal dates span from ~260 BC to 140 AD, overlapping with the dendrochronology dates from the site. These dates also overlap with the expected age of the site based on artefact typology. ¹⁴C dates on reindeer bone have a slightly younger modeled age range, from ~110 BC to 350 AD. In contrast, dates on the site's numerous dog remains, and on human and fish bone, all predate these modeled age ranges by over 500 years, despite being from the same deposits. Several sets of paired dates demonstrate significant age differences. Bone dates with lower $\delta^{13}\text{C}$ values tend to be over 500 years older than those with higher $\delta^{13}\text{C}$ values. Stable isotope data for the humans, dogs, and other faunal remains are also presented. These data suggest the dogs and the humans were regularly consuming freshwater fish. The dogs were probably fed fish by their human counterparts. Overall, the dog and human dietary patterns at Ust'-Polui created ¹⁴C dates biased with major freshwater reservoir effects.

KEYWORDS: dogs, freshwater reservoir effect, radiocarbon dating, Siberia, stable isotopes.

INTRODUCTION

The Arctic region of Western Siberia has a rich archaeological record, particularly for the Late Holocene, with perhaps the most widely known site in this region being Ust'-Polui. Located just above the Arctic Circle at the southern end of the Yamal Peninsula (Figure 1), this Iron Age site was first discovered in 1932 and then excavated in 1935–1936, 1946, and 1991, with the most recent period of excavations occurring from 1993 to 1995, and 2006 to 2015 (Adrianov 1936a, 1936b, 1936c; Moshinskaia 1953, 1965; Fedorova and Gusev 2008; Gusev and Fedorova 2012). This long history of excavation at Ust'-Polui, and the intermittent presence of permafrost at the site, has resulted in the recovery of over 50,000 artifacts, several sets of human remains, and a very large faunal assemblage (Chernetsov and Moszyńska 1974; Fedorova and Gusev 2008; Gusev and Fedorova 2012; Razhev and Poshekhonova 2012; Vizgalov et al. 2013). Ust'-Polui is perhaps most notable because it has produced possible early evidence for reindeer (*Rangifer tarandus*) keeping in the Arctic, including multiple artifacts that seem to be parts of reindeer headgear or bridles (Gusev et al. 2016).

Our initial interests in Ust'-Polui were not the reindeer-related items there, but rather the roles of the dogs (*Canis lupus familiaris*) at this site and the various practices involved in keeping them. Well over 100 dogs are represented at Ust'-Polui, mostly as disarticulated skeletal elements found scattered among other faunal remains and artifacts. Moszyńska (1974) argued that the abundance of dog remains, the presence of antler swivels (possible tethering equipment), and a knife handle decorated with a possible depiction of a dog wearing a harness, all indicated that dog sledding was practiced at Ust'-Polui. Sacrifice of dogs was also said to have occurred here, evidenced by 15 dog skulls found in single concentration in 1935, all

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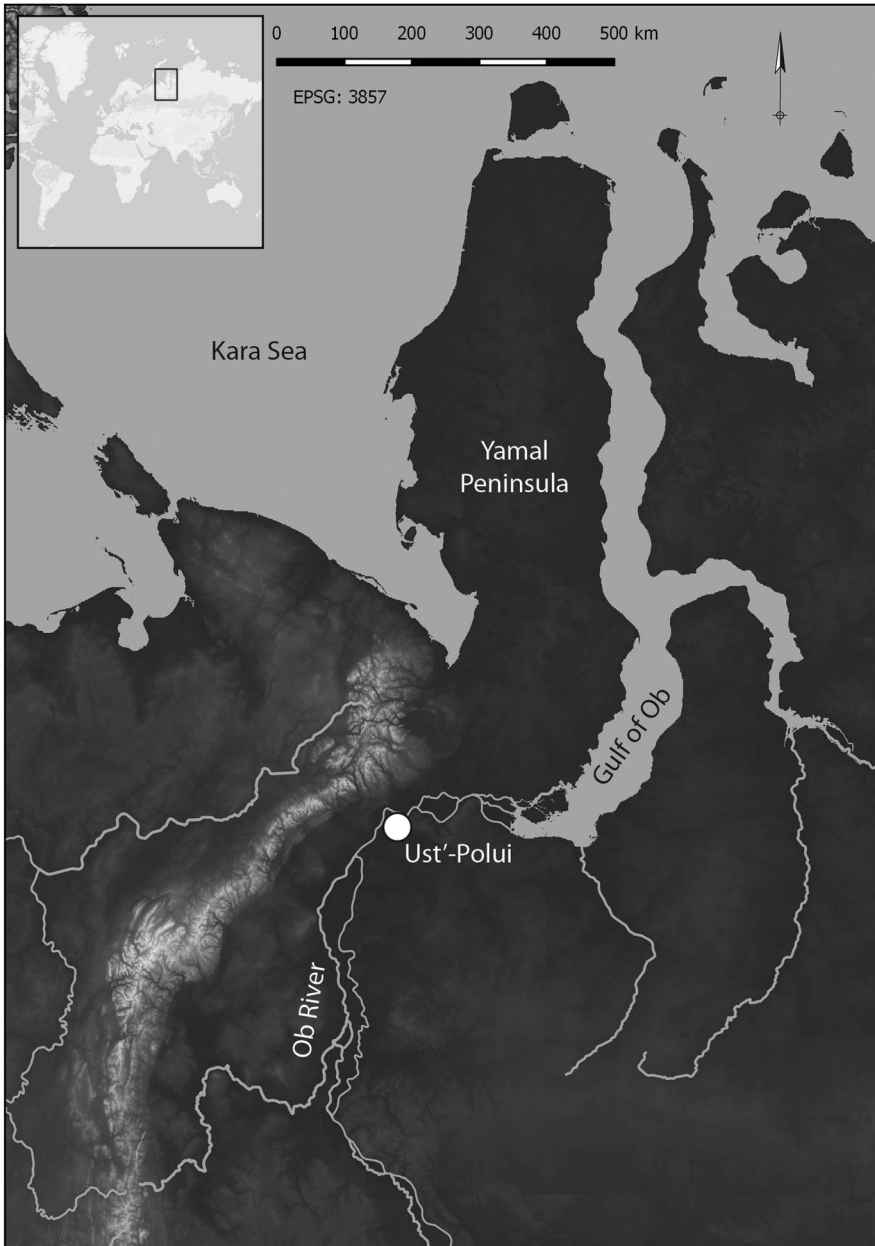


Figure 1 Map of the study area (66.5576 N, 66.5605 E), with the location of Ust'-Polui and major geographical features indicated. The map was created using Landsat open access data, courtesy of the U.S. Geological Survey.

without their mandibles and having their brain cases fractured open (Moszyńska 1974). Further, the more recent excavations at Ust'-Polui have uncovered articulated whole skeletons of several dogs that were intentionally buried.

To best interpret these dog remains and the other materials at Ust'-Polui, a reliable chronology for the site's occupation is needed. The early phase of reporting on Ust'-Polui was prior to the

widespread use of radiocarbon (^{14}C) dating in Siberia, and assessment of its chronology at that time was based on artifact cross-dating. Specifically, Moszyńska (1974:321–4) noted similarities in some of the bronze and antler items at Ust'-Polui with those from the Ananino culture in the Kama River basin of northeastern Europe, and based on this suggested Ust'-Polui dated between the 5th and 3rd centuries BC. Prior to the present study, the only other published chronological data for Ust'-Polui consisted of four dendrochronology assessments, which ranged in age from 76 to 49 BC, and a ^{14}C date on one of these wood samples of 2070 ± 30 BP (B-7063) (Khantemirov and Shiatov 2012).

Given our initial interests, a way forward is to directly date the dog remains recovered from the site. However, one challenge in studying the chronologies of ancient dogs and other omnivores, including humans, is that such organisms can acquire carbon from various sources, including environments with significant old-carbon reservoirs. While marine reservoir effects have been widely studied in archaeology for decades (Gillespie and Temple 1977), freshwater reservoir effects (FREs) have only recently become broadly acknowledged in the field, particularly in Siberia. For example, several recent papers have clearly documented FREs in this region of Russia, particularly at and near Lake Baikal and in southwest Siberia (Nomokonova et al. 2013; Marchenko et al. 2015; Bronk Ramsey et al. 2014; Schulting et al. 2014, 2015; Svyatko et al. 2015). Ideally, the presence of old carbon biases is demonstrated through paired ^{14}C dates, one on the organism that fed in the potential old carbon environment, the other on the remains of an associated organism that acquired its carbon outside of such food chains. Such dates can then be paired with stable carbon and nitrogen isotope data, which helps in reconstructing past food webs, and in understanding the extent to which the dated organisms were incorporating old carbon from ^{14}C depleted environments such as freshwater rivers or lakes.

This paper presents new ^{14}C dates for wood charcoal, faunal remains, and human bone from Ust'-Polui, including a few sets of paired dates. Stable isotope data are also presented for this site in an effort to reconstruct dietary patterns, including those of dogs and people. Together, these data allow the chronology of Ust'-Polui to be clarified, human dietary patterns and dog provisioning practices to be better understood, and a major FRE to be clearly documented for the first time in Arctic Siberia.

SETTING AND BACKGROUND

Ust'-Polui is located in the city of Salekhard, Russian Federation, and on the edge of a peninsula that forms the northeast bank of the Polui River near its junction with the Ob River (Figure 1). Today the site is in a zone of forested tundra, with open tundra being present within a few kilometers. The Ob River, which has its upper tributaries in central Asia and the Altai Mountains of Russia, is nearly 5 km wide and highly braided where it joins the Polui River. The Ob in this region is flanked by broad floodplains with extensive wetlands. About 150 km downstream of Ust'-Polui, this river joins the Gulf of Ob. This body of water separates the Yamal and Gydan peninsulas and is an extension of the Kara Sea. The foothills of the Polar Ural Mountains are about 60 km to the west.

While portions of the site were destroyed by modern construction, several hundred square meters of intact deposits at Ust'-Polui have been excavated. The site is considered by all investigators to have a single major Iron Age component, and a very minor and short-lived medieval occupation (Gusev and Fedorova 2012). Gusev and Fedorova (2012), who excavated the site over the last several decades, refer to Ust'-Polui as a sanctuary (“sviatilishche”) or sacrifice site that was it mostly used for sacred practices by various regional forager groups.

Their interpretation is based on several sets of evidence. First, at least the northern and eastern margins of the site were enclosed by a moat and wood fence. A wooden foot bridge, oriented due north, spanned the moat about 10 m from its northern end. The presence of this bridge, and the shallow and narrow nature of the trench (1.2–1.6 m deep by 1.3–1.6 m wide) are thought to have rendered this feature unsuitable for use as a fortification, perhaps indicating its use as a symbolic barrier. Second, a large number of ornamental objects have been found at Ust'-Polui, including several human figurines and other anthropomorphic depictions, some of which are very similar to historical idols from the region. Third, several sets of human remains were present, including burials and isolated skeletal elements. Human remains appear to be rare at most regional habitation sites. Fourth, the unusual abundance of dog remains at the site, particularly the concentration of crania mentioned previously, has been interpreted as evidence of dog sacrifices. Fifth, artifacts at the site were often found in loose concentrations, sometimes in oval or round patches, and occasionally around large stones or on prepared surfaces. These concentrations are thought to be remnants of prepared sacrificial offerings. Earlier researchers too argued that many ritual activities occurred at Ust'-Polui, but also suggested the location, or portions of it, functioned at times as a fortified habitation site (Moszyńska 1974; Gusev and Fedorova 2012).

Faunal remains from Ust'-Polui have been most recently summarized by Bachura et al. (2016). Despite the inconsistent use of sieves during excavation, fish remains were still most numerically abundant in the site's overall faunal assemblage, accounting for ~48% of the identified specimens. Burbot (*Lota lota*) make up just over 62% of the identified fish remains, with inconnu (*Stenodus nelma*) and whitefish (*Coregonus* spp.) being the only other fish to make up 10% or more of the identified specimens. All of these fish are freshwater or anadromous species that at least seasonally inhabit the Ob and its lower tributaries. Mammal remains account for 28% of the identified remains with ~63% of these being from reindeer, and ~21% from dogs. All other mammals are represented by far smaller quantities of specimens, with only hare (*Lepus timidus*), beaver (*Castor fiber*), and arctic fox (*Lagopus lagopus*) remains each accounting for more than one percent of the identified mammals. Finally, bird remains constitute about 24% of the identified faunal specimens, with ~59% of the identified specimens being from ptarmigan (mostly *Lagopus lagopus*). Waterfowl constituted ~28% of the identified specimens, with the other avian remains mostly being from birds of prey.

METHODS AND MATERIALS

Radiocarbon dates on 42 wood charcoal samples are available for this study (Table 1). One sample (B-7063) was dated by accelerator mass spectrometry (AMS) at the University of Bern Laboratory for the Analysis of Radiocarbon. All other dates on charcoal were generated through the conventional radiometric technique. These include six dates obtained through the Institute of the History of Material Culture, Russian Academy of Science (samples with LE prefix), and 35 dates from the Institute of Geology and Mineralogy, Siberian Branch of the Russian Academy of Sciences (prefix SOAN). In addition, 22 AMS ¹⁴C dates were obtained through the Tandem Laboratory, University of Uppsala (prefix Ua), including 20 dates on human and faunal bones, along with one date each on birch bark and leather (Table 2).

The only well-preserved human skeleton at Ust'-Polui, represented by date Ua52103, was found 30–40 cm below the modern soil surface. It was about one meter outside the moat and 13 m southeast of the wood foot bridge. Based on this contextual information, the skeleton was considered to be of similar age to the main site component. The skeleton belonged to a 35–40-yr-old female and was found in a flexed position on its left side. Among the skeletal

Table 1 Radiocarbon determinations on wood charcoal from Ust'-Polui.

Lab nr	¹⁴ C age	±	Unit	Depth below surface (cm)	Calibrated age (2σ)	Context and notes
SOAN-9317	1480	65	И/9	33	428 AD to 656 AD	Level of ancient buried surface
SOAN-9318	1675	70	И/11	65	177 AD to 548 AD	Redeposited sand at the edge of long narrow trench
SOAN-9429	1820	75	М/23	30	52 AD to 386 AD	Dot 785, level +83, Spot in grey charcoal layer
SOAN-9533	1850	90	М/32	40	386 BC to 1 BC	Dot 778, level +140, horizon 2, brown cultural layer
LE-8308	1860	45	Ж/6	66	54 AD to 311 AD	Hearth spot
SOAN-9418	1890	75	Г/4	20–40	46 BC to 327 AD	Trench 1, level 7, cultural layer
LE-8305	1900	70	Ж/6	56	49 BC to 321 AD	Hearth spot
SOAN-9321	1900	80	К/11	60	89 BC to 330 AD	Hearth spot (one of ash interlayers) (1316) –87
SOAN-9412	1905	90	И/9	86	111 BC to 335 AD	Dot 646, level –186, concentration of burnt branches
SOAN-9431	1910	80	О/26	60	94 BC to 326 AD	Dot 2365, level +121, horizon 5, ash spot
LE-8307	1950	100	Ж/6	42	201 BC to 325 AD	Hearth spot
SOAN-9416	1965	75	Л/11	30	165 BC to 220 AD	Dot 773, level –75, redeposited layer at the edge of long narrow trench
SOAN-9417	1995	80	К/11	170	201 BC to 214 AD	Dot 3753, level –220, ash lens, eastern bulk trench
SOAN-9532	1995	75	М/32	40	382 BC to 47 AD	Dot 766, level +139, horizon 2, brown cultural layer
SOAN-9413	2000	110	И/11	110	357 BC to 243 AD	Dot 3546, layer -128, northern bulk trench, lens of golden interlayer
SOAN-9319	2000	85	К/11	80	342 BC to 217 AD	Grey-charcoal layer (4465)–117
SOAN-9434	2005	75	П/26	68	341 BC to 209 AD	Dot 2522, level +135, horizon 5, upper portion of brown cultural layer
SOAN-9437	2030	100	М/24	50	358 BC to 210 AD	Dot 3015, level +74, grey charcoal layer, next to antler made tool blanks
SOAN-9421	2030	105	Р/18	156	359 BC to 212 AD	Dot 2469, level +2, charcoal under branches inside layer of discard
SOAN-9435	2035	100	М/24	20	360 BC to 209 AD	Dot 2920, level +83, horizon 6, ash layer under hearth
SOAN-9531	2045	70	П/30	60	105 BC to 326 AD	Dot 964, level +137, horizon 3, brown cultural layer
LE-8306	2070	100	З/5	55	366 BC to 124 AD	Hearth spot
B-7063	2070	30	Ж/7	?	174 BC to 1 BC	Dendrochronology sample 95-011
SOAN-9415	2080	100	Л/12	125	357 BC to 117 AD	Dot 1922, Level –130, upper layer of organics
SOAN-9436	2080	110	Л/22	45	382 BC to 125 AD	Dot 1648, Level +69, horizon 4, Brown cultural layer
LE-8309	2090	45	Ж/8	26	347 BC to 5 AD	Bulk trench, near wooden bridge (?) in square Ж/8
SOAN-9420	2135	105	В/3	20–40	397 BC to 55 AD	Level -8, cultural layer
LE-8304	2150	100	З/4	65	399 BC to 49 AD	Hearth spot

Table 1 (*Continued*)

Lab nr	¹⁴ C age	±	Unit	Depth below surface (cm)	Calibrated age (2σ)	Context and notes
SOAN-9422	2150	100	P/18	160	399 BC to 49 AD	Dot 2118, level -6, hor. 6, grey charcoal layer at edge of long narrow trench
SOAN-9419	2155	105	Γ/3	20-40	403 BC to 54 AD	Trench 1, level 0, cultural layer
SOAN-9427	2160	90	H/22	40	396 BC to 2 AD	Dot 1505, level +98, horizon 4, charcoal-rich spot
SOAN-9432	2180	115	M/25	20	510 BC to 66 AD	Dot 1268, level +87, horizon 4, ash layer
SOAN-9322	2185	95	K/11	110	408 BC to 16 AD	Layer of organics under 'bridge-transfer' (3297)-107
SOAN-9433	2200	100	Π/27	73	481 BC to 21 AD	Dot 557, level +146, horizon 2, Humus layer
SOAN-9414	2205	100	W/11	130	488 BC to 17 AD	Dot 2421, level -198, charcoal spot in layer of organics
SOAN-9430	2220	100	M/22	35	536 BC to 2 AD	Dot 1301, level +84, horizon 4, Brown cultural layer
SOAN-9425	2255	105	O/19	43	748 BC to 42 BC	Dot 732, level +113, brown cultural layer, hearth
SOAN-9426	2310	105	Π/21	65	767 BC to 118 BC	Dot 1170, level +107, brown cultural layer
SOAN-9423	2330	110	O/19	77	776 BC to 169 BC	Dot 1302, level +94, charcoal from buried soil
SOAN-9536	2410	125	JI/30	40	355 BC to 125 AD	Dot 1492, level +111, horizon 4, layer under light sandy loam
SOAN-9428	3650	170	O/20	73	2559 BC to 1614 BC	Dot 1878, level +91, horizon 6, burnt branch in bedrock, under cultural layer
SOAN-9424	5275	135	O/16	87	4365 BC to 3783 BC	Dot 1533, level +18, grey charcoal layer at the edge of long narrow trench

Table 2 Non-charcoal radiocarbon determinations from Ust'-Polui. Stable isotope values are those obtained during radiocarbon dating, where available.

Lab nr	Sample nr	Material	^{14}C age	\pm	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	Calibrated age (2σ)	Context and notes
Ua47749	Polui #10 2013; 736-2519	<i>R. tarandus</i> phalanx	1732	31	-20.0	—	240 AD to 387 AD	2006, unit Ж/7
Ua47747	Polui #8 2013; 736-3131	<i>R. tarandus</i> humerus	1784	30	-18.8	—	135 AD to 333 AD	1991–1995 trench
Ua47748	Polui #9 2013; 736-3788	<i>R. tarandus</i> phalanx	1852	31	-19.1	—	83 AD to 236 AD	2009 trench
Ua52104	Polui-2015-004; 736-3114	<i>R. tarandus</i> metapodial	1977	31	-18.9	7.2	46 BC to 81 AD	1991–1995 trench
Ua52105	Polui-2015-005; 736-716	<i>R. tarandus</i> metapodial	2052	30	-18.4	6.6	166 BC to 16 AD	1991–1995 trench
Ua54159	Polui-2016-001	<i>R. tarandus</i> antler, cut	2012	28	-19.1	3.4	91 BC to 61 AD	2014, O/27, horizon 6, wooden frame layer
Ua54161	Polui-2016-003	<i>R. tarandus</i> sesmoid	1916	27	-18.9	3.7	18 AD to 136 AD	2008, H/26, horizon 3, grey charcoal layer
Ua54157	Polui-2016-006	Leather from clothing	1946	30	-13.7	—	21 BC to 128 AD	From grave of sample Ua52103
Ua54158	Polui-2016-007	<i>Betula</i> sp. bark	2213	28	-27.8	—	369 BC to 201 BC	From grave of sample Ua52102
Ua47741	Polui #2 2013; (114) 62	<i>C. l. familiaris</i> parietal	2515	30	-25.9	—	793 BC to 541 BC	1935–1936 trench, unit 47
Ua47740	Polui #1 2013; (118) 62	<i>C. l. familiaris</i> parietal	2606	30	-26.3	13.5	825 BC to 768 BC	1935–1936 trench, unit 47
Ua47742	Polui #3 2013; (121) 63	<i>C. l. familiaris</i> parietal	2700	30	-26.3	13.3	905 BC to 806 BC	1935–1936 trench, unit 47
Ua47743	Polui #4 2013; 736-6515	<i>C. l. familiaris</i> R scapula	2723	30	-26.9	13.9	922 BC to 811 BC	2011 trench, unit 552
Ua47746	Polui #7 2013; 736-1918	<i>C. l. familiaris</i> R scapula	2818	30	-26.8	14.1	1052 BC to 900 BC	2011 trench
Ua47744	Polui #5 2013; 736-4921	<i>C. l. familiaris</i> R scapula	2849	30	-25.8	—	1111 BC to 926 BC	2010 trench, unit JI/12, eastern bulk trench
Ua47745	Polui #6 2013; 736-5164	<i>C. l. familiaris</i> R scapula	2912	30	-26.5	14.2	1209 BC to 1013 BC	2010 trench, unit K/11, redeposited layer
Ua54160	Polui-2016-002	<i>Stenodus nelma</i> vertebra	2594	28	-24.7	11.2	819 BC to 762 BC	2014, O/27, horizon 6, layer wooden frame
Ua54162	Polui-2016-004	<i>Stenodus nelma</i> vertebra	2882	28	-25.9	13.0	1192 BC to 943 BC	2008, H/26, horizon 3, grey charcoalish layer
Ua54163	Polui-2016-005	<i>Lota lota</i> vertebra	2946	29	-26.7	13.6	1257 BC to 1051 BC	2010, 3/8, layer of fine organic material
Ua52103	Polui-2015-003	<i>H. sapiens</i> long bone	2514	31	-21.1	13.0	793 BC to 540 BC	2011, grave 2, 101-2
Ua52102	Polui-2015-002	<i>H. sapiens</i> long bone	3234	32	-25.8	14.2	1610 BC to 1434 BC	1994, unit Ж/10
Ua52101	Polui-2015-001	<i>H. sapiens</i> long bone	3165	30	-25.7	14.1	1503 BC to 1329 BC	2014, unit П/27

remains were bits of hide, likely parts of clothing worn by the deceased. A sample of this hide material was also dated (Ua54157). Fragments of birch (*Betula* sp.) bark were found under the skeleton, and remnants of fir (*Abies* sp.) branches were found resting on its upper surface.

A second burial at Ust'-Polui was found within the main site area and 110–130 cm below the modern surface, well below the site's other archaeological deposits. Based on its position, the burial was believed to predate Ust'-Polui's main component. This adult skeleton was poorly preserved, and it was tightly flexed and resting on its left side. The body was interred within a rectangular-shaped grave pit possibly supported by a wooden frame; a layer of birch bark was found directly under the skeleton, and fir twigs were found resting on its upper surface. The bark and twigs likely formed a container for the body. The skeleton was directly dated (Ua52102), as was a sample of the birch bark found directly below it (Ua54158).

The final human bone dated in this study (Ua52101) was an isolated adult tibia from the main site area found among artifacts and faunal remains. Note that other isolated human remains were found in the main site area in the 1930s and 1990s (Fedorova and Gusev 2008). These remains could be from earlier graves that were disturbed during the main period of site use. Alternatively, they could have been transported to Ust'-Polui as disarticulated skeletal elements and then deposited at the site as part of secondary mortuary rituals.

The final two sets of paired dates from the site, Ua-54159/54160 and 54161/54162, consist of reindeer bone and fish bone samples. In both cases the reindeer bones and fish bones were found directly next to each other within 3–5 cm thick sediment layers (designated by the excavators as "horizons").

All dates were calibrated and modeled in Oxcal 4.2.4 using the IntCal-13 dataset (Bronk Ramsey 2009; Bronk Ramsey 2014; Reimer et al. 2013). Site stratigraphy and artifact typology indicate that all objects dated here, perhaps with the exception of the human remains and their associated items, come from a single period or phase of site occupation. Sets of dates are thus analyzed as single phases using the default settings in the Oxcal phase model. In these models, age range estimates are given for the start and end of the phase at the 95.4% confidence interval in years cal BP [highest posterior distribution (HPD) intervals]. Means and standard deviations for the starts and end intervals of phases, generated by OxCal, are also provided, also at the 95.4% confidence level. Age offset uncertainties for paired dates are the sums of the squares of the uncertainties of the two dates being compared (following Svyatko et al. 2015). Provenience information for all samples was translated directly from Russian-language reports. The amount of contextual information available for the dated samples varies widely depending upon the year of excavation.

A total of 45 archaeological bone fragments yielded collagen suitable for stable isotope analysis, including two samples from humans, 32 from dogs, and 11 from nine from other fauna taxa represented in the site assemblage (Table 3). Stable isotope analysis was conducted at the University of Alberta Department of Anthropology archaeological laboratory using a modified version of the Oxford sample preparation method (Bronk Ramsey et al. 2004). All samples were cleaned, and ~1 mm of outer bone surfaces were removed. Samples were then sonicated for 10 min in three changes of double-distilled water, and air dried. The samples were ground to powder consistency in a Spex Certiprep liquid nitrogen mill. Approximately 500 mg of powder from each sample was placed in a polyethylene vial with 12 mL of 1% hydrochloric acid (HCl) and allowed to demineralize. After demineralization, samples were centrifuged and rinsed in double-distilled water until they reached neutrality as determined by pH testing strips. Upon

Table 3 All $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for Ust'-Polui obtained in this study through the University of Alberta laboratory.

Lab nr	Taxon	Element	Pre-lyophilization vial weight (mg)	Post-lyophilization vial weight (mg)	Collagen yield	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	C content (%)	N content (%)	C/N atomic
LPO-22F	<i>Alces alces</i>	Ph 1	6689.0	6695.2	1.2	-21.8	3.9	43.6	14.8	3.4
LPO-18F	<i>Vulpes lagopus</i>	Costa	6642.7	6646.2	1.8	-22.6	9.1	43.2	14.4	3.5
LPO-80F	<i>Anas</i> sp.	Humerus	6638.5	6646.0	2.5	-23.5	8.7	39.1	12.8	3.6
LPO-17F	<i>Canis lupus</i>	Pelvis	6647.0	6653.2	1.4	-19.3	11.6	44.3	14.5	3.6
LPO-29F	<i>Canis lupus familiaris</i>	Scapula (R)	9369.0	9377.1	1.6	-26.0	14.5	46.0	16.3	3.3
LPO-30F	<i>Canis lupus familiaris</i>	Scapula (R)	9458.3	9464.5	1.2	-24.7	13.6	44.7	15.7	3.3
LPO-31F	<i>Canis lupus familiaris</i>	Scapula (R)	9389.2	9453.9	12.7	-24.4	12.6	46.0	16.1	3.3
LPO-32F	<i>Canis lupus familiaris</i>	Scapula (R)	6630.5	6635.7	1.0	-24.5	13.1	44.7	15.7	3.3
LPO-33F	<i>Canis lupus familiaris</i>	Scapula (R)	9425.0	9430.6	1.1	-26.3	14.6	43.9	15.1	3.4
LPO-34F	<i>Canis lupus familiaris</i>	Scapula (R)	9294.3	9300.9	1.2	-26.2	14.1	46.2	15.8	3.4
LPO-35F	<i>Canis lupus familiaris</i>	Scapula (R)	9376.3	9384.1	1.5	-26.2	14.4	44.3	15.2	3.4
LPO-36F	<i>Canis lupus familiaris</i>	Scapula (R)	9288.9	9294.2	1.0	-26.1	14.6	45.6	15.6	3.4
LPO-37F	<i>Canis lupus familiaris</i>	Scapula (R)	9428.5	9438.9	2.0	-26.7	14.2	45.5	16.2	3.3
LPO-39F	<i>Canis lupus familiaris</i>	Scapula (R)	9434.1	9441.5	1.4	-25.3	14.5	46.0	15.9	3.4
LPO-42F	<i>Canis lupus familiaris</i>	Scapula (R)	9382.4	9391.3	1.7	-27.0	15.3	46.3	16.5	3.3
LPO-44F	<i>Canis lupus familiaris</i>	Scapula (R)	9392.1	9401.0	1.7	-27.1	14.7	45.7	15.7	3.4
LPO-47F	<i>Canis lupus familiaris</i>	Scapula (R)	9372.1	9378.3	1.2	-26.6	14.5	45.3	16.0	3.3
LPO-50F	<i>Canis lupus familiaris</i>	Scapula (R)	9387.4	9396.9	1.8	-25.5	14.2	44.2	15.6	3.3
LPO-51F	<i>Canis lupus familiaris</i>	Scapula (R)	9286.4	9294.2	1.4	-25.8	15.0	45.7	16.3	3.3
LPO-53F	<i>Canis lupus familiaris</i>	Scapula (R)	6617.2	6630.2	2.5	-26.8	15.0	44.6	15.7	3.3
LPO-54F	<i>Canis lupus familiaris</i>	Scapula (R)	6682.1	6693.4	2.2	-26.2	14.7	45.5	15.9	3.3
LPO-55F	<i>Canis lupus familiaris</i>	Scapula (R)	6629.4	6635.6	1.2	-27.0	15.3	43.5	15.1	3.4
LPO-57F	<i>Canis lupus familiaris</i>	Scapula (R)	6619.0	6631.6	2.5	-24.9	13.6	44.6	15.6	3.3
LPO-58F	<i>Canis lupus familiaris</i>	Scapula (R)	9459.8	9466.4	1.3	-25.5	13.5	45.3	15.8	3.3
LPO-59F	<i>Canis lupus familiaris</i>	Scapula (R)	9459.2	9469.8	2.0	-26.7	14.5	43.6	15.4	3.3
LPO-62F	<i>Canis lupus familiaris</i>	Scapula (R)	6682.7	6688.6	1.1	-27.1	14.0	43.9	14.7	3.5
LPO-63F	<i>Canis lupus familiaris</i>	Scapula (R)	6656.9	6671.5	2.8	-26.1	14.9	42.7	15.1	3.3
LPO-64F	<i>Canis lupus familiaris</i>	Parietal frag	6678.4	6681.5	1.0	-25.5	12.4	42.7	14.0	3.6
LPO-65F	<i>Canis lupus familiaris</i>	Parietal frag	6625.9	6634.0	1.6	-24.7	12.6	44.0	15.9	3.2
LPO-66F	<i>Canis lupus familiaris</i>	Parietal frag	6629.0	6638.7	1.9	-25.6	12.5	41.7	14.3	3.4
LPO-67F	<i>Canis lupus familiaris</i>	Parietal frag	6692.5	6699.7	1.4	-25.9	13.6	44.4	15.4	3.4
LPO-68F	<i>Canis lupus familiaris</i>	Parietal frag	6683.8	6691.6	1.6	-25.1	12.6	45.3	16.1	3.3
LPO-70F	<i>Canis lupus familiaris</i>	Parietal frag	6612.7	6619.8	1.4	-25.2	13.2	45.3	16.0	3.3

Table 3 (Continued)

Lab nr	Taxon	Element	Pre-lyophilization vial weight (mg)	Post-lyophilization vial weight (mg)	Collagen yield	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	C content (%)	N content (%)	C/N atomic
LPO-71F	<i>Canis lupus familiaris</i>	Parietal frag	6622.2	6630.5	1.7	-25.6	13.3	45.1	16.0	3.3
LPO-72F	<i>Canis lupus familiaris</i>	Parietal frag	6634.5	6638.9	1.5	-25.1	12.4	44.9	15.8	3.3
LPO-73F	<i>Canis lupus familiaris</i>	Parietal frag	6641.9	6654.8	2.6	-25.5	13.5	44.3	15.3	3.4
LPO-84F	<i>Homo sapiens</i>	Long Bone	6666.3	6686.6	2.0	-26.1	17.3	42.9	14.5	3.5
LPO-86F	<i>Homo sapiens</i>	Long Bone	6677.8	6687.5	1.8	-26.2	17.0	44.2	15.1	3.4
LPO-10F	<i>Lagopus lagopus</i>	Coracoid	6714.6	6719.2	1.5	-21.1	1.5	45.4	15.8	3.4
LPO-79F	<i>Martes zibellina</i>	Tibia	6618.2	6619.8	1.1	-22.0	8.7	42.5	13.9	3.6
LPO-11F	<i>Odobenus rosmarinus</i>	Ph 1	6634.6	6639.2	1.5	-17.3	12.5	45.4	16.2	3.3
LPO-12F	<i>Phoca</i> sp.	Costa	6619.4	6626.6	1.4	-18.8	4.8	45.6	15.9	3.3
LPO-25F	<i>Rangifer tarandus</i>	Talus	6638.1	6646.8	1.9	-19.3	6.9	43.0	15.2	3.3
LPO-75F	<i>Rangifer tarandus</i>	Metacarpus	6652.8	6662.5	1.8	-19.6	8.5	45.9	15.9	3.4
LPO-76F	<i>Rangifer tarandus</i>	Tibia	6626.0	6630.6	1.0	-19.4	3.3	45.8	15.5	3.4
Sample below removed due to failing quality standards										
LPO-38F	<i>Canis lupus familiaris</i>	Scapula (R)	9376.7	9378.9	0.4	-26.9	14.3	43.5	14.3	3.5
LPO-40F	<i>Canis lupus familiaris</i>	Scapula (R)	9312.6	9316.7	0.8	-25.9	13.0	45.2	15.6	3.4
LPO-41F	<i>Canis lupus familiaris</i>	Scapula (R)	9312.1	9314.8	0.5	-25.7	13.8	46.2	16.4	3.3
LPO-43F	<i>Canis lupus familiaris</i>	Scapula (R)	9449.6	9450.4	0.2	-25.9	13.8	44.9	15.9	3.3
LPO-46F	<i>Canis lupus familiaris</i>	Scapula (R)	9403.9	9407.6	0.7	-25.1	14.7	45.0	14.9	3.5
LPO-48F	<i>Canis lupus familiaris</i>	Scapula (R)	9390.9	9392.1	0.2	-25.6	13.5	46.1	16.3	3.3
LPO-49F	<i>Canis lupus familiaris</i>	Scapula (R)	9403.2	9403.5	0.1	-26.4	13.8	40.8	13.3	3.6
LPO-52F	<i>Canis lupus familiaris</i>	Scapula (R)	9514.0	9516.3	0.4	-25.2	13.8	45.8	16.1	3.3
LPO-56F	<i>Canis lupus familiaris</i>	Scapula (R)	9442.3	9442.6	0.1	-26.3	13.3	45.1	16.0	3.3
LPO-60F	<i>Canis lupus familiaris</i>	Scapula (R)	6628.5	6629.8	0.3	-26.7	15.4	45.9	15.8	3.4
LPO-61F	<i>Canis lupus familiaris</i>	Scapula (R)	6626.9	6630.7	0.8	-25.0	14.3	43.3	14.7	3.4
LPO-69F	<i>Canis lupus familiaris</i>	Parietal frag	9378.7	9382.5	0.8	-25.6	13.2	45.7	16.2	3.3
LPO-01F	<i>Coregonus muskun</i>	Vertebra	6616.9	6620.3	1.1	-21.1	1.50	45.4	15.8	3.4
LPO-85F	<i>Homo sapiens sapiens</i>	Long bone	6677.0	6681.4	0.5	-23.5	16.4	43.3	14.1	3.6
LPO-07F	<i>Lagopus lagopus</i>	Scapula	6638.5	6640.4	0.4	-21.3	3.2	47.3	15.8	3.5
LPO-14F	<i>Lepus timidus</i>	Vertebra	6634.6	6638.2	0.7	-22.8	3.1	44.2	15.1	3.4
LPO-24F	<i>Rangifer tarandus</i>	Humerus	6652.1	6652.9	0.2	-19.8	7.6	44.8	15.0	3.5
LPO-77F	<i>Rangifer tarandus</i>	Humerus	6627.9	6629.8	0.4	-19.3	6.2	44.4	14.8	3.5

reaching neutrality, the samples were drained of water. Twelve mL of .01M sodium hydroxide (NaOH) solution was then added to remove humates. Vials were shaken and allowed to react at room temperature for 20 hr. Samples were then centrifuged and rinsed in changes of double-distilled water until they reached neutrality, and were drained of water. Immediately following this step, another 12 mL of 1% HCl was added to sample vials. Vials were shaken and left to react for 2 hr at room temperature. Samples were then centrifuged and rinsed with double-distilled water until neutrality and then drained.

Six mL of acidulated water with a pH of 3 were added to each vial and shaken. The samples were then placed in a 75°C water bath and left to allow the collagen to gelatinize into solution for 20 hr. The supernatant from each sample was filtered through a glass fiber filter paper using a Nalgene 40 mm Büchner filter and a 125 mL sidearm/filtering flask. Approximately 6 mL of filtrate from each sample was poured into a dual-chambered Vivaspin® 30 µL ultrafiltration vial and centrifuged until 1 mL remained in the upper chamber. This amount was pipetted into a pre-weighed centrifuge vial, frozen, lyophilized and then analyzed at the University of Alberta's Biogeochemical Analytical Services Laboratory (BASL). Samples were analyzed for $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ ratios using a EuroVector EuroEA3028-HT elemental analyzer coupled to a GV Instruments IsoPrime continuous-flow isotope ratio mass spectrometer. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios (‰) were determined using the following equation:

$$\delta R\text{‰} = \left(\left(R_{\text{sample}} / R_{\text{standard}} \right) - 1 \right) \times 1000$$

where R_{sample} is the ratio of $^{15}\text{N}/^{14}\text{N}$ or $^{13}\text{C}/^{12}\text{C}$ in the sample, and R_{standard} refers to the international standards Vienna Pee Dee Belemite (VPDB) and AIR, respectively. BASL used NIST 8415 whole egg powder SRM as a $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ QA/QC check throughout analyses. Measurement accuracy for the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ was $\pm 0.1\text{‰}$ and $\pm 0.2\text{‰}$, respectively. Assessment of collagen sample validity involved the following quality indicators: (1) percent collagen yield above 1% by weight; (2) percent carbon and nitrogen by weight above ~26% for carbon and 11% for nitrogen; and (3) atomic C/N ratio values between 3.1 and 3.6 (DeNiro 1985; DeNiro and Weiner 1988; Ambrose 1990; van Klinken 1999).

RESULTS

Charcoal Dates

Charcoal dates SOAH-9424 and 9428 were excluded prior to modeling, as both are from sediments under the archaeological deposits at the site. The remaining 40 dates are from the primary Iron Age component and were entered into a single phase model in Oxcal. In the first run of the model, samples SOAH-9317 and 9536, the youngest and oldest dates, respectively, were marked as in poor agreement. With these dates included, the mean start and end dates for the phase were 354 BC and 352 AD (Table 3). In the next run of the model, SOAH-9317 and 9536 were removed, which then resulted in SOAN-9318 being identified as in poor agreement. This date was then removed and the model was run a third time. In this final model, none of the 37 dates were in poor agreement, and the mean modeled starting and ending dates were 260 BC and 139 AD, respectively (Table 4; Figure 2).

Importantly, many of the charcoal dates have relatively large margins of error, some just over a century. The imprecision of these dates helps create the relatively wide starting and ending age ranges in the phase models. Further, all but one of the charcoal dates were obtained through standard radiometric dating, which requires comparatively large samples, meaning individual dates nearly always reflect the ages of multiple sets of tree rings rather than the death of

Table 4 Phase model age ranges for subsets of radiocarbon ages from Ust'-Polui.

Materials	95.4% HPD start	Mean modeled start (2 σ)	95.4% HPD end	Mean modeled end (2 σ)	Notes
Charcoal (n = 40)	476 BC to 226 BC	354 BC \pm 63	238 AD to 535 AD	352 AD \pm 86	
Charcoal (n = 37)	396 BC to 136 BC	260 BC \pm 65	65 AD to 236 AD	139 AD \pm 42	SOAN-9317, 9536, 9318 excluded
Reindeer bone (n = 7)	294 BC to 13 AD	111 BC \pm 91	195 AD to 556 AD	352 AD \pm 93	
Dog bone (n = 7)	1330 BC to 997 BC	1129 BC \pm 95	792 BC to 472 BC	679 BC \pm 103	
Charcoal/reindeer bone (n = 47)	437 BC to 209 BC	318 BC \pm 60	256 AD to 478 AD	339 AD \pm 67	
Charcoal/reindeer bone (n = 44)	386 BC to 147 BC	262 BC \pm 61	145 AD to 316 AD	231 AD \pm 47	SOAN-9317, 9536, 9318 excluded

individual trees. In other words, the bulk or mixed nature of these samples also may render some of the dates inaccurate. Some old carbon effects (in-built age effects) also potentially influence these dates, including the burning of old wood, and the presence of naturally occurring charcoal in the site sediments. Both would produce ^{14}C ages somewhat older than the events of interest and potentially lengthen the estimate age of the phase. Overall, we suspect the combination of these possible biases in the charcoal dates perhaps makes the age range estimates for Ust'-Polui slightly too old, but the extent of this bias is unclear. Note that the three previously published dendrochronology dates for Ust'-Polui ranged from 76 to 49 BC (Khantemirov and Shiatov 2012), well within the modeled time range of the 37 charcoal ^{14}C dates.

Reindeer and Dog Bone Dates

The ^{14}C dates on all other material at the site, including bone and antler, were obtained through the AMS dating method, and all have margins of error around 30 or fewer years—they are far more precise than nearly all of the charcoal dates. These dates also each represent shorter periods of time, such as the last few years prior to the death of an animal, which means they are potentially more accurate than the dates on bulk charcoal samples just presented. In analyzing the reindeer and dog dates, models were created for each species individually, as their very different diets potentially means their bone carbon was acquired from very different environments.

The seven ^{14}C dates on reindeer bone were modeled as a single phase in Oxcal, as all samples come from the site's primary component. This produced a modeled mean start age of 111 BC and a mean end age of 352 AD (Table 4; Figure 2). While this model was built on a far smaller set of samples than the charcoal phase models just described, the age range estimates of the phase model still overlap those generated by the charcoal dates. For example, the mean start age for the reindeer dates is only about one century later, and the end mean about two centuries later than those of the charcoal model with the poor agreement samples removed. Given the overlap in the reindeer bone and charcoal models, and the lack of evidence for an age bias in the reindeer dates, all charcoal and reindeer bone dates (n = 47) were entered into a single phase model. In the first run of the model, SOAN-9317 and 9536 were identified as being in poor agreement with the other dates, just as in the charcoal model. With all dates included, the mean

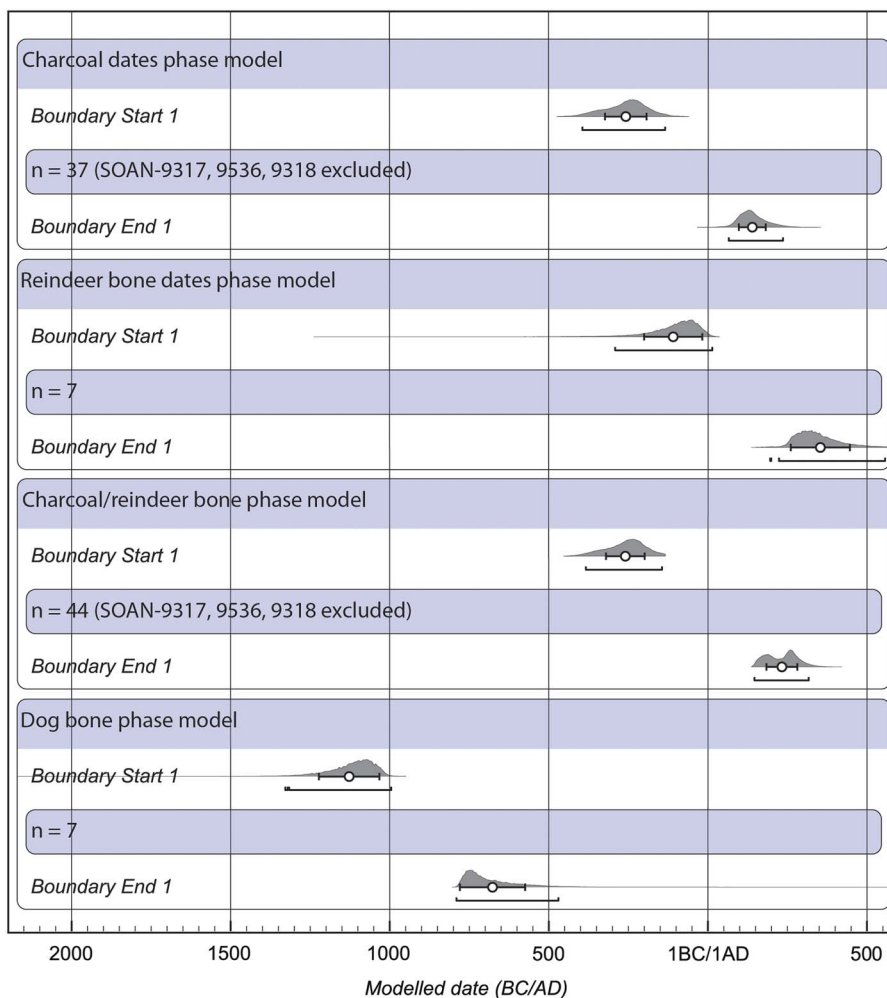


Figure 2 Results of Bayesian modelling of radiocarbon determinations with phase boundaries marked for each subset of dated materials.

of the start age was $318 \text{ BC} \pm 60$, and the mean of the end date of $339 \text{ AD} \pm 67$ (Table 4). Excluding SOAH 9317 and 9536, the model then identified SOAH-9318 as being in poor agreement, just as in the charcoal model second run. Removing all three poor agreement dates, the start and end date means were $262 \text{ BC} \pm 61$ and $231 \text{ AD} \pm 47$, respectively (Table 4; Figure 2). Subsequent runs of the model with poor agreement dates removed recurrently identified additional dates as being in poor agreement, and progressively narrowed the estimate of the phase duration. Taking a conservative approach, we have excluded these age models.

The seven dates on dog bones were also modeled as a single phase. These includes dates on dog remains recovered in the 1930s and those from more recent excavations at Ust'-Polui, and all were assigned to the site's primary component. When modeled, the dog bone dates showed no overlap with the reindeer or charcoal phase models (Table 4; Figure 2). The mean modeled start date of the phase is 1129 BC , which is 775 yr prior to the youngest mean starting date for the other five models. The modeled end date for the dog dates is 679 BC , or 818 yr before the oldest

end date in the other models. In other words, the dog dates at face value are far older than the other dated materials from Ust'-Polui, despite all contextual information indicating they should be of similar age.

Human and Paired Dates

Given that only three ^{14}C dates are available for human remains, and that one of the two graves is thought to predate the primary occupation component, a phase model is inappropriate. When the human dates were calibrated, all clearly predate the reindeer and charcoal modeled age ranges, just as was seen with the dog bone dates (Table 2). Date Ua52103, from the grave thought to be most closely associated with the site's main occupation, is at face value the youngest of the three dated human skeletons, with a calibrated age range of 793 to 540 BC. Its age is within the modeled age range of the dog remains at the site. The other two human dates are similar in age to each other and just predate the site's dog remains.

The paired dates most clearly indicate that the dog, human, and fish bone samples have an old carbon bias that renders them centuries too old. Paired dates are available for both human burials at the site, and for two sets of stratigraphically associated fish bone and reindeer bone samples (Table 2). A single date (Ua54163) on an isolated fish bone is available for comparative purposes. These dates show a fairly clear pattern (Table 5). First, the age offsets in the paired samples range from 568 ± 43 to 1021 ± 43 yr, with an average offset of 784.25 yr. Second, the three fish bone dates are similar in age to the site's dated dog remains, and the two paired fish bone samples have age offsets of 582 ± 40 and 966 ± 39 yr. Third, the human bone dates are far older than their associated paired dates. Specifically, the site's youngest human bone date (Ua52103) is 568 yr older than the leather material (date Ua54157) found with it, while the date on the deeply buried skeleton (Ua52102) is 1021 yr older than the birch bark it was lying directly on. Notably, the youngest human burial here and its paired date should be cautiously evaluated. The $\delta^{13}\text{C}$ value of the leather is -13.7 (Table 2), which is far higher than all terrestrial mammals at the site, suggesting that it may be from a marine mammal, which could have some marine reservoir offset (discussed below). Further, this human has far higher $\delta^{13}\text{C}$ values than the other dated human and dog remains at Ust'-Polui, indicating that its dietary protein differed from that consumed by the other dated organisms. Overall, the leather date (Ua54157) falls within the modeled age range of the reindeer bone and charcoal dates from Ust'-Polui, while the birch bark date (Ua54158) predates the reindeer bone age range by just over a century, but falls within the modeled age range of the charcoal dates.

The final indication of a patterned age bias in some of the bone dates is the $\delta^{13}\text{C}$ values obtained during ^{14}C dating. When all bone ^{14}C ages are plotted against their $\delta^{13}\text{C}$ values, two data point clusters are evident (Figure 3). The first cluster, with $\delta^{13}\text{C}$ values between -20.0 and -18.4‰ (mean = -19.0‰), and ^{14}C ages from 2052 to 1732 BP, is formed by the site's seven reindeer

Table 5 Age offsets observed in paired radiocarbon age determinations for Ust'-Polui.

Paired sample lab numbers	Materials	Age offset
Ua52103/54157	Human bone/leather clothing	568 ± 43
Ua52102/54158	Human bone/birch bark	1021 ± 43
Ua52160/52159	Fish bone/reindeer antler	582 ± 40
Ua54162/54161	Fish bone/reindeer bone	966 ± 39
Mean offset		784.25

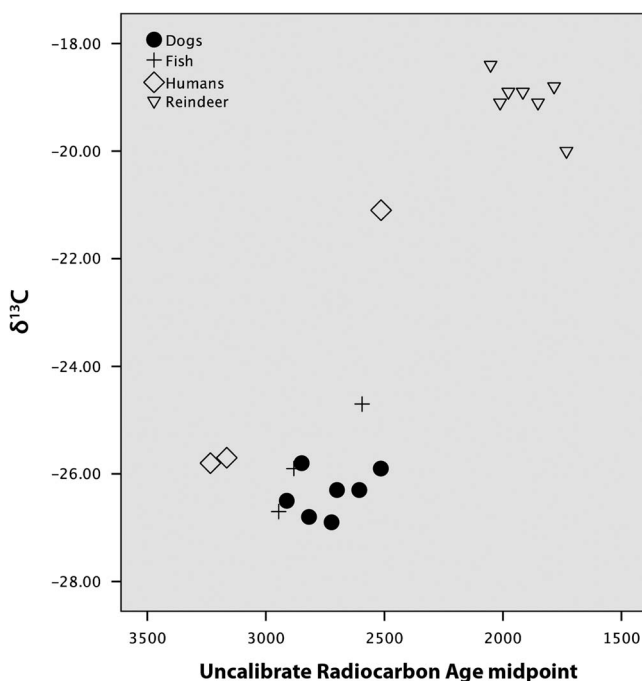


Figure 3 Biplot of $\delta^{13}\text{C}$ values obtained during radiocarbon dating and uncalibrated radiocarbon age midpoints for bones dated from Ust'-Polui.

bone dates. The second cluster has far lower $\delta^{13}\text{C}$ values, between -26.9 to -24.7‰ (mean = -26.1‰), and older ^{14}C ages, spanning from 3234 to 2515 BP. This cluster consists of all of the dog and fish bone dates, and two of the human dates. The final human sample, Ua52103, falls midway between the two clusters. In other words, bones with lower $\delta^{13}\text{C}$ values produce dates inconsistent with those on charcoal and the dendrochronology dates, while those with higher $\delta^{13}\text{C}$ values tend to be far more consistent with these other datasets. The fact that lower $\delta^{13}\text{C}$ values are seen in the human and dog samples (both omnivores) as well as in the fish samples, while higher values are only found in the herbivorous reindeer bones, suggests that aquatic environments and regular consumption of aquatic foods is causing the observed age differences in the Ust'-Polui datasets.

Stable Isotopes

A biplot of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values obtained at the University of Alberta shows that the humans and dogs exhibit the highest $\delta^{15}\text{N}$ values of all analyzed samples, with means of 17.2‰ and 13.9‰ , respectively (Table 3; Figure 4). The two humans have a mean $\delta^{13}\text{C}$ value of -26.2‰ , and the dogs a mean value of -25.8‰ , which are the lowest $\delta^{13}\text{C}$ values in the study. The dominant terrestrial herbivores at Ust'-Polui, reindeer, have a mean $\delta^{15}\text{N}$ value of 6.2‰ and mean $\delta^{13}\text{C}$ value of -19.4‰ . Waterfowl were relatively abundant in the site's faunal assemblage and these are represented by a single duck (*Anas* sp.) specimen, which has isotope values most similar to two small carnivores, the sable (*Martes zibellina*) and the arctic fox. All three have far higher $\delta^{13}\text{C}$ values than those of the dogs and humans. Ptarmigan were also relatively abundant at the site, and the one analyzed specimen has a very low $\delta^{15}\text{N}$ value of 1.5‰ , and a $\delta^{13}\text{C}$ value of -21.1‰ . Similar values have been found for modern Arctic ptarmigan flesh in other studies (Feige et al. 2002; Ehrich et al. 2015). The values for two Ust'-Polui marine mammal samples,

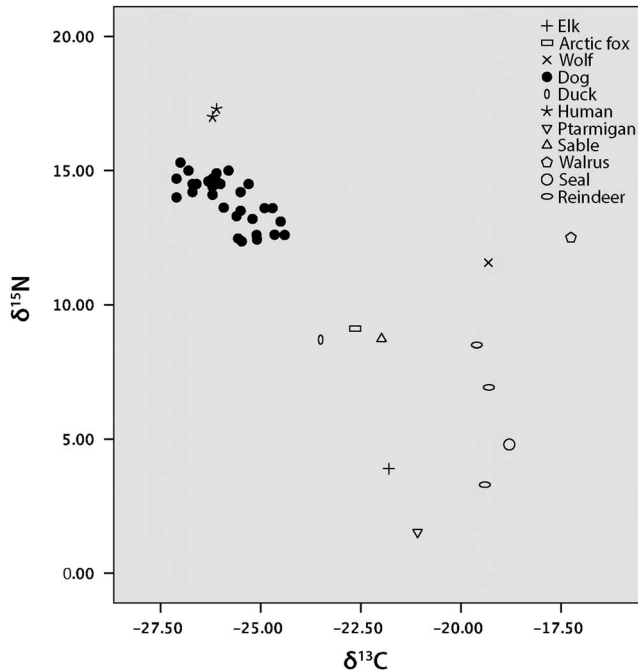


Figure 4 Biplot of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for bone collagen from Ust'-Polui, all obtained through the University of Alberta laboratory.

from walrus (*Odobus rosmarinus*; $\delta^{13}\text{C} = -17.3\text{‰}$, $\delta^{15}\text{N} = 12.5\text{‰}$) and seal (*Phoca* sp.; $\delta^{13}\text{C} = -18.8\text{‰}$, $\delta^{15}\text{N} = 4.8\text{‰}$), both have far higher $\delta^{13}\text{C}$ values than any of the above fauna. This is consistent with expectations based on other studies, which report arctic pinniped flesh $\delta^{13}\text{C}$ values no lower than about -22‰ (Hoekstra et al. 2002, 2003; Muir et al. 2003; Dehn et al. 2006; Matley et al. 2015; Jaouen et al. 2016). Note that the seal $\delta^{15}\text{N}$ value is unusually low compared to modern arctic pinnipeds, which typically have $\delta^{15}\text{N}$ values (for flesh samples) greater than 10.0‰ (see Hoekstra et al. 2002, 2003; Muir et al. 2003; Dehn et al. 2006; Matley et al. 2015; Jaouen et al. 2016). It is possible that the specimen was misidentified prior to sampling. If the humans and dogs at Ust'-Polui were heavily reliant on any of the above terrestrial or marine fauna, we would expect their $\delta^{13}\text{C}$ values to fall somewhat above those of these fauna, which they do not.

While freshwater fish bones were very abundant at Ust'-Polui, our efforts to generate reliable fish bone collagen stable isotope values were unsuccessful. Note, however, that $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values were obtained for two Ust'-Polui inconnu and one burbot sample during ^{14}C dating (Table 2). As these values were attained through different methods than those used to generate the dog and human data described above, they cannot be directly compared to the University of Alberta laboratory values. Nonetheless, the $\delta^{13}\text{C}$ values for these specimens are quite low, ranging between -26.7‰ and -24.7‰ , and their $\delta^{15}\text{N}$ values are between 11.2‰ and 13.6‰ . This is consistent with the results of research on modern freshwater river and lake fish from the Arctic. Stable carbon and nitrogen isotope values in freshwater systems are complex and vary widely, reflecting factors including the productivity of the body of water and contributions of terrestrial organic matter to its food web as well as the microhabitat and feeding niche of the organism in question (e.g. Hecky and Hesslein 1995; Chetelat et al. 2010; Premke et al. 2010; for reviews and applications in archaeology see Katzenberg and Weber 1999; Miller et al. 2010;

Fuller et al. 2012). Studies of Arctic freshwater river and lake fish typically report very low $\delta^{13}\text{C}$ values for these organisms ranging from about -30‰ to -20‰ (Hesslein et al. 1991; Hecky and Hesslein 1995; Feige et al. 2012).

The human and dogs at Ust'-Polui have $\delta^{13}\text{C}$ values well within the range of such freshwater fish. Further, the comparatively high $\delta^{15}\text{N}$ values of the humans and dogs are also consistent with regular consumption of fish.

Overall, the stable isotope data, and the dominance of freshwater fish within the site's faunal assemblage, strongly suggest both people and dogs at Ust'-Polui were consuming significant amounts of freshwater fish. Given that dogs cannot effectively fish for themselves, particularly in the far North where surface water is frozen for much of the year, these data also indicate human provisioning of dogs with fish. Note that the single analyzed wolf (*Canis lupus*) specimen has a markedly different dietary signature from the Ust'-Polui dogs, with a $\delta^{13}\text{C}$ value of -19.3‰ and a $\delta^{15}\text{N}$ value of 11.6‰ . Unlike the dogs, it was clearly consuming very little aquatic fauna in its diet.

DISCUSSION

Marine reservoir effects are unlikely to account for the old carbon offsets observed in our data. First, marine environments are considerable distances from Ust'-Polui. The southern half of the Gulf of Ob is heavily dominated by the outflow of the Ob River, meaning that freshwater environments continue to be found for several hundred kilometers to the northeast within this body of water (Diansky et al. 2015). The nearest high salinity marine environments to Ust'-Polui are at Baydaratskaya Bay on the west side of the Yamal peninsula, about 200 km directly overland to the north; this bay is an extension of the Kara Sea. Second, the local proposed marine reservoir effect in this region is too small to account for the age offsets observed in our study. Marine reservoir values for known-age bivalves from the eastern shore of Novaya Zemlya far to the northwest on the Kara Sea range from 330 to 764 yr (Forman and Polyak 1997). However, the highest such values are from dates on a single species (*Portlandia arctica*) that inhabits low salinity waters. Forman and Polyak (1997) postulated that the high offset values result from these bivalves incorporating old carbon from glaciers or streams on Novaya Zemlya (a freshwater reservoir effect), or from the substrate they inhabit. The authors further argue that dates ($n = 9$) on other shellfish species from the Kara and Barents seas are more representative of the regional open marine reservoir effect in this region, and these have an average offset value of 277 ± 78 yr (Forman and Polyak 1997). This is far less than the average age offset observed in our paired ^{14}C dates.

Far more parsimonious with the location of Ust'-Polui on the landscape, its stable isotope and faunal data, and the ^{14}C age offsets observed in this study is a freshwater source for the old carbon effects. As described above, the low $\delta^{13}\text{C}$ values of the dog and human remains provide no indication of reliance on marine foods, perhaps with the exception of the youngest human burial at the site (represented by date Ua52103), which has a higher $\delta^{13}\text{C}$ value than the other dated dogs and humans at the site. Overall, the dog and human stable isotope values at Ust'-Polui are most consistent with diets of a mixture of terrestrial mammals and freshwater organisms, the latter most likely local fish. As mentioned, fish remains were numerically dominant at the site, and burbot, whitefish, and inconnu were most abundant among the identified specimens. Conversely, birds remains were third in relative abundance following fish and mammals, and waterfowl account for less than one-third of the site's identified bird remains, being far outnumbered by remains of ptarmigan, which inhabit the forest and tundra.

Further, access to waterfowl was probably more seasonally restricted than access to fish or mammals (from late spring through early fall), as these birds are largely dependent on the presence of open water (Vizgalov et al. 2013). Fishing in the Ob was probably most effective in the warmer part of the year but could have occurred nearly year-round. Rivers in this region, except those flowing from the Ural Mountains to the west, experience a period of low oxygen and high organic input beginning around January (± 1.5 months) and lasting until the breakup of the ice in May or June (Dunin-Gorkavich 1995). In anticipation of this phenomenon in the fall, most fish, including burbot and whitefish, move out of the rivers and into the Gulf of Ob, or into locations such as the mouths of rivers originating in the Urals (Vizgalov et al. 2013). Runs of anadromous fish such as inconnu also occur in the lower Ob only in summer (Vizgalov et al. 2013). Some winter fishing in the Ob and its tributaries is also possible, particularly at the river mouths and in other areas that remained well oxygenated.

Provisioning dogs with fish is in some ways expected. Previous stable isotope work on Middle Holocene archaeological dog remains from the Cis-Baikal region of Siberia indicates that most dogs had diets consisting of significant quantities of aquatic foods (Losey et al. 2011, 2013), particularly along the western shore of Lake Baikal, and on the lake's outlet river, the Angara; both regions are rich freshwater fisheries. Ethnographic sources commonly report that dogs were regularly provisioned with fish bones and flesh in Northwest Siberia, particularly in areas where fishing was common (Khomich 1966; Lukina and Ryndina 1987; Perevalova 2004; Aksenova et al. 2005; Gemuev et al. 2005; Elert 2006; Lukina 2010). Dog predation on or scavenging of fish outside of human settlements was probably rare in the Arctic, except in tidal areas in summer, and isotope data showing that dogs consumed significant amounts of aquatic protein are likely a good indication that humans intentionally provisioned dogs mostly with fish. Dogs of course can feed themselves by preying on terrestrial mammals, and in this regard the isotope data are more ambiguous. Any terrestrial component in their diets could be interpreted as dog self-provisioning, human provisioning, scavenging, or potentially all three in various combinations. Finally, the general similarity in dietary structure between humans and dogs at Ust'-Polui is also not surprising, as similar patterns have been observed in stable isotope studies in many locations (Guiry 2012, 2013; Losey et al. 2013), and the abundance of fish remains at Ust'-Polui indicate some human reliance on these animals as food sources.

Several sources of old carbon in the Ob River watershed potentially contributed to the offsets observed in our human, dog, and fish samples. First, limestone, a major source of fossil carbon in some freshwater systems (Philippsen 2013), is present within the watershed (Larin 2004; Vyssotski et al. 2006). Second, extensive areas of the river basin are peatlands, many of which began forming early in the Holocene (Kremenetski et al. 2003), and dissolved old carbon from them could have entered the aquatic food chain. Third, permafrost is widespread in the Ob basin, and melting of these sediments could have been another source of old carbon. Finally, small (<1 km in area) cirque glaciers are present in the Polar Ural Mountains (Svendsen et al. 2014), and their meltwater also could have contributed some ^{14}C depleted carbon to the northern portion of the Ob watershed. While variable combinations of all four of these sources likely shaped the FREs carried by the fish that were consumed at Ust'-Polui, the factors influencing waterfowl were probably more complex, as their seasonal migrations exposed them to a wider array of carbon sources, including those beyond western Siberia.

Returning to the chronology of Ust'-Polui, several key points can be made. First, given the old carbon offsets in the dated human, dog, and fish bones, we propose that the charcoal or charcoal/reindeer bone phase models (with poor agreement samples removed) provide the most

reasonable estimates for the primary occupation of Ust'-Polui. Using the means of the modeled start and end ranges suggests the primary component spanned from ~260 BC to 140 AD, or to as late as 230 AD (Table 4). These dates encompass the dendrochronology dates available for the Ust'-Polui (Khantemirov and Shiatov 2012), and just post-date the earlier typological age estimate for this site (Moszyńska 1974). Second, the earliest human burial at the site, represented by date Ua54158 (birch bark from the grave), appears to have been created just prior to formation of the primary component, or very early in its history. The other burial, represented by date Ua54157 (leather from the grave), was contemporaneous with the primary component, as was assumed based on its context. Third, it is difficult to precisely estimate the age offsets in the dog remains and the isolated human bone dated in this study. While these samples have no paired dates for calculation of such offsets, all were found within site's primary deposits. The dog dates have a modeled start period mean of 1129 BC (Table 4), which predates our accepted start mean of 260 BC by 869 yr. Further, the earliest modeled mean start date in this study, based on all available charcoal dates (poor agreement samples included), is 354 BC, or 775 yr later than the dog dates start mean. These age differences are roughly similar to the average age offset value for our four paired samples, which is 784 yr. Removing the pair of dates from the youngest human burial at the site, where the human may have consumed at least some marine foods and thus carries an age offset from different or mixed carbon reservoirs, the average offset in the remaining three paired samples increases to 856 yr.

CONCLUSION

This study is the first to demonstrate a major freshwater reservoir effect in the lower Ob River region of Arctic Siberia. The resulting age bias in ¹⁴C dates from this region will depend on many factors, including organisms' overall reliance on aquatic foods, and the particular offset values of the specific aquatic foods that are eaten by those organisms over time. The two sets of dated human remains with paired dates in this study have age offsets of 568 and 1021 yr, and the suggested age bias in the site's dog remains is at least 775 yr. Such large age offsets are potentially very misleading in terms of understanding site chronologies and developing broader culture histories. This points to the need for stable isotope data on all dated bone samples, and the necessity of dating more than one material type from any given context. To develop methods for more precisely estimating FRE offsets in the region's ¹⁴C-dated samples, additional paired samples with stable carbon and nitrogen isotope data are needed. Better understanding of the region's stable isotope ecology is also required, particularly for local fish and waterfowl.

The partial dietary reliance on aquatic foods by both the people and dogs at Ust'-Polui matches well the zooarchaeological data from this site, which indicates that fish remains were highly abundant. Provisioning of dogs with fish is widely reported in the region's ethnographic literature, and the data presented here indicate that such animal management practices have a deep history along the lower Ob River. The extent of human reliance on fish and other aquatic foods beyond Ust'-Polui in Arctic Siberia remains poorly documented, but could be assessed in future stable isotope studies. Study of paleodiet in this region will of course be informative about diachronic and ecological patterning in subsistence practices, but also may reveal other old carbon reservoir effects that are presently causing unrecognized biases in archaeological ¹⁴C dates.

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