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Integrated stable isotopic and radiocarbon analyses of Neolithic and bronze age hunter-gatherers from the Little Sea and Upper Lena micro- regions, Cis-Baikal, Siberia

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ABSTRACT

The Lake Baikal region of southern Siberia has a rich mortuary record that has provided the most comprehensive isotopic database for palaeodietary studies of north-temperate hunter-gatherers in the world, permitting more detailed reconstructions and finer-grained research questions than are usually possible. Building on previous work, this study contributes new $\delta^{13}C$, $\delta^{15}N$, and AMS radiocarbon dating results from the cemeteries of Verkholensk ($n = 44$) in the Upper Lena River micro-region and Ulan-Khada ($n = 19$) in the Little Sea micro-region. Our results reveal that the Late Neolithic (LN, 5570–4600 cal BP) individuals at Verkholensk exhibit higher $\delta^{15}N$ values than in the Early Bronze Age (EBA, 4600–3700 cal BP), suggesting a shift to a more terrestrial diet, possibly in response to climate-induced environmental changes. In addition, EBA individuals at Verkholensk differ in both $\delta^{13}C$ and $\delta^{15}N$ from those at the nearby site of Obkhoi, suggesting territorial divisions at a surprisingly small scale, although there is a diachronic component that needs to be considered, highlighting the need for additional work on freshwater reservoir corrections for the Upper Lena micro-region. The Ulan-Khada EBA results are consistent with the 'Game-Fish' and 'Game-Fish-Seal' dietary patterns previously identified in the Little Sea micro-region. The now substantial Little Sea micro-region EBA dataset—— allows for more subtle differences in diet to be identified, namely that EBA females with Game-Fish-Seal diets for the whole of the Little Sea sample display significantly lower mean $\delta^{13}C$ values than their male counterparts, providing some of the first evidence for sex-based dietary distinctions in Lake Baikal.

A small number of $\delta^{13}C$ and/or $\delta^{15}N$ outliers were identified at both Verkholensk and Ulan-Khada that may support previous suggestions of individual mobility between the Upper Lena and Little Sea micro-regions. Exploratory use of $\delta^{18}O$ isotopes in bone collagen offers a novel line of support for this scenario, confirming a number of independently identified outliers.

1. Introduction

The Lake Baikal region of eastern Siberia has been well-studied archaeologically for over a century (Okladnikov, 1950, 1955, 1959). More recently, the Baikal Archaeology Project (BAP, 1995–2011) and the Baikal–Hokkaido Archaeology Project (BHAP, 2011–2018) have contributed much new data focused on the excavation and analysis of human and faunal remains. The extensive comparative isotopic and

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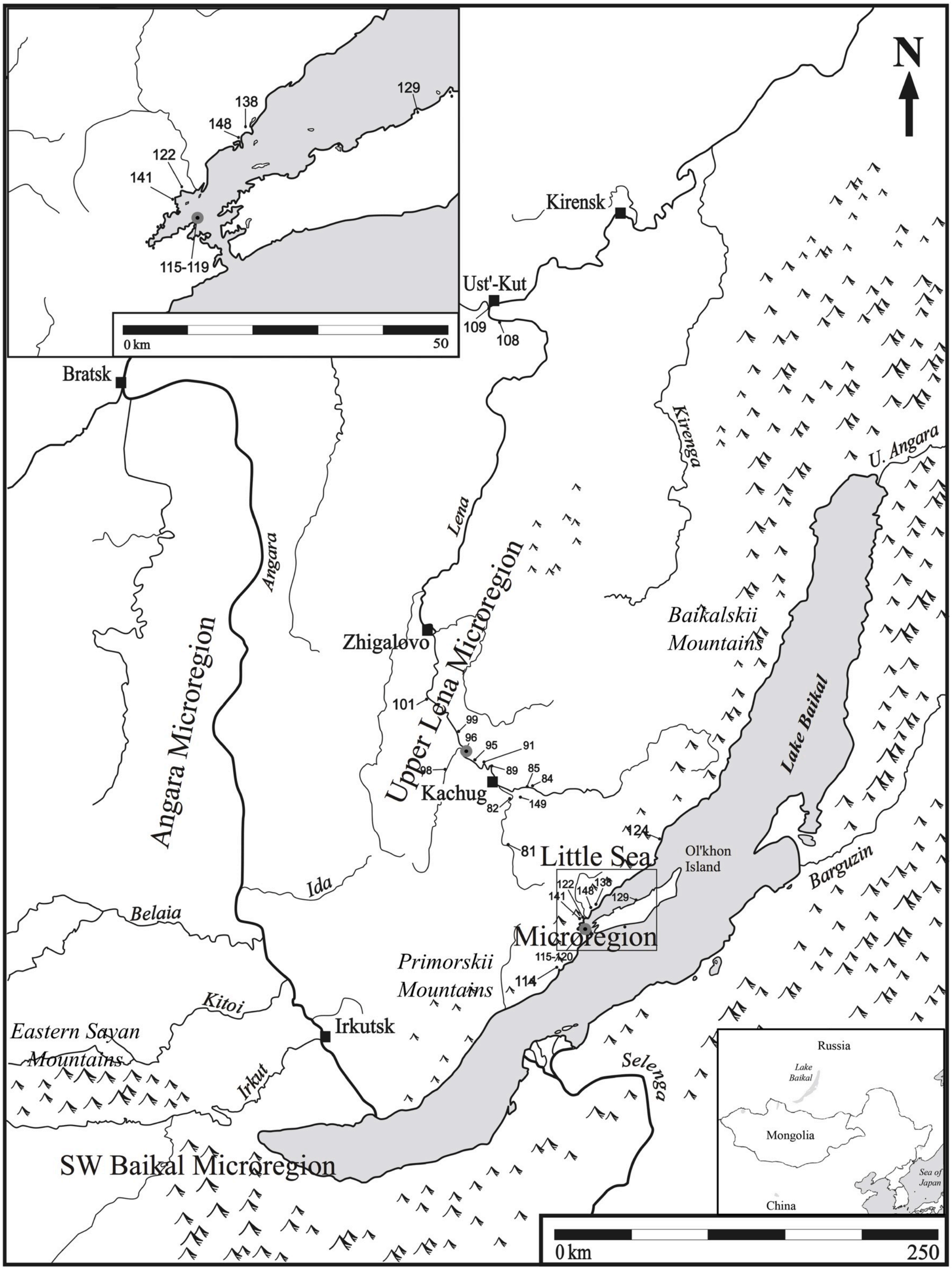

Fig. 1. Map of the Cis-Baikal region showing the micro-regions (Angara, Upper, Lena, Little Sea, and Southwest Baikal), sites sampled ([96] Verkholensk and [115–119] Ulan-Khada II, III, IV, V), and relevant sites in the Upper Lena ([81] Manzurka, [82] Ulus Khal'skii, [84] Makrushino, [85] Iushino, [89] Popovskii Lug 2, [91] Makarovo, [95] Nikol'skii Grot, [98] Obkhoi, [99] Ust'-Iamnaia, [101] Zapleskino, [108] Turuka, [109] Zakuta, and [149] Borki) and Little Sea ([114] Khotoruk, [122] Sarminskii Mys, [124] Kulgana, [129] Shamanskii Mys, [138] Kurma XI, [141] Khuzhir-Nuge XIV, and [148] Khadarta IV). Regional map sources: Esri, DeLorme, HERE, MapmyIndia.

radiocarbon datasets now available make it possible to obtain a finer resolution understanding of prehistoric hunter-gatherer lifestyles than is usually feasible. The current study builds on previous research by exploring the interactions between two micro-regions: Lake Baikal's Little Sea and the Upper Lena River (Fig. 1). Specifically, this study sheds light on our understanding of intergroup dietary variation, land tenure, and temporal shifts in diet and mobility.

Carbon and nitrogen stable isotope analyses are useful in the study of past diets because they can semi-quantify the contributions of certain broad food groups (e.g., terrestrial or aquatic). Oxygen isotopes reflect sources of water consumed (from drink and food), and so can be used to investigate mobility. Reconstruction of specific dietary patterns is

Table 1
Middle Holocene chronology for Cis-Baikal (after Weber et al., 2016) and mortuary traditions present in the Upper Lena and Little Sea. HPD signifies the Highest Posterior Density interval.

Archaeological Period	Mortuary Tradition	Radiocarbon Dates
Late Mesolithic	–	ca. 8280–7500 mean HPD cal BP
Early Neolithic	Kitoi (Angara & SW Baikal)	ca. 7500–7030 mean HPD cal BP
Middle Neolithic	–	ca. 7030–5570[a] mean HPD cal BP
Late Neolithic	Isakovo and Serovo	ca.[a]5570–4600 mean HPD cal BP
Early Bronze Age	Glazkovo	ca. 4600–3730 mean HPD cal BP

[a] The start of the LN (and hence the end of the MN) is currently being revised, and now looks likely to be a few centuries earlier (BAP project data).

predicated upon the knowledge of potential sources of food and drinking water and the ability to distinguish them isotopically. Previous studies have analysed substantial collections of modern and archaeological faunal samples to create an isotopic baseline for 'Cis-Baikal', the region to the west of the lake (Katzenberg et al., 2012; Katzenberg and Weber, 1999; Weber et al., 2002). Due to the distinctive isotopic ecologies of Lake Baikal and its surrounding rivers (discussed in detail in 3.2 and in SI), it is possible to evaluate the contribution of aquatic resources in more detail than is usually possible for freshwater systems. Furthermore, a number of water bodies have distinct oxygen isotope values (Seal and Shanks, 1998), providing the potential to address mobility.

For this study, bone samples representing 63 individuals from the cemeteries of Verkholensk (n = 44), mainly associated with the Late Neolithic (LN, 5570–4600 cal BP) and Early Bronze Age (EBA, 4600–3700 cal BP), in the Upper Lena micro-region, and from Ulan-Khada (n = 19), primarily associated with the EBA in the Little Sea micro-region, were analysed (Weber et al., 2016). Hunting, gathering and fishing continued throughout the sequence: there is no evidence for domesticated plants or animals, other than the dog.

Analysis of individuals from Ulan-Khada allows us to expand upon an extensive dataset for the Little Sea micro-region and to further assess previously identified dietary patterns, e.g. to test the validity of the Little Sea 'Game-Fish' and 'Game-Fish-Seal' diet groups (Weber and Bettinger, 2010; Weber and Goriunova, 2013; Weber et al., 2011), as well as any age- or sex-based patterning within them. Particularly significant is the

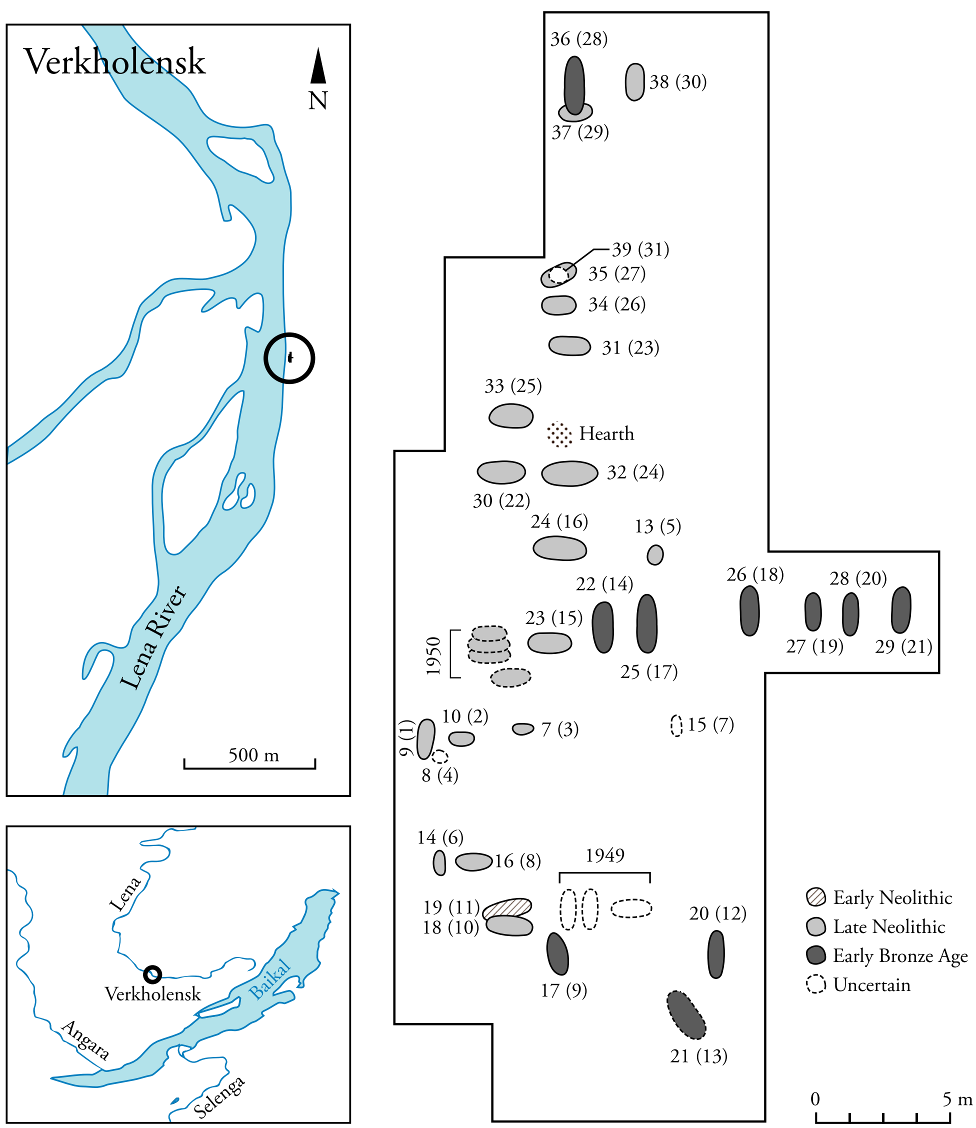

Fig. 2. Verkholensk cemetery plan and location along the Lena River. Adapted by PH and RJS from Okladnikov (1955:219) Figure 104 and Okladnikov (1978:5) Fig. 1. For clarity, our map includes the cumulative grave numbers assigned by Okladnikov in his 1978 publication and those assigned during the original excavation (in brackets), see Supplementary Information (SI 1) for more details. The period assignments reflect the results of this study.

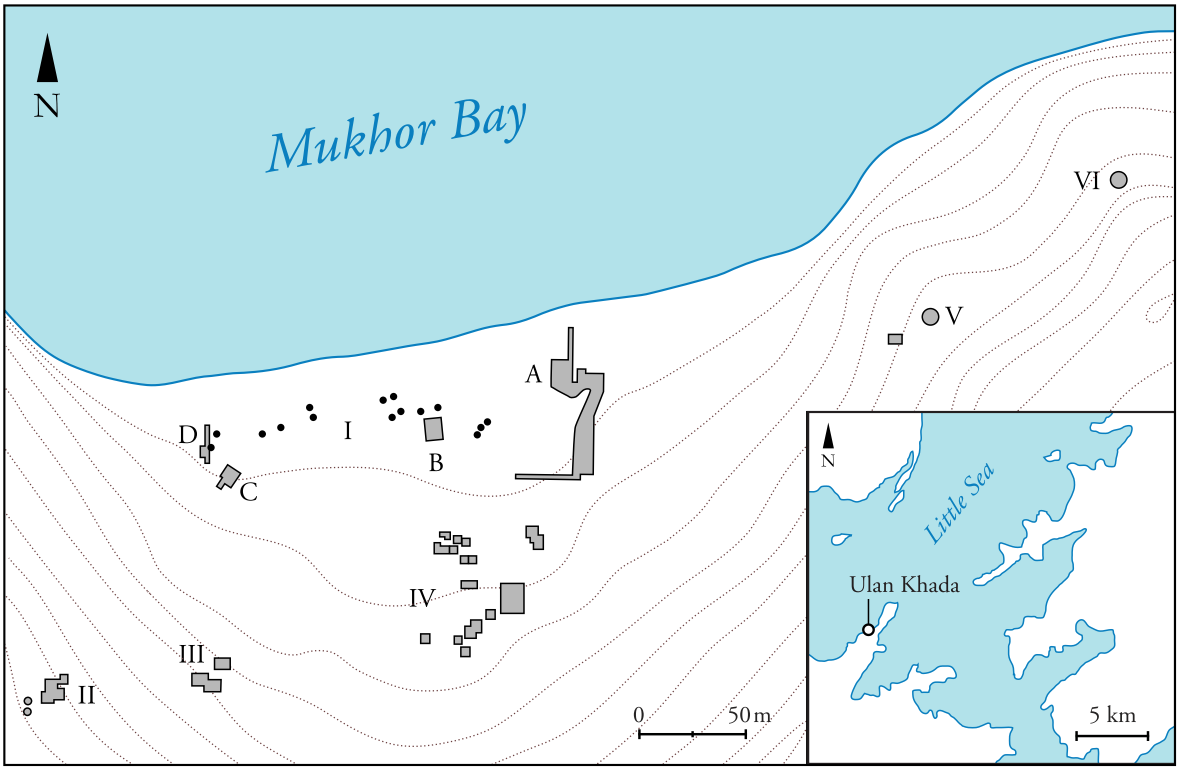

Fig. 3. Map of Ulan-Khada stratified site (A–D) and Ulan-Khada cemeteries (II-VI) (adapted by PH from Komarova and Sher, 1992:148, Fig. 2).

inclusion of data from Verkholensk, the largest excavated cemetery along the Upper Lena River, which has received less study than other micro-regions, and allows testing of previously proposed hypotheses. Specifically, hunter-gatherer travel between the Upper Lena and the Little Sea has been suggested based on carbon, nitrogen, and strontium isotope results (Weber and Goriunova, 2013). Moreover, unlike other cemeteries previously investigated in the Upper Lena micro-region, Verkholensk spans the LN and EBA, making it possible to investigate diachronic diet change at a single location, particularly with reference to potential human responses to environmental change.

Following the standard research methodology of BAP/BHAP, all the individuals are directly radiocarbon-dated. This provides a robust chronological framework, allowing the (re)assessment of the typological period assignment of each burial, with the possibility of fine-tuning our understanding of both mortuary variability, and the absolute chronology of the main culture-historical sequence.

2. The sites in their regional context

2.1. Archaeological background

Research on Lake Baikal hunter-gatherers has mainly focused on the abundant Neolithic and EBA cemeteries of the region (Weber et al., 2016) (Table 1). The Kitoi mortuary complex from the Angara valley and southwest Baikal is associated with the Early Neolithic (EN), characterised by rich grave goods and the abundant use of red ochre (Bazaliiskii, 2010; Weber, 1995; Weber and Bettinger, 2010; Weber et al., 2016). Burials dating to the Middle Neolithic (MN) are extremely rare and there have been no cemeteries found dating to the period.

During the LN, cemetery use was reinstated and continued throughout the EBA (Weber et al., 2016). The identifying characteristics of the period's Serovo mortuary complex vary regionally. In the Little Sea and Upper Lena, skeletons are often covered by birch bark and many show evidence of light burning within the grave pits and red ochre in small patches. Upper Lena graves tend to contain more fishing gear and antler picks than seen in Little Sea graves, whereas small clay vessels are more common in the latter (Bazaliiskii, 2010; Weber et al., 2016).

The Glazkovo mortuary tradition dates to the EBA, but metal grave goods are rare and its defining characteristic is the orientation of graves along the courses of major rivers or shoreline (Weber, 1995; Weber et al., 2016). For instance, Upper Lena graves tend to be arranged parallel to the Lena, whereas graves from the Little Sea tend to be oriented southwest-northeast, roughly parallel to the shoreline (Weber et al., 2016). Nevertheless, it has been noted that Glazkovo is more uniform in Cis-Baikal than earlier traditions (Shepard et al., 2016). The practice of lighting small fires within or over the graves continued. Clay vessels and fishing tackle are less common than in the preceding Serovo, but ornaments made from small beads or animal bones are common. LN and EBA graves tend to co-occur within the same cemeteries and their burial structures are often visible (Weber et al., 2016).

There is extensive archaeological and isotopic evidence for reliance on fishing along with ungulate and seal hunting (Weber and Bettinger, 2010; Weber et al., 2002, 2011). Net-impressed EN pottery offers indirect evidence of net fishing technology. Harpoons, fishhook shanks, and composite fishhooks are common in Kitoi graves. While there is as yet no direct evidence for watercraft, it has been argued that entheseal changes (musculoskeletal stress markers) on the upper limbs of some individuals may reflect their use (Lieverse et al., 2009; Losey et al., 2012).

2.2. Verkholensk

Verkholensk is located on the right bank of the Lena River at the edge of a modern village of the same name (Fig. 2). The cemetery sits on a high river terrace that is visible from a distance. Okladnikov (1978) provides detailed descriptions of the cemetery and individual graves, most of which were disturbed to some degree prior to excavation. Common grave goods included arrowheads and arrow shaft straighteners, boar and beaver teeth, bone awls, harpoons, needle cases, bone and stone representations of fish, composite fishhooks, flint flakes, and blades, shell beads, stone and nephrite adzes, net-impressed pottery, and

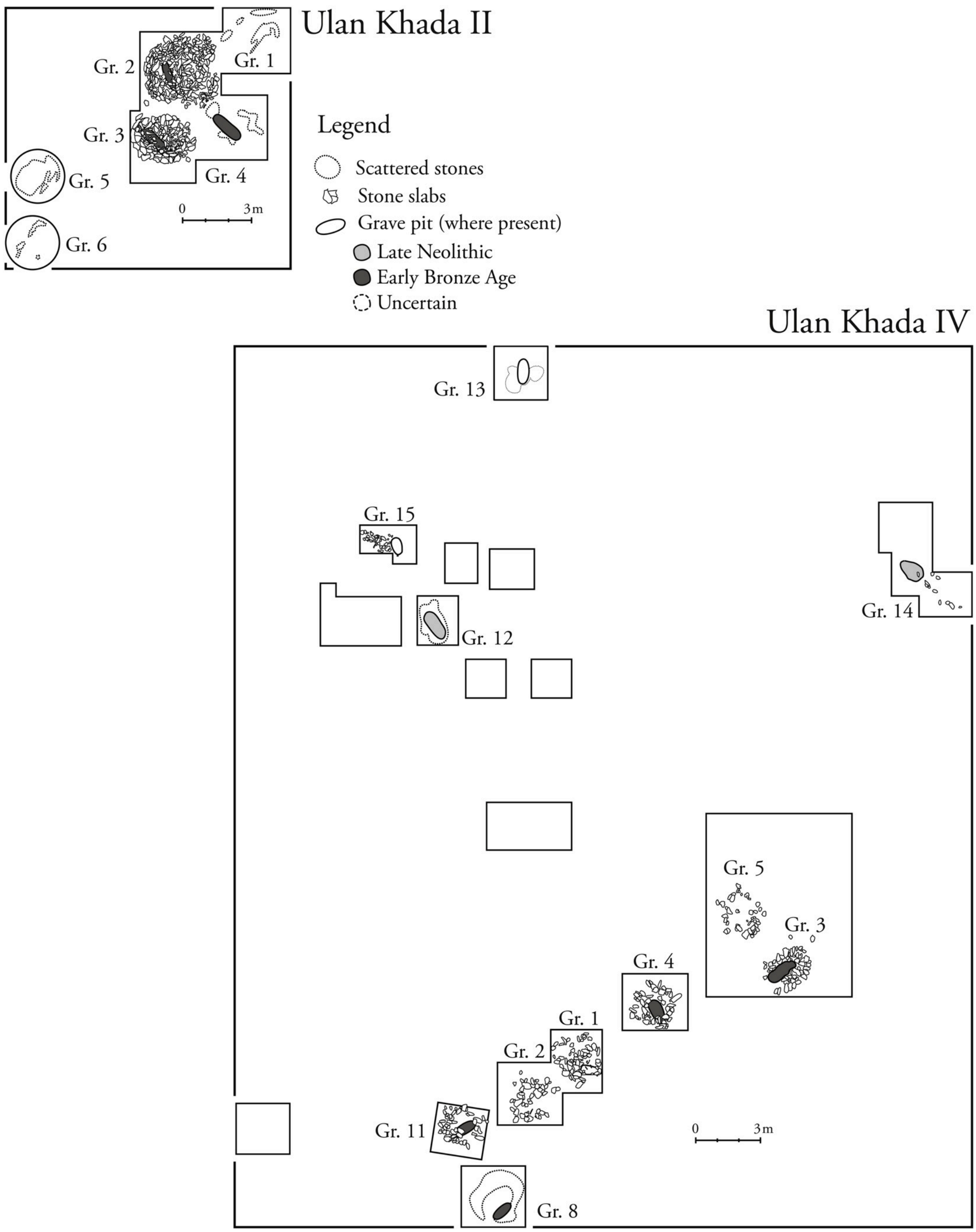

Fig. 4. Ulan-Khada II and IV cemetery plans adapted by PH from Komarova and Sher, (1992:181) Fig. 35. The period assignments reflect the results of this study. The spatial relationship between Ulan-Khada II and IV is not shown.

worked antler objects. These, along with grave orientation, typologically classify burials as LN or EBA. There were both single and multiple inhumations, as well as evidence for later burials being added to or intruding upon previous inhumations (e.g., Graves 19 and 24).

2.3. Ulan-Khada

Ulan-Khada is located on the south coast of the Little Sea's Mukhor Bay. Komarova and Sher (1992) describe the cemetery and individual burials in detail, while Goriunova and Khlobystin (1992)—discuss the chronology of the graves based on typological criteria. Unusually, the Ulan-Khada cemetery is in close proximity to a habitation site (Fig. 3, A–D) (Khlobystin and Clark, 1969; Komarova and Sher, 1992; Okladnikov, 1950). The cemetery was divided into six sectors, ca. 50–250 m apart, the significance of which is not clear: they could represent familial burial places or other sub-groups within the community. Most of the individuals analysed in this study come from sectors II and IV (Fig. 4). A number of graves appear to have been looted or otherwise disturbed in the past.

Ulan-Khada II and III are located on a slope, and all the graves were marked by two layers of stone. Ulan-Khada II grave goods included a bone harpoon, a bronze knife, flint arrowheads, flint knives, nephrite disks and axes, plain pottery, and red deer tooth pendants. Ulan-Khada III is 55 m downslope from Ulan-Khada II. Three areas covered by stones were excavated, but only one yielded a grave with a burial dating to the EBA.

Ten of the 21 stone clusters excavated at Ulan-Khada IV marked graves, with the remainder being either random groupings of natural stones, or, as the excavators suggested, perhaps marked infant graves whose bones did not survive in the sandy soils (Komarova and Sher, 1992). Grave goods included a bear tooth, birch bark, boar tusk plates and plaques, bone awls, a bone carving of a moose, ceramic fragments, charcoal, a copper plate, flint prismatic blades, a small axe-shaped nephrite pendant, ochre, a composite fishhook shank, and red deer tooth pendants. Ulan-Khada IV Graves 12, 13, and 15 were thought to be EN based on the presence of red ochre and characteristic grave goods, though only the burials from Grave 12 were available for sampling. The remaining graves were classified as Glazkovo (Goriunova and Khlobystin, 1992). Ulan-Khada V is located directly on the slope that borders the bay to the east. The single individual available for analysis came from a rectangular burial pit covered by stones and lacked grave goods. Finally, Ulan-Khada VI yielded only a single grave – reported to be Late Bronze Age typologically (Goriunova and Khlobystin, 1992) – that was unavailable for this study.

Further details concerning Verkholensk and Ulan-Khada can be found in Supplementary Information (SI 1). The original cultural classifications for the Verkholensk and Ulan-Khada graves to specific mortuary traditions and archaeological periods were proposed on typological grounds using culture historical schemes (e.g. Komarova and Sher, 1992; Okladnikov, 1978) that predate the recent extensive program of radiocarbon dating (Weber, 1995; Weber et al., 2016). Although for Verkholensk and Ulan-Khada these generally remain valid, their chronological position relative to one another has been revised and in a few instances radiocarbon dates warranted a reassignment to a different period (see 5.1).

3. Local isotopic ecology and previous analyses

3.1. Stable isotopic analyses

Stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes in adult bone collagen reflect aspects of average diet over approximately the last decade of life (Hedges et al., 2007; Tieszen et al., 1983). Due to the preferential routing of amino acids in metabolic processes, $\delta^{13}C$ measurements on collagen are biased towards the protein component of the diet (Ambrose and Norr, 1993; Tieszen and Fagre, 1993). Values vary significantly by photosynthetic pathway and by carbon source, differentiating between plants using C_3, C_4, and CAM pathways and the animals reliant on them. C_3 and marine systems can also be distinguished through differences in the baseline values of atmospheric and ocean

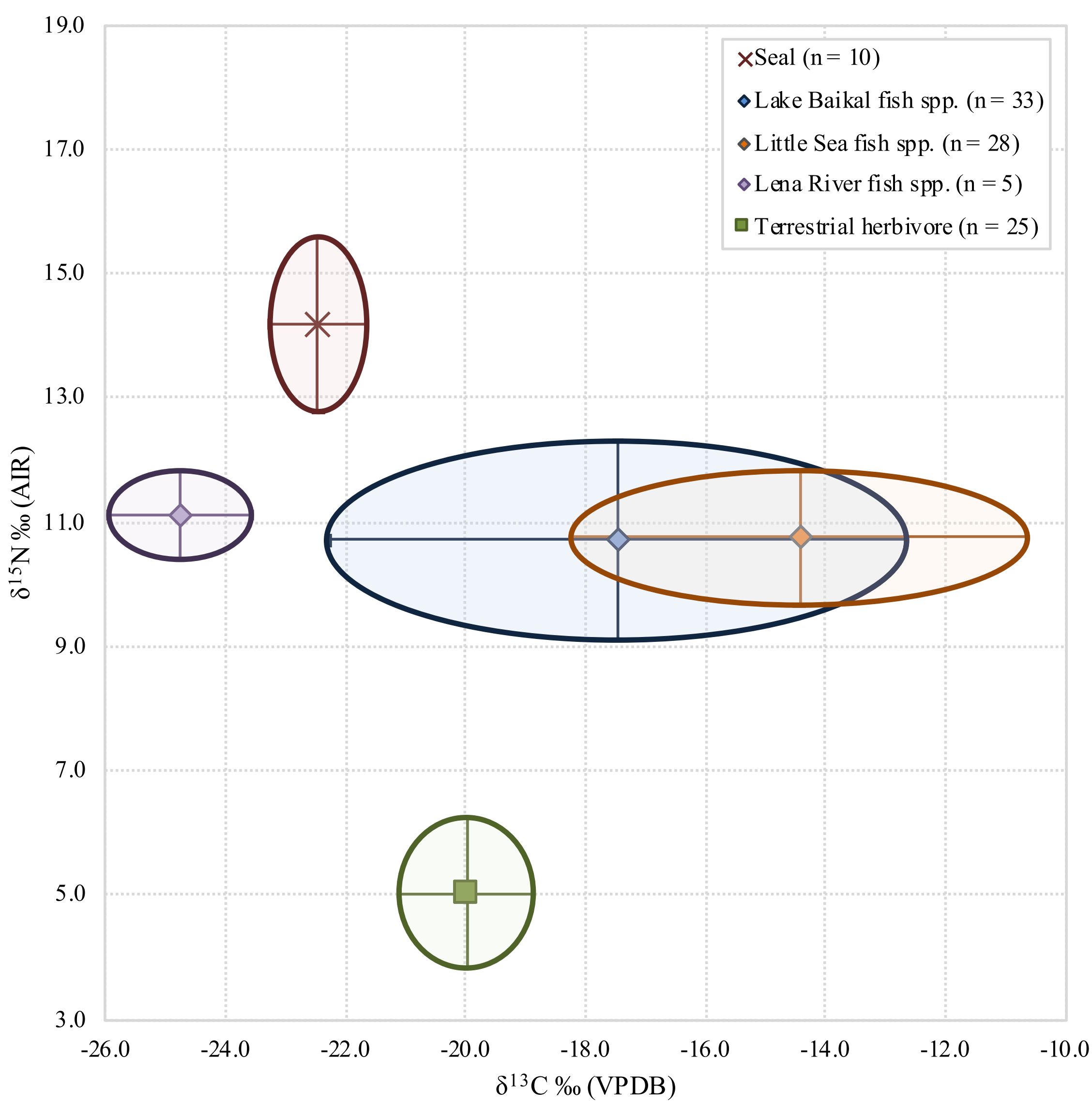

Fig. 5. Lake Baikal, Little Sea, and Lena River aquatic and terrestrial faunal isotope ranges (mean ± one standard deviation) from Katzenberg et al. (2012) and Weber et al. (2002). The fish values are modern and are adjusted for a fossil fuel effect. The terrestrial herbivore and seal values are from archaeological samples.

carbon pools (DeNiro and Epstein, 1978; Schoeninger and DeNiro, 1984). Cis-Baikal presents a typical C_3 ecosystem, lacking significant C_4 plants. Nevertheless, as discussed further below, the lake's unique isotopic ecology features a wide range of ^{13}C values, overlapping those seen in marine systems (Yoshii, 1999; Yoshii et al., 1999).

Nitrogen derives from the protein component of the diet; δ^{15}N increases by +3–6‰ with trophic level, providing information on an organism's position in its food web (Bocherens and Drucker, 2003; DeNiro and Epstein, 1981; Hedges and Reynard, 2007; Minagawa and Wada, 1984; O'Connell et al., 2012; Schoeninger and DeNiro, 1984). Nursing infants partly reflect this trophic level shift, being ^{15}N-enriched relative to their mothers (Fuller et al., 2006; Schurr, 1998). For this reason, care needs to be taken to treat their values separately from those of older children and adults. Waters-Rist et al. (2011) found that EN and LN infants from the Angara valley were normally nursed until about 2–3 years old, whereas children from 4 to 10 years old were not isotopically distinct from adults in the same groups. Fish are typically ^{15}N-enriched due to the longer food chains in aquatic systems; when contributing significantly to the diet, as is the case in Cis-Baikal, they result in high human δ^{15}N values well above those normally seen in terrestrial systems.

Oxygen isotopes (δ^{18}O) in human tissues reflect sources of ingested water from both drinking water and food. Processes of evaporation and precipitation lead to isotopic differences in precipitation on regional scales (Jouzel et al., 2000). Because δ^{18}O in drinking water is strongly related to local precipitation, measurements made on humans can in theory be compared against environmental precipitation and drinking water data in order to determine whether they are consistent with a local origin (Darling and Talbot, 2003). In practice, making any such direct comparisons is problematic (cf. Pellegrini et al., 2016).

Measurements are usually undertaken on carbonate or phosphate in tooth enamel, which was not available for the present analysis. Instead, we present the results of a small pilot study exploring the utility of measuring δ^{18}O in bone collagen, using the same material prepared for δ^{13}C and δ^{15}N analysis. While this avoids the problem of post-depositional diagenesis affecting bone apatite, sample preparation leads to the exchange of a portion of the oxygen (<20%) in collagen with H_2O in the laboratory's atmosphere and in the reagent waters used for demineralisation (von Holstein et al., 2018; cf. Bowen et al., 2005). Direct comparisons with results from other laboratories as well as with environmental datasets are therefore not possible. Nevertheless, while attenuating the biogenic signal, the exchangeable oxygen is expected to be similarly affected as long as the samples were prepared using the same methods, at the same time and in the same laboratory (i.e., the 'principle of identical treatment'), and so the results can still be compared in *relative* terms with one another. Another issue involves uncertainty over the proportional contributions of ^{18}O from drinking water and from dietary protein to bone collagen. For our purposes it is sufficient to note that both are relevant, and that studies have shown that δ^{18}O in proteinaceous tissues (i.e., collagen and keratin) still tracks environmental trends, since drinking water and food are not independent (Chesson et al., 2011; Kirsanow and Tuross, 2011—). Thus, even if δ^{18}O in collagen derives primarily from food, the food items will still ultimately reflect environmental waters. We are mainly interested here in: 1) determining whether or not the expected direction and magnitude of difference in δ^{18}O can be identified between Verkholensk and Ulan-Khada, suggesting that at least part of the endogenous signal survives; and 2) determining whether outliers identified through δ^{13}C and δ^{15}N analysis are also outliers in δ^{18}O.

3.2. Local isotopic ecology

Isotopic data (δ^{13}C and δ^{15}N) are available for a range of terrestrial and aquatic fauna from Cis-Baikal (Katzenberg and Weber, 1999; Katzenberg et al., 2012; Weber et al., 2002, 2011). Most of the aquatic fauna derive from Lake Baikal, the Little Sea, and Angara micro-regions, with only a few results available for the Upper Lena. Due to the limited availability of archaeological specimens, the fish are mainly modern, adjusted for the fossil fuel effect (Friedli et al., 1986). The region's flora has not yet been analysed isotopically, with the exception of 'cedar' (*Pinus sibirica*) nuts (Lam, 1994; Weber et al., 2002).

Lake Baikal presents a very unusual isotope ecology. Its two primary producers—phytoplankton and periphytic algae—differ by over 20‰ in their mean δ^{13}C values (Yoshii, 1999; Yoshii et al., 1999). This results in fish bone collagen δ^{13}C values ranging from −24.6‰ (omul', *Coregonus migratorius*) to −12.9‰ (ide, *Leuciscus idus*) (Fig. 5), depending largely on habitat preferences, which can vary even within the same species. Fish from shallow coves and lagoons, where photosynthetic productivity is dominated by attached green algae, tend to be ^{13}C-enriched and pelagic species such as the omul' and endemic Baikal seal (*Phoca sibirica*), on the other hand, are ^{13}C-depleted (Katzenberg et al., 2012; Weber, 2003; Weber and Bettinger, 2010; Weber et al., 2011). The Little Sea mainly contains cove, lagoon and littoral fishes (with a δ^{13}C range of 10‰). Since the Lena River is not connected to Lake Baikal, it does not have ^{13}C-enriched fishes and thus lacks the high δ^{13}C values seen in the lake's inshore fishes. Seals and pike (*Esox lucius*) are top predators and so have correspondingly high δ^{15}N values (Katzenberg and Weber, 1999; Katzenberg et al., 2010). Pike is the Lena's top predator (for further details on the aquatic resources see SI 2).

Baikal's isotopic water values are determined by river inputs and outputs as well as by precipitation and evaporation (Mackay et al., 2011; Morley et al., 2005; Seal and Shanks, 1998). The lake has a mean $\delta^{18}O_{VSMOW}$ value of -15.8 ± 0.3‰ ($n = 32$), with the low variability reflecting the lake's well-mixed waters (Morley et al., 2005; Seal and Shanks, 1998). The Upper Lena is more variable, but has a significantly lower mean $\delta^{18}O_{VSMOW}$ value of -19.6 ± 1.4‰ ($n = 33$) that generally conforms to the Global Meteoric Water Line (Seal and Shanks, 1998).

3.3. Previous research

Focusing on the two micro-regions directly relevant to this paper, stable isotope investigations have been carried out on many EBA individuals in the Little Sea and far fewer in the Upper Lena.[1] The Little Sea results indicate that inhabitants relied on cove and lagoon fish and seal in addition to terrestrial game. The LM/EN individuals in the Little Sea relied mainly on terrestrial mammals and littoral fish, but the EBA sees a conspicuous shift to two different contemporaneous dietary patterns (Weber and Bettinger, 2010; Weber and Goriunova, 2013; Weber et al., 2011). The 'Game-Fish-Seal' (GFS) (δ^{15}N ca. 13.5–16.5‰; δ^{13}C ca. −18.0‰) diet is defined by a greater reliance on littoral lake fish and seals than the 'Game-Fish' diet (δ^{15}N ca. 10.3–13.0‰; δ^{13}C ca. −19‰) (Fig. 6). Though its sample size is considerably smaller, the intervening LN is clearly dominated by the GFS diet. In addition to the visual evidence for bimodality (see Fig. 6 inset histogram), the distribution of the δ^{15}N values for the EBA Little Sea dataset as a whole departs significantly from normality (Shapiro-Wilk test, $p = 0.0005$, $n = 110$), while the separate GF ($p = 0.539$, $n = 30$) and GFS ($p = 0.290$, $n = 80$) distributions do not.

At Khuzhir-Nuge XIV, strontium isotope (^{87}Sr/^{86}Sr) analysis revealed that individuals identified as born locally all had GFS diets ($n = 11$), whereas those identified as non-local ($n = 13$) displayed both GF and GFS diets (Weber and Goriunova, 2013; Weber et al.,

[1] Most human samples were previously analysed at the University of Calgary, but have now been re-analysed at Oxford to make them more directly comparable, taking advantage of advances in stable isotope methods and instrumentation. The samples from Khuzhir-Nuge XIV used in section 6.2 are the only ones used in this study that have not yet been re-assessed. While this may affect individual results to a small degree (based on inter-laboratory comparisons), it should not impact significantly on the overall patterns in the data (Weber et al., 2016).

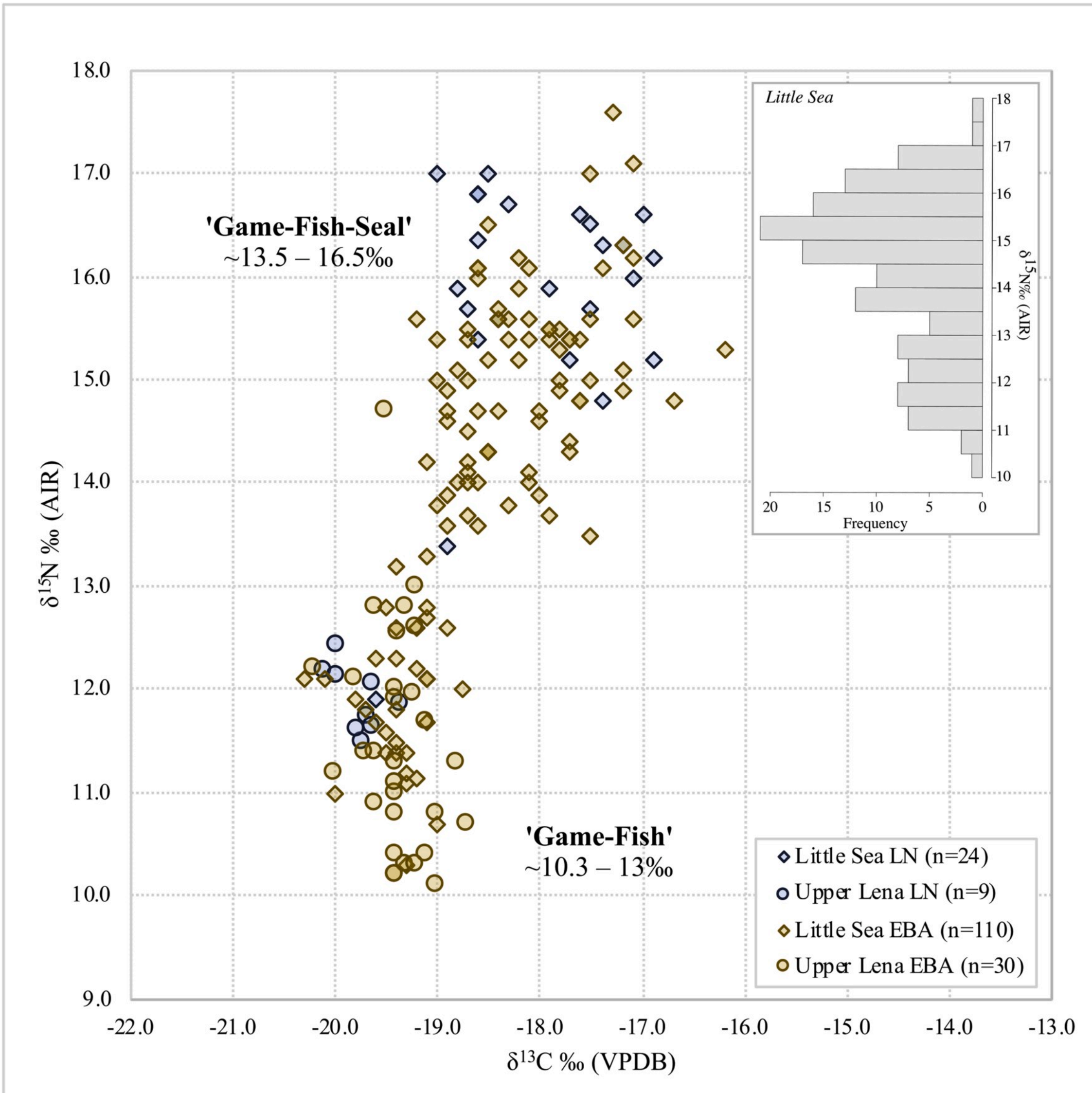

Fig. 6. Game-Fish vs. Game-Fish-Seal dietary patterns in the Little Sea and Upper Lena during the LN and EBA currently in the BAP/BHAP database. The $\delta^{15}N$ results for the Little Sea are bimodally distributed.

2011). Most non-local individuals had strontium isotopic ranges consistent with either the Angara or Upper Lena, though other areas yet to be characterised may exhibit similar ratios. Based on its proximity, the Upper Lena (~65 km north) has been proposed as their most probable origin.

However, recent examination of the Upper Lena's freshwater reservoir effect (FRE) suggests that this scenario may be more complicated (Schulting et al., 2015). The old carbon offset for EBA individuals with GF diets is significantly lower in the Little Sea (149 ± 91 ^{14}C yr, n = 7) than for the Upper Lena (432 ± 101 ^{14}C yr, n = 6) (Schulting et al., 2014). Thus, if non-local individuals from the Little Sea cemeteries with GF diets were in fact from the Upper Lena, they would have had to have changed their diet to one with a lower old carbon offset while avoiding the higher amounts of littoral fish and seal common to the GFS diet after arriving at the lake-side. It must be kept in mind that the nature of movement and contact between these two micro-regions was likely complex, and is only partially visible in the archaeological record. Since more research is needed regarding the FRE on the Upper Lena, for this study we provisionally propose that the Little Sea non-locals likely arrived there from that area.

4. Materials and methods

4.1. Materials

The 63 individuals analysed in this study are from the skeletal collection housed at the Peter the Great Museum of Anthropology and Ethnography (Kunstkamera), St. Petersburg.[2] Samples were collected by RJS and AW in 2015 and prepared by JAW and staff at the Oxford Radiocarbon Accelerator Unit (ORAU) for $\delta^{13}C$, $\delta^{15}N$, and ^{14}C measurement at the University of Oxford's Research Laboratory for Archaeology and the History of Art (RLAHA). AL conducted the $\delta^{18}O$ analysis on the same samples in 2017 at RLAHA.

[2] Most of the individuals had age and sex information published in the Russian literature reviewed earlier, though these are not always reliable. RJS re-examined the skeletons and provisionally assigned new age and sex determinations based on the available material, which in many cases was quite limited.

Catalogue: This catalogue provides information about all the samples used in this study (site name, grave number, age, sex) and results of radiocarbon and stable isotope analyses (^{14}C date BP and error, FRE corrected date BP and error, FRE offset, 95.4% confidence, and mean calibrated date BP and error, percent yield, percent carbon, δ^{13}C, δ^{15}N, pretreatment protocols used, assigned dietary pattern, and δ^{18}O). See Table 2 for details on the FRE correction equations used. The 'Period' assignment is the result of the radiocarbon analysis and assessment of the archaeological evidence. The R_Combine results are listed for every individual that was used in the test for individuals analysed twice, double burials, and multiple burials. δ^{13}C and δ^{15}N values in bold text identify site outliers. 'Pretreat' refers to which protocols were used to pretreat the samples, whether just those in the ORAU (A) or the ORAU and palaeodiet (B) laboratories outlined in 4.2.

Master ID	Grave	Period	Age	Sex	OxA	Element/Side	DateBP	+/-	FRE	CorrDateBP	CorrError	DateDiff	FromCalBP95	ToCalBP95	µ cal BP	cal BP σ	R_Combine	%Yld	%C	δ^{13}C	δ^{15}N	C:N	Pretreat	GF/GFS	δ^{18}O	Notes
Ulan-Khada																										
UK2_1959.002	UK_II 2	EBA	Mid? adult	M?	33943	radius/ L	3977	35	1	3684	63	293	4227	3845	4024	90		5.4	45.1	-18.3	14.0	3.3	A	GFS		
UK2_1959.003	UK_II 3	EBA	Yng/Mid-adult	M?	33941	occipital/R	4169	35	1	3819	63	350	4416	4002	4225	103		12.5	44.9	-18.2	14.7	3.3	B	GFS	9.9	
UK2_1959.004	UK_II 4	EBA	Child, c. 12 yrs.	I	33976	occipital/L	4018	32	1	3629	61	389	4146	3730	3952	88		10.2	44.5	-18.5	14.6	3.3	B	GFS		
UK2_1959.005	UK_II 5	EN	Adolescent	F	33942	femur/L	6665	40	1	6414	65	251	7439	7178	7341	59		6.0	44.8	-17.0	15.1	3.2	B	GFS	8.8	
UK3_1959.001	UK III 1	EBA	Adult	I	33944	mandible/R	4149	33	1	3873	61	276	4495	4094	4294	91		10.2	45.3	-18.6	13.4	3.3	B	GFS		
UK4_1959.003.C	UK IV 3	EBA	Adolescent	F?	33945	occipital/R	4444	37	1	3990	64	454	4798	4243	4467	111		4.6	44.1	-18.4	15.5	3.3	B	GFS	11.4	
UK4_1959.004.A	UK IV 4	EBA	Yng/Mid-adult	M?	33946	occipital/?	4461	37	1	4097	64	364	4824	4440	4633	109	χ2 t-test, df = 4, T = 6.2 (5% 9.5)	5.4	44.0	-17.7	15.4	3.3	B	GFS	11.8	
UK4_1959.004.B	UK IV 4	EBA	Adult	M?	33947	occipital/R	4469	36	1	4166	63	303	4841	4530	4693	90	χ2 t-test, df = 4, T = 6.2 (5% 9.5)	13.8	44.7	-17.8	14.7	3.3	B	GFS	11.1	
UK4_1959.004.C	UK IV 4	EBA	Mid/Old adult	I	33948	mandible/R	4326	36	1	4052	63	274	4817	4414	4574	115	χ2 t-test, df = 4, T = 6.2 (5% 9.5)	5.0	43.8	-18.1	13.9	3.3	B	GFS	8.6	
UK4_1959.004.D	UK IV 4	EBA	Adult	M?	33954	femur/R	4346	37	1	4074	64	272	4820	4422	4605	114	χ2 t-test, df = 4, T = 6.2 (5% 9.5)	9.9	44.2	-18.0	14.0	3.2	B	GFS	10.3	
UK4_1959.004.E	UK IV 4	EBA	Mid adult	M?	33955	mandible/R	4304	38	1	3947	64	357	4569	4159	4389	102	χ2 t-test, df = 4, T = 6.2 (5% 9.5)	10.6	43.0	-18.1	14.9	3.3	A	GFS		
UK4_1959.005.02	UK IV 5	EBA	Adult	I	33949	mandible/R	4129	35	1	3954	63	175	4574	4160	4400	102	χ2 t-test, df = 1, T = 1.6 (5% 3.8)	6.1	44.1	-19.0	11.8	3.3	A	GF		
UK4_1959.005.03	UK IV 5	EBA	Old adult	M	33950	occipital/L	4324	35	1	4066	63	258	4817	4420	4594	115	χ2 t-test, df = 1, T = 1.6 (5% 3.8)	10.1	44.4	-18.9	12.8	3.2	A	GF		
UK4_1959.011.02	UK IV 11	EBA	Child, c. 8 yrs.	I	33951	mandible/L	4536	34	1	4085	62	451	4821	4436	4619	111		5.1	43.4	-18.6	15.2	3.3	B	GFS	12.7	
UK4_1959.012	UK IV 12	LN	Old adult	M	33952	occipital/R	5500	38	1	5391	64	109	6295	6001	6168	87		12.4	42.1	-17.7	12.8	3.3	B		6.3	Little Sea FRE
									3	5281	75	219	6270	5915	6072	93										Angara/SW Baikal FRE
UK4_1959.014.02	UK IV 14	LN	Adult	F?	33953	mandible/R	5495	38	1	5418	64	77	6312	6002	6198	84		4.5	42.9	-17.3	13.0	3.3	B		9.0	Little Sea FRE
									3	5258	75	237	6270	5902	6052	96										Angara/SW Baikal FRE
UK5_1959.001	UK_V 1	LN	Adult	F?	33956	ulna/R	4865	38	1	4824	64	41	5710	5327	5541	81		7.3	45.2	-16.8	13.2	3.2	B		6.2	Little Sea FRE
									3	4594	75	271	5578	4988	5276	143										Angara/SW Baikal FRE
Verkholensk																										
VKL_1950.005	5	LN	Adult	F?	33875	parietal,frontal/R	5015	40	2	4504	57	511	5316	4970	5153	101		4.7	45.9	-20.2	11.8	3.2	B		8.6	
VKL_1950.006	6	LN	Adult	M?	33877	humerus/L	5090	37	2	4663	55	427	5581	5300	5410	81		4.9	45.9	-19.7	12.1	3.2	B		8.2	
VKL_1950.007	7	LN	Adult	I	33878	occipital/?	5065	35	2	4570	53	495	5450	5045	5228	119		3.9	44.6	-20.0	12.5	3.2	B			
VKL_1950.008	8	LN	Child, c. 12	I	33876	temporal/L	5052	38	2	4513	55	539	5317	4975	5161	98		3.8	44.7	-20.3	12.0	3.2	B		7.9	
VKL_1951.009	9	LN	Mid/Old adult	F	33879	tibia/R	4575	33	2	4199	52	376	4853	4577	4722	78		4.6	45.1	-19.7	11.0	3.2	A			
VKL_1951.010	10	LN	Yng adult	M?	33911	femur/R	5141	38	2	4735	55	406	5588	5323	5464	82		2.7	43.6	-19.8	11.6	3.2	B			
VKL_1951.013	13	LN	Adult	U	33880	humerus/L	5650	40	2	5330	57	320	6276	5950	6110	81		7.4	46.0	-19.2	12.4	3.2	A			
VKL_1951.014	14	LN	Old adult	M?	33881	femur/L	5105	35	2	4663	53	442	5580	5300	5410	78		3.6	44.2	-19.7	12.4	3.2	B			
VKL_1951.016.01	16	LN	Child, c. 10 yrs.	I	33882	humerus/R	5311	37	2	4833	55	478	5698	5332	5553	70		4.0	44.8	-20.1	11.7	3.2	A			
VKL_1951.017.02	17	EBA	Mid/Old adult	F?	33883	temporal/L	4515	35										5.6	44.5	-20.2	12.0	3.2	A			Combined values (Method 2, Weber et al., 2016)
					33884	tibia/L	4606	37																		
									2	4041	39	518	4787	4419	4527	84	χ2 t-test, df=1 T=0.4 (5% 3.8)									
VKL_1951.018	18	LN	Mid/Old adult	M?	33912	humerus/R	5166	37	2	4683	55	483	5581	5312	5425	80		4.7	43.6	-19.9	12.3	3.2	B			
VKL_1951.020	20	EBA	Mid adult	F	33913	femur/R	3788	37	2	3379	55	409	3825	3475	3627	77		5.8	46.9	-19.9	10.9	3.2	B		7.3	
VKL_1951.022	22	EBA	Yng adult	M	34212	tibia/R	3869	38	2	3370	55	499	3819	3459	3614	76		6.3	51.3	-20.2	11.4	3.2	B			
VKL_1951.023	23	LN	Mid/Old adult	F	33887	femur/L	5091	37	2	4656	55	435	5581	5295	5404	83		3.9	44.4	-19.8	11.9	3.2	B			
VKL_1951.024.01	24	LN	Yng/Mid adult	M	33914	femur/R	5150	40	2	4656	57	494	5583	5290	5403	87	χ2 t-test, df = 1, T = 0.6 (5% 3.8)	6.8	47.0	-20.0	12.4	3.2	B		7.1	
VKL_1951.024.02	24	LN	Yng adult, c. 18 yrs.	F?	33915	humerus/R	5198	37	2	4717	55	481	5585	5321	5450	82	χ2 t-test, df = 1, T = 0.6 (5% 3.8)	13.8	42.3	-20.0	12.2	3.2	A			
VKL_1951.025	25	EBA	Mid/Old adult	M?	33723	femur/R	3727	33	2	3314	52	413	3688	3410	3544	63		2.0	41.0	-19.9	10.9	3.4	B			
VKL_1951.026.01	26	EBA	Yng adult	M	33888	femur/L	3911	38	2	3452	55	459	3849	3578	3723	75		1.9	44.9	-20.0	11.6	3.2	A			
VKL_1951.027	27	EBA	Yng adult	F	33919	parietal/L	3570	33	2	3235	52	335	3574	3364	3466	60		4.4	44.1	-19.7	**10.2**	3.3	B			
VKL_1951.028	28	EBA	Adolescent	F?	33920	parietal/L	3666	33	2	3286	52	380	3634	3398	3516	60		4.8	43.5	-19.8	10.6	3.2	A			
VKL_1951.029	29	EBA	Mid/Old adult	M?	33916	humerus/L	3590	35	2	3269	53	321	3612	3382	3500	60		14.4	43.0	-19.6	10.6	3.2	B		9.1	
VKL_1951.030.01	30	LN	Yng adult	M?	33917	femur/L	4924	37	2	4591	55	333	5466	5052	5279	128	χ2 t-test, df = 3, T = 14.7 (5% 7.8)	11.1	42.7	-19.6	10.6	3.2	B		7.2	
VKL_1951.030.02	30	LN	Old adult	F?	33918	femur/R	4831	35	2	4620	53	211	5577	5065	5354	108	χ2 t-test, df = 3, T = 14.7 (5% 7.8)	9.6	43.6	**-18.7**	12.1	3.3	B		8.7	
VKL_1951.030.03	30	LN	Yng adult	F	33930	femur/R	5006	37	2	4487	55	519	5313	4894	5140	104	χ2 t-test, df = 3, T = 14.7 (5% 7.8)	12.9	43.6	-20.1	12.3	3.2	A			
VKL_1951.030.04	30	LN	Yng/Mid adult	M	33931	tibia/L	4784	39	2	4350	56	434	5260	4829	4948	89	χ2 t-test, df = 3, T = 14.7 (5% 7.8)	10.1	44.0	-19.9	11.6	3.2	A			
VKL_1951.031	31	LN	Child, c. 7 yrs.	I	34409	sphenoid/L	5239	36	2	4624	54	615	5578	5066	5361	106		5.8	44.0	-20.6	12.2	3.3	B		6.5	
VKL_1951.032.01	32	LN	Yng adult	M	33932	femur/R	4986	38	2	4618	55	368	5576	5060	5347	114	χ2 t-test, df = 2, T = 0.1 (5% 6.0)	14.8	43.4	-19.4	12.2	3.2	B			
VKL_1951.032.02	32	LN	Child, c. 9 yrs.	I	33968	parietal/R	5096	35	2	4622	53	474	5577	5066	5358	106	χ2 t-test, df = 2, T = 0.1 (5% 6.0)	10.5	43.6	-20.0	11.8	3.2	B		5.3	
VKL_1951.032.03	32	LN	Adol., c. 15 yrs.	F	33969	occipital/L	5027	37	2	4603	55	424	5569	5053	5311	125	χ2 t-test, df = 2, T = 0.1 (5% 6.0)	15.0	43.5	-19.9	11.3	3.2	A			
VKL_1951.033.01	33	LN	Mid adult	F	33933	occipital/R	4814	36	2	4674	54	140	5581	5308	5418	79	χ2 t-test, df = 6, T = 9.6 (5% 12.6)	7.7	45.3	**-18.1**	13.3	3.2	B		9.9	Upper Lena EBA FRE
							4674	54	1	4605	63	209	5574	5050	5307	132										Little Sea FRE
VKL_1951.033.02	33	LN	Yng adult	M	33970	occipital/L	5008	33	2	4622	52	386	5577	5067	5360	104	χ2 t-test, df = 6, T = 9.6 (5% 12.6)	13.4	43.4	-19.6	12.0	3.2	A			
VKL_1951.033.03	33	LN	Adol., c. 14 yrs.	F	33934	parietal/L	5217	37	2	4720	55	497	5585	5321	5453	82	χ2 t-test, df = 6, T = 9.6 (5% 12.6)	8.6	43.8	-20.0	12.3	3.2	B		5.7	
VKL_1951.033.04	33	LN	Child, c. 8-10? yrs.	I	33971	occipital/R	5150	37	2	4652	55	498	5581	5290	5400	85	χ2 t-test, df = 6, T = 9.6 (5% 12.6)	9.5	43.3	-19.8	13.3	3.2	B		10.0	
VKL_1951.033.05	33	LN	Child, c. 8-10? yrs.	I	33935	occipital/R	5155	35	2	4692	53	463	5581	5316	5431	79	χ2 t-test, df = 6, T = 9.6 (5% 12.6)	6.8	44.1	-19.5	**13.8**	3.2	B		6.0	
VKL_1951.033.06	33	LN	Child, c. 6 yrs.	I	33936	parietal/R	5158	39	2	4562	56	596	5454	5039	5214	116	χ2 t-test, df = 6, T = 9.6 (5% 12.6)	7.7	45.6	-20.2	**13.6**	3.2	B		7.0	
VKL_1951.033.07	33	LN	Child, c. 6? yrs.	I	33972	parietal/R	4929	37	2	4529	55	400	5435	4978	5174	99	χ2 t-test, df = 6, T = 9.6 (5% 12.6)	11.2	42.9	-19.2	**13.9**	3.2	B		6.4	
VKL_1951.034	34	LN	Yng/Mid-adult	M?	33973	zygomatic/R	5191	37	2	4646	55	545	5581	5088	5393	89		15.7	44.5	-20.1	13.0	3.2	B		6.2	
VKL_1951.035.01	35	LN	Adult	F	33974	occipital/R	5056	39	2	4548	56	508	5446	4980	5193	108	χ2 t-test, df = 1, T = 3.0 (5% 3.8)	9.5	44.8	-20.1	12.3	3.2	A			
VKL_1951.035.02	35	LN	Adolescent	F	33975	occipital/L	5151	38	2	4683	55	468	5581	5312	5425	80	χ2 t-test, df = 1, T = 3.0 (5% 3.8)	11.8	44.9	-19.8	12.5	3.2	B		7.7	
VKL_1951.036	36	EBA	Adult	M	33937	occipital/R	3941	32	2	3525	51	416	3964	3645	3800	72		8.5	44.3	-19.8	11.8	3.2	B		7.9	
VKL_1951.037	37	LN	Yng adult	F	33938	mandible/R	4983	36	2	4567	54	416	5452	5043	5222	118		7.9	45.7	-19.5	12.9	3.3	B		7.0	
VKL_1951.038	38	LN	Child, c. 6 yrs.	I	33939	occipital/R	4946	36	2	4422	54	524	5284	4863	5052	122		7.0	44.5	-20.2	12.0	3.2	B			
Younger Children																										
Ulan-Khada																										
UK2_1959.001	UK_II 1	EBA	Child	I	33940	tibia/L	4068	36										7.2	45.7	-17.9	15.3	3.2	B		8.3	
UK4_1959.008	UK_IV 8	EBA	Child, c. 5 yrs.	I	33977	cranium/?	4424	35										13.0	46.4	-19.0	15.9	3.2	B			
Verkholensk																										
VKL_1951.019.01	19	EN	Child, 4-5 yrs.	I	33886	tibia/R	6695	40										4.3	45.3	-19.8	11.6	3.2	A			
VKL_1951.026.02	26	EBA	Child, c. 5 yrs.	I	33889	rib/R	3803	36										5.1	43.1	-19.7	11.6	3.2	B		7.9	

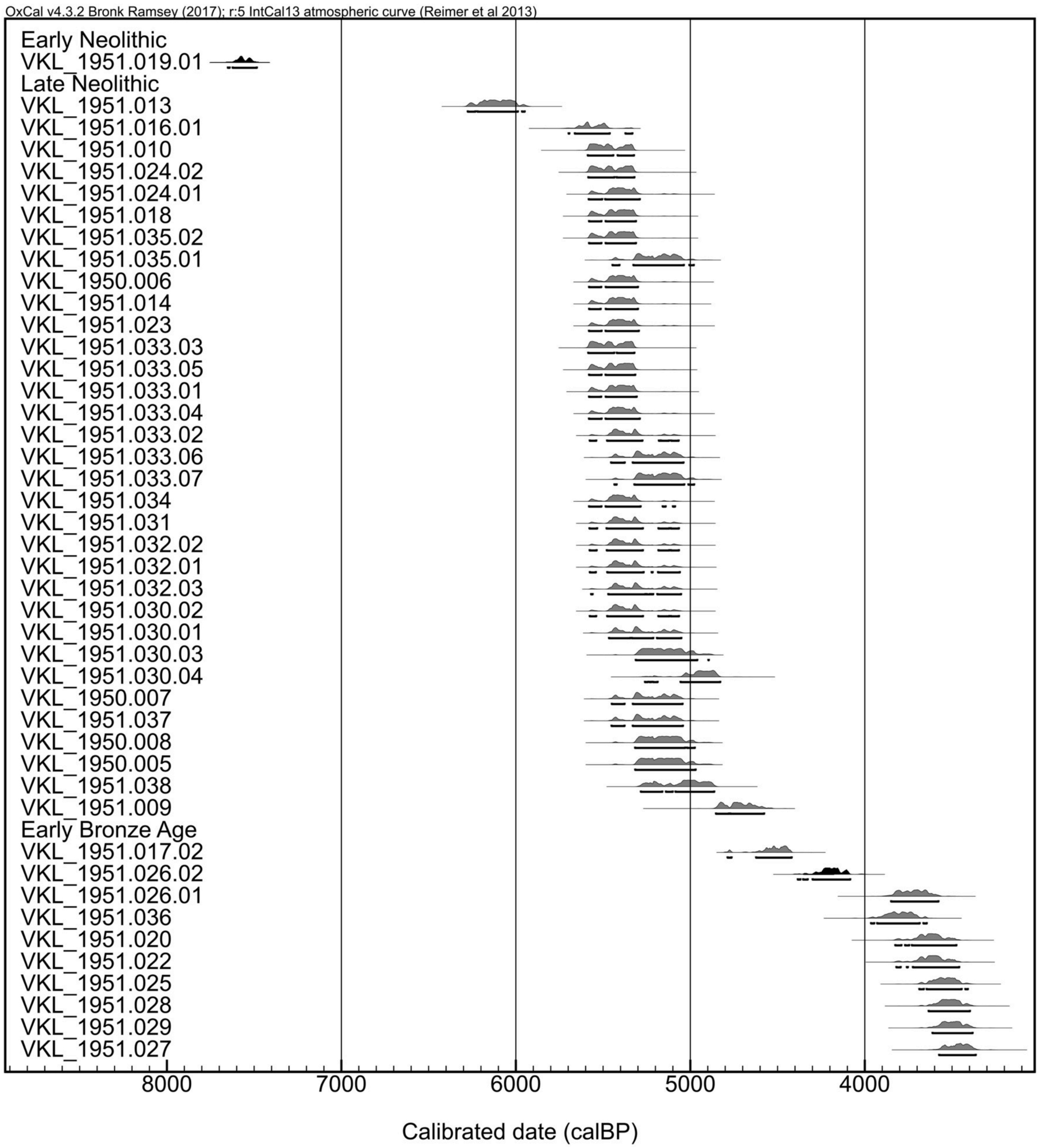

Fig. 7. FRE-corrected (Table 2, Formula 2) radiocarbon dates from post-weaning age individuals from Verkholensk (see Catalogue). Note that VKL_1951.19.01 and VKL_1951.026.02 are young children and their radiocarbon dates (in black) were not FRE-corrected and therefore appear older.

(See Catalogue for sample details, and SI 3 for discrepancies noted between the written archaeological reports and the extant skeletal remains.)

4.2. Stable isotopic analysis

Bone samples were surface-cleaned using an aluminium oxide shotblaster. Forty-five samples weighing over 1g were sub-sampled and prepared separately for stable isotopic analyses in RLAHA's radiocarbon (ORAU) and palaeodiet laboratories. The preparation and measurement methods differ slightly, as detailed below. Nineteen were prepared and analysed using the ORAU protocol only, as insufficient material remained for both protocols.

All samples were ground and soaked in 0.5 M hydrochloric acid (HCl) at 5 °C for approximately three days. Samples prepared using the palaeodiet protocols proceeded from this point to gelatinization. Those following the ORAU protocol received a base wash of 0.1 M sodium hydroxide (NaOH) intended to remove humic acids. Each acid/base wash was followed by multiple rinses with ultrapure (MilliQ) water. All samples were gelatinized in pH3 H_2O for 24 h before being sealed and heated at 70 °C for three days. The supernatant was then filtered through an Ezee-filter and freeze-dried until only 'collagen' remained. The ORAU samples in addition underwent ultrafiltration (30kD) to remove small molecular contaminants (Brock et al., 2010, 2007). Samples following the palaeodiet protocols were analysed in duplicate on a Sercon 20/22 Isotope Ratio Mass Spectrometer (IRMS), accompanied by alanine standards to correct for machine drift, and in-house standards of cow ($\delta^{13}C = -24.21‰$, $\delta^{15}N = 8.00‰$) and seal ($\delta^{13}C = -12.00‰$, $\delta^{15}N = 16.61‰$) collagen, referenced to international standards through repeated measurements at the laboratory. Those following the ORAU protocols were measured in the same IRMS alongside alanine and USGS40 and USGS41 standards.

The carbon and nitrogen isotopic values reported here are the averages of the duplicate runs, drift-corrected, and calibrated relative to the international standards for δ^{13}C (VPDB) and δ^{15}N (AIR) using a two-point calibration supplied by the in-house standards for the palaeodiet samples, and a three-point calibration using alanine, USGS40 and USGS41 for the ORAU samples (cf. Coplen et al., 2006). Measurement precision is on the order of ±0.2‰ for δ^{13}C and δ^{15}N based on repeated analyses of the standards. Collagen quality was assessed following widely accepted criteria (Ambrose, 1990; DeNiro, 1985; van Klinken, 1999).

Stable oxygen isotope analysis was undertaken on the same collagen preparation used for δ^{13}C and δ^{15}N, using 21 samples from Verkholensk and 12 from Ulan Khada (see further details in SI 4.1). Importantly, these samples were prepared at the same time and remained thereafter in sealed tubes. Approximately 0.5 mg of material was weighed out into silver capsules for analysis on a Sercon 20/22 IRMS. Results were calibrated to VSMOW against human hair standards USGS42 and USGS43, with a measurement error during the runs of ca. ±0.23‰.

4.3. Radiocarbon dating

The standard bone collagen pretreatment method for radiocarbon analysis is outlined in Brock et al. (2010, 2007) and summarized above. Measurements were corrected for the freshwater reservoir effect (FRE) for each micro-region using linear regression formulae based on paired radiocarbon dating of human and terrestrial animal teeth from the same graves (Table 2). The human δ^{13}C and δ^{15}N results provide estimates of the amount of aquatic resources in the diet, which in turn are used to estimate the extent of the FRE for each individual. Radiocarbon dates for four children less than age five were not corrected, since any residual nursing effect could invalidate the regression equation.

FRE-corrected radiocarbon dates were calibrated in OxCal v.4.3.2 using the IntCal13 northern hemisphere atmospheric calibration curve (Bronk Ramsey, 2009; Reimer et al., 2013). The conventional ^{14}C yr, FRE offsets, and calibrated dates (95.4% range, mean, and sigma) are all reported in the Catalogue (SI).

4.4. Data analysis

Statistical analyses were conducted using IBM Statistical Package for the Social Sciences (SPSS) 24.0. Data were assessed for normality using Shapiro-Wilk tests, and then analysed using parametric or non-parametric statistics as appropriate (further details in SI 5). Heteroscedastic t-tests were used when the data did not depart significantly from normality, but the variance of one group was ≥ twice that of the other. Outliers are defined as any value greater than 1.5 × the Inter-Quartile Range (IQR).

5. Results

All samples provided well-preserved collagen with yields greater than 1% (averaging 7.9 ± 3.6%) and atomic weight C to N ratios ranging from 3.2 to 3.4 (averaging 3.2 ± 0.05), well within accepted standards for stable isotope and ^{14}C analyses (Ambrose, 1990; DeNiro, 1985; van Klinken, 1999). The δ^{13}C and δ^{15}N values obtained from the two preparation methods described above were statistically indistinguishable (see SI 6), and they were therefore averaged for the 45 samples for which both were available, such that the reported values are the average of five measurements. One individual (VKL_1951.017.02) was sampled twice using two different skeletal elements. The isotopic results were averaged and the radiocarbon dates (OxA-33883 and 33884) were combined in OxCal 4.2.

Table 2
FRE correction formulae, where 's.d.' = error term of the 14C determination and 'S' = standard deviation of the residuals from the linear regression model.

Source	Formula
1. "Little Sea, δ^{13}C & δ^{15}N" (Schulting et al., 2014)	$-3329.5 - 125.6\,(\delta^{13}C) + 95.1\,(\delta^{15}N)$
2. "Upper Lena, δ^{13}C & δ^{15}N" (Schulting et al., 2015)	$-4289.9 - 211.2\,(\delta^{13}C) + 45.4\,(\delta^{15}N)$
3. "SW Baikal/Angara" (Schulting et al., 2014)	$-1388.9 + 125.5\,(\delta^{15}N)$
Adjusted Error Range (Weber et al., 2016)	$\sqrt{(s.d.)^2 + S^2}$

5.1. Radiocarbon dating and typological assessments

Okladnikov's (1978) typological classification suggested the presence of only LN and EBA graves at Verkholensk. Nevertheless, the radiocarbon determinations identify at least two graves as much earlier. The first, Grave 19, dates to the late EN (Fig. 7). The second, Grave 13, falls within what is now within the boundaries of the MN and is noteworthy as being the only burial at Verkholensk oriented to the south and lacking grave goods. However, the lower boundary of the LN is based upon only 22 radiocarbon dates and may shift with further analysis (Weber et al., 2016). Therefore, this individual is provisionally classified as 'LN' pending further study. With one exception, there is a gap of over 500 years between the LN burials and those dating to the EBA. Although the cemetery was not excavated in its entirety, based on the available evidence it seems that it was used discontinuously. Additionally, all double and multiple burials from Verkholensk produced dates that were consistent with single burial events, except for Grave 30 (see Catalogue for R_Combine results). Grave 30 contained five individuals (four adults and one child) of which we sampled four adults. Okladnikov (1978) believed that all were buried at the same time, but the ^{14}C results suggest at least two burial episodes. Further work on the Upper Lena FRE correction will allow us to revisit this conclusion in the future.

As expected based on the original typological assignments, most burials from Ulan-Khada date to the EBA, with the main phase of use spanning ca. 5200 to 4000 cal BP (Fig. 8). Two individuals (Graves 12 and 14.02) fall well before the beginning of the LN as currently understood, though, as noted above, there is uncertainty regarding this boundary (Weber et al., 2016). Lastly, the only burial dating to the EN (Grave 5) was located slightly apart from the other graves in sector II (Fig. 4).

The presence of a few clear outliers in the δ^{13}C and δ^{15}N results from Verkholensk and Ulan-Khada presents an issue in the FRE corrections applied. Some individuals' isotopic values fall closer to those of other micro-regions. Specifically, one individual from Grave 33 at Verkholensk had values approaching the GFS diet range of the Little Sea (i.e., higher δ^{13}C and δ^{15}N values), while the three LN individuals from Ulan-Khada have values that fall within the LN-EBA range of the Angara micro-region (i.e., higher δ^{13}C and lower δ^{15}N) (discussed below and illustrated in Figs. 12 and 13). The latter are not only outliers at Ulan-Khada, but for the entire Little Sea. If these individuals were recent migrants and do not have the same old carbon offset as those from the area in which they were buried, the question arises as to whether the FRE equations developed for the Little Sea and Angara, respectively, are more appropriate (Schulting et al., 2014). In any case, applying the FRE correction for the regions that best match their stable isotopic results in differences of less than 300 years that, while certainly significant, do not alter the cultural period assignments (Catalogue and Table 2).

5.2. Stable isotope results

All statistical analyses were carried out on individuals aged approximately five and older to avoid nursing effects and the possibility of different diets in early childhood (Tables 3 and 4; Figs. 9 and 10). The results of the post-weaning individuals from LN Verkholensk include two outliers in δ^{13}C and four in δ^{15}N (in one case the same individual is involved), greater than 1.5 times the IQR (in bold in the Catalogue). The δ^{13}C and δ^{15}N values are normally distributed once these outliers are removed, and show no correlation ($r^2 = -0.074$, $p = 0.67$). Notably, four of the five individuals formally identified as outliers are from LN Grave

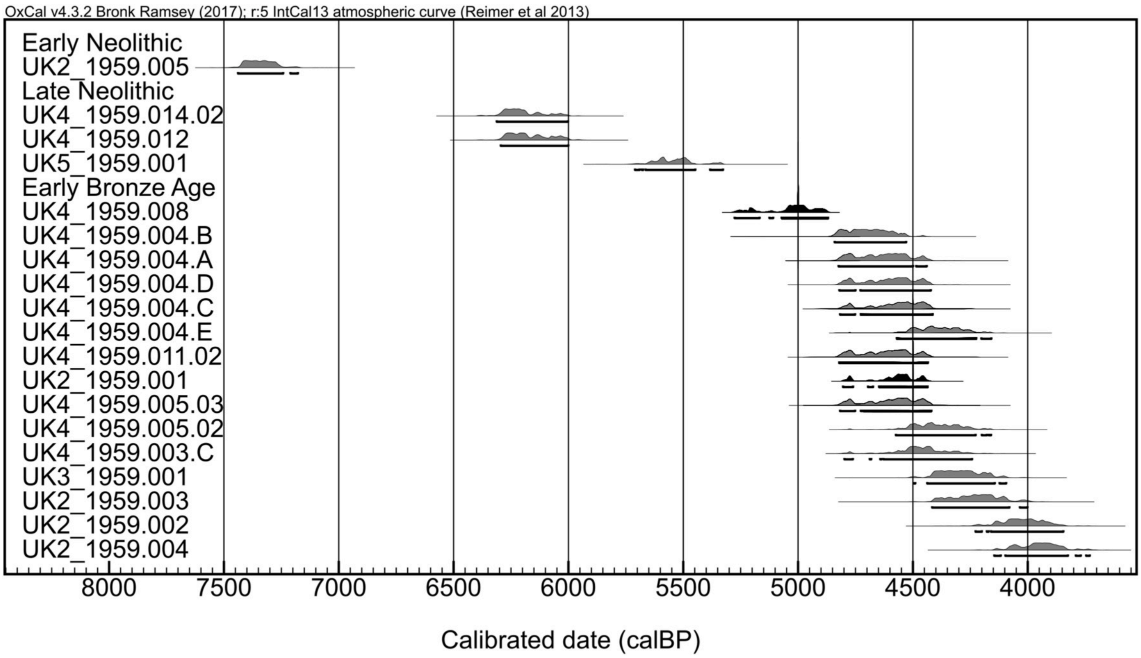

Fig. 8. FRE corrected (Table 2, Formula 1) Radiocarbon results from post-weaning age individuals from Ulan-Khada (see Catalogue). Note that UK4_1959.008 and UK2_1959.001 are young children and their radiocarbon dates (in black) were not FRE-corrected and therefore appear older.

33. An additional individual from Grave 33 is also more elevated in δ^{15}N than all but the abovementioned outliers at Verkholensk (see box on Fig. 9). Thus, five of the seven individuals from Grave 33 stand out, exhibiting higher δ^{15}N values than all of the remaining LN individuals (Fig. 9). The LN individuals at Verkholensk, even excluding Grave 33, show higher δ^{15}N values (12.02 ± 0.56‰, n = 23) than the EBA individuals (11.23 ± 0.55‰, n = 8) (Student's *t*-test, $df = 29$, $t = 3.460$, $p = 0.002$). This is reinforced by the fact that δ^{15}N values and mean date cal BP are positively correlated (Spearman's rank-order, $r^2 = 0.522$, $p = 0.000$). Including Grave 33 only accentuates this difference.

At Ulan-Khada post-weaning individuals of all periods considered together (EN, LN, and EBA) show normally distributed δ^{13}C and δ^{15}N values, with no significant correlation ($r^2 = 0.152$, $p = 0.593$). However, the δ^{13}C values are correlated with mean cal BP dates (Spearman's rank-order, $r^2 = 0.705$, $p = 0.002$), reflecting a more ^{13}C-depleted diet over time. The EBA considered on its own is also normally distributed with one δ^{15}N outlier (UK4_1959.005.02). The three LN samples fall outside of the EBA range at Ulan-Khada (Fig. 10). The single EN sample is higher in δ^{13}C (−17.0‰) than the EBA samples (−18.3 ± 0.4‰) and higher in δ^{15}N (15.1‰) than the LN samples (13.0 ± 0.2‰). Due to small sample size and poor preservation limiting osteological assessment of sex, it is not possible to assess sex-based dietary differences during the EBA.

Stable oxygen isotope results from both sites are normally distributed. While there is a degree of overlap, the site means of 7.5 ± 1.3‰ at Verkholensk and 9.5 ± 2.1‰ at Ulan-Khada differ significantly (heteroscedastic $t = 3.095$, $p = 0.007$) (Fig. 11). In addition, two of the five outliers from Grave 33 at Verkholensk identified on the basis of δ^{13}C and δ^{15}N results are also outliers in δ^{18}O, as are two of the three LN individuals at Ulan Khada that taken as a group differ markedly in their δ^{13}C and δ^{15}N values from the EBA individuals. Removing the four outlier δ^{18}O values from the analysis results in an even clearer distinction between the sites (Verkholensk: 7.24 ± 1.10‰; Ulan-Khada: 10.19 ± 2.28‰; heteroscedastic $t = 5.51$, df = 14, $p = 0.0001$). While they are more variable, the δ^{18}O Z-scores associated with the δ^{13}C and δ^{15}N outliers (1.69 ± 0.86) are on average significantly higher than those of the remaining measurements (0.80 ± 0.29; heteroscedastic $t = 2.573$, $p = 0.030$). Furthermore, the difference of 2.9‰ between these two means is broadly in keeping, in both direction and magnitude, with a difference of ca. 3.8‰ documented in δ^{18}O between the waters of Lake Baikal and those of the Lena (Seal and Shanks, 1998, Table 1). Despite the degree of exchange with atmospheric and liquid waters in the laboratory that undoubtedly occurred (von Holstein et al., 2018), this must still partly reflect a biogenic signal. There is no other reasonable explanation for this pattern. We are thus confident that, within the limitations of a pilot study, the data are meaningful and interpretable. See SI 4.2 for further details on the δ^{18}O results.

6. Discussion

Interpretation of this study's results is undertaken within the context of previous isotopic research in Cis-Baikal (Figs. 12 and 13). The discussion focuses on the isotopic and dietary changes between the LN and EBA at Verkholensk, Verkholensk Grave 33, the differences between EBA isotopic values from Verkholensk and Obkhoi, LN outliers at Ulan-Khada, the Little Sea GF and GFS diets, and the difference in δ^{13}C between EBA Little Sea females and males with GFS diets.

6.1. Verkholensk and the Upper Lena

The analysis of the individuals from Verkholensk has considerably added to our knowledge of LN and EBA stable isotope and dietary variation in the Upper Lena, making it possible to examine trends spatiotemporally both within and outside of this micro-region (Table 5).

In a pattern not seen at any single location in Cis-Baikal previously,

Table 3
Descriptive statistics for Verkholensk isotopic data.

Verkholensk Statistic	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N
	Age ≥5		All ages	
n	42		44	
Mean	−19.8	12.0	−19.8	12.0
Median	−19.9	12.1	−19.9	12.0
Std. Deviation	0.4	0.9	0.4	0.8
Minimum	−20.6	10.2	−20.6	10.2
Maximum	−18.1	13.9	−18.1	13.9

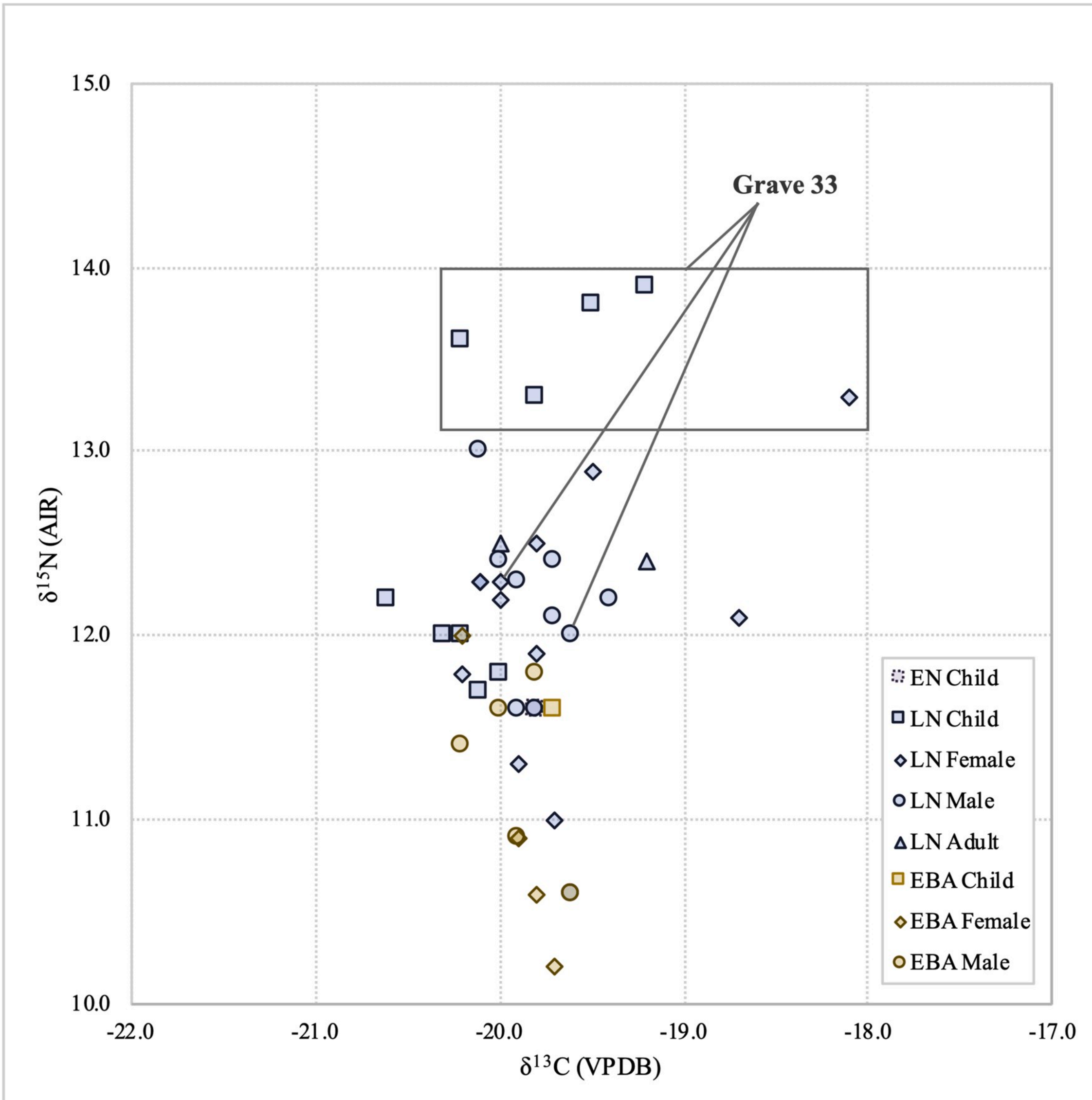

Fig. 9. Isotopic values from Verkholensk differentiated by time period and sex. Individuals from LN Grave 33 are identified by the box and lines.

the Verkholensk δ^{13}C and δ^{15}N results indicate a shift to slightly but significantly greater reliance on terrestrial resources during the EBA compared to the LN. This may relate to human adaptions to an underlying environmental change: the LN burials fall within a relatively cool period, whereas the EBA component falls within a warmer and drier period, between ca. 4000 and 3000 cal BP (Bezrukova et al., 2013, 2014; Mayewski et al., 2004). The resulting more open landscape would have supported a greater abundance of game, allowing for the EBA group to focus more on higher-ranked terrestrial resources, such as roe and red deer (cf. Weber and Bettinger, 2010). These resources might have been even more appealing along the Lena River as it is less productive that the — main waterways in the other Lake Baikal micro-regions (Weber and Bettinger, 2010). Additionally, it is worth noting that, although it is problematic to relate grave goods directly to subsistence practices, the LN graves at Verkholensk contain considerably more fishing gear than the EBA graves. Eleven graves from the LN contained fishing tools and, occasionally, representations of fish, while two graves were found to have net-impressed pottery sherds. There were only four LN graves (10, 23, 31, and 38; 12%) without any fishing-related objects. Conversely, only one out of nine (11%) EBA graves (Grave 22) contained fishing-related material: a bone carving of a fish.

6.1.1. *Grave 33*

LN Grave 33 deserves particular attention. It contained one young adult male, one mid-adult female, one adolescent female, and four children aged 6 to 10.[3] While the radiocarbon dates for these individuals are consistent with one burial event, this is inconclusive given the tight chronological grouping of all the LN burials at the site. More telling are their distinctive stable isotopic values, which warrant further discussion. The mid-adult female in Grave 33 is isotopically distinct from all other individuals at Verkholensk, with values (δ^{13}C = −18.1‰; δ^{15}N = 13.3‰) approaching the lower boundary of the Little Sea GFS range. Moreover, three of the four children attributed to Grave 33 are outliers within the LN δ^{15}N values and all four have higher δ^{15}N values (13.7 ± 0.3‰) than other LN individuals from Verkholensk (12.0 ± 0.5‰). Given their ages, even residual nursing effects can be excluded.

One possible explanation for the variable isotopic values from Grave 33 is that the adult female and children originated from the Little Sea and were still in the process of acquiring the Upper Lena isotopic signal. The children would have done so more quickly than the adult female due to higher bone turnover rates. Nevertheless, their δ^{13}C values are similar

[3] See SI 7 for a note on the number of individuals attributed to Grave 33.

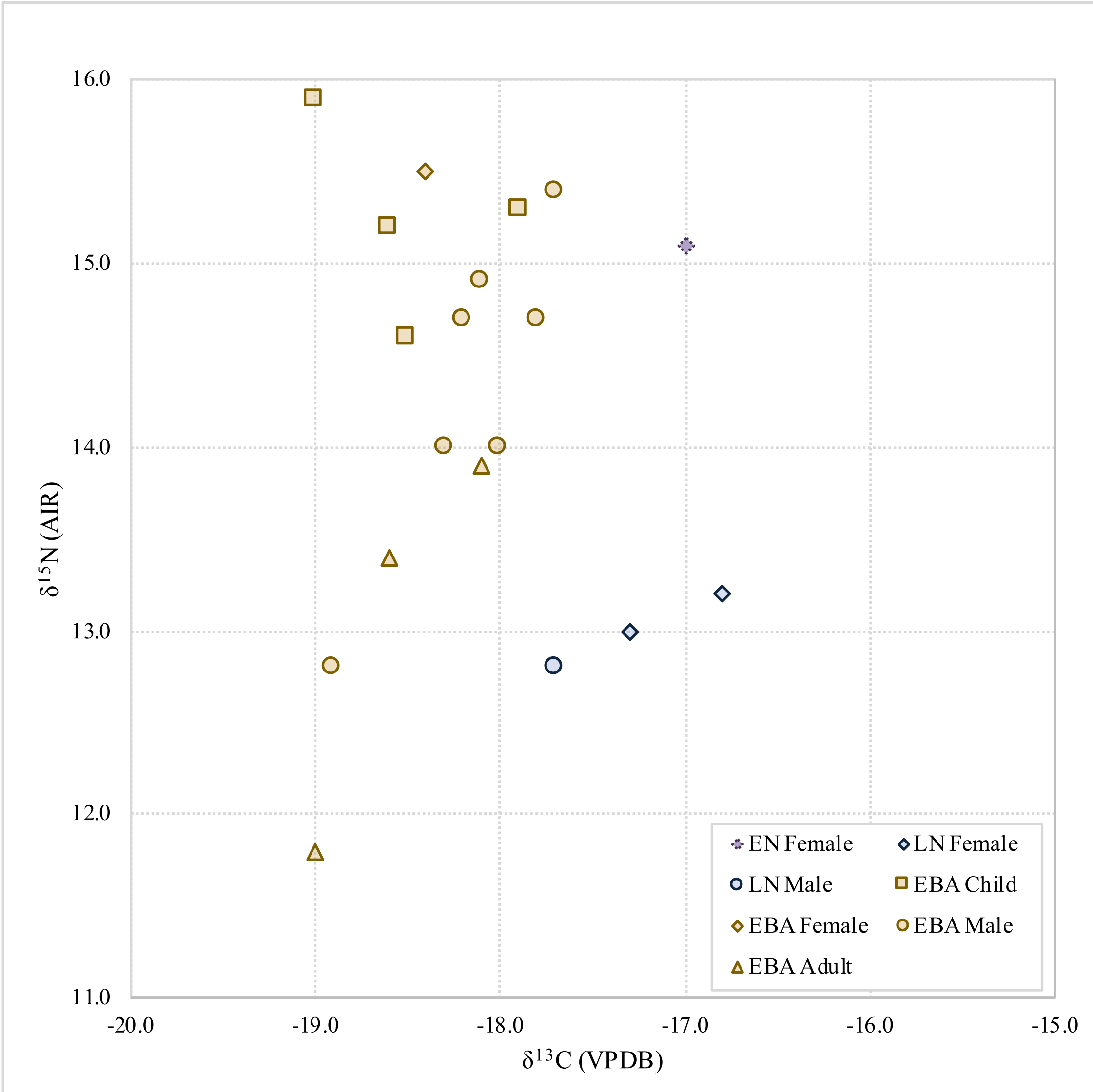

Fig. 10. Isotopic values from Ulan-Khada differentiated by time period and sex.

to those of the LN Verkholensk individuals and are not as high as those in the GFS range. An alternative explanation is that they were consuming a significantly greater quantity of aquatic foods, possibly replicating a more fish-based Little Sea diet. Yet, if this was the case and if the grave contained related individuals, then it would be odd that the male and adolescent female's isotopic values were indistinguishable from the rest of the Verkholensk individuals. The bone collagen $\delta^{18}O$ results from these suspected 'non-local' individuals, confirms that only one of the children, aged 8–10 years old, was probably non-local (VKL_1951.033.04), together with the mid-adult female (see SI 4), with both exhibiting higher $\delta^{18}O$ ratios consistent with those seen at Ulan-Khada on the Little Sea. Interpretation of Grave 33 is complex and further work, including ancient DNA and strontium isotopic analyses, is required, but it may be tentatively proposed to consist of a family unit – perhaps a local father, a mother from the Little Sea, a local second wife or daughter, and four children.

Table 4
Descriptive statistics for Ulan-Khada isotopic data.

Ulan-Khada Statistic	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
	Age ≥5		All ages	
n	17		19	
Mean	−18.1	14.1	−18.1	14.2
Median	−18.1	14.0	−18.1	14.6
Std. Deviation	0.6	1.1	0.6	1.1
Minimum	−19.0	11.8	−19.0	11.8
Maximum	−16.8	15.5	−16.8	15.9

6.1.2. *Verkholensk and Obkhoi*

The cemetery of Obkhoi, located on a small tributary of the Lena, the Kulgana River, is the only EBA cemetery with a sufficient sample size to compare to Verkholensk (Fig. 1). Despite being only approximately 17 km apart, Obkhoi exhibits significantly higher $\delta^{13}C$ values (−19.3 ± 0.3‰) than Verkholensk ($\delta^{13}C$: −19.9 ± 0.2‰, Student's t-tests, df = 19, t = –6.099, p = 0.000). The $\delta^{15}N$ values just fail to reject the null hypothesis but are suggestive, with lower values at Obkhoi (10.6 ± 0.4‰) than at Verkholensk (11.1 ± 0.6‰; Student's t-tests, df = 19, t = 2.063, p = 0.053) (Table 5, Fig. 14). The differences are large enough to be considered meaningful, with Cohen's d statistics of 2.35 for $\delta^{13}C$ for and 0.98 for $\delta^{15}N$ (Cohen, 1988). Given their proximity, and the fact that the tributary feeds into the main river, it is unlikely that there are any appreciable differences in the isotopic baselines between Lena and Kulgana fish. Therefore, the results should reflect distinct subsistence

Table 5
Summary of stable isotope data for all individuals aged ≥5 in the Upper Lena by site and period (other site data after Weber et al., 2016).

Upper Lena															
Site	LM/EN					LN					EBA				
	n	$\delta^{13}C$		$\delta^{15}N$		n	$\delta^{13}C$		$\delta^{15}N$		n	$\delta^{13}C$		$\delta^{15}N$	
		$\bar{x}$	±	$\bar{x}$	±		$\bar{x}$	±	$\bar{x}$	±		$\bar{x}$	±	$\bar{x}$	±
Borki											4	−19.2	0.4	11.0	0.6
Iushino I	2	−19.7		11.9											
Makarovo											1	−19.6		11.4	
Makrushino	1	−19.8		10.8							2	−19.4		13.9	
Manzurka	1	−19.1		12.3							1	−19.2		12.6	
Nikolskii Grot						4	−19.8	0.1	11.7	0.3					
Obkhoi											12	−19.3	0.3	10.6	0.4
Popovskii Lug 2	1	−19.8		12.4											
Turuka	3	−20.3	0.2	13.0	0.3										
Ulus Khalskii											1	−19.4		12.6	
Ust'-Iamnaia											2	−19.6		11.6	
Verkholensk						**33**	**−19.8**	**0.5**	**12.3**	**0.7**	**9**	**−19.9**	**0.2**	**11.1**	**0.6**
Zakuta						4	−19.8	0.3	12.1	0.2					
Zapleskino						1	−19.6		11.6						

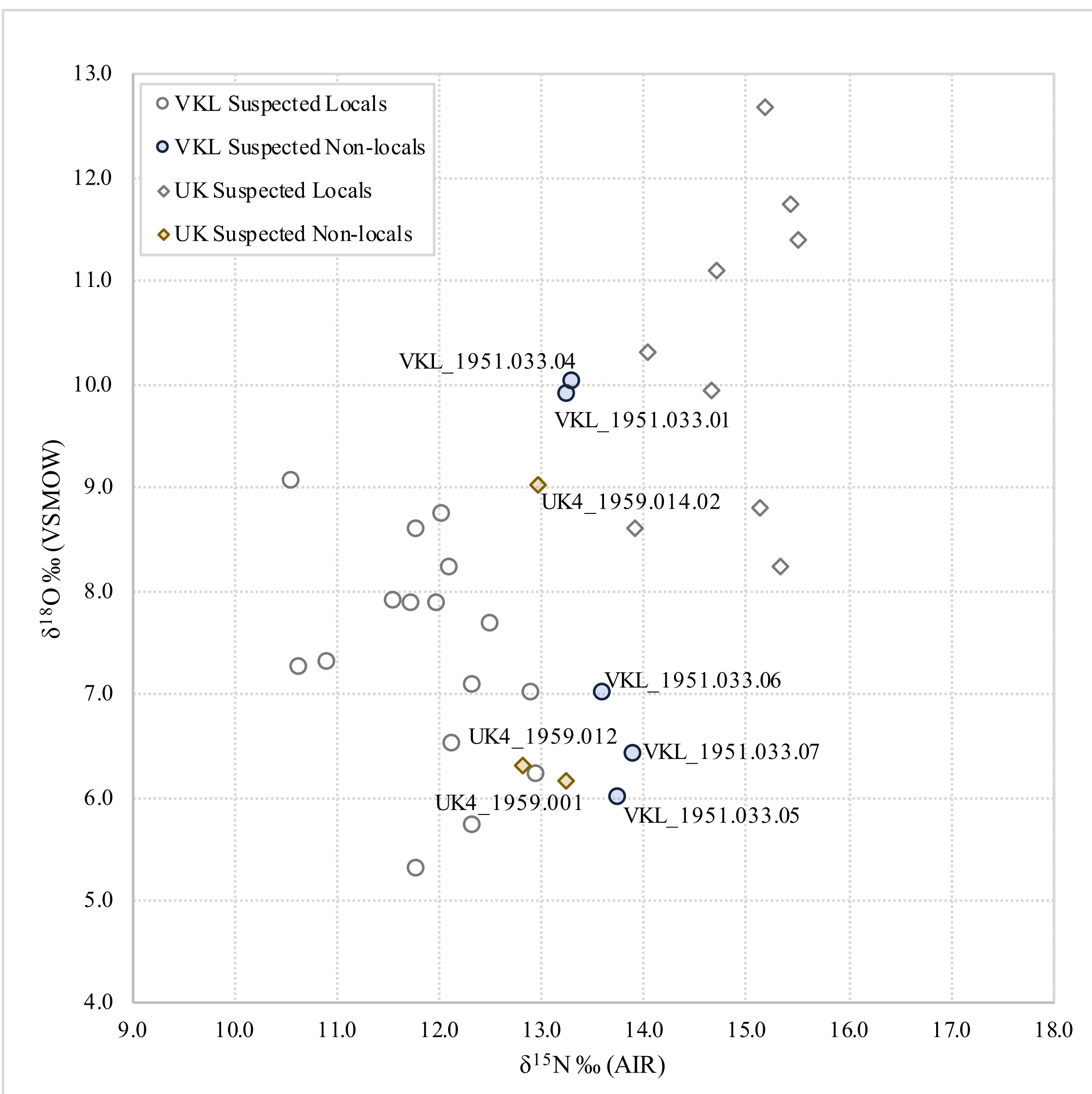

Fig. 11. Bone collagen $\delta^{18}O$ (2017 analysis) and $\delta^{15}N$ (2016 analysis) values for individuals interred at Verkholensk and Ulan-Khada. Individuals suspected of being non-local to the site based on $\delta^{13}C$ and $\delta^{15}N$ results are highlighted and their Master ID's provided. Those from Verkholensk are all from Grave 33 (see box on Fig. 9).

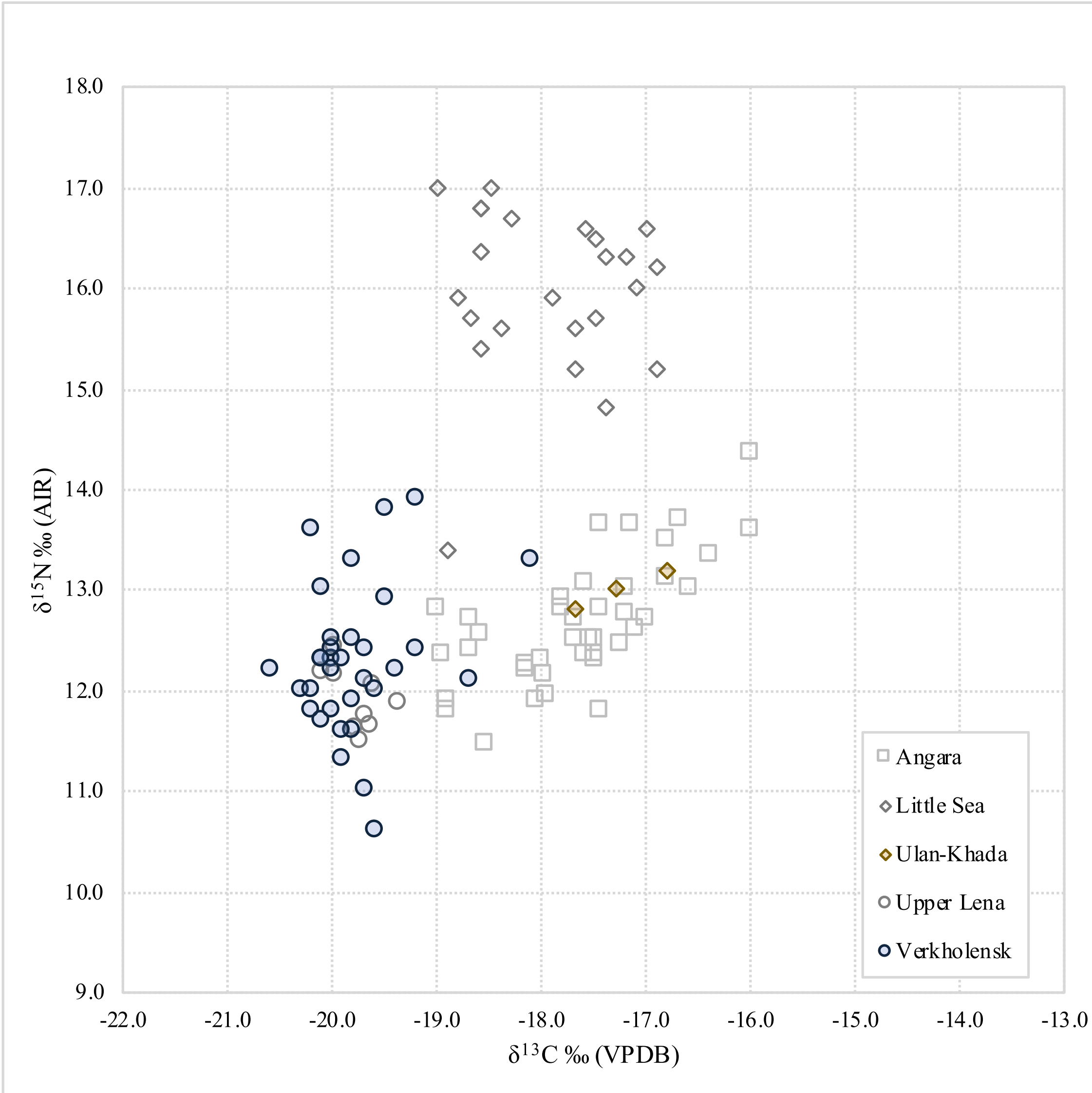

Fig. 12. All post-weaning human LN isotopic data in the BHAP database compared to the data in this study.

practices. Fish in the Upper Lena are the most ^{13}C-depleted aquatic fauna (ca. −26.0‰) currently known from Cis-Baikal, while their δ^{15}N values are on par with fish from other rivers and Lake Baikal. Terrestrial herbivores in the Baikal region display typical C_3 isotope values of ca. −21.3‰ for δ^{13}C and ca. 5.7‰ for δ^{15}N (Katzenberg et al., 2012). The Kulgana fishery would be less productive than the Lena, but the area around Obkhoi is more open and hence might have provided better opportunities for hunting terrestrial game, particularly deer.

In ethnographic studies of hunter-gatherers, it has been much debated how sharing, exchange, and land tenure (or territoriality) practices unfold or are structured within different environments and/or subsistence practices (Kelly, 2013). Given the diversity of environments

Table 6
Summary of stable isotope data for all individuals aged ≥5 in the Little Sea by site and period. Khuzhir-Nuge XIV data are from Weber et al. (2011) and Katzenberg et al. (2009), whereas all the remaining data are after Weber et al. (2016).

Site	LM/EN					LN					EBA				
	n	δ^{13}C		δ^{15}N		n	δ^{13}C		δ^{15}N		n	δ^{13}C		δ^{15}N	
		$\bar{x}$	s	$\bar{x}$	s		$\bar{x}$	s	$\bar{x}$	s		$\bar{x}$	S	$\bar{x}$	s
Khadarta IV											9	−18.2	0.5	15.0	0.8
Khotoruk	3	−17.3	1.4	14.0	1.9										
Khuzhir-Nuge XIV						1	−19.6		11.9		63	−18.5	0.9	13.7	1.6
Kulgana											1	−19.2		13.7	
Kurma XI	2	−17.6		13.8							19	−18.6	0.6	14.5	1.5
Sarminskii Mys	1	−17.9		12.8		7	−17.4	0.5	15.7	0.7	5	−18.2	0.8	14.5	1.6
Shamanskii Mys						1	−16.9		16.2		7	−18.4	0.6	15.7	0.9
Ulan Khada	**1**	**−17.0**		**15.1**		**3**	**−17.3**	**0.5**	**13.0**	**0.2**	**13**	**−18.3**	**0.4**	**14.2**	**1.1**

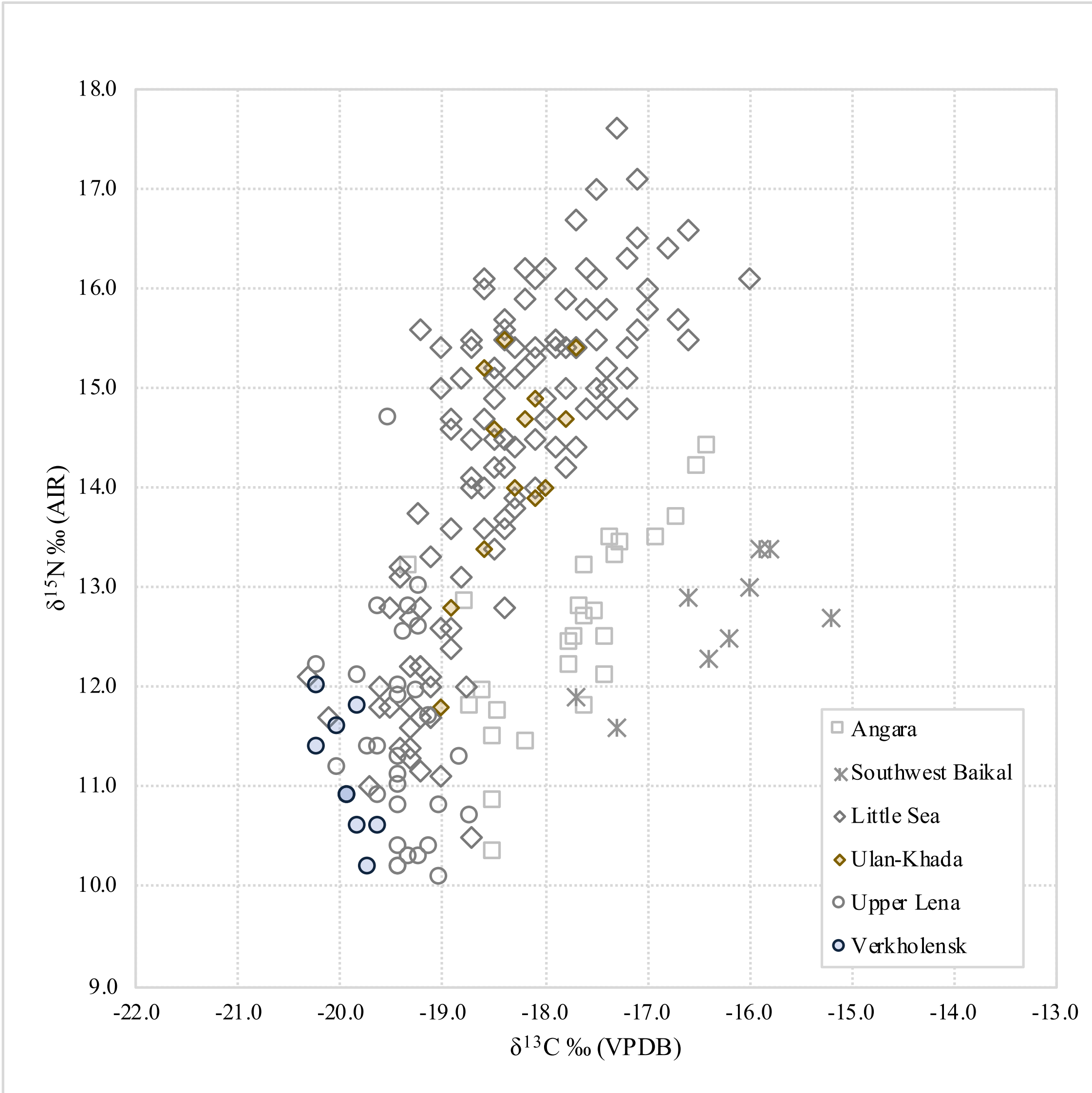

Fig. 13. All post-weaning human EBA isotopic data in the BHAP database compared to the data in this study.

in which hunter-gatherers live, unsurprisingly their practices vary considerably, ranging from socially negotiated sharing to the maintenance and active defence of exclusive rights to resources (Baker, 2003; Kroeber, 1925; Layton, 1986; Leacock and Rothschild, 1994; Teit, 1930). Stable isotopic approaches offer a means of tackling this issue in prehistoric hunter–gatherers, informing on the long-term use of dietary resources and exploitation of distinct territories by contemporaneous groups (Schulting, 2010). No matter the source of the dietary distinction between Verkholensk and Obkhoi, its mere presence suggests the exploitation of distinct resources and a surprisingly persistent division of the landscape, or of particular resource patches within it. The implication is that these two groups, and possibly others in the surrounding region, would have been firmly embedded in their respective landscapes at a relatively fine spatial scale.

However, a complicating factor is that, while the individuals being compared all date to the EBA, the Obkhoi dates are older on average by ca. 700 years than those from Verkholensk (Fig. 15). Additionally, the δ^{13}C values are correlated with the mean cal BP (Spearman's rank-order, $r^2 = 0.539$, $p = 0.012$), reflecting an overall more enriched ^{13}C diet over time. That said, the single Verkholensk individual (VKL_1951.017.02; labelled on Fig. 14) appearing contemporaneous with Obkhoi also exhibits a more negative δ^{13}C value (−20.2‰). At this point, it is unclear whether the isotopic differences reflect a long-term divergence in subsistence adaptations, or a diachronic shift to a more terrestrial diet to differing extents regionally, perhaps encouraged by the abovementioned environmental changes. The ability to identify this as an issue emphasises the value of the systematic radiocarbon dating programme being carried out in Cis-Baikal (Weber et al., 2016).

Lastly, the EBA component of the Upper Lena is significantly lower in δ^{15}N (n = 31, 11.1 ± 0.8‰) than those with GF diets in the EBA Little Sea (n = 29, 11.9 ± 0.7‰; Student's *t*-test, $df = 58$, $p = 0.000$). However, while the sample size remains small, those Little Sea individuals with GF diets (n = 6, δ^{13}C: 19.4 ± 0.2‰, δ^{15}N: 11.6 ± 0.8‰) identified as non-locals through ^{87}Sr/^{86}Sr analysis (Weber and Goriunova, 2013) are similar to the Upper Lena in δ^{13}C and δ^{15}N (n = 32, δ^{13}C: 19.5 ± 0.4‰, δ^{15}N: 11.2 ± 1.0‰).

6.2. Little Sea

There is now a substantial dataset for the Little Sea micro-region (Fig. 1, Table 6), particularly for the EBA (n = 117), whereas the Late Mesolithic/EN (n = 7), and LN (n = 12) datasets remain much smaller.

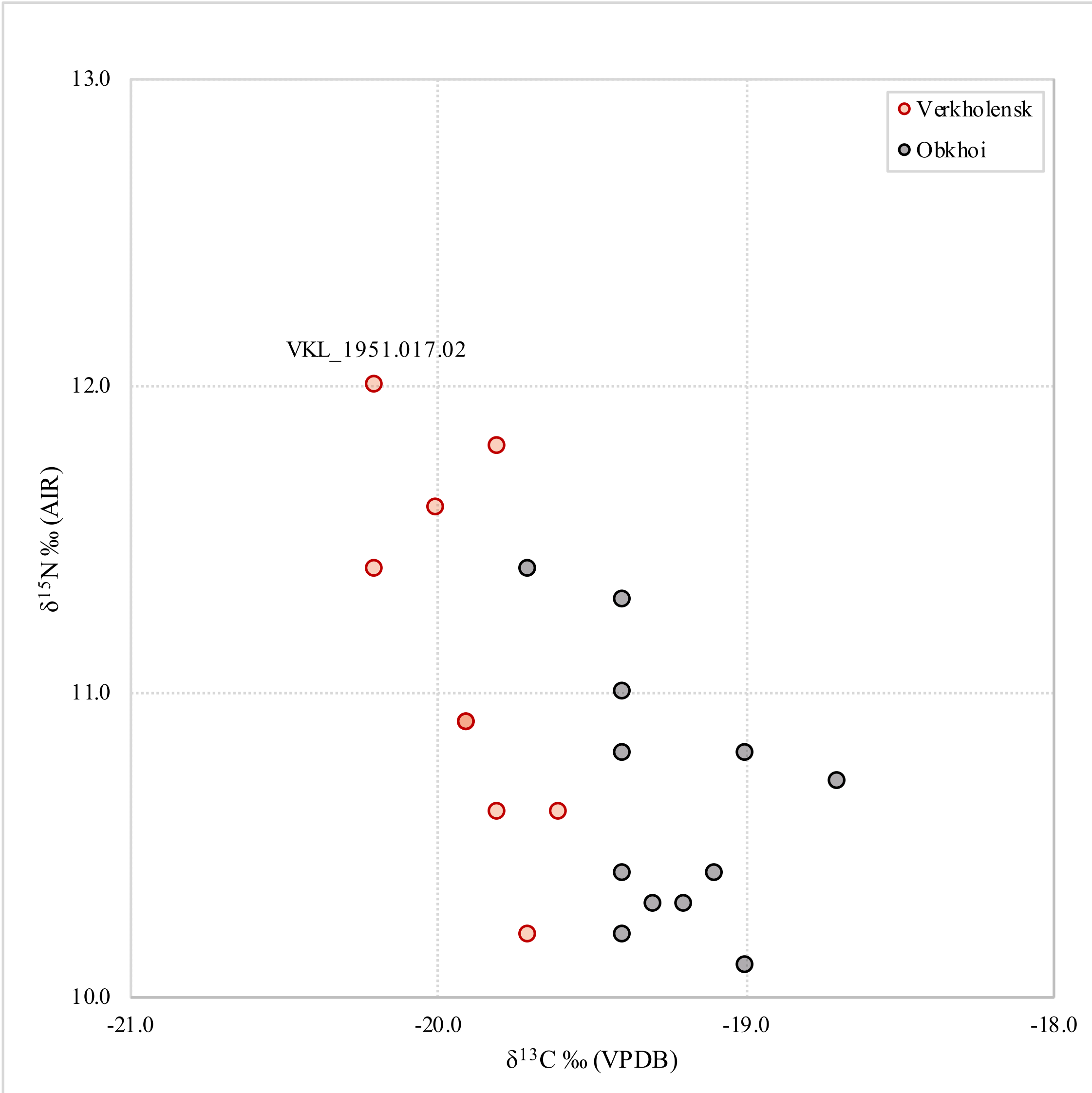

Fig. 14. Human $\delta^{13}C$ and $\delta^{15}N$ values for EBA Verkholensk and Obkhoi.

6.2.1. *Ulan-Khada LN*

The three LN individuals from Ulan-Khada are markedly lower in $\delta^{15}N$ than all other Little Sea individuals analysed to date. Nor do they match the Upper Lena values, with which connections have been previously posited, due to their more positive $\delta^{13}C$ values. In fact, the most similar values are those from the LN–EBA Angara micro-region, some 200 km to the west (Fig. 12). Alternatively, it may be that the LN community at Ulan-Khada focused on a particular set of aquatic and terrestrial resources that coincidentally resulted in similar stable isotope values. Complicating matters further, $\delta^{18}O$ analysis of collagen from these three individuals reveals that two (UK4_1959.012 and UK5_1959.001) have similar values to those at Verkholensk. While the Angara initially shares $\delta^{18}O$ values with its Lake Baikal source (Seal and Shanks, 1998), it is likely that further downstream the river becomes increasingly ^{18}O-depleted as tributaries dilute the influence of the lake's waters, and so may come to resemble more closely the value of the Upper Lena. This dilution would concomitantly lead to increasingly ^{13}C-depleted fish, but humans along the Angara show a considerable

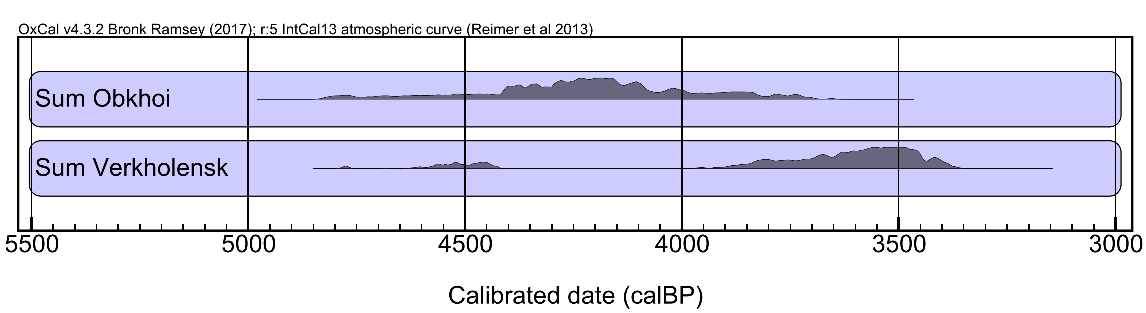

Fig. 15. The summed FRE-corrected radiocarbon dates for EBA individuals included in the statistical analyses for Obkhoi and Verkholensk.

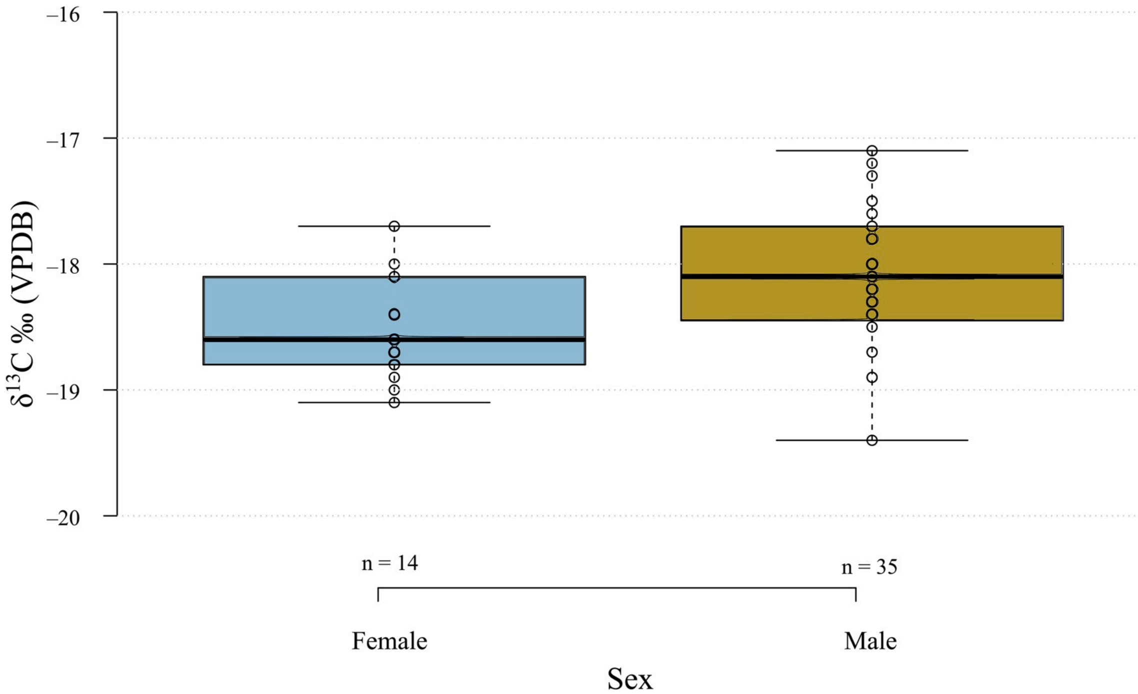

Fig. 16. The difference in δ^{13}C between all Little Sea EBA males and females with the GFS diet.

range in their δ^{13}C values, so that the proposed scenario may still be plausible, though further investigation is required to confirm this hypothesis.

6.2.2. Ulan-Khada EBA

The Ulan-Khada EBA data provide additional support for the increasingly well-documented division into GF and GFS dietary patterns in the Little Sea (Fig. 13). With the removal of a single outlier, the δ^{13}C values for the EBA are normally distributed, but the δ^{15}N are not, unsurprisingly given the bimodal distribution of GF and GFS diets. A new finding emerges, however, in terms of sex-based dietary differences. Considering all the Little Sea EBA data, males with GFS diets have slightly but significantly higher δ^{13}C (−18.1 ± 0.5‰, n = 34) values than females with GFS diets (−18.5 ± 0.4‰, n = 14, Student's t-test, $df = 46$, $t = -2.656$, $p = 0.011$; Fig. 16). This pattern holds when the sexed individuals from each site are standardized, to control for the different means of individual sites (males n = 34, females n = 14, $df = 46$, Student's t-test, $t = -2.530$ $p = 0.015$). While there are a large number of unsexed individuals, this should not introduce any particular bias in the isotopic results. Moreover, the effect size is large (Cohen's $d = 0.84$ for the standardized dataset). The small sample size of the GF group precludes testing for a comparable difference.

The higher δ^{13}C values in EBA GFS males than females suggests that males consumed more littoral fish. This would account for the elevated ^{13}C without concomitant enrichment in ^{15}N, whereas the females would have consumed more terrestrial resources. An alternative explanation is that some of the females originated in the Upper Lena and retained a residual dietary signal from there. As the isotopic dataset continues to be expanded upon, other such subtle differences may emerge.

7. Conclusions

This paper has presented new δ^{13}C, δ^{15}N and ^{14}C results for 63 individuals from the prehistoric hunter-gatherer cemeteries of Verkholensk in the Upper Lena, and Ulan-Khada in the Little Sea of Cis-Baikal. We have also explored the use of δ^{18}O measurements on bone collagen, with promising results, confirming the expected difference between the two sites based on environmental waters, and offering additional support for the presence of non-locals first identified as outliers based on their δ^{13}C and δ^{15}N values. That not all the suspected non-locals differed in their δ^{18}O values may be because that assumption was itself flawed, or that exchange with laboratory waters smeared the signal.

The results reveal a number of previously unrecognized patterns that add to our knowledge or hunter-gatherer adaptations and social dynamics in Cis-Baikal. LN and EBA individuals at Verkholensk differ in their average δ^{13}C and δ^{15}N values, showing an apparent shift to greater use of terrestrial resources in the EBA that may relate to more favourable conditions for large game at this time. The non-overlapping δ^{13}C values in EBA individuals from Verkholensk and Obkhoi, despite their proximity, could imply an unexpected degree of territoriality, though the alternative explanation of a diachronic dietary shift through the EBA also needs to be considered and will be addressed through new excavations on the Upper Lena.

The isotopically distinct LN individuals from Ulan-Khada offer the opportunity to explore possible migration from the Angara micro-region. The EBA results from Ulan-Khada are consistent with other findings from the Little Sea micro-region and provide further support for the previously identified division of long-term dietary patterns into 'Game-Fish' and 'Game-Fish-Seal'. However, the increasing sample size now available for the Little Sea is beginning to reveal more subtle patterns in the data. Thus, within the GFS diet, males have slightly higher δ^{13}C values on average than females. Whether this should be interpreted as sex-based differential resource use, or to an exogamous marriage pattern, requires further investigation.

Important questions about travel between the Little Sea and Upper Lena remain in terms of its extent, direction, and demographic composition. The mid-adult female from Grave 33 at Verkholensk provides a possible example of reciprocal movement between micro-regions, which will be further explored using other methods. Further research will focus on a range of sites along the Upper Lena and around the Little Sea, utilising additional analytical techniques, including the systematic application of strontium and oxygen isotope analysis on tooth enamel and sequential sampling of dentition for a range of biochemical tracers. New ancient DNA research of adults and children is also planned, which will help elucidate population relationships across Cis-Baikal.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jas.2020.105161.

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