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 with good skeletal preservation that has provided the most comprehensive isotopic database for palaeodietary studies of north-temperate hunter-gatherers in the world. 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 several previously unrecognized patterns. Early Bronze Age (EBA, 4600–3700 cal BP) individuals at Verkholensk exhibit lower $\delta^{15}N$ values than in the Late Neolithic (LN, 5570–4600 cal BP), suggesting a shift to a more terrestrial diet in the later period. 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, though there is a diachronic component that also needs to be considered. The comparison highlights the need for additional work on freshwater reservoir corrections for the Upper Lena. The Ulan-Khada EBA results are consistent with the dietary patterns previously identified for the Little Sea micro-region, with a division into distinct 'Game-Fish' and 'Game-Fish-Seal' diets. A new finding is 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.

A small number of outliers in $\delta^{13}C$ and/or $\delta^{15}N$ were identified at both Verkholensk and Ulan-Khada that may support previous suggestions of migration 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, but further research is needed.

Keywords: Lake Baikal, Hunter–gatherers, Middle Holocene, Diet, Stable Isotopes, Radiocarbon dating

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 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 (Figure 1). Specifically, this study sheds light on our understanding of intergroup dietary variation, practices of land tenure and sharing, and temporal shifts in diet and mobility.

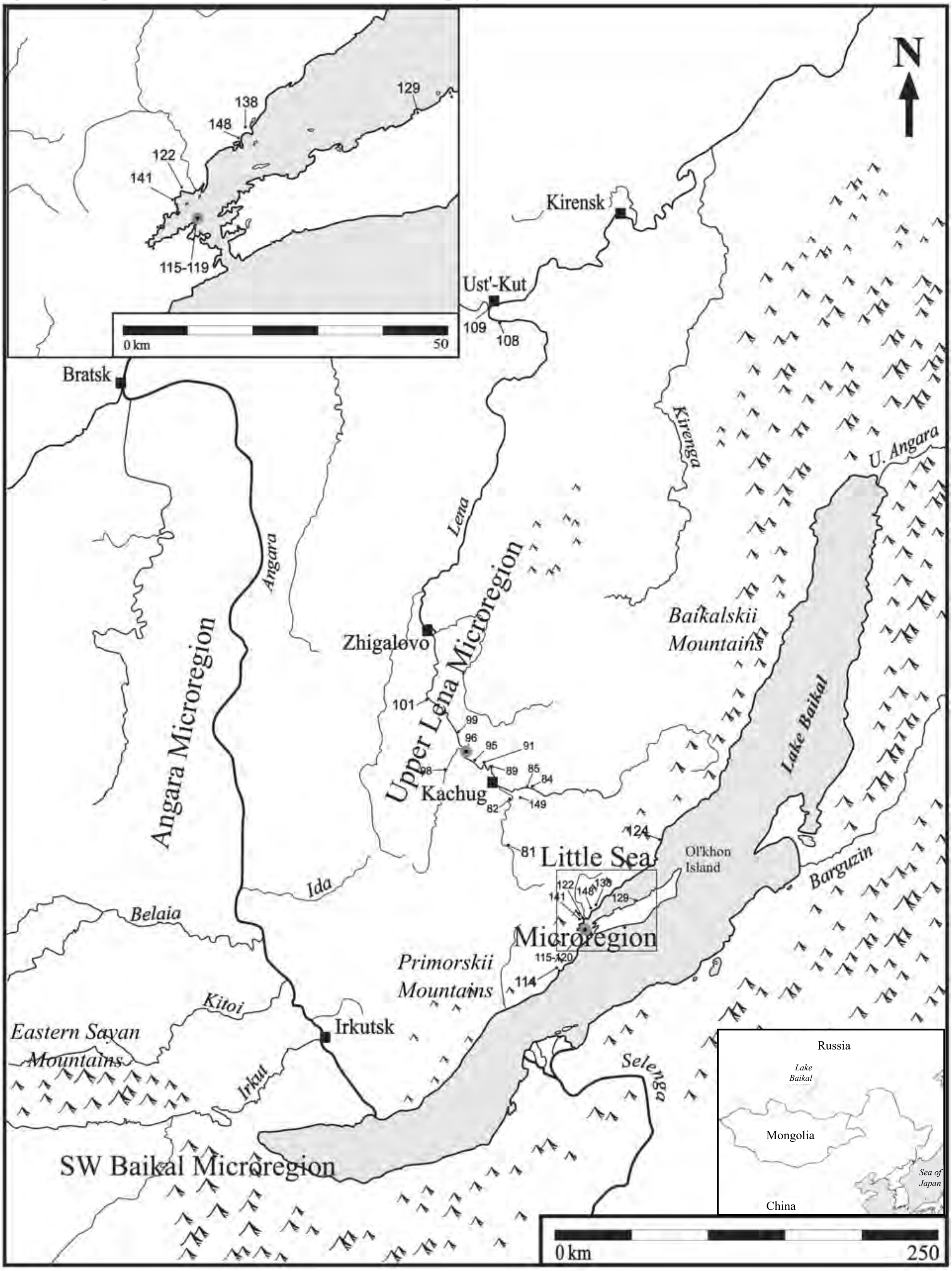
Carbon and nitrogen stable isotope analyses are useful in the study of past diets because they can semi-quantify the contributions of certain broad food groups (e.g., terrestrial or aquatic). Oxygen isotopes reflect sources of water consumed (from drink and food), and so can be used to investigate mobility. Reconstruction of specific dietary patterns is 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 the region to the west of the lake, commonly referred to as 'Cis-Baikal' (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 Section 3.2 and 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) and Early Bronze Age (EBA), 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). It should be emphasised that 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. Yet, the analysis of individuals from Verkholensk is particularly significant because previous investigations in Cis-Baikal have focused less on groups living along the Upper Lena River. The inclusion of data from Verkholensk, the largest excavated cemetery there to date, begins to fill this gap, and allows testing of previously proposed hypotheses. Specifically, hunter-gatherer travel between the Upper Lena to 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.

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.

Figure 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.



2. The sites in their regional context

2.1. Archaeological background

Research on Lake Baikal hunter-gatherers has mainly focused on Neolithic and EBA cemeteries (Weber et al., 2016) (Table 1). The Kitoi mortuary complex from the Angara valley and southwest Baikal is associated with the Early Neolithic (EN), which is often 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.

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* mean HPD cal BP
Late Neolithic	Isakovo and Serovo	ca. *5570 – 4600 mean HPD cal BP
Early Bronze Age	Glazkovo	ca. 4600 – 3730 mean HPD cal BP

**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).*

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).

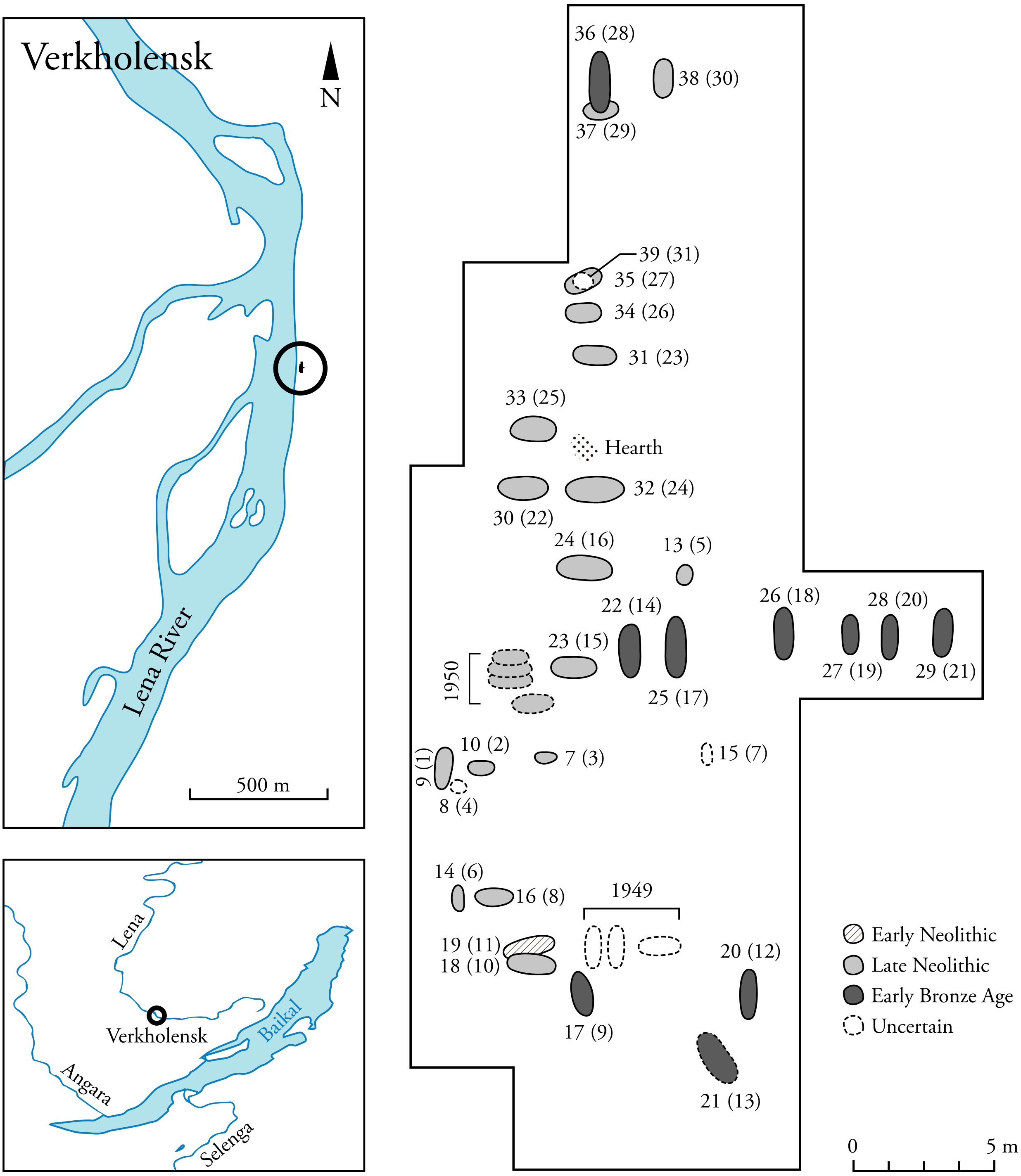
The Glazkovo mortuary tradition dates to the EBA, but metal grave goods are rare and its defining characteristic is the orientation of graves along the courses of major rivers or coastline (Weber, 1995; Weber et al., 2016). For instance, Upper Lena graves tend to be arranged parallel to the Lena, whereas graves from the Little Sea tend to be oriented southwest-northeast, roughly parallel to the coastline (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 found frequently. LN and EBA graves tend to co-occur within the same cemeteries and their burial structures are often visible (Weber et al., 2016). For instance, Little Sea graves have stone coverings on the surface, including those at Ulan-Khada.

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 the availability of net fishing technology. Harpoons, fishhook shanks, and composite fishhooks are common in the graves of the Kitoi mortuary tradition. 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).

2.3. Verkholensk

Verkholensk is located on the right bank of the Lena River at the edge of a modern village of the same name (Figure 2). The cemetery sits on a river terrace that rises high above the riverbend and 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, and needle cases; bone and stone representations of fish, composite fishhooks, flint flakes, and blades; shell beads; stone and nephrite adze; net-impressed pottery; and worked antler objects. These, along with grave orientation, allowed the burials to be classified typologically as LN or EBA. There were both single and multiple internments, as well as evidence for later burials being added to or intruding upon previous interments (e.g., Graves 19 and 24).

Figure 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) Figure 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 Supplemental Information section 1 for more details. The period assignments reflect the results of this study.

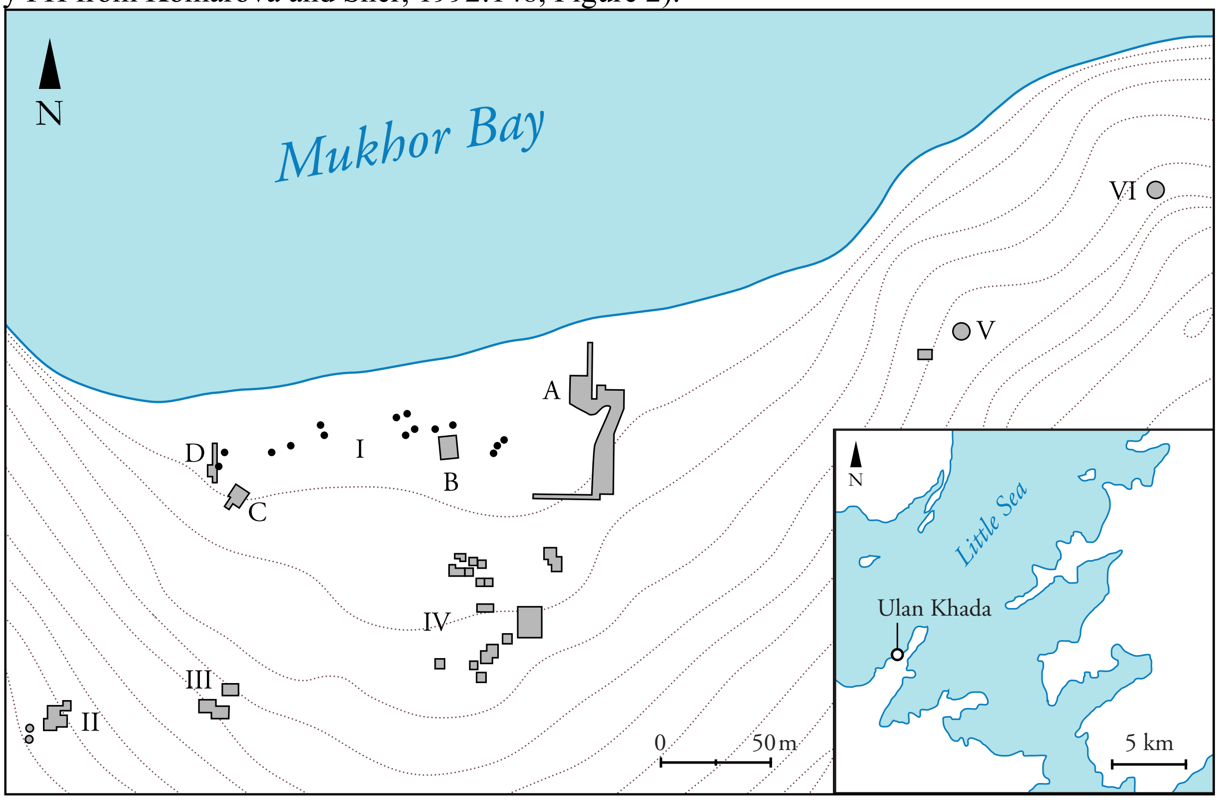


2.4. Ulan-Khada

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 (Figure 3, A–D), located nearer the beach (Khlobystin and Clark, 1969; Komarova and Sher, 1992; Okladnikov, 1950). The cemetery was divided into six sectors, ca. 50 to 250 m apart, though their significance 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 (Figure 4). A number of graves appear to have been looted or otherwise disturbed in the past.

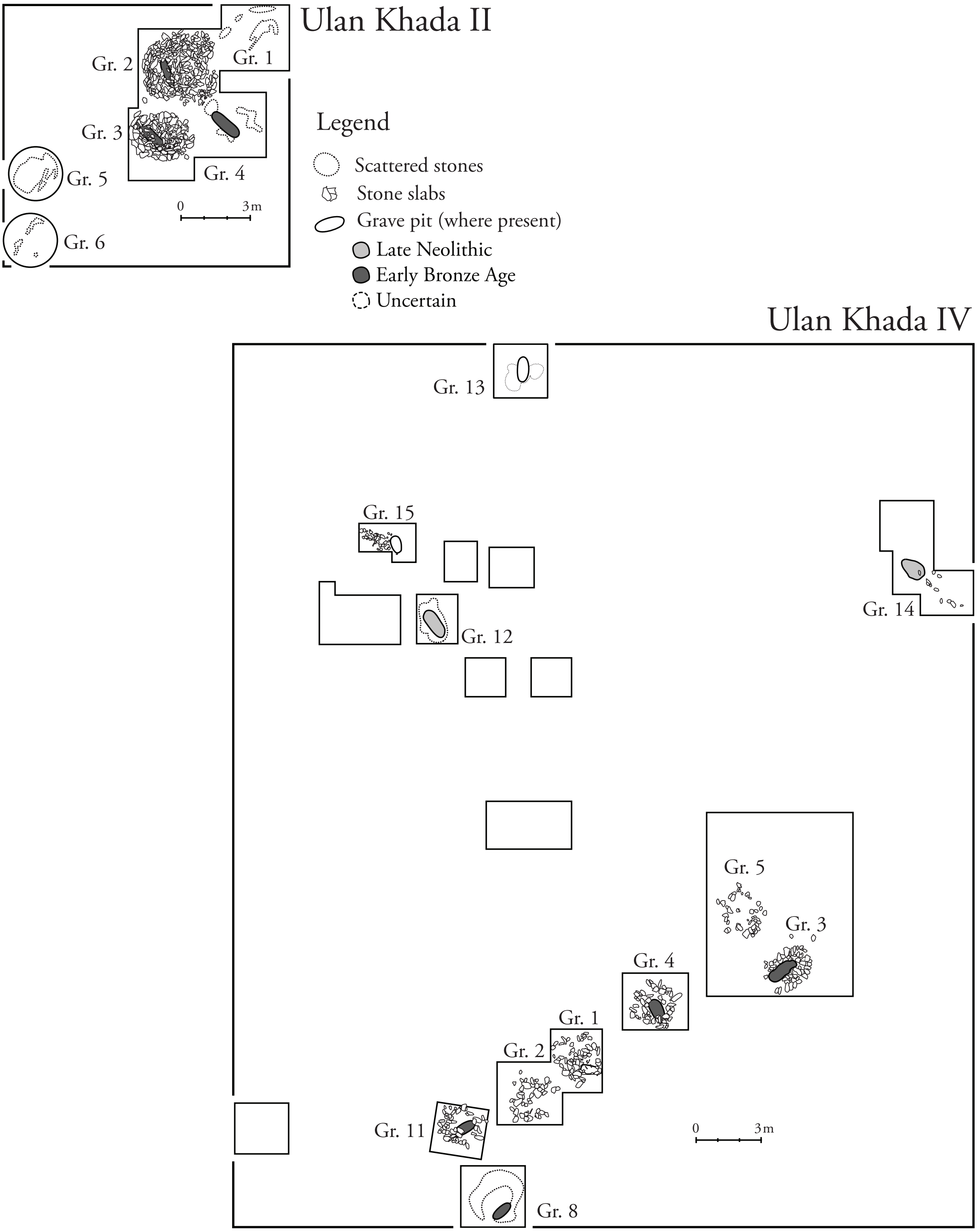
Ulan-Khada II and III are located on a slope, and all the graves were marked by two layers of stone structures. Ulan-Khada II grave goods included a bone harpoon, a bronze knife, flint arrowheads, flint knives, nephrite disks and axes, plain pottery, and red deer tooth pendants. Ulan-Khada III is 55 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.

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



Twenty-one stone clusters were excavated at Ulan-Khada IV, of which ten 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 nephrite pendant in the shape of a small axe, 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, 1991). 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 has yielded only a single grave – reported to be Late Bronze Age typologically – that was not available for inclusion in this study (Goriunova and Khlobystin, 1991).

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



Further details concerning Verkholensk and Ulan-Khada can be found in Supplementary Information (SI, section 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). $\delta^{13}C$ values vary significantly by photosynthetic pathway and by carbon source, such that it differentiates between plants using C_3, C_4, and CAM pathways and the animals reliant on them. It also distinguishes between C_3 and marine systems, since these reflect differences in the baseline values of atmospheric and ocean carbon pools (DeNiro and Epstein, 1978; Schoeninger and DeNiro, 1984). The Baikal region is a typical C_3 ecosystem, lacking significant C_4 plants. Nevertheless, as discussed further below, the lake's unique isotopic ecology features a very wide range of ^{13}C values, which at their upper end overlap those seen in marine systems (Yoshii, 1999; Yoshii et al., 1999).

Nitrogen is only found in the protein component of the diet. Its stable isotope ratio ($\delta^{15}N$) increases with trophic level, providing information on an organism's position in its food web. Aquatic predators tend to be ^{15}N-enriched due to the longer food chains in these systems. The $\delta^{15}N$ trophic level shift in humans is in the range of +3–6‰ while in $\delta^{13}C$ it is approximately +1‰ (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. For this reason, care needs to be taken to treat their values separately from those of older children and adults. The findings of Waters-Rist et al. (2011) suggest that EN and LN infants from the Angara valley were normally nursed until about 2 to 3 years old, whereas children from 4 to 10 years old were not isotopically distinct from adults in the same groups.

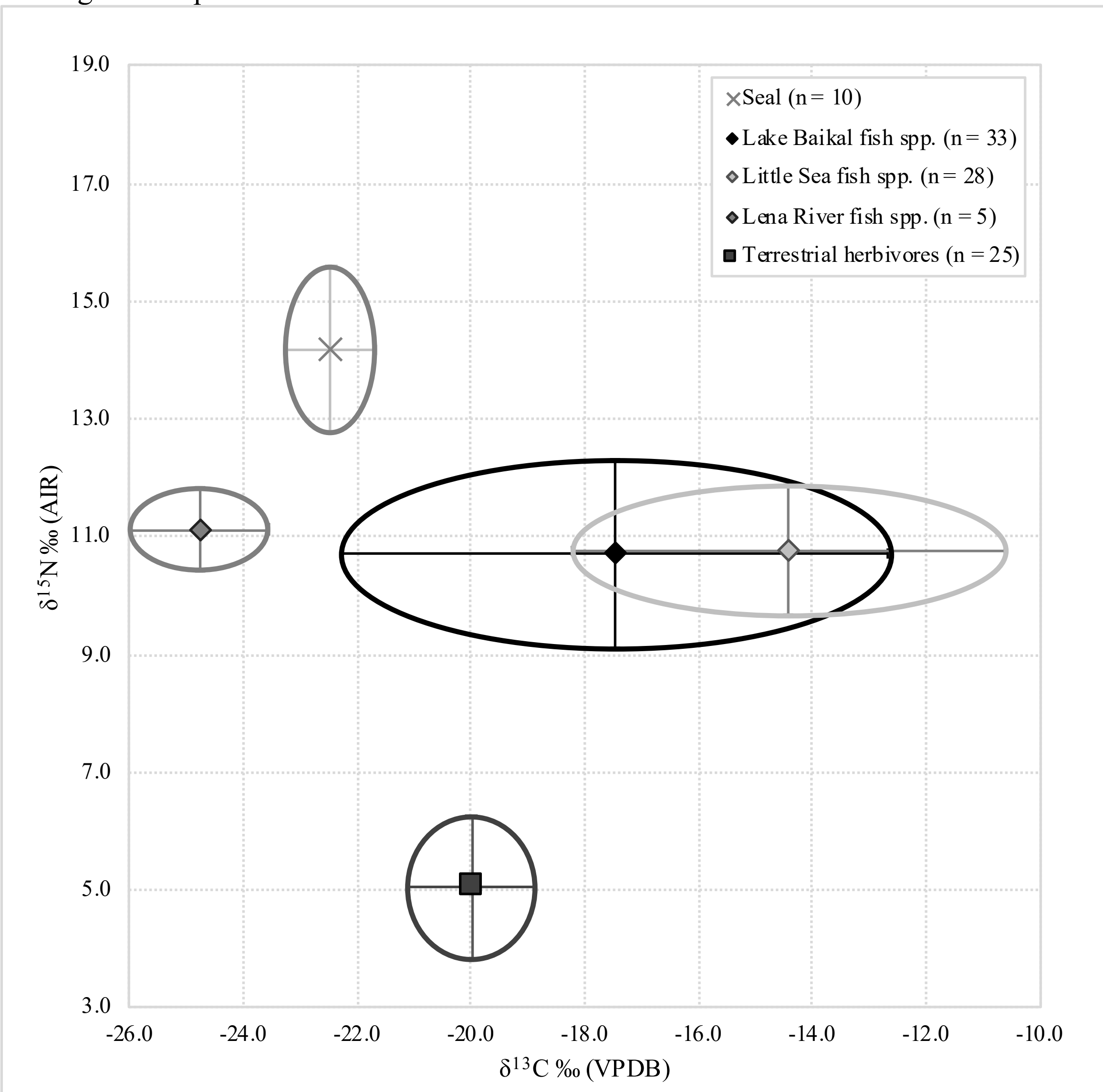
Since humans are obligate drinkers, oxygen isotopes ($\delta^{18}O$) reflect sources of ingested water, mainly drinking water but also food (Pellegrini et al., 2016). Processes of evaporation and precipitation lead to isotopic differences in precipitation on regional scales (Jouzel et al., 2000). Because $\delta^{18}O$ 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 et al., 2003). In practice, there are problems making any such direct comparisons. Stable oxygen isotope analysis is usually undertaken on carbonate or phosphate in tooth enamel, which was not available for the present analysis. Here, we present the results of a small pilot study exploring the utility of measuring $\delta^{18}O$ in bone collagen, using the same material prepared for $\delta^{13}C$ and $\delta^{15}N$ 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 in collagen with H_2O in the laboratory's atmosphere and in the reagent waters used for demineralisation (von Holstein et al., 2018). Comparisons with results from other laboratories as well as with environmental datasets are therefore problematic. Nevertheless, while attenuating the biogenic signal, the exchangeable oxygen is expected to be similarly affected as long as the samples were prepared at the same time in the same laboratory (i.e., the 'principle of identical treatment'), and so can still be compared in relative terms with one another. We are mainly interested in: 1) determining whether or not the expected difference in $\delta^{18}O$ can be identified between the two sites, indicating that at least part of the endogenous signal survives; and 2) to further investigate outliers identified through $\delta^{13}C$ and $\delta^{15}N$ analysis.

3.2. Local Isotopic Ecology

Lake Baikal is the oldest and largest lake (by volume) in the world. Its two primary producers—phytoplankton and periphytic algae—differ by over 20‰ in their average $\delta^{13}C$ values (Yoshii, 1999; Yoshii et al., 1999). This results in a range of $\delta^{13}C$ in fish bone collagen values from approximately −24.6‰ (omul') to –12.9‰ (ide) (Figure 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 very ^{13}C-enriched. Pelagic species such as the omul', on the other hand, are ^{13}C-depleted, as are the Baikal seals that feed on pelagic species in the lake's deep waters (Katzenberg et al., 2012; Weber, 2003; Weber and Bettinger, 2010; Weber et al., 2011). Seals (*Phoca sibirica*) and pike (*Esox lucius*) are top predators and so have correspondingly high $\delta^{15}N$ values (Katzenberg and Weber, 1999; Katzenberg et al., 2010). The Little Sea mainly contains cove, lagoon and littoral fishes (with a $\delta^{13}C$ range of 10‰). Since the Lena River is not connected to Lake Baikal, beginning approximately 75 km north of Ol'khon Island, it does not have ^{13}C-enriched fishes and thus lacks the high $\delta^{13}C$ values seen in the lake's inshore fishes (Katzenberg et al., 2012; Weber et al., 2011). Pike is the Lena's top predator (for further details on the aquatic resources see section SI section 2).

Katzenberg and Weber (1999), Weber et al. (2002), Katzenberg et al. (2012), and Weber et al. (2011) have compiled and analysed the carbon and nitrogen values for a range of terrestrial and aquatic fauna from Cis-Baikal. Most of the aquatic fauna analysed come from Lake Baikal, the Little Sea, and Angara micro-regions, with only a few results available for the Upper Lena (Katzenberg et al., 2012; Schulting et al., 2015; Weber et al., 2011, 2016). In these studies, modern fish, adjusted for the fossil fuel effect (Friedli et al., 1986), were sampled due to the limited availability of archaeological fish remains from Cis-Baikal. Isotopic values for the flora of Cis-Baikal have not yet been analysed systematically with the exception of 'cedar' (*Pinus sibirica*) nuts (Lam, 1994; Weber et al., 2002).

Figure 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 all modern and were adjusted for a fossil fuel effect. The seal values are from archaeological samples.



Baikal's isotopic water values are determined by river inputs and output as well as by precipitation and evaporation (Mackay et al., 2011; Morley et al., 2005; Seal and Shanks, 1998). It has a mean $\delta^{18}O$ 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 more negative mean $\delta^{18}O$ value of –19.6 ± 1.4‰ (n = 33) that generally conforms to the Global Meteoric Water Line (Seal and Shanks, 1998).

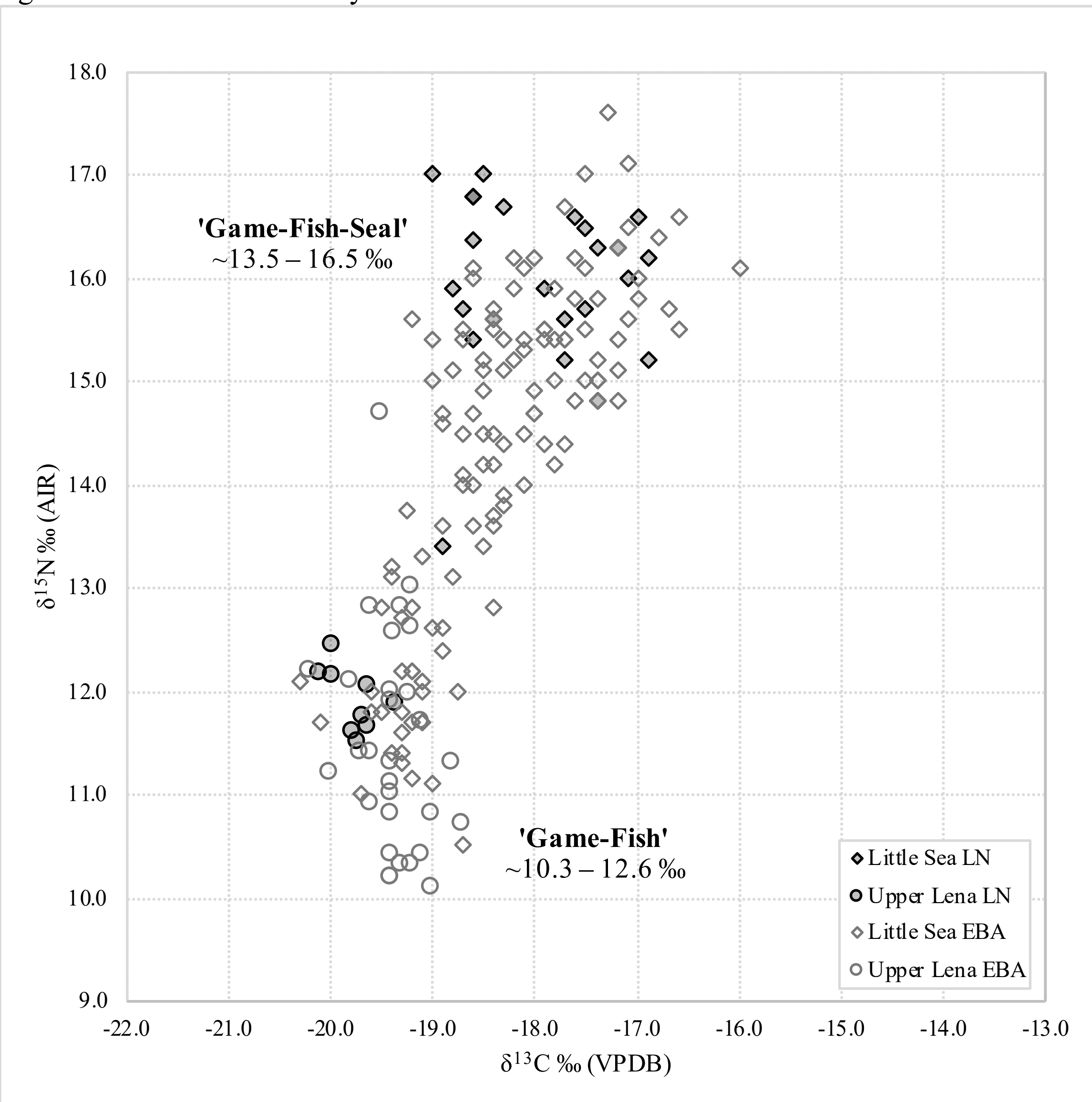
3.3. Previous research

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

[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

and seal in addition to terrestrial game. Moreover, some importance has been placed on the possible cultural significance of seal hunting and use in mortuary rituals and feasting (Nomokonova et al., 2013a; Shepard et al., 2016; Weber and Link, 1998; Weber et al., 2002;). The LM/EN individuals in the Little Sea relied mainly on terrestrial mammals and littoral fish, but during the LN and EBA there was 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) ($\delta^{15}N$ ca. 13.5−16.5‰) diet is defined by a much greater reliance on aquatic mammal protein than the 'Game-Fish' diet ($\delta^{15}N$ ca. 10.3−13.0‰; Figure 6) (Weber et al., 2011; Weber and Goriunova, 2013). These patterns are clearest in the EBA, either because most human remains date to this period or because diet was more differentiated at that time.

Figure 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.



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 =

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).

13) displayed both GF and GFS diets (Weber and Goriunova, 2013; Weber et al., 2011). Most non-local individuals had strontium isotopic ranges consistent with either the Angara or Upper Lena, though other areas yet to be characterised isotopically may also have similar strontium ratios. Based on its proximity, the Upper Lena (~65 km north) has been proposed as their most probable origin.

However, recent examination of the freshwater reservoir effect (FRE) in the Upper Lena 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). Therefore, 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 when they migrated to 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 δ^{13}C, δ^{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 δ^{18}O analysis on the same samples in 2017 at RLAHA. Age and sex data can be found in the Catalogue. See SI section 3 for noted discrepancies 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 sample remained for both protocols.

All samples were ground and soaked in 0.5 M of hydrochloric acid (HCl) at 5°C for approximately three days or until they no longer reacted. 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 of sodium hydroxide (NaOH) to remove humic acids. Each acid/base wash was followed by multiple rinses with ultrapure (MilliQ) water.

Both sets of samples were gelatinized by being placed in pH3 H_2O for 24 hours before being sealed and heated at 70°C for three days. The resulting liquid was then filtered through an Ezee-filter and the filtrate freeze-dried until only 'collagen' remained. The ORAU samples also

[2] Most of the individuals had age and sex information published in the Russian literature reviewed earlier, though these are not always reliable. One of us (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.

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 $\delta^{13}C$ (VPDB) and $\delta^{15}N$ (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 (Coplen, 2011). Measurement precision is on the order of ±0.2‰ for $\delta^{13}C$ and $\delta^{15}N$. Collagen quality was assessed following the accepted standards in palaeodietary research (Ambrose, 1990; DeNiro, 1985; van Klinken, 1999).

Stable oxygen isotope analysis was undertaken on the same collagen preparation used for $\delta^{13}C$ and $\delta^{15}N$, using 21 samples from Verkholensk and 12 from Ulan Khada (see further details in SI section 4.1). Importantly, these samples were prepared at the same time and remained thereafter in sealed tubes subject to the same atmospheric exchange. 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. The ^{14}C measurements were corrected for the freshwater reservoir effect (FRE) that has been demonstrated in the region (Bronk Ramsey, 2014; Nomokonova et al., 2013b; Schulting et al., 2014; Schulting et al., 2015). Linear regression formulae based on paired radiocarbon dating of human and terrestrial animal teeth from the same graves were used from Schulting et al. (2014) for the Little Sea and from Schulting et al. (2015) for the southern Upper Lena (Table 2). The human $\delta^{13}C$ & $\delta^{15}N$ results provide estimates of the amount of aquatic sources in the diets, which in turn are used to estimate the extent of the FRE for each individual. The increased error terms for the FRE-corrected dates were calculated as described in Weber et al. (2016). Radiocarbon dates for four children aged younger than five were not corrected, since any residual nursing effect could skew the regression equation calculation.

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

Source	Formula
1. "Little Sea, $\delta^{13}C$ & $\delta^{15}N$" (Schulting et al. 2014)	-3329.5 - 125.6 ($\delta^{13}C$) + 95.1 ($\delta^{15}N$)
2. "Upper Lena, $\delta^{13}C$ & $\delta^{15}N$" (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)	$\sqrt{(s.d.)^2 + S^2}$

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. Period Assignment

The original cultural classifications for the Verkholensk and Ulan-Khada graves to specific mortuary traditions and archaeological periods were proposed on typological grounds using older culture historical schemes (e.g. Komarova and Sher, 1992; Okladnikov, 1978) that predate changes effected by 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 Section 5.1).

4.5. 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 section 5). Heteroscedastic t-tests were used when the data did not depart significantly from normality, and the variance of one group was ≥ twice that of the other.

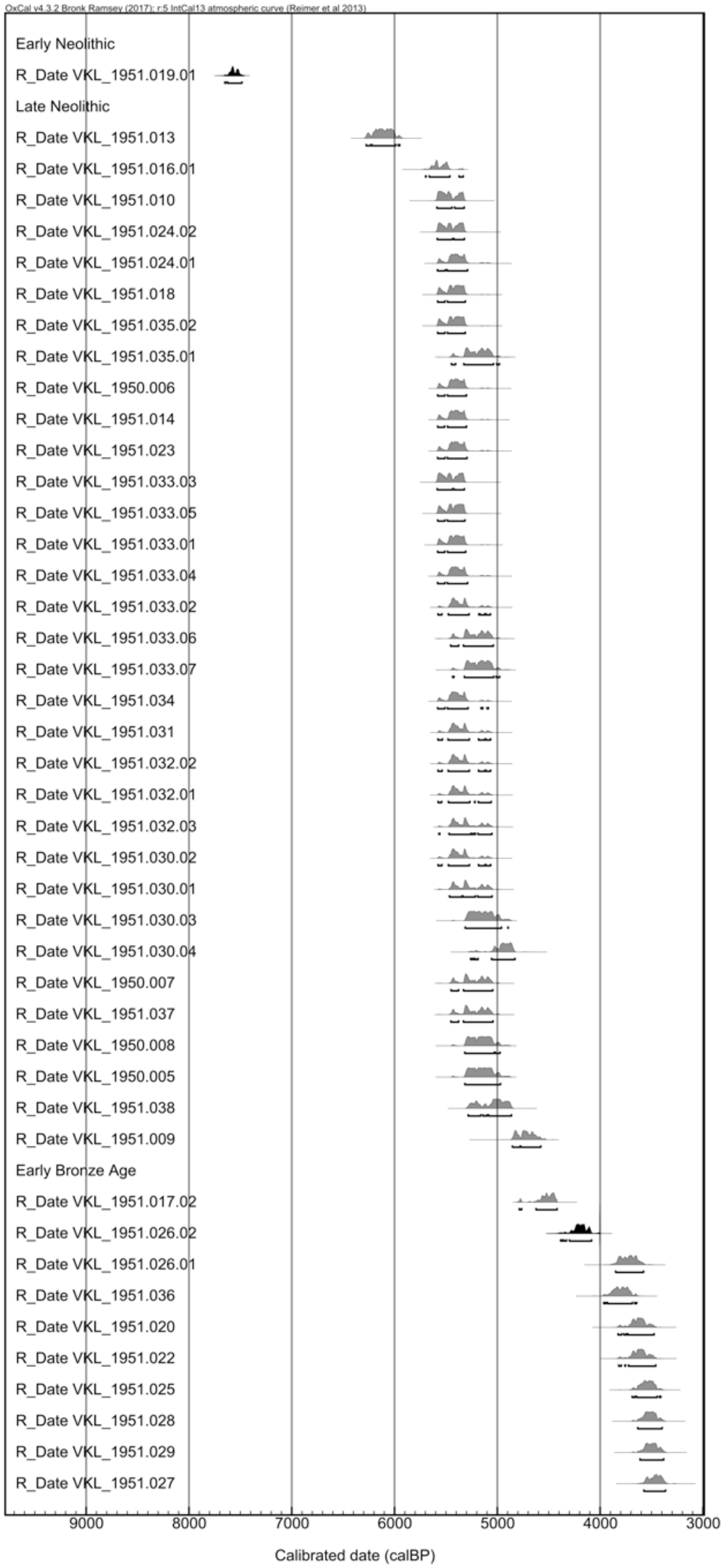
5. Results

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 both stable isotope and ^{14}C analyses (Ambrose, 1990; DeNiro, 1985; van Klinken, 1999). The $\delta^{13}C$ and $\delta^{15}N$ values obtained from the two preparation methods described above were statistically indistinguishable (see SI section 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.

5.1. Radiocarbon dating and typological assessments

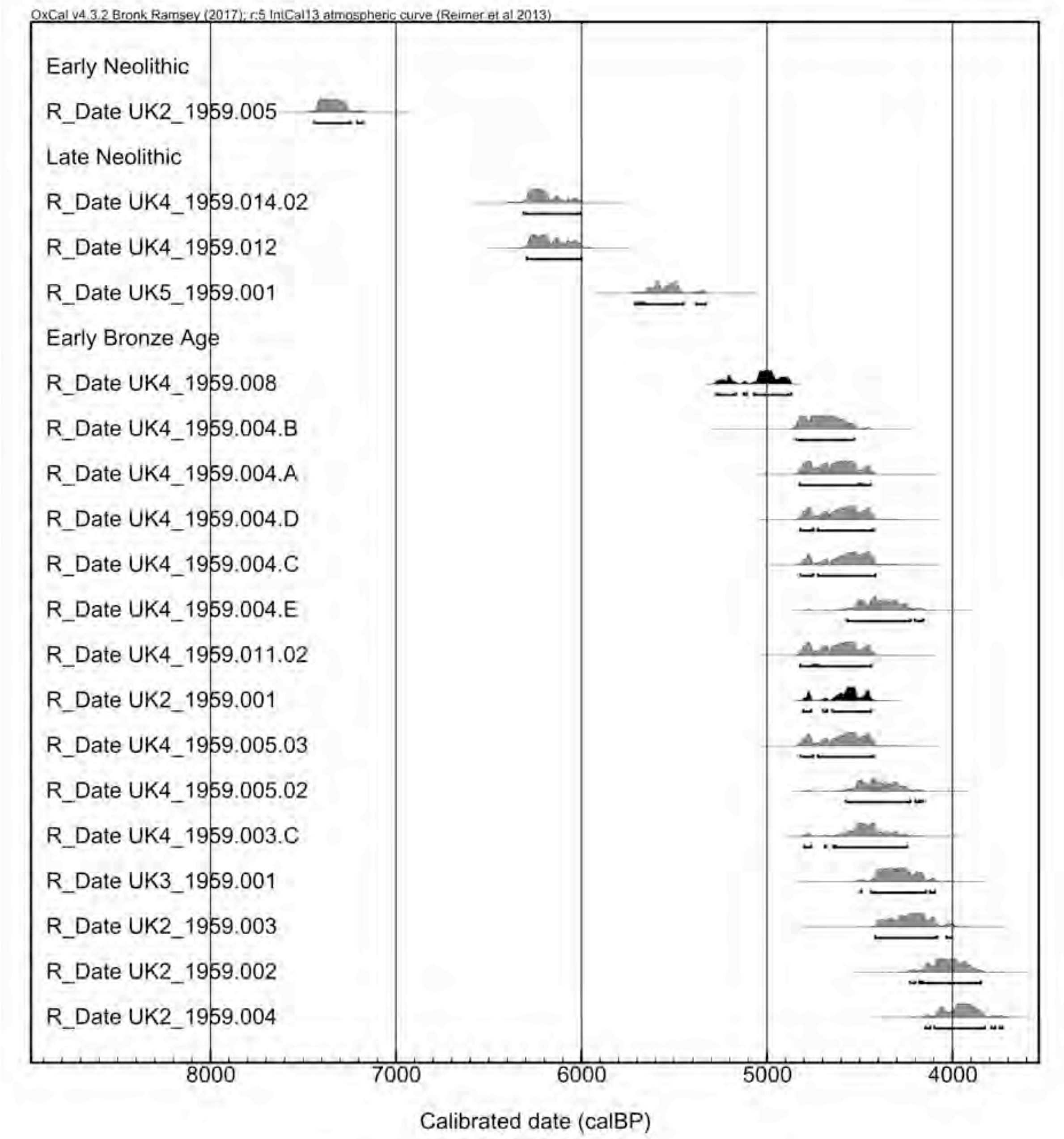
Okladnikov's (1978) typological classification suggested the presence of only LN and EBA graves at Verkholensk. Nevertheless, the radiocarbon evidence identifies at least two burials as much earlier. Grave 19, a child c. 4-5 years old, dates to the late EN (Figure 7). Okladnikov expressed some doubts about the typochronological classification of this grave, omitting it from his final chronological assessment (Okladnikov 1978: 69–94). 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. It should be noted that the lower, older, boundary of the LN as defined in Weber et al. (2016) was based upon only 22 radiocarbon dates and will possibly shift with further analysis. Therefore, this individual is classified as 'LN' pending further study. Most individuals at Verkholensk were interred during the LN. With one exception, there is a gap of over 500 years between these and the following EBA burials. 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 interred at the same time, but the ^{14}C dates suggest at least two burial episodes. Further work on the Upper Lena FRE correction will allow us to revisit this conclusion in the future.

Figure 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 (shaded in black) were not FRE-corrected and therefore appear older.



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 (Figure 8). Two dates (Graves 14.04 and 12) fall well before the beginning of the LN as currently understood (Table 1), though uncertainty regarding this boundary is not unexpected as it was the least well-represented period in the most recent chronological analysis of Cis-Baikal (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 (Figure 4).

Figure 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.



The presence of a few clear outliers in the $\delta^{13}C$ and $\delta^{15}N$ 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 $\delta^{13}C$ and $\delta^{15}N$ 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 $\delta^{13}C$ and lower $\delta^{15}N$ values) (discussed below and illustrated in Figures 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). Applying the FRE correction for the regions that best matched their stable isotopic results, resulted in differences of less than 300 years that do not alter the cultural period assignments despite providing an older date (Catalogue and Table 2).

5.2. Stable Isotope results

All statistical analyses were carried out on individuals aged approximately five and older to avoid any offset due to nursing and the possibility of different diets in early childhood, which is consistent with previous isotopic studies in Cis-Baikal (Tables 3–4; Figures 9–10). The results of the post-weaning individuals from all periods at Verkholensk contain two $\delta^{13}C$ outliers and four $\delta^{15}N$ outliers in different individuals (in bold in the Catalogue). The $\delta^{13}C$ and $\delta^{15}N$ values are normally distributed once these outliers are removed, and show no significant correlation ($r^2 = -0.074$, $p = 0.67$). Within the LN sample, the seven individuals from Grave 33 stand out, with all but two exhibiting higher $\delta^{15}N$ values than the remaining LN individuals (Figure 9). Moreover, one individual, VKL_1951.033.01, has the most elevated $\delta^{13}C$ value at the site. The LN individuals at Verkholensk, even excluding Grave 33, show higher $\delta^{15}N$ values (12.02 ± 0.56‰, n = 23) than those during the EBA (11.23 ± 0.55‰, n = 8) (Student's *t*-test, $df = 29$, $t = 3.460$, $p = 0.002$) and the mean cal BP is positively correlated to the $\delta^{15}N$ values as well (Spearman's rank-order, $r^2 = 0.522$, $p = 0.000$). Including Grave 33 only accentuates this difference.

Table 3: Descriptive statistics for Verkholensk isotopic data.

Verkholensk

Statistic	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**
	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

Figure 9: Isotopic values from Verkholensk differentiated by time period and sex. Individuals from LN Grave 33 are identified.

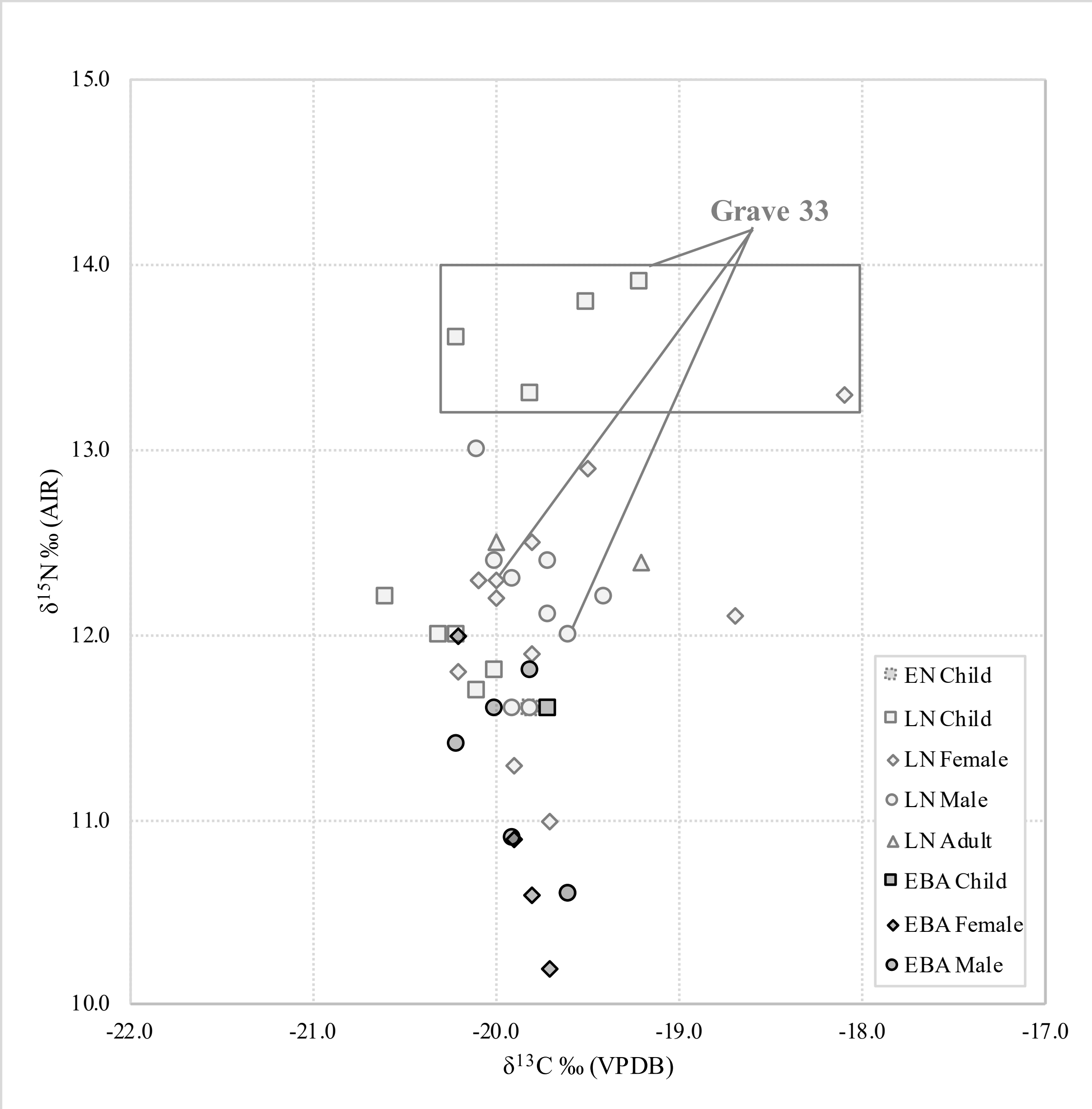
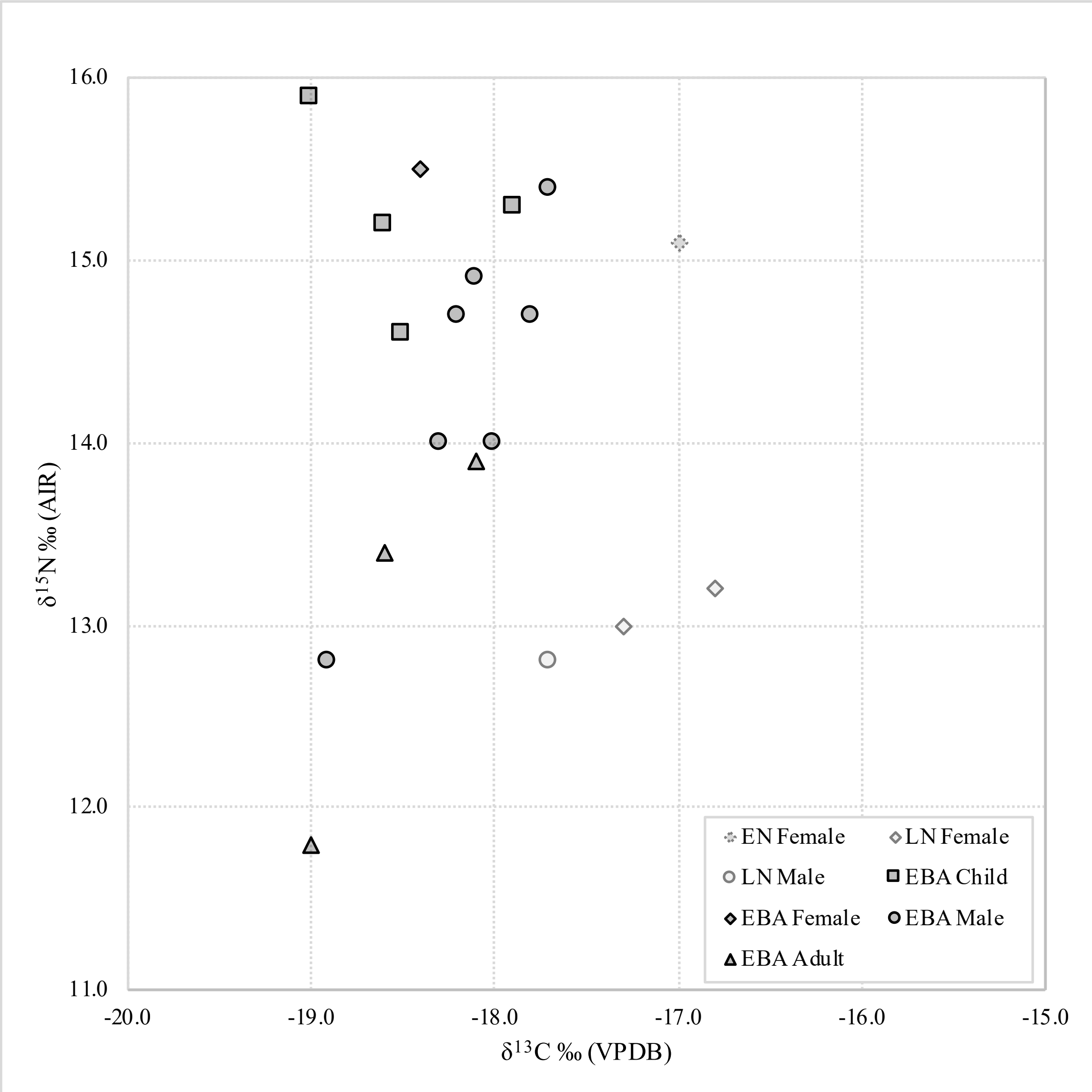


Table 4: Descriptive statistics for Ulan-Khada isotopic data.

Ulan-Khada

Statistic	**δ^{13}C**	**δ^{15}N**	**δ^{13}C**	**δ^{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

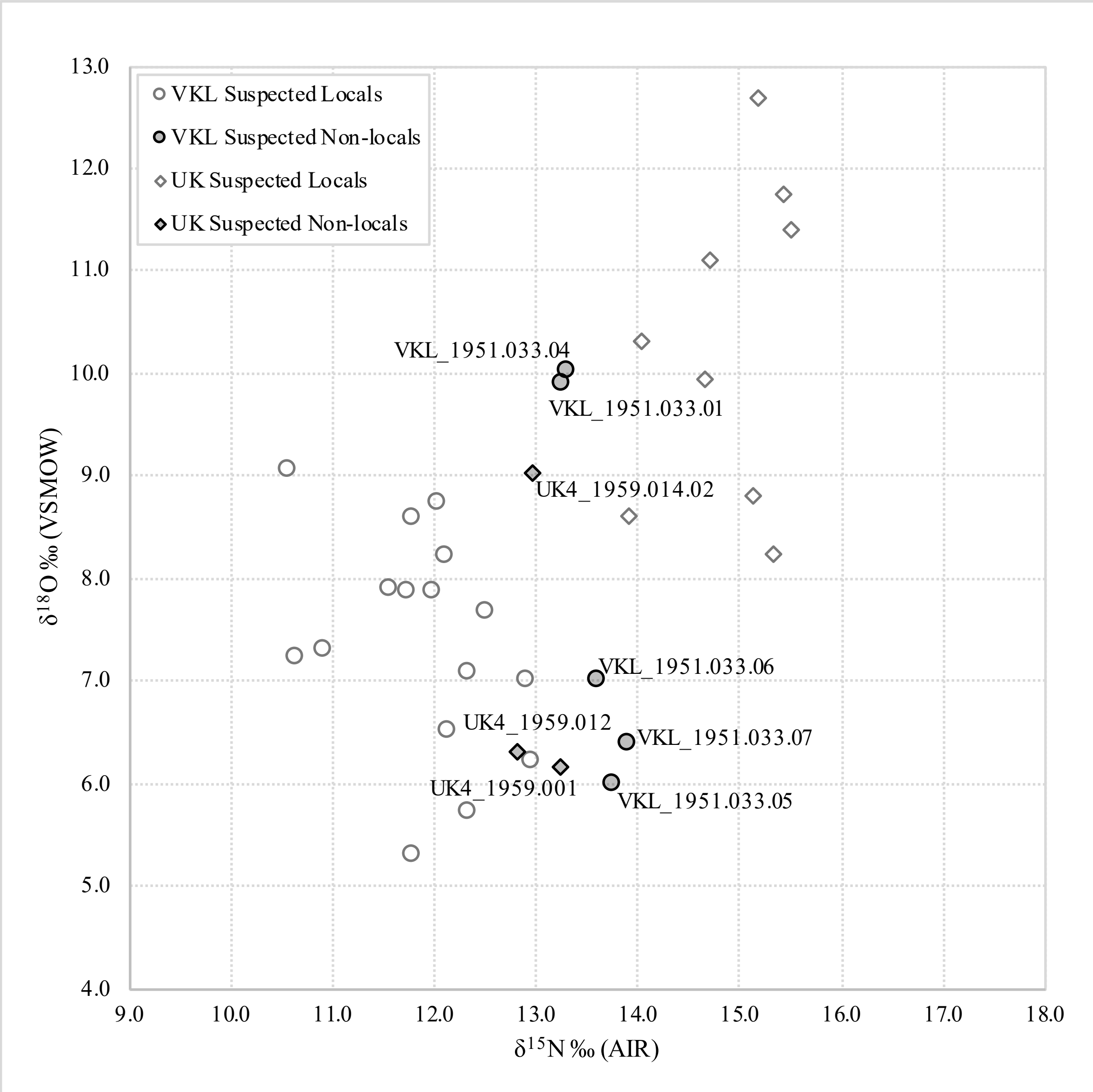
Figure 10: Isotopic values from Ulan-Khada differentiated by time period and sex.



At Ulan-Khada post-weaning individuals of all archaeological ages considered together (EN, LN, and EBA) show δ^{13}C and δ^{15}N normally distributed values without any outliers, and display 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 depleted ^{13}C 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 (Figure 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 test for any sex-based differences in diet during the EBA.

Stable oxygen isotope results from both sites are normally distributed. The site means of 7.5 ± 1.3‰ at Verkholensk and 9.5 ± 2.1‰ at Ulan-Khada differ significantly (heteroscedastic $t = 3.095$, $p = 0.007$) (Figure 11). In addition, four of the eight outliers at both sites identified on the basis of δ^{15}N results are also outliers in δ^{18}O. Removing these eight δ^{18}O values from the analysis results in an even clearer distinction between the sites (Verkholensk 7.39 ± 1.07‰ and Ulan-Khada 10.32 ± 1.54‰; heteroscedastic $t = 5.056$, $p = 0.0003$). While they are more variable, the δ^{18}O Z-scores associated with the 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 $\delta^{18}O$ 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 section 4.2 for further details on the $\delta^{18}O$ results.

Figure 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 dietary analyses are highlighted and the Master ID's provided.



6. Discussion

Interpretation of the results of the present study is undertaken within the context of previous isotopic research in the Baikal region (Figures 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 $\delta^{13}C$ between EBA Little Sea females and males with GFS diets.

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

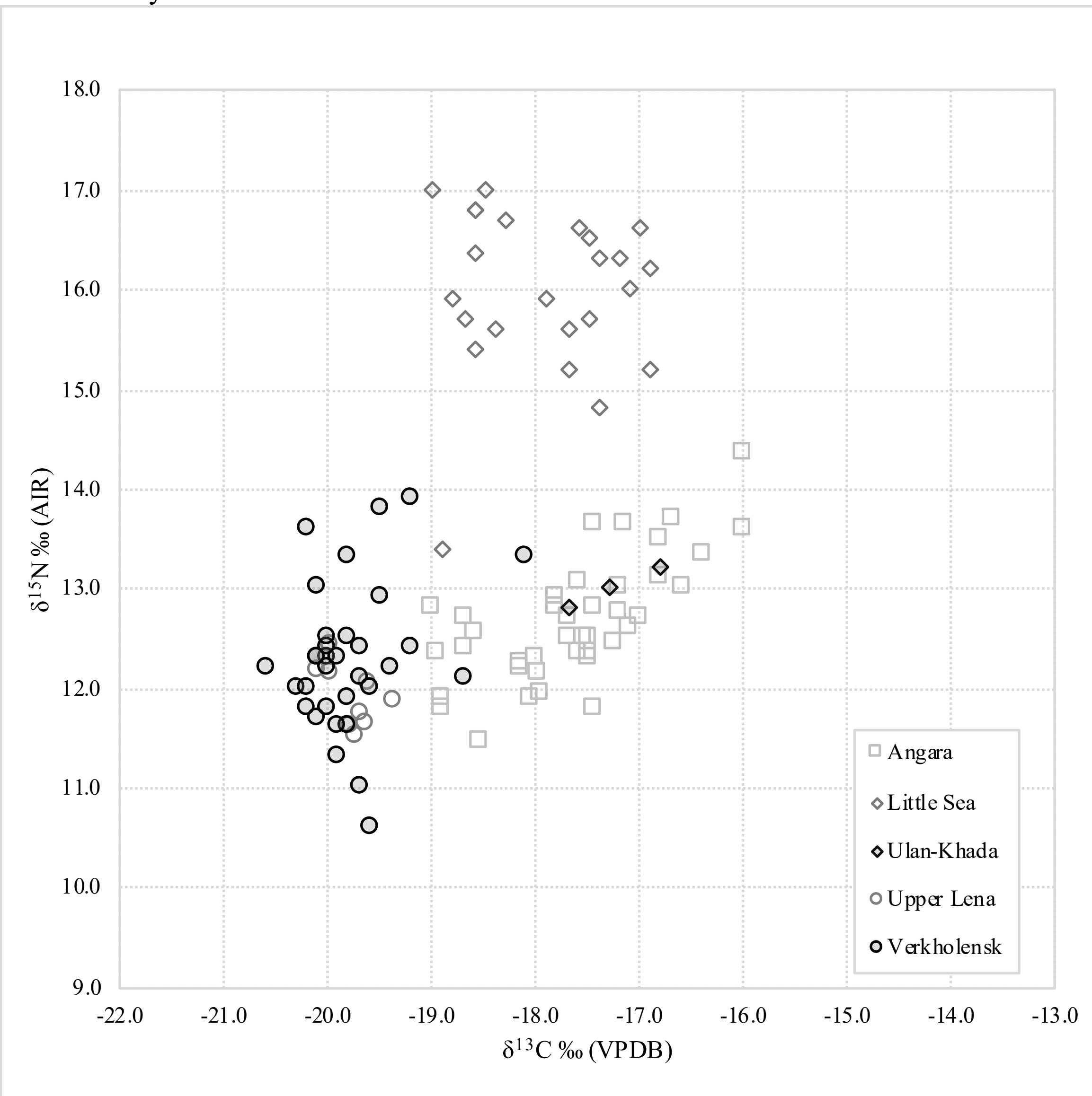
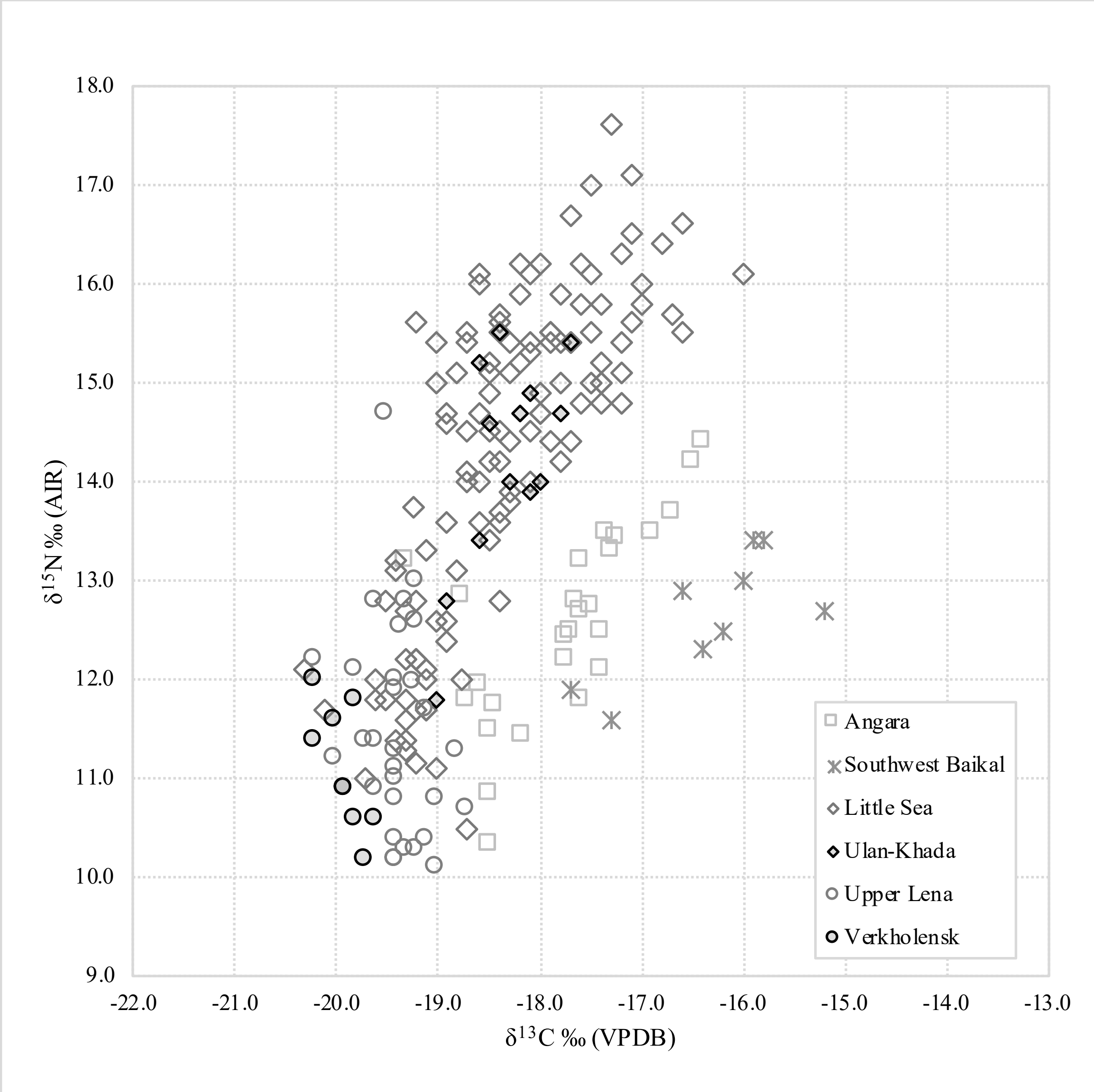


Figure 13: All post-weaning human EBA isotopic data in the BHAP database compared to the data in this study.



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 micro-region, making it possible to examine trends spatiotemporally within the micro-region (Table 5) and in comparison to other micro-regions.

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	**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**
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						

In a pattern not seen at any single location in Cis-Baikal previously, the Verkholensk δ^{13}C and δ^{15}N results indicate slightly but significantly greater reliance on aquatic resources during the LN compared to the EBA. It is possible that a contributing cause of this apparent dietary difference was 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). Thus, a more open landscape and a greater abundance of game during the EBA may have prevailed, allowing for an increased emphasis on higher-ranked terrestrial resources, such as roe and red deer (cf. 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.

The 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 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, the three of the four children attributed to Grave 33 are outliers in δ^{15}N and all four have higher 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.

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

One possible explanation for the irregular 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 $\delta^{13}C$ values are similar 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 individuals from Verkholensk. 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 section 4), with both exhibiting higher values 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 child, and four children.

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 (Figure 1). Despite being only approximately 17 km apart, Obkhoi exhibits higher $\delta^{13}C$ (−19.3 ± 0.3‰) and lower $\delta^{15}N$ values (10.6 ± 0.4‰) than Verkholensk ($\delta^{13}C$: −19.9 ± 0.2‰, $\delta^{15}N$: 11.1 ± 0.6‰; Student's *t*-tests, $df = 19$, $\delta^{13}C$, $t = –6.099$, $p = 0.000$, $\delta^{15}N$, $t = 2.063$, $p = 0.053$) (Table 5, Figure 14). Furthermore, 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 practices. Fish in the Upper Lena are the most ^{13}C-depleted aquatic fauna (ca. –26.0‰) currently known from Cis-Baikal, while their $\delta^{15}N$ 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 $\delta^{13}C$ and ca. 5.7‰ for $\delta^{15}N$ (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 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. Either way, the implication is that these two groups (and possibly others in the surrounding region) were firmly embedded in their taskscapes at a relatively fine scale. However, an undeniably 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 (Figure 15). Additionally, the $\delta^{13}C$ 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) that possibly is contemporaneous with Obkhoi also exhibits a more negative $\delta^{13}C$ 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).

Figure 14: The difference in $\delta^{13}C$ and $\delta^{15}N$ between EBA Verkholensk and Obkhoi.

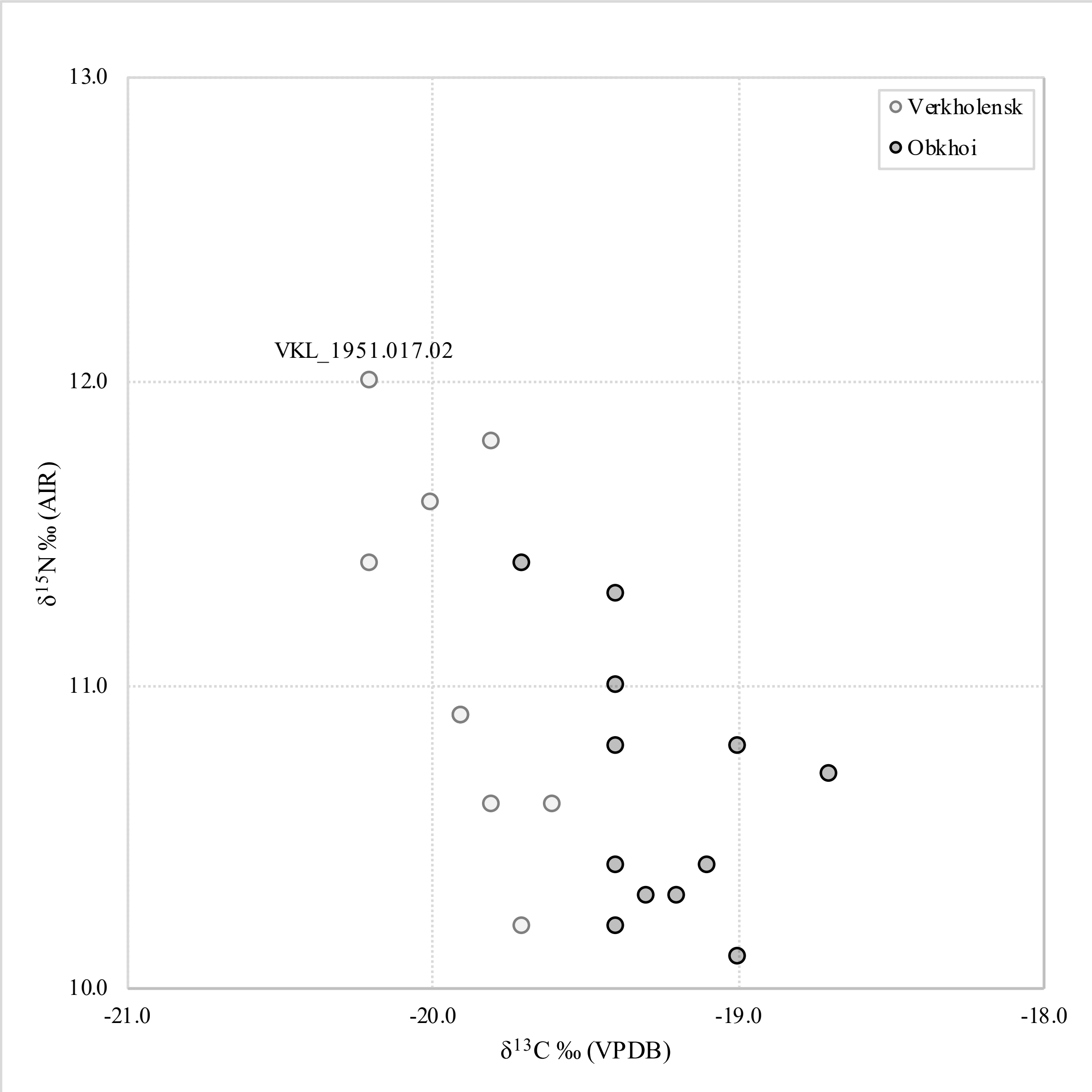
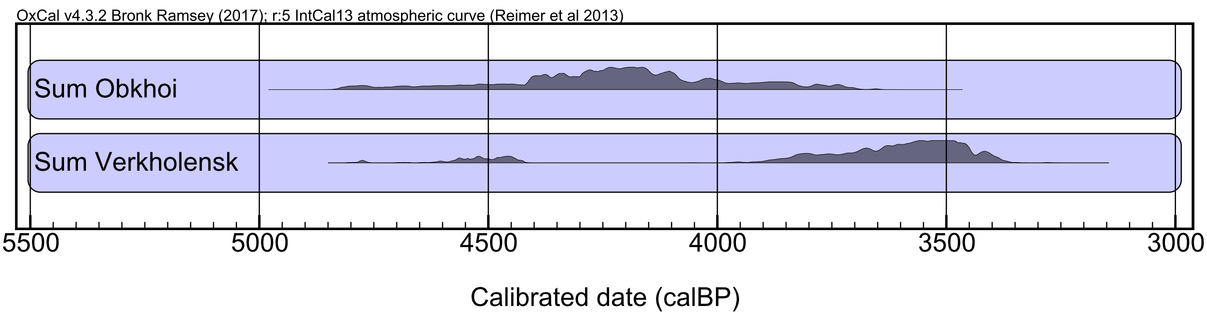


Figure 15: The summed FRE-corrected radiocarbon dates for EBA individuals included in the statistical analyses for Obkhoi and Verkholensk.



Lastly, the EBA component of the Upper Lena is significantly lower in $\delta^{15}N$ (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, Little Sea individuals with GF diet (n = 6, $\delta^{13}C$: –19.4 ± 0.2‰, $\delta^{15}N$: 11.6 ± 0.8‰) identified as non-locals through radiogenic strontium isotope analysis (Weber and Goriunova, 2013) are similar to the Upper Lena in $\delta^{13}C$ and $\delta^{15}N$ (n = 32, $\delta^{13}C$: –19.5 ± 0.4‰, $\delta^{15}N$: 11.2 ± 1.0‰).

6.2. Little Sea

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

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

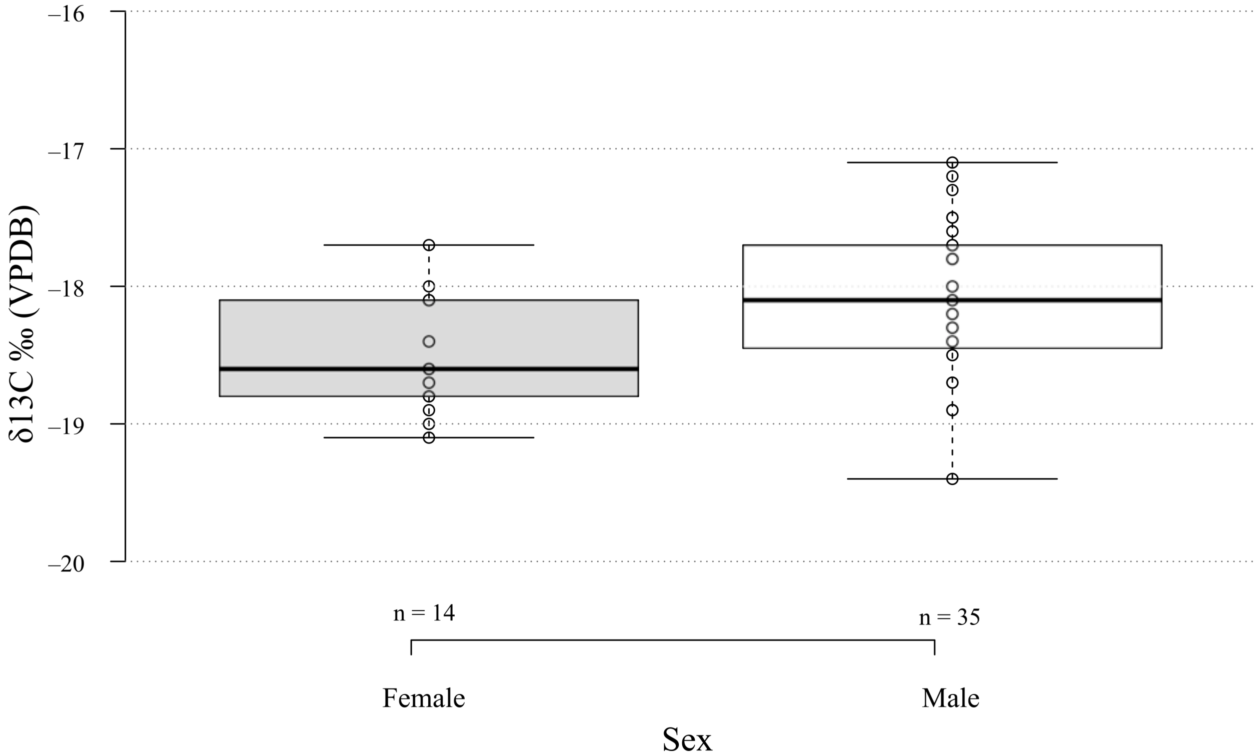
Little Sea

Site	**LM/EN**					**LN**					**EBA**				
	n	**$\delta^{13}C$**		**$\delta^{15}N$**		**n**	**$\delta^{13}C$**		**$\delta^{15}N$**		**n**	**$\delta^{13}C$**		**$\delta^{15}N$**	
		$\bar{x}$	**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

The three LN individuals from Ulan-Khada are markedly lower in $\delta^{15}N$ than the 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 (Figure 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 ratios to those at Verkholensk. While the Angara initially shares $\delta^{18}O$ values with its Lake Baikal sources, 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, although this hypothesis needs further study.

The Ulan-Khada EBA data provide additional support for the increasingly well-documented division into GF and GFS dietary patterns in the Little Sea (Figure 13). With the removal of a single outlier, the $\delta^{13}C$ values for the EBA are normally distributed, but the $\delta^{15}N$ are not, which is expected given the presence of distinct GF and GFS diets (i.e., these show a bimodal distribution). A new finding emerges, however, in terms of sex-based dietary differences. Considering all the Little Sea EBA data, males with GFS diets have higher $\delta^{13}C$ (−18.1 ± 0.5‰, n = 34) values than females with GFS diets (−18.5 ± 0.4‰, n = 14, Student's t-test, *df* = 46, $t = -2.656$, $p = 0.011$; Figure 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, it is difficult to see why this should 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.

Figure 16: The difference in $\delta^{13}C$ between all Little Sea EBA males and females with the GFS diet.



The higher $\delta^{13}C$ 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 provided new $\delta^{13}C$ and $\delta^{15}N$ analysis and ^{14}C dating 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 $\delta^{18}O$ 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 $\delta^{13}C$ and $\delta^{15}N$ ratios.

The results reveal a number of previously unrecognized patterns. LN and EBA individuals at Verkholensk differ in their average $\delta^{13}C$ and $\delta^{15}N$ 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, though this requires further research. The non-overlapping carbon values from the EBA individuals from Verkholensk and Obkhoi, despite their proximity, could imply an unexpected degree of territoriality. This analysis may be further explored by juxtaposing dietary differences with material culture evidence (e.g. nephrite) to explore wide-ranging interactions. The alternative explanation of a diachronic dietary shift through the EBA also needs to be considered.

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 $\delta^{13}C$ values on average than females. It is unknown, however, whether this relates to differential resource use between sexes, or whether this could be a hint of an exogamous marriage pattern.

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.

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