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Prehistoric dietary adaptations among hunter-fisher-gatherers from the Little Sea of Lake Baikal, Siberia, Russian Federation

M. Anne Katzenberg [a,*], Hugh G. McKenzie [b], Robert J. Losey [c], Olga I. Goriunova [d], Andrzej Weber [c]

[a] *Department of Archaeology, University of Calgary, 2500 University Dr. N.W., Calgary, Alberta T2N 1N4, Canada*
[b] *Department of Anthropology, Economics and Political Science, Grant MacEwan University, 10700-104 Avenue, Edmonton, Alberta T5J 4S2, Canada*
[c] *Department of Anthropology, 13-15 HM Tory Building, University of Alberta, Edmonton, Alberta T6G 2H4, Canada*
[d] *Laboratory of Archaeology and Palaeoecology, Irkutsk State University and Institute of Archaeology and Ethnography, Russian Academy of Sciences (Siberian Branch), Russia*

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ABSTRACT

Dietary adaptations of prehistoric hunter-gatherers from Neolithic and Early Bronze Age cemeteries in the Little Sea region of Cis-Baikal (the region to the west and north of Lake Baikal) are explored using stable isotopes of carbon and nitrogen. Stable isotope data, including stable carbon isotopes from bone carbonate, are presented for 22 individuals from the site of Kurma XI, dated to approximately 6500 B.P. to 4000 B.P. Data are compared to previously analyzed individuals from the larger Early Bronze Age cemetery, Khuzhir-Nuge XIV (Katzenberg et al., 2009 JAS) and to smaller sites located along the shore of the Little Sea, including sites on Olkhon Island. An extensive collection of fauna, both prehistoric and modern, from the Little Sea and neighboring regions is also analyzed for stable isotopes of carbon and nitrogen. Clear distinctions are found in modern fish recovered from the Little Sea, in contrast to those from the open waters of the lake and from the neighboring Angara and Lena rivers. Considerable variation is seen in stable carbon isotope ratios from fish while stable nitrogen isotope ratios are not as variable, regardless of habitat. Isotope source modeling is used to assist in reconstructing past dietary adaptations. While there is ample evidence from other studies for cultural change over this temporal span, diet appears to have been relatively stable.

1. Introduction

Dietary adaptations of high latitude hunter-gatherers include diets high in meat and fish (e.g., Cordain et al., 2000; Ziker, 2002). In the archaeological record, evidence for hunting and eating large terrestrial mammals is relatively easily detected, while evidence for fishing and fish consumption has been given less attention until recently (e.g., Erlandson, 2001; Losey et al., 2008; Yoneda et al., 2004). Stable carbon isotopes have been used to differentiate marine and terrestrial foods for many years, following the work of Chisholm et al. (1982). Katzenberg (1989) demonstrated the ability of stable isotopes of nitrogen to distinguish freshwater fish from terrestrial food sources in an archaeological context and numerous subsequent studies have incorporated both stable carbon and nitrogen isotope data to reveal past dietary adaptations in which human groups relied on marine and/or freshwater resources (e.g., Dufour et al., 1999; Polet and Katzenberg, 2003; Richards et al., 2005; Muldner and Richards, 2005; Grupe et al., 2009). In the Cis-Baikal region of Siberia, Russian Federation, stable isotope methods have proven to be useful in determining the relative reliance on terrestrial mammals versus freshwater fish and seals, since these food sources vary in their stable carbon and nitrogen isotope signatures (Katzenberg and Weber, 1999; Katzenberg et al., 2010). Our initial studies of the food resources from Lake Baikal (Katzenberg and Weber, 1999) illustrated the wide range of variation in the stable isotope ratios of freshwater fish in this complex lake environment.

In this study we present stable isotope data on a large variety of fauna and additional human samples with a focus on one region of Cis-Baikal, the Little Sea (Maloye More) over a long time span of 4000 years (from 8000 to 4000 cal B P). There is evidence for variation in cultural practices (Weber et al., 2002; Bazaliiskii, 2010; Goriunova and Novikov, 2010) and the genetic composition of populations across this time span (Mooder et al., 2010) so it is of interest to determine whether or not there were also differences in dietary adaptations.

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[*] Corresponding author. Tel.: +1 403 220 3334; fax: +1 403 282 9567.
E-mail addresses: katzenbe@ucalgary.ca (M.A. Katzenberg), hugh.mckenzie@gmail.com (H.G. McKenzie), robert.losey@ualberta.ca (R.J. Losey), as122@yandex.ru (O.I. Goriunova), aweber@ualberta.ca (A. Weber).

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1.1. Background to the region

Neolithic and Early Bronze Age hunter-fisher-gatherers of southern Siberia created mortuary sites of varying sizes around the Little Sea region of Lake Baikal. Baikal is the deepest lake in the world, occupying a tectonic rift in southern Siberia. The Little Sea, located between the western shore and Olkhon Island, is one of the shallower parts of the lake, and provides access to shallow bays, small rivers (e.g., Kulenga, Sarma and Anga rivers), ample fresh water and food resources from both terrestrial and aquatic habitats for prehistoric human groups. As such, it was a likely gathering place for past people. This paper focuses on dietary adaptations of individuals interred in the mortuary site, Kurma XI, with comparisons to other mortuary sites on the western shore of the lake and the western shore of Olkhon Island, bordering on the Little Sea (Fig. 1). Specifically, the paper presents data on stable isotopes of carbon and nitrogen from preserved bone collagen, and stable isotopes of carbon from preserved bone apatite from individuals buried at Kurma XI, which includes both Early Neolithic and Early Bronze Age burials. These data are discussed with reference to other evidence for diet and subsistence. In particular, stable isotope data from fauna available in the region provide the basis for the interpretation of human stable isotope data. We include data from numerous samples of faunal bone, both modern and prehistoric. Recent zooarchaeological research in the area adds an important perspective (Losey et al., 2008; Nomokonova et al., 2009). Earlier interpretations of subsistence in the region suggest varying emphasis on fish and game over both time and space. For example, Okladnikov (1959) suggested that the earlier Kitoi culture (Early Neolithic) placed greater emphasis on fishing, while the later Glazkovo (Early Bronze Age) culture placed greater emphasis on hunting, based on the abundance of fishing equipment in Kitoi graves and the relative paucity of such equipment in later dating graves. Ethnographic evidence from hunter-fisher-gatherers living in similar habitats suggests a seasonal round with emphasis on hunting during the winter and fishing during the summer (e.g., Golubchikova and Khvtisiashvili, 2005; Ziker, 2002). Stable isotope evidence can address this discrepancy since terrestrial and lake resources differ in their stable nitrogen isotope ratios, and some fish are distinctive with respect to their stable carbon isotope ratios

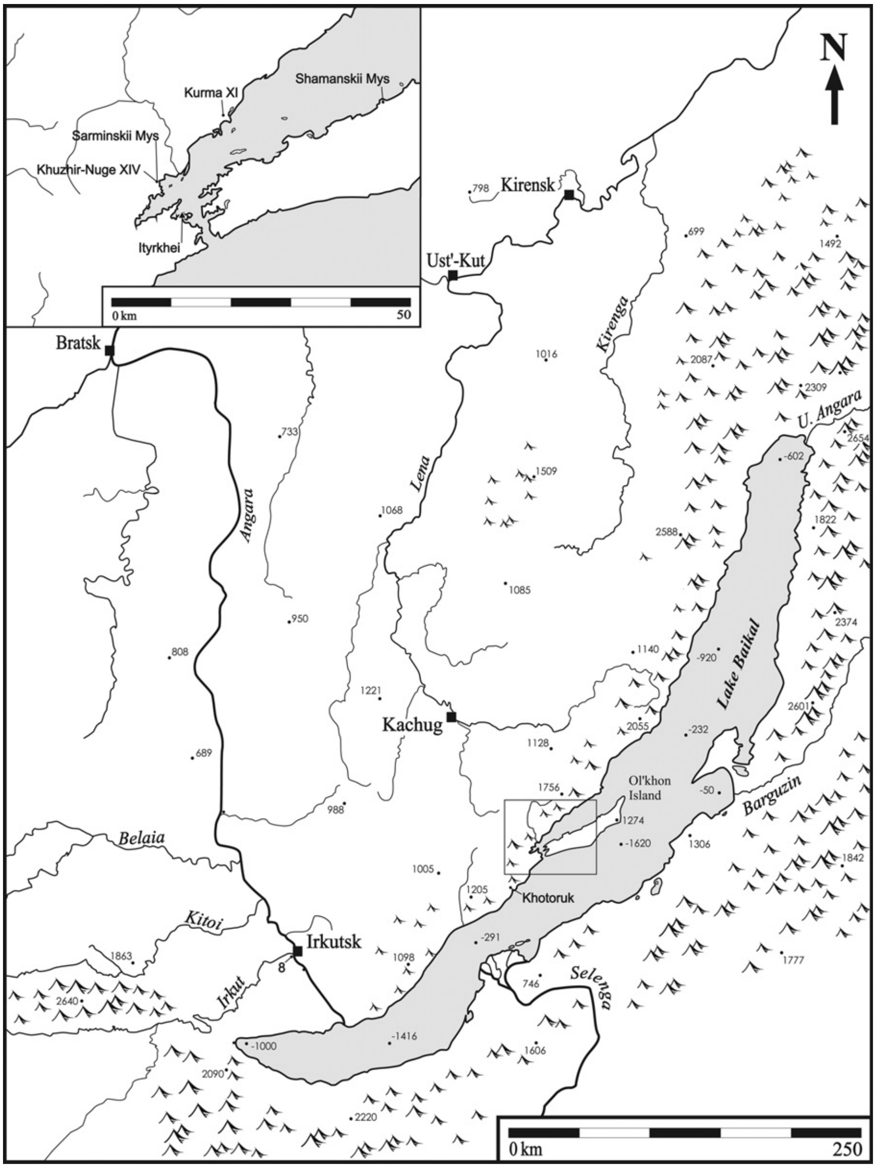

Fig. 1. Map of Lake Baikal and the surrounding region, showing the location of sites mentioned in the text. Inset shows the Little Sea and Olkhon Island with site locations.

(Katzenberg and Weber, 1999). Previous paleodiet studies from contemporaneous sites in the region also suggest a seasonal round, including both terrestrial and aquatic resources (Katzenberg et al., 2009, 2010).

1.2. Background to the site of Kurma XI

The cemetery, Kurma XI was excavated in 1994 by Kharinskii and Sosnovskaia (Sosnovskaia, 1996) and, in 2002 and 2003, by members of the Baikal Archaeological Project under the direction of Drs. Olga Goriunova and Andrzej Weber. The site yielded the skeletal remains of 22 individuals from 26 graves and dates from approximately 6500 B.P. to 4000 B P (Fig. 2). Burials from both Early Neolithic (3 individuals ranging in age from 6500 to 5800 B.P.) and Early Bronze Age (19 individuals clustered around 4000 B.P.) contexts were excavated. Radiocarbon dates were obtained for all 22 individuals (Metcalf, 2006). The youngest individual was aged 16–18 years of age at death and one other individual was also aged in the late teens. Eleven individuals were in their 20s or early 30s, two were in their 30s to 40s and one was aged in the 40s. Five of the 22 individuals could only be aged as “adult” and one as “unknown” due to poor preservation of diagnostic elements or incomplete remains (Lieverse et al., forthcoming). Using the criteria for sex estimation in “Standards for Data Recording” (Buikstra and Ubelaker, 1994) two individuals were estimated to be female, one is a “probable” female, three are male, five are “probable” male and the remaining 11 are indeterminate with respect to sex. According to McKenzie (2006) it appears to be a special use cemetery based on grave inclusions and on the absence of children. It is not possible to tell if the skewed sex ratio is real or if it is a result of incomplete remains and poor preservation that preferentially affect female skeletal remains. Indeed other cemeteries in the region also contain few skeletons that have been determined to be female (Link, 1996). Historically, at least one instance of preferential female infanticide among boreal forest peoples was documented by June Helm in Canada (Helm, 1980) and infanticide has been documented among some Inuit groups (Scrimshaw, 1984), but the antiquity of this practice is unknown. Link (1996:74) discusses preferential female infanticide as a possible explanation for the lack of individuals aged less than six months and the skewed sex ratio of buried individuals in two Cis-Baikal cemeteries along the Angara River and one of its tributaries. Harsh climate and periodic food scarcity may force people to make difficult choices and skewed sex ratios in skeletal samples may provide evidence for the practice.

Stable isotope analysis was carried out in order to characterize dietary adaptations, to compare Early Neolithic and Bronze Age individuals within the site, and to compare them with contemporaneous individuals excavated from numerous other sites in the region. Specifically, the stable isotope data from Kurma XI are compared to data from the neighboring site of Khuzhir-Nuge XIV (Katzenberg et al., 2009), which is considerably larger (89 individuals) and, with the exception of one burial, also dates to the Bronze Age (dates cluster around 4000BP, Weber et al., 2005). Both McKenzie (2006) and Metcalf (2006) have noted clear differences between these two cemeteries with respect to spatial organization, demographic profiles, and diversity of mortuary rituals. However, mortuary characteristics of Kurma XI compare well with the east cluster of graves from Khuzhir-Nuge XIV. Those graves were larger and included more grave goods than graves in the other parts of the cemetery (McKenzie, 2006). Stable isotope analysis suggests that individuals buried in the east cluster had diets that included more terrestrial animals relative to aquatic species in comparison to the west and central clusters at KN XIV, although the differences are subtle (Katzenberg et al., 2009). Thus, it was desirable to compare stable isotope data from Kurma XI to data from individuals buried in the east cluster at Khuzhir-Nuge XIV.

1.3. Food resources

The harsh climate near the shore of the Little Sea, in contrast to more sheltered forested areas, makes it unlikely that people would have lived there year-round, yet the existence of numerous

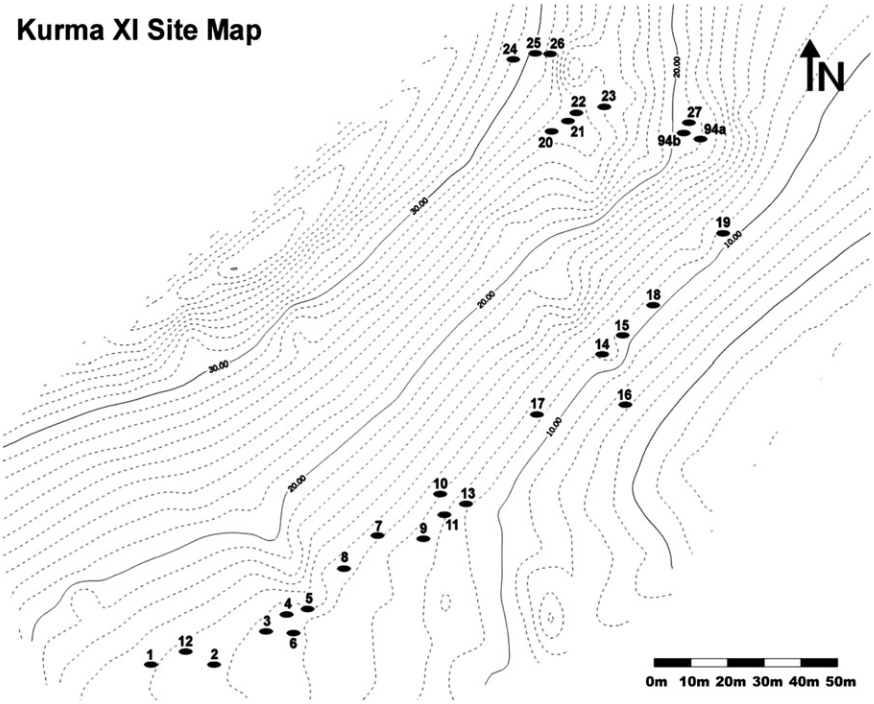

Fig. 2. Detailed site map for Kurma XI, showing the location of individual graves and elevations.

cemeteries indicates regular seasonal occupation, suggesting that these sites were regular stops on an annual round. Predictable resources, such as fish during spawning runs, would encourage seasonal return to specific locations as well as providing opportunities for larger groups of people to come together (Meyer and Thistle, 1995). In particular, several rivers that enter the Little Sea near mortuary sites have runs of black grayling (*Thymallus arcticus baicalensis*), and omul (*Coregonus autumnalis*), and arctic grayling (*Thymallus arcticus arcticus*) are residents in some streams (Sideleva, 2003; Kozhova and Izmest'eva, 1998; Levin, 1897). Abundant archaeological evidence for seal hunting (*Phoca siberica*) is found in sites primarily from the open coastline of the central portion of the lake (on Olkhon's east coast, and the adjacent portions of the main coastline)—but not the shorelines of the Little Sea itself. Recent work by Nomokonova et al. (2010) as well as earlier work by Weber et al. (1998) suggests that seal hunting occurred in spring.

Two major sources of variation (terrestrial and aquatic food webs), with respect to stable isotopes of carbon and nitrogen, are found in this region. Terrestrial mammals, including moose, red deer and roe deer, are characterized by relatively low δ^{15}N and δ^{13}C, reflecting their herbivorous diets based on C_3 plants. The nerpa (Baikal seal) is the only economically important aquatic mammal and it is considerably enriched in the heavier isotope of nitrogen since it is near the top of the aquatic food web, but is similar to terrestrial mammals with respect to δ^{13}C. The greatest variation in terms of stable carbon isotope ratios is seen in the numerous fish species. Ecological studies of the lake indicate there is a 21.5‰ range of variation in δ^{13}C at the base of the aquatic food web (Kiyashko et al., 1998), thus a great deal of variation occurs in fish with respect to habitat within the lake as well as diet. There have been numerous studies of the stable isotope ecology of lakes worldwide (e.g., Hecky and Hesslein, 1995; France, 1995; Beaudoin et al., 2001) including Lake Baikal (Kiyashko et al., 1998; Ogawa et al., 2000; Yoshii et al., 1999). Unlike terrestrial food webs where the source of carbon is atmospheric $C0_2$, there are numerous sources of carbon in freshwater lakes and these sources vary in their carbon isotope ratios. In general, organisms occupying the littoral zone of lakes have δ^{13}C values that are enriched in the heavier isotope relative to organisms in the pelagic zone (France, 1995). Fish vary in their habitats and diets and as a result they exhibit variable stable carbon isotope values, as illustrated by the differences within species from different areas of the lake and surrounding rivers.

2. Materials and methods

2.1. Human samples

Bone samples (fragments of ribs or long bones) were obtained from all 22 individuals from Kurma XI for stable isotope analysis. Bone samples from the smaller sites in the Little Sea region (Shamanskii Mys $n = 9$, Sarminskii Mys $n = 10$; and Khotoruk $n = 1$) were also collected with some previously reported (Weber et al., 2002) and some new to this study. Stable isotope results for Khuzhir-Nuge XIV were reported previously (Katzenberg et al., 2009).

2.2. Faunal samples

Lake Baikal has a highly varied fauna including some species that are unique (Kozhov, 1963). In order to better understand the sources of stable isotope variation found among the prehistoric human inhabitants of the region, we collected faunal remains from numerous archaeological sites and from modern contexts beginning in the 1990s (Katzenberg and Weber, 1999; Weber et al., 2002). We have continued to add samples but at present, all fish are from a modern context. Most were purchased from local fishermen or collected by project members during fieldwork at the Khuzhir-Nuge XIV mortuary site, and some were purchased from local street markets. Bone samples were obtained for stable isotope analysis.

2.3. Sample preparation

2.3.1. Collagen

Collagen was isolated following the method of Sealy (1986). Bones were soaked in 1% HCl with repeated changes of acid until all mineral was removed. Remaining material was then soaked in 0.125 M NaOH for 20 h in order to remove any humic contaminants from the burial environment. Remaining collagen was freeze-dried, then ground in a Spex™ freezer mill. Approximately 5 mg of collagen was weighed into tin boats and analyzed on a Finnigan Mat Delta + mass spectrometer interfaced with a Carlo Erba gas analyzer in the Isotope Science Laboratory at the University of Calgary. Precision for both δ^{13}C and δ^{15}N is ±0.2‰. Collagen integrity is evaluated from %C, %N and the atomic C/N. Precision is ±2% for C and N. Samples from the small sites were similarly prepared but were run on an earlier instrument (Tracer Mat mass spectrometer). C/N ratios were calculated from peak areas of CO_2 and N_2 but %C and %N data were not included in the output. Some of the faunal samples analyzed early in the project were also run on that instrument so %C and %N data are provided for samples run on the later instrument. Lipids were removed from modern faunal samples using 1:2 solution of chloroform and methanol (Bligh and Dyer, 1959).

2.3.2. Carbonate apatite

Carbonate was isolated from bone samples following a slight modification of the method described by Lee-Thorp (1989). Ground bone (100–500 mg) was soaked in sodium hypochlorite to remove organic matter. Dilute acetic acid (0.1 M) was used to remove recently deposited carbonate. Rinsed and dried samples were analyzed in the Institute of Geology and Mineralogy, University of Erlangen under the direction of Dr. Michael Joachimski. There, carbonate powders were reacted with 100% phosphoric acid at 75 °C (Wachter and Hayes, 1985) using a Kiel III online carbonate preparation line connected to a ThermoFinnigan 252 mass spectrometer. Reproducibility of replicate analyses of laboratory standards (IAEA C01 and IAEA C09) is better than ± 0.03‰. Fourier transform infrared spectroscopy (FTIR) scans were carried out on all samples from Kurma XI in order to test for diagenetic alteration of bone mineral. Approximately 2 mg of carbonate powder was ground with 200 mg KBr then pressed into a pellet and analyzed in the Department of Chemistry, University of Calgary. Crystallinity index and carbonate content were determined following the methods described by Wright and Schwarcz (1996) and Garvie-Lok et al. (2004). Precision of CI is ±0.2 and for C/P is ±0.01.

3. Results

3.1. Kurma XI

All 22 samples yielded collagen of sufficient quality to obtain stable isotope data for both carbon and nitrogen, and stable carbon isotope data also were obtained from bone carbonate for all 22 samples. One sample fell outside the range of 2.9–3.6 for C/N but is just outside at 3.7. Given the ±2% range of error for %C and %N, this sample is included in the analysis. Results are presented in Table 1 and summary data are presented in Table 2. Comparisons were made for the three variables, δ^{13}C collagen, δ^{15}N collagen and δ^{13}C carbonate between Early Neolithic and Bronze Age burials and between burials from the east and west sectors. There are no

Table 1
Stable isotope data and preservation indicators for human burials from Kurma XI.

Collagen									Apatite					
Sample ID	Master ID	Cultural affinity	Sex	Age	δ^{13}C‰PDB	δ^{15}N‰AIR	C/N (atomic)	Yield	δ^{13}C‰PDB	Δd^{13}Ccollagen-apatite	CI	C/P	%C	%N
02.096	KUR_2002.014	Bronze Age	Female	20–29	−19.2	13.2	3.2	16.2	−14.1	5.1	3.82	0.17	42.7	15.6
02.113	KUR_2002.006	Bronze Age	Female	20–29	−18.7	14.9	3.2	5.5	−14.2	4.5	4.81	0.11	42.1	15.3
02.145	KUR_2002.016	Bronze Age	PF	20–30	−19.3	14.3	3.2	11.0	−10.4	8.9	5.07	0.14	43.5	15.8
02.135	KUR_2002.015	Bronze Age	Male	19–21	−19.3	12.7	3.2	13.9	−13.7	5.6	3.40	0.29	43.0	15.8
02.110	KUR_2002.001	Bronze Age	Male	25–35	−19.5	11.5	3.2	10.3	−14.5	5.0	4.83	0.11	43.9	16.0
02.117	KUR_2002.004	Bronze Age	Male	35–45	−15.0	17.4	3.2	9.2	−15.1	−0.1	4.20	0.13	43.9	16.0
02.101	KUR_2002.010	Bronze Age	PM	15–25	−17.2	15.8	3.2	6.4	−12.5	4.8	3.85	0.14	43.5	15.9
03.012	KUR_2003.019	Bronze Age	PM	20–34	−19.4	11.3	3.2	5.6	−14.6	4.8	5.16	0.10	44.6	16.2
02.122	KUR_2002.013	Bronze Age	PM	35–45	−19.2	14.6	3.2	10.0	−14.4	4.8	5.29	0.13	46.1	16.9
03.036	KUR_2003.026	Bronze Age	PM	40–44	−18.2	15.2	3.4	7.1	−14.2	4.0	4.49	0.14	43.0	14.9
03.016	KUR_2003.017	Bronze Age	PM	Adult	−18.3	16.7	3.2	9.7	−13.2	5.2	3.80	0.18	46.1	16.7
03.006	KUR_2003.018	Bronze Age	Unknown	16–18	−18.1	15.0	3.3	9.7	−12.1	6.0	4.18	0.21	43.3	15.5
02.130	KUR_2002.003	Bronze Age	Unknown	20–30	−18.3	15.0	3.2	13.1	−14.1	4.1	4.70	0.11	43.2	15.7
02.141	KUR_2002.005	Bronze Age	Unknown	25–35	−18.4	15.1	3.2	3.8	−12.4	5.9	4.18	0.17	44.2	16.2
02.127	KUR_2002.012	Bronze Age	Unknown	Adult	−19.8	11.7	3.2	11.0	−15.0	4.8	3.76	0.25	42.8	15.5
02.090	KUR_2002.007.01	Bronze Age	Unknown	20–35	−18.4	15.9	3.2	7.4	−13.6	4.8	3.92	0.16	42.7	15.4
02.103	KUR_2002.007.02	Bronze Age	Unknown	Adult	−18.5	14.2	3.2	12.8	−13.3	5.2	4.05	0.16	43.8	15.9
03.041	KUR_2003.025	Bronze Age	Unknown	Adult	−18.8	15.2	3.6	15.7	−15.0	3.8	3.39	0.12	41.2	13.5
02.151	KUR_2002.009	Bronze Age	Unknown	Unknown	−19.7	12.6	3.2	12.3	−13.6	6.1	3.63	0.16	43.7	15.9
03.022	KUR_2003.021	Early Neolithic	Unknown	20–34	−17.8	15.9	3.7	2.8	−13.6	4.2	4.90	0.12	41.2	13.0
03.027	KUR_2003.022	Early Neolithic	Unknown	20–34	−19.0	12.0	3.3	8.2	−13.8	5.3	4.43	0.15	43.2	15.2
03.033	KUR_2003.024	Early Neolithic	Unknown	Adult	−18.0	15.2	3.5	5.9	−13.4	4.6	4.75	0.12	42.7	14.2

statistically significant differences between burials dated to the Early Bronze Age and those dated to the Early Neolithic. Nor are there statistically significant differences between the southwestern and northeastern sectors of burials. There is a strong positive correlation between δ^{13}C and δ^{15}N from collagen ($r = 0.786$; see Fig. 3) however there is no significant correlation between δ^{13}C for collagen and carbonate (correlation coefficient = −0.019; Fig. 4). Similarly we found no correlation between δ^{13}C for collagen and carbonate at the neighboring site of Khuzhir-Nuge XIV (Katzenberg et al., 2009). There is no correlation between the crystallinity index and δ^{13}C of carbonate ($r = 0.082$). There is one outlier evident in both Figs. 3 and 4, burial 4 (KUR_2002.004), with the highest δ^{13}C at −15, the highest δ^{15}N at 17.4 and the lowest spacing between δ^{13}C of collagen and δ^{13}C of carbonate at −0.1. There is no evidence from mortuary customs including burial placement and grave inclusions that suggests anything unusual about this individual.

3.2. *Other human burials from the Little Sea region*

Stable isotope data from Kurma XI are provided along with data from other sites in the Little Sea region of Lake Baikal for comparison (Tables 2 and 3). These sites date from the Early Neolithic (one sample from Khotoruk and one sample from Shamanskii Mys), Late Neolithic (Sarminskii Mys) and Bronze Age (KN XIV, Sarminskii Mys and Shamanskii Mys). Some of these data were previously published (Weber et al., 2002) and are so noted (Table 3), while others are first presented herein. The Late Neolithic burials from Sarminskii Mys have slightly higher δ^{13}C values (for both collagen and

Table 2
Summary statistics (sample size, and means) for stable isotope data from Kurma XI and other sites from the Little Sea region.

	Collagen					Bone apatite		
	n	δ^{13}C‰PDB	s.d.	δ^{15}N‰AIR	s.d.	δ^{13}C‰PDB	s.d.	Δd^{13}C collagen-apatite
Kurma XI (all)	22	−18.5	1.0	14.3	1.7	−13.7	1.1	4.9
Kurma XI (BA)	19	−18.6	1.1	14.3	1.7	−13.7	1.2	4.9
Kurma XI (EN)	3	−18.3	0.7	14.4	2.1	−13.6	0.2	4.7
Bronze Age								
KN XIV (all)[a]	73	−18.6	0.9	13.7	1.6	−13.5	1.3	5.1
KN XIV (west)[b]	10	−18.1	0.6	15.0	0.9	−13.1	1.7	5.0
KN XIV (central)[c]	34	−18.5	1.0	13.7	1.6	−13.3	1.3	5.2
KN XIV (east)	19	−18.9	0.7	12.9	1.6	−13.7	1.1	5.2
Sarminskii Mys	5	−18.7	0.6	14.2	1.8	−13.9	0.7	4.8
Shamanskii Mys[d]	6	−18.3	0.5	14.8	1.1	−14.0	0.5	4.3
Late Neolithic								
Sarminskii Mys	5	−17.9	0.5	14.8	2.3	−12.8	0.7	5.1
Shamanskii Mys	1	−16.9		15.9				
Early Neolithic								
Khotoruk	1	−17.0		14.1		−13.6		3.4
Shamanskii Mys[e]	2	−18.3		13.8		−14.6		3.7

Data for Khuzhir-Nuge XIV are from Katzenberg et al. (2009).
[a] sample size for ’δ15N is 72 (2–3 yr old not included) and for carbonate, 81.
[b] individuals aged less than 8 years not included.
[c] four infants/young children excluded.
[d] $n = 5$ for apatite.
[e] $n = 1$ for apatite.

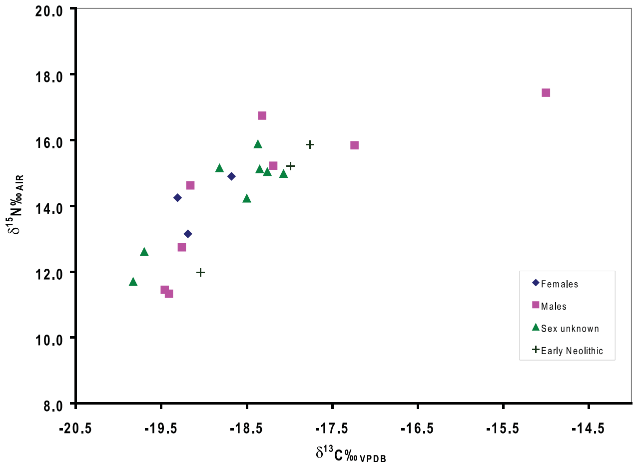

Fig. 3. Plot of δ^{13}C and δ^{15}N values from bone collagen of individuals buried in the Kurma XI mortuary site.

apatite) as well as slightly higher δ^{15}N values in comparison to the other sites (except Khotoruk with a sample size of one). Otherwise, the comparative data show little change in diet over time, however the summary statistics do gloss over some variation that was noted between burial clusters at the site of Khuzhir-Nuge XIV (Katzenberg et al., 2009). Specifically, individuals buried in the eastern cluster where graves were larger and contained more grave inclusions had statistically significantly lower δ^{15}N values in comparison to individuals from the western and central clusters ($F = 6.453$; $p = 0.003$; in Table 3, Katzenberg et al., 2009:669). Stable isotope data from Bronze Age burials from Kurma XI were compared to stable isotope data from burials in the west, central and east clusters at Khuzhir-Nuge XIV. According to McKenzie, 2010, the mortuary characteristics of Kurma XI are most similar to the east cluster of Khuzhir-Nuge XIV. Results of an analysis of variance show no significant differences between the Bronze Age burials at Kurma XI and any of the three clusters at Khuzhir-Nuge XIV.

3.3. Faunal samples

Results of stable isotope analysis of faunal bone samples from both prehistoric and modern samples are presented in Table 4. Some samples were published previously in a paper by Weber et al. (2002) and are so indicated. Here we have added additional faunal specimens to species analyzed in our previous work, as well as adding additional species. Not all species analyzed were thought to be a major source of food. Some, such as the Siberian ground squirrels (*Citellus undulatus*) were collected as indicators of the local environments. The δ^{13}C values of the Siberian ground squirrels (as well as the δ^{13}C of other terrestrial mammals) indicates the absence of any C_4 plants that might contribute to higher δ^{13}C values in humans through consumption of terrestrial mammals. Thus it is clear that any elevated δ^{13}C among humans is related to consumption of some of the fish species that inhabit the shallower regions of the lake and/or consumption of migratory waterfowl and/or their eggs. Other species, such as the lynx, provide ecological information about specific diets. Lynx are true carnivores, feeding on terrestrial animals and their δ^{15}N values average 7.1‰. Lynx may be taken for furs and food, as has been documented for the Alaskan Ingalik (Heffley, 1981:142, citing Osgood, 1958:281) but they were unlikely to have been a major food source. The fact that the δ^{15}N values of lynx and ground squirrels overlap indicates the variable nature of nitrogen isotope fractionation which does not strictly follow trophic levels. Some of the observed variation in δ^{15}N of *C. undulatus* appears to be linked to location, with specimens from the region of the Ida River exhibiting higher δ^{15}N values. Another possible variable is hibernation and the accompanying seasonal fluctuations in body composition. During hibernation, weight loss in arctic ground squirrels is largely due to utilization of fat, but protein is also used to provide energy (Galster and Morrison, 1976) and this may result in reutilization of nitrogen already depleted in the lighter isotope. Elevated δ^{15}N values are also seen in hares, which may be related to caecotrophy (consumption of soft faeces) which has been shown to significantly enhance nitrogen availability including bacterial protein from the caecum (Pehrson, 1983). Other factors such as seasonal fluctuations in diet, precipitation and soil conditions, as discussed in a recent study of North American hares from the arid Great Basin (Ugan and Coltrain, 2011) may also contribute to the observed variation in δ^{15}N.

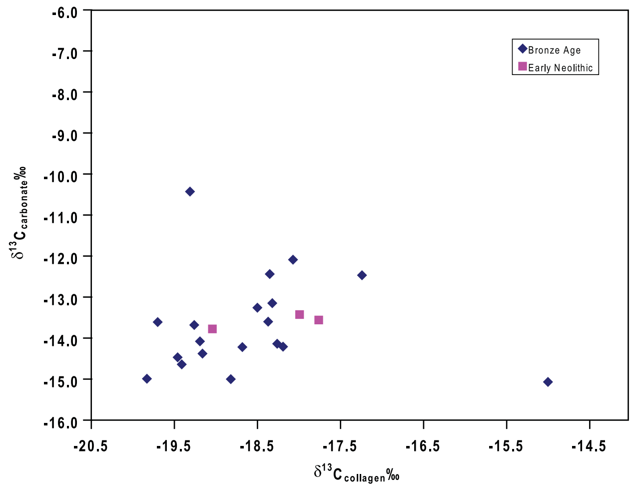

Fig. 4. Plot of δ^{13}C from bone carbonate and bone collagen from individuals buried in the Kurma XI mortuary site.

Fig. 5 graphically illustrates much, but not all of the data presented in Table 4. All mammals with the exception of hare and lynx are from prehistoric contexts. All fish, hare and lynx are modern. For modern mammals, it is necessary to correct for the industrial isotope effect (also known as the Suess effect). Due to the widespread burning of fossil fuels, modern atmospheric CO_2 is approximately 1.2‰ lower (less enriched in the heavier isotope) than preindustrial levels (Boutton, 1991). Since the source of carbon in the lake is from a wide range of sources this effect is probably dampened somewhat. The only aquatic species for which we have both prehistoric and modern samples is the Baikal seal. For prehistoric seals ($n = 10$), mean δ^{13}C is -22.5 ± 0.8‰ and for modern seals ($n = 9$), mean is -21.3 ± 1.6‰. In contrast, prehistoric moose ($n = 2$) mean δ^{13}C is -19.1‰ and modern moose ($n = 6$) mean δ^{13}C is -21.0‰; prehistoric roe deer ($n = 9$), mean δ^{13}C is -20.2 ± 0.6‰ and modern roe deer ($n = 30$), mean δ^{13}C is -21.7 ± 1.3‰. Prehistoric red deer ($n = 9$) mean δ^{13}C is -19.2 ± 0.3‰ and modern red deer ($n = 21$) mean δ^{13}C is -22.0 ± 1.1‰. Table 5 presents these data along with the mean differences, illustrating that for all three terrestrial species, modern δ^{13}C is 1.5–2.8‰ more depleted in the heavier isotope of carbon while for seals, modern δ^{13}C is enriched by 1.2‰ when compared to prehistoric species.

Among fish there is considerable variation within species that is related to habitat. The variation in δ^{13}C exhibited in organisms living in large, deep lakes with varied habitats (described by Katzenberg and Weber, 1999 and references therein, e.g., Hecky and Hesslein, 1995) is not seen in rivers due to the constant mixing in the latter. In Fig. 5, several fish species are plotted separately based on where they were caught. For example, four perch from the Little

Table 3
Stable isotope data from smaller mortuary sites in the Little Sea region.

Site	Cultural Affinity	Grave	Sex	Age	δ^{13}C collagen	δ^{15}N	C/N	Collagen Yield (%)	δ^{13}C apatite	Reference	%C	%N
Shamanskii Mys	Early Neolithic ?	01-1 (1972)	Female	Adult	−18.3	14.0	3.3	21.1	−14.6	2002[a]		
Shamanskii Mys	Early Neolithic	3 (72)			−18.3	13.7	3.3	10.8			45.5	16.5
Shamanskii Mys	Late Neolithic	76-1-1	Indeterminate	Adult	−16.9	15.9	3.3	16.3			53.0	19.0
Shamanskii Mys	Early Bronze Age	01-1 (1973)	Male	20–40	−17.7	13.7	3.3	23.0	−13.8	2002		
Shamanskii Mys	Early Bronze Age	02-1 (1972)	Male	40–50	−18.4	13.9	3.4	20.7	−14.0	2002		
Shamanskii Mys	Early Bronze Age	02-1(1973)	Female	20–40	−18.8	14.5	3.4	23.2	−14.8	2002		
Shamanskii Mys	Early Bronze Age	03-1 (1973)	Female	Adult	−18.4	14.6	3.2	15.1	−13.7	2002		
Shamanskii Mys	Early Bronze Age	04-1(1973)	Indeterminate	Adult	−18.6	14.9	3.5	16.9	−13.8	2002		
Shamanskii Mys	Bronze Age	Kl. 6 (75), 75-X-1	Male	Adult	−17.7	16.9	3.3	10.6			52	18
Khotoruk	Early Neolithic	03–1	Indeterminate	Adult	−17.0	14.1	3.5	2.4	−13.6	2002		
Sarminskii Mys	Late Neolithic	11 lower		4	−18.9	15.0	3.3	10.4	−9.8			
Sarminskii Mys	Late Neolithic	11-1 upper		6–7	−17.7	16.0	3.5	5.4	−13.5			
Sarminskii Mys	Late Neolithic	11-2 upper	Male	20–35	−18.3	16.4	3.4	15.6	−12.1			
Sarminskii Mys	Late Neolithic	11-3 upper		inf 1	−17.5	16.3	3.4	5.9	−14.0			
Sarminskii Mys	Late Neolithic	11-4 upper	Male?	20–35	−17.6	16.1	3.4	11.0	−13.1			
Sarminskii Mys	Late Neolithic	19–1		14–18	−18.7	15.0	3.5	36.9	−14.3			
Sarminskii Mys	Late Neolithic	19–5	Female	35+	−17.6	15.6	3.4	18.0	−12.9			
Sarminskii Mys	Late Neolithic	24	Male	13–20	−18.7	14.9	3.5	2.6	−12.1			
Sarminskii Mys	Late Neolithic	31 lower		Adult	−17.5	10.8	3.3	15.1	−13.8			
Sarminskii Mys	Bronze Age	9			−18.1	16.1	3.4	3.0	−13.7			
Sarminskii Mys	Bronze Age	12	Female	Adult	−18.1	15.4	3.4	6.2	−14.2			
Sarminskii Mys	Bronze Age	13			−18.7	14.9	3.3	15.5	−14.6			
Sarminskii Mys	Bronze Age	21			−19.5	12.2	3.3	20.9	−14.3			
Sarminskii Mys	Bronze Age	32			−19.0	12.2	3.4	12.8	−12.9			

[a] Shamanskii Mys data reported in Weber et al. (2002) are listed under the alternate site name, Khuzhir.

Table 4
Stable isotope data for all faunal samples analyzed from Cis-Baikal.

Sample ID	Species	C/N	Yield (%)	δ^{13}C	δ^{15}N	%C	%N	Site
Mammals (Archaeological)								
91.054[a]	*Alces alces* (Moose)	3.4	15.9	−19.2	3.7			Tudugu
93.151	*Alces alces* (Moose)	3.1	13.6	−18.9	6.7	44	17	Sagan Zaba, Lr. 3
91.013[a]	*Canis* sp. (other Dog or Wolf sp.)	3.2	20.0	−19.1	9.7			Obkhoi
97.28	*Canis* sp. (other Dog or Wolf sp.)	3.3	8.1	−18.3	13.0			Khuzhir
97.28	*Canis* sp. (other Dog or Wolf sp.)	3.3	20.5	−18.5	12.9			Khuzhir
97.280	*Canis* sp. (other Dog or Wolf sp.)	3.3	6.5	−17.6	13.4	46	16	Khuzhir
97.28	*Canis* sp. (other Dog or Wolf sp.)	3.3	10.9	−17.5	13.1			Khuzhir
97.28	*Canis* sp. (other Dog or Wolf sp.)	3.3	22.1	−18.8	9.8			Khotoruk
97.29	*Canis* sp. (other Dog or Wolf sp.)	3.3	16.0	−19.1	8.7			Sagan Zaba
91.102[a]	*Capreolus capreolus* (Roe deer)	3.5	4.9	−19.4	6.9			Khuzhir
91.107[a]	*Capreolus capreolus* (Roe deer)	3.6	10.7	−19.7	4.6			Khuzhir
93.087[a]	*Capreolus capreolus* (Roe deer)	3.5	11.0	−21.1	4.6			Gorelyi Les, Lr. 6, 1G
93.088[a]	*Capreolus capreolus* (Roe deer)	3.5	19.1	−20.3	6.0			Gorelyi Les, Lr. 6, 1G
93.091[a]	*Capreolus capreolus* (Roe deer)	3.6	13.6	−19.9	5.2			Gorelyi Les, Lr. 6, 1A
93.092[a]	*Capreolus capreolus* (Roe deer)	3.6	9.8	−20.6	5.2			Gorelyi Les, Lr. 6, 1A
93.150[a]	*Capreolus capreolus* (Roe deer)	3.5	26.0	−20.1	6.3			Gorelyi Les, Lr. 6, 1A
93.153[a]	*Capreolus capreolus* (Roe deer)	3.6	12.6	−20.0	4.2			Sagan Zaba, Lr. 4
SZ 007	*Capreolus capreolus* (Roe deer)	3.2	11.5	−21.0	7.3	44	16	Sagan Zaba
91.104[a]	*Cervus elaphus* (Red Deer)	3.5	12.8	−18.6	5.0			Khuzhir
91.108[a]	*Cervus elaphus* (Red Deer)	3.4	12.0	−19.1	6.6			Khuzhir
93.079[a]	*Cervus elaphus* (Red Deer)	3.7	11.0	−19.6	4.8			Gorelyi Les, Lr. 2
93.080[a]	*Cervus elaphus* (Red Deer)	3.5	20.1	−18.7	4.9			Gorelyi Les, Lr. 5, 1B
93.081[a]	*Cervus elaphus* (Red Deer)	3.4	14.3	−19.1	5.1			Gorelyi Les, Lr. 5A, 1W
93.094[a]	*Cervus elaphus* (Red Deer)	3.6	11.4	−20.2	3.1			Gorelyi Les, Lr. 6, 1A
93.152[a]	*Cervus elaphus* (Red Deer)	3.5	14.2	−18.6	5.7			Sagan Zaba, Lr. 4
SZ 002	*Cervus elaphus* (Red Deer)	3.3	10.4	−19.5	5.2	46	16	Sagan Zaba
SZ003	*Cervus elaphus* (Red Deer)	3.2	9.6	−19.3	5.2	44	16	Sagan Zaba
91.068[a]	*Phoca sibirica* (Baikal Seal)	3.4	16.1	−22.7	15.2			Tyshkine 2, Lr. 9
91.073[a]	*Phoca sibirica* (Baikal Seal)	3.5	18.6	−21.2	13.6			Tyshkine 3, Lr. 8
91.100[a]	*Phoca sibirica* (Baikal Seal)	3.4	16.8	−22.8	14.0			Khuzhir, Se/Is lr bone c
91.106[a]	*Phoca sibirica* (Baikal Seal)	3.5	8.4	−22.9	11.4			Khuzhir
93.023[a]	*Phoca sibirica* (Baikal Seal)	3.5	12.8	−22.2	13.8			Tyshkine 2, Lr. 8b
93.024[a]	*Phoca sibirica* (Baikal Seal)	3.4	16.8	−23.2	15.6			Tyshkine 2, Lr. 8b
93.034[a]	*Phoca sibirica* (Baikal Seal)	3.6	17.5	−21.1	13.7			Tyshkine 3, Lr. 8a
93.035[a]	*Phoca sibirica* (Baikal Seal)	3.5	16.9	−22.2	13.4			Tyshkine 3, Lr. 8a
SZ 001	*Phoca sibirica* (Baikal Seal)	3.3	13.1	−23.0	16.2	46	16	Sagan Zaba
SZ 006	*Phoca sibirica* (Baikal Seal)	3.2	11.7	−23.3	14.9	46	17	Sagan Zaba
SZ 008	*Sus Scrofa* (Wild boar)	3.4	6.1	−19.2	4.3	56	19	Sagan Zaba
Modern mammals								

Table 4 (*continued*)

Sample ID	Species	C/N	Yield (%)	δ^{13}C	δ^{15}N	%C	%N	Site
91.116[a]	*Alces alces* (Moose)	3.3	17.5	−19.9	3.1			Sarminskskaia Pesh.
93.051[a]	*Alces alces* (Moose)	3.4	17.6	−19.9	1.5			Siberia
93.050[a]	*Alces alces* (Moose)	3.5	24.7	−21.8	1.4			Siberia
M 2001.697	*Alces alces* (Moose)	3.2	27.4	−21.8	6.8	47	17	Batchai
M 2001.750	*Alces alces* (Moose)	3.2	17.4	−20.8	1.1	44	16	Batchai
M 2001.777	*Alces alces* (Moose)	3.4	26.2	−21.9	4.1	44	15	Bratsk
95.203	*Canis lupus* (Gray wolf)	3.4	27.4	−20.8	11.8	44	15	Irkutsk oblast
93.058[a]	*Capreolus capreolus* (Roe deer)	3.6	17.0	−20.0	7.8			Siberia
93.057[a]	*Capreolus capreolus* (Roe deer)	3.4	20.8	−20.6	5.4			Siberia
93.059[a]	*Capreolus capreolus* (Roe deer)	3.6	23.3	−21.6	3.6			Siberia
93.060[a]	*Capreolus capreolus* (Roe deer)	3.3	23.0	−20.4	3.6			Siberia
93.061[a]	*Capreolus capreolus* (Roe deer)	3.4	19.6	−20.4	9.7			Siberia
93.062[a]	*Capreolus capreolus* (Roe deer)	3.5	21.3	−22.9	2.6			Irkutsk oblast
M 2001.657	*Capreolus capreolus* (Roe deer)	2.9	15.2	−23.4	4.3	42	17	Batchai
M 2001.658	*Capreolus capreolus* (Roe deer)	3.1	10.8	−21.0	3.6	45	17	Batchai
M 2001.659	*Capreolus capreolus* (Roe deer)	3.1	12.0	−22.5	6.0	43	17	Batchai
M 2001.656	*Capreolus capreolus* (Roe deer)	3.1	14.5	−22.4	7.6	45	17	Batchai
M 2001.687	*Capreolus capreolus* (Roe deer)	2.9	10.7	−23.3	3.6	38	15	Irkutsk
M 2001.726	*Capreolus capreolus* (Roe deer)	3.2	13.2	−21.4	9.1	41	15	Little Sea
M 2001.728	*Capreolus capreolus* (Roe deer)	2.9	13.8	−21.4	7.7	36	14	Little Sea
M 2001.729	*Capreolus capreolus* (Roe deer)	3.2	3.2	−20.6	7.7	39	14	Little Sea
M 2001.785	*Capreolus capreolus* (Roe deer)	3.0	13.9	−21.7	5.1	41	16	Bolshie Koty
M 2001.787	*Capreolus capreolus* (Roe deer)	3.3	14.3	−23.3	4.0	43	15	Bolshie Koty
M 2002.363	*Capreolus capreolus* (Roe deer)	2.9	7.8	−22.5	8.7	40	16	Upper Lena
M 2002.365	*Capreolus capreolus* (Roe deer)	2.9	13.8	−23.8	5.3	39	16	Upper Lena
M 2002.368	*Capreolus capreolus* (Roe deer)	2.9	15.9	−22.9	6.9	40	16	Upper Lena
M 2002.371	*Capreolus capreolus* (Roe deer)	2.9	17.2	−23.3	4.1	40	16	Upper Lena
M 2002.421	*Capreolus capreolus* (Roe deer)	3.1	12.0	−20.4	9.9	43	16	Ida River
M 2002.422	*Capreolus capreolus* (Roe deer)	3.3	11.0	−20.8	9.1	43	15	Ida River
M 2002.423	*Capreolus capreolus* (Roe deer)	3.3	8.5	−21.7	5.0	40	14	Ida River
M 2002.424	*Capreolus capreolus* (Roe deer)	3.3	16.0	−21.3	3.6	43	15	Ida River
M 2002.456	*Capreolus capreolus* (Roe deer)	3.2	12.7	−18.9	10.6	44	16	Little Sea
M 2001.727	*Capreolus capreolus* (Roe deer)	2.8	7.8	−19.4	7.6	34	14	Little Sea
M 2001.786	*Capreolus capreolus* (Roe deer)	2.8	13.9	−23.6	3.3	40	17	Bolshie Koty
M 2002.364	*Capreolus capreolus* (Roe deer)	2.8	15.2	−23.4	9.1	39	16	Upper Lena
M 2002.366	*Capreolus capreolus* (Roe deer)	2.8	10.6	−23.0	5.0	39	16	Upper Lena
M 2002.367	*Capreolus capreolus* (Roe deer)	2.8	14.2	−21.7	5.3	40	17	Upper Lena
93.052[a]	*Cervus elaphus* (Red Deer)	3.5	24.4	−22.1	3.4			Irkutsk oblast
93.053[a]	*Cervus elaphus* (Red Deer)	3.5	24.9	−20.4	3.1			Irkutsk oblast
93.066[a]	*Cervus elaphus* (Red Deer)	3.5	22.5	−22.7	3.1			Irkutsk oblast
93.149[a]	*Cervus elaphus* (Red Deer)	3.3	25.3	−22.1	5.0			Bol'shye Koty, beach
M 1995.198	*Cervus elaphus* (Red Deer)	3.1	8.8	−23.0	3.0	44	17	Baikal
M 1995.199	*Cervus elaphus* (Red Deer)	3.1	11.8	−21.1	2.6	45	17	Irkutskaia
M 2001.735	*Cervus elaphus* (Red Deer)	3.5	11.8	−20.6	7.9	41	14	Little Sea
M 2001.736	*Cervus elaphus* (Red Deer)	3.1	14.4	−19.8	3.6	43	16	Little Sea
M 2001.738	*Cervus elaphus* (Red Deer)	3.2	12.6	−21.5	6.8	47	17	Little Sea
M 2001.739	*Cervus elaphus* (Red Deer)	3.4	11.9	−21.4	6.7	44	15	Little Sea
M 2001.740	*Cervus elaphus* (Red Deer)	3.2	9.1	−21.7	6.5	46	17	Little Sea
M 2001.760	*Cervus elaphus* (Red Deer)	3.5	12.6	−22.3	6.0	42	14	Bratsk
M 2001.773	*Cervus elaphus* (Red Deer)	3.4	20.9	−22.7	4.3	44	15	Bratsk
M 2001.774	*Cervus elaphus* (Red Deer)	3.1	14.3	−23.1	4.3	45	17	Bratsk
M 2001.776	*Cervus elaphus* (Red Deer)	3.2	10.4	−22.5	3.8	42	15	Bratsk
M 2001.779	*Cervus elaphus* (Red Deer)	3.2	15.0	−22.9	3.2	43	16	Bolshie Koty
M 2001.780	*Cervus elaphus* (Red Deer)	3.0	19.3	−23.2	5.6	40	16	Bolshie Koty
M 2001.781	*Cervus elaphus* (Red Deer)	3.4	14.0	−23.5	5.4	44	15	Bolshie Koty
M 2001.782	*Cervus elaphus* (Red Deer)	2.9	5.7	−22.9	2.6	38	15	Bolshie Koty
M 2002.315	*Cervus elaphus* (Red Deer)	3.1	18.8	−22.8	3.4	43	16	South Baikal
M 2001.737	*Cervus elaphus* (Red Deer)	2.9	10.4	−20.3	7.6	42	17	Little Sea
M 2001.699	*Citellus undulatus* (Siberian Ground Squirrel)	3.0	9.9	−22.5	7.8	42	16	Little Sea
M 2001.700	*Citellus undulatus* (Siberian Ground Squirrel)	3.2	17.9	−22.0	7.7	43	16	Little Sea
M 2001.701	*Citellus undulatus* (Siberian Ground Squirrel)	3.1	0.7	−23.0	6.0	41	15	Little Sea
M 2001.702	*Citellus undulatus* (Siberian Ground Squirrel)	3.0	14.3	−21.7	4.8	42	16	Little Sea
M 2002.392	*Citellus undulatus* (Siberian Ground Squirrel)	3.3	16.4	−19.9	4.8	45	16	Kultuk
M 2002.396	*Citellus undulatus* (Siberian Ground Squirrel)	3.1	15.1	−23.2	2.4	37	14	Belaia River
M 2002.414	*Citellus undulatus* (Siberian Ground Squirrel)	3.3	15.9	−23.1	9.8	42	15	Ida River
M 2002.415	*Citellus undulatus* (Siberian Ground Squirrel)	3.0	16.5	−23.5	11.0	39	15	Ida River
M 2002.418	*Citellus undulatus* (Siberian Ground Squirrel)	3.6	4.6	−22.2	9.9	34	11	Ida River
M 2002.397	*Citellus undulatus* (Siberian Ground Squirrel)	2.8	16.1	−24.0	2.7	38	16	Belaia River
M 2002.416	*Citellus undulatus* (Siberian Ground Squirrel)	2.8	12.3	−23.4	10.8	40	17	Ida River
LB 2001.670	*Lepus* sp. (other Hare sp.)	3.3	11.0	−24.2	1.7	45	16	Batchai, Angara
LB 2001.671	*Lepus* sp. (other Hare sp.)	3.2	13.1	−24.7	3.7	43	16	Batchai, Angara
LB 2001.672	*Lepus* sp. (other Hare sp.)	3.2	11.8	−24.4	2.2	45	16	Batchai, Angara
M 2001.676	*Lepus* sp. (other Hare sp.)	3.0	11.3	−23.8	6.9	44	17	Batchai
M 2001.677	*Lepus* sp. (other Hare sp.)	3.1	12.4	−23.7	6.6	45	17	Batchai

(*continued on next page*)

Table 4 (*continued*)

Sample ID	Species	C/N	Yield (%)	δ^{13}C	δ^{15}N	%C	%N	Site
M 2001.688	*Lepus* sp. (other Hare sp.)	3.1	11.1	−23.7	2.6	45	17	Irkutsk
M 2002.384	*Lepus* sp. (other Hare sp.)	3.2	8.3	−25.0	4.0	43	16	Ida
M 2002.438	*Lepus* sp. (other Hare sp.)	3.5	13.6	−19.8	12.1	42	14	Belaia River
M 2002.460	*Lepus* sp. (other Hare sp.)	3.0	5.9	−21.7	15.2	39	15	Bolshie Koty
M 2002.383	*Lepus* sp. (other Hare sp.)	2.8	6.6	−25.7	3.1	38	16	Ida
M 1991.119	*Lynx lynx wrangeli* (Siberian Lynx)	2.8	8.5	−21.4	6.8	33	14	Altai
M 2002.360	*Lynx lynx wrangeli* (Siberian Lynx)	3.0	13.5	−21.9	7.2	41	16	Upper Lena
M 2002.361	*Lynx lynx wrangeli* (Siberian Lynx)	2.8	13.0	−22.4	7.2	39	16	Upper Lena
M 1991.118	*Moschus moschiferus moschiferus* (Musk Deer)	3.1	18.1	−20.0	6.2	43	16	Baikal
M 1995.202	*Moschus moschiferus moschiferus* (Musk Deer)	3.4	13.4	−20.9	5.5	46	16	Irkutsk oblast
M 2001.668	*Moschus moschiferus moschiferus* (Musk Deer)	3.2	21.0	−20.3	6.8	47	17	Batchai
M 2002.359	*Ondatra zibethicus* (Muskrat)	3.3	10.3	−22.5	8.2	43	15	Upper Lena
93.098[a]	*Phoca sibirica* (Baikal Seal)	3.7	21.9	−22.2	15.5			Bol'shye Koty, beach
93.099[a]	*Phoca sibirica* (Baikal Seal)	3.4	38.2	−21.0	13.1			Baikal
93.100[a]	*Phoca sibirica* (Baikal Seal)	3.7	38.5	−20.2	13.8			Baikal
93.102	*Phoca sibirica* (Baikal Seal)	3.3	23.9	−22.8	14.9	48	17	Bol'shye Koty, beach
93.104[a]	*Phoca sibirica* (Baikal Seal)	3.5	38.7	−21.6	13.5			Baikal
M 2000.549	*Phoca sibirica* (Baikal Seal)	3.2	13.0	−22.2	13.4	46	17	Tyshkine
M 2000.550	*Phoca sibirica* (Baikal Seal)	3.3	12.3	−20.9	9.0	48	17	Tyshkine
M 2000.551	*Phoca sibirica* (Baikal Seal)	3.3	8.6	−17.8	9.4	51	18	Tyshkine
M 2001.698	*Phoca sibirica* (Baikal Seal)	2.9	22.1	−22.8	6.1	41	16	Little Sea
M 1991.120	*Rangifer tarandus* (Reindeer)	3.2	20.6	−19.9	1.5	44	16	Myrmanskaia
M 2001.690	*Taxidea taxus* (Badger)	3.3	16.5	−20.7	4.9	49	17	Irkutsk
M 2001.751	*Taxidea taxus* (Badger)	3.1	12.7	−20.1	7.7	43	16	Batchai
93.063[a]	*Ursus arctos* (Grizzly Bear)	3.5	23.0	−19.5	4.5			Siberia
93.064[a]	*Ursus arctos* (Grizzly Bear)	3.4	26.5	−20.3	6.5			Siberia
93.065[a]	*Ursus arctos* (Grizzly Bear)	3.6	22.7	−19.7	4.2			Siberia
M 1991.122	*Ursus thibetanus* (Asiatic Black Bear)	3.5	12.7	−20.1	1.5	48	16	Krasnoiars
M 1995.194	*Ursus thibetanus* (Asiatic Black Bear)	3.5	20.3	−17.8	4.6	46	15	Irkutsk oblast
M 2001.757	*Ursus* sp. (other Bear sp.)	3.2	15.7	−19.7	4.9	41	15	Bratsk
M 2001.685	*Vulpes vulpes* (European Red Fox)	3.4	16.3	−23.2	9.2	46	16	Batchai
M 2001.691	*Vulpes vulpes* (European Red Fox)	3.3	25.8	−21.6	13.9	46	17	Bolshie Koty
Fish (modern)								
98.01	*Acipenser baerii baicalensis* (Baikal Sturgeon)	3.6	0.6	−22.9	14.6	48	15	Baikal-Ostroumov
98.01	*Acipenser baerii baicalensis* (Baikal Sturgeon)	3.3	12.3	−22.3	14.1			Baikal-Ostroumov
95.223[a]	*Brachymystax lenok* (Lenok)	3.6	nd	−13.9	11.5			Bol'shie Koty
95.224[a]	*Brachymystax lenok* (Lenok)	4.2	11.0	−15.2	11.7			Bol'shie Koty
95.225[a]	*Brachymystax lenok* (Lenok)	2.9	7.1	−13.3	11.0			Bol'shie Koty
95.226[a]	*Brachymystax lenok* (Lenok)	4.0	9.9	−14.5	10.2			Bol'shie Koty
M 2001.752	*Brachymystax lenok* (Lenok)	3.5	7.6	−15.6	13.7	45	15	Angarsk
M 2002.352	*Brachymystax lenok* (Lenok)	3.1	8.4	−26.7	11.5	42	16	Upper Lena
M 2002.351	*Brachymystax lenok* (Lenok)	3.0	13.7	−27.0	10.8	41	16	Upper Lena
M 2002.353	*Brachymystax lenok* (Lenok)	2.8	16.8	−26.5	11.9	39	16	Upper Lena
95.230[a]	*Carassius auratus* (Carp)	3.3	24.5	−21.4	7.3			Bol'shie Koty
LB 2002.441	*Carassius gibelio* (Prussian Carp)	3.3	0.5	−24.1	7.8	45	16	Ida
LB 2002.443	*Carassius gibelio* (Prussian Carp)	3.6	2.4	−23.2	10.3	46	15	Ida
95.216[a]	*Coregonus autumnalis migratorius* (Omul)	3.2	12.8	−24.0	10.8			Bol'shie Koty
95.217[a]	*Coregonus autumnalis migratorius* (Omul)	3.6	nd	−24.9	11.9			Bol'shie Koty
95.218[a]	*Coregonus autumnalis migratorius* (Omul)	3.2	nd	−24.7	11.0			Bol'shie Koty
97.39	*Coregonus autumnalis migratorius* (Omul)	3.3	14.3	−18.9	9.3			Little Sea
97.4	*Coregonus autumnalis migratorius* (Omul)	3.3	10.7	−14.0	9.2			Little Sea
M 2001.709	*Coregonus autumnalis migratorius* (Omul)	3.4	11.1	−15.9	9.4	43	15	Little Sea
M 2001.710	*Coregonus autumnalis migratorius* (Omul)	3.0	12.4	−16.2	9.5	43	17	Little sea
M 2001.749	*Coregonus autumnalis migratorius* (Omul)	3.1	9.0	−22.5	10.6	43	16	Baikal
M 2001.763	*Coregonus autumnalis migratorius* (Omul)	3.0	11.8	−21.8	10.7	41	16	Bratsk
M 2001.764	*Coregonus autumnalis migratorius* (Omul)	3.0	15.3	−24.0	11.6	41	16	Bratsk
M 2001.770	*Coregonus autumnalis migratorius* (Omul)	2.8	13.7	−23.3	11.0	39	16	Bratsk
97.08	*Coregonus laveretus* (European Whitefish)	3.3	18.9	−17.5	12.6			Khuzhir-Nuge
97.088	*Coregonus laveretus* (European Whitefish)	3.6	3.5	−20.6	12.5	46	15	Little Sea
M 2001.703	*Coregonus* sp. (other Whitefish sp.)	3.0	7.6	−20.5	12.3	39	15	Little Sea
M 2001.704	*Coregonus* sp. (other Whitefish sp.)	2.9	21.3	−16.8	11.3	37	15	Little Sea
M 2001.761	*Coregonus* sp. (other Whitefish sp.)	3.2	7.0	−21.6	8.8	39	14	Bratsk
M 2001.789	*Coregonus* sp. (other Whitefish sp.)	3.1	14.2	−20.4	11.9	43	16	Little Sea
M 2001.790	*Coregonus* sp. (other Whitefish sp.)	3.1	13.7	−18.2	11.1	45	17	Little Sea
M 2001.791	*Coregonus* sp. (other Whitefish sp.)	3.1	13.3	−20.5	11.5	43	16	Little Sea
M 2001.792	*Coregonus* sp. (other Whitefish sp.)	3.1	12.4	−19.2	12.0	43	16	Little Sea
95.219[a]	*Esox lucius* (Northern Pike)	3.6	nd	−19.1	11.9			
95.220[a]	*Esox lucius* (Northern Pike)	3.1	17.0	−19.0	12.0			
97.03	*Esox lucius* (Northern Pike)	3.4	4.2	−19.2	18.5			Angara
97.030	*Esox lucius* (Northern Pike)	3.3	5.0	−20.2	20.6			Angara
97.06	*Esox lucius* (Northern Pike)	3.3	6.8	−16.0	11.6			Little Sea
97.4	*Esox lucius* (Northern Pike)	3.3	6.9	−17.0	11.5			Little Sea
98.005	*Esox lucius* (Northern Pike)	3.4	14.7	−15.7	12.4	44	15	Baikal-Ostroumov
98.01	*Esox lucius* (Northern Pike)	3.5	1.6	−22.8	12.0			Baikal-Ostroumov

Table 4 (*continued*)

Sample ID	Species	C/N	Yield (%)	δ^{13}C	δ^{15}N	%C	%N	Site
M 2001.778	*Esox lucius* (Northern Pike)	3.1	15.2	−22.0	9.8	45	17	Bratsk
M 2002.389	*Esox lucius* (Northern Pike)	3.3	3.0	−24.0	11.2	43	15	Ust-Kut
M 2002.355	*Leuciscus baicalensis* (Dace)	3.4	9.6	−25.6	10.2	46	16	Upper Lena
95.221	*Leuciscus idus*	3.4	12.9	−13.0	9.4			
95.222	*Leuciscus idus*	3.5	11.7	−12.8	9.4			
97.010	*Leuciscus idus*	3.5	22.0	−25.3	12.4			Baikal
97.01	*Leuciscus idus*	3.4	26.3	−25.5	9.8			Baikal
LB 2002.448	*Lota lota* (Burbot)	3.4	2.8	−23.6	12.4	45	16	Ida
M 2002.450	*Lota lota* (Burbot)	3.6	15.0	−21.7	10.6	46	15	Ida River
M 2002.451	*Lota lota* (Burbot)	3.3	11.5	−19.7	13.6	42	15	Ida River
95.227[a]	*Perca fluviatilis* (European Perch)	2.8	17.3	−20.5	12.2			
95.228[a]	*Perca fluviatilis* (European Perch)	2.8	13.0	−21.5	11.5			
97.02	*Perca fluviatilis* (European Perch)	3.5	19.6	−25.8	10.6			Baikal
97.02	*Perca fluviatilis* (European Perch)	3.5	19.2	−26.0	10.0			Baikal
97.020	*Perca fluviatilis* (European Perch)	3.6	21.9	−16.0	11.6	34	11	Baikal
98.01	*Perca fluviatilis* (European Perch)	3.5	14.8	−11.3	10.6			Baikal-Ostroumov
98.01	*Perca fluviatilis* (European Perch)	3.6	16.7	−9.6	10.2			Baikal-Ostroumov
98.01	*Perca fluviatilis* (European Perch)	3.4	5.4	−23.6	12.7			Baikal-Ostroumov
M 2000.544	*Perca fluviatilis* (European Perch)	3.4	11.6	−16.3	11.5	45	16	Little Sea
M 2001.720	*Perca fluviatilis* (European Perch)	3.3	9.8	−11.9	10.6	43	15	Little Sea
M 2001.762	*Perca fluviatilis* (European Perch)	3.1	6.6	−25.6	11.4	43	16	Bratsk
M 2001.769	*Perca fluviatilis* (European Perch)	3.4	14.3	−24.9	11.5	46	16	Bratsk
M 2001.772	*Perca fluviatilis* (European Perch)	2.8	7.9	−25.4	11.8	39	16	Bratsk
M 2001.795	*Perca fluviatilis* (European Perch)	3.0	10.0	−13.6	11.3	41	16	Little Sea
M 2001.796	*Perca fluviatilis* (European Perch)	2.8	12.0	−10.6	11.4	40	17	Little Sea
97.023	*Rutilus rutilus lacustris* (Siberian Roach)	3.3	23.1	−23.8	6.9	43	15	Baikal
97.02	*Rutilus rutilus lacustris* (Siberian Roach)	3.6	36.9	−21.2	7.6	45	15	Baikal
97.03	*Rutilus rutilus lacustris* (Siberian Roach)	3.4	18.7	−28.6	6.2			Baikal
97.036	*Rutilus rutilus lacustris* (Siberian Roach)	3.5	22.9	−25.1	7.8	45	15	Baikal
M 2001.756	*Rutilus rutilus lacustris* (Siberian Roach)	3.6	16.5	−16.4	12.0	46	15	Irkutsk
M 2001.759	*Rutilus rutilus lacustris* (Siberian Roach)	3.0	14.9	−25.2	8.4	41	16	Bratsk
M 2001.768	*Rutilus rutilus lacustris* (Siberian Roach)	3.0	9.3	−25.8	8.9	41	16	Bratsk
M 2002.339	*Rutilus rutilus lacustris* (Siberian Roach)	3.1	9.9	−24.1	7.7	42	16	Modern - Ust-Ilimsk
M 2002.340	*Rutilus rutilus lacustris* (Siberian Roach)	3.3	11.6	−24.5	7.5	43	15	Ust-Ilimsk
M 2002.341	*Rutilus rutilus lacustris* (Siberian Roach)	3.2	9.6	−26.6	7.8	47	17	Ust-Ilimsk
M 2001.771	*Rutilus rutilus lacustris* (Siberian Roach)	2.8	13.1	−25.1	9.6	40	17	Bratsk
95.209[a]	*Thymallus arcticus* (grayling)	3.0	7.3	−20.4	13.7			Bol'shie Koty
95.210[a]	*Thymallus arcticus* (grayling)	3.0	7.2	−13.5	9.9			Bol'shie Koty
95.211[a]	*Thymallus arcticus* (grayling)	3.6	6.6	−12.4	9.1			Bol'shie Koty
95.212[a]	*Thymallus arcticus* (grayling)	3.8	6.0	−21.1	10.8			Bol'shie Koty
95.213[a]	*Thymallus arcticus* (grayling)	3.3	5.5	−15.0	10.4			Bol'shie Koty
95.214[a]	*Thymallus arcticus* (grayling)	2.8	6.7	−13.9	10.3			Bol'shie Koty
98.01	*Thymallus arcticus* baicalensis (Baikal Grayling)	3.5	2.6	−23.2	11.0			Baikal-Ostroumov
98.01	*Thymallus arcticus* baicalensis (Baikal Grayling)	3.5	3.1	−22.5	12.0			Baikal-Ostroumov
M 2001.712	*Thymallus arcticus* sp. (other Grayling sp.)	3.2	10.1	−19.7	10.8	45	16	Little Sea
M 2001.713	*Thymallus arcticus* sp. (other Grayling sp.)	3.1	6.2	−12.7	9.5	43	16	Little Sea
M 2001.714	*Thymallus arcticus* sp. (other Grayling sp.)	3.1	7.1	−11.9	10.4	44	16	Little Sea
M 2001.753	*Thymallus arcticus* sp. (other Grayling sp.)	3.4	10.7	−16.4	12.9	46	16	Angarsk
M 2001.754	*Thymallus arcticus* sp. (other Grayling sp.)	3.2	12.2	−17.3	11.7	41	15	Angarsk
M 2001.755	*Thymallus arcticus* sp. (other Grayling sp.)	3.1	13.3	−16.4	12.0	42	16	Angarsk
M 2001.797	*Thymallus arcticus* brevipinnis (White Grayling)	3.0	11.9	−9.9	10.0	44	17	Little Sea
M 2001.798	*Thymallus arcticus* brevipinnis (White Grayling)	3.0	11.1	−10.8	9.9	40	16	Little Sea
M 2001.799	*Thymallus arcticus* brevipinnis (White Grayling)	2.8	12.4	−14.9	11.8	39	16	Little Sea
M 2001.801	*Thymallus arcticus* brevipinnis (White Grayling)	3.0	7.3	−13.0	9.8	42	17	Little Sea
M 2001.802	*Thymallus arcticus* brevipinnis (White Grayling)	3.0	7.5	−11.0	9.7	43	16	Little Sea
M2001.817	*Thymallus arcticus* brevipinnis (White Grayling)	3.1	5.0	−8.1	10.1	32	12	Little Sea
Birds (modern)								
Duck 1	*Anas strepera* (Gray duck)	3.5	18.7	−15.3	14.8	43	14	Angara
Duck 2	*Anas formosa* (Baikal teal)	3.5	19.8	−23.5	19.1	49	16	Angara
97.06	*Larus* sp. (other Herring Gull sp.)	3.4	25.4	−20.2	14.3	42	14	Khuzhir-Nuge XIV
97.06	*Larus* sp. (other Herring Gull sp.)	3.5	28.6	−20.0	14.6	48	16	Khuzhir-Nuge XIV
97.06	*Larus* sp. (other Herring Gull sp.)	3.6	31.8	−20.4	14.4	42	14	Khuzhir-Nuge XIV
97.07	*Larus* sp. (other Herring Gull sp.)	3.6	31.8	−19.6	14.0	48	16	Khuzhir-Nuge XIV
97.4	*Larus* sp. (other Herring Gull sp.)	3.3	21.9	−21.3	14.1			Khuzhir-Nuge XIV
97.4	*Larus* sp. (other Herring Gull sp.)	3.5	18.1	−19.5	13.7			Khuzhir-Nuge
97.06	*Larus* sp. (other Herring Gull sp.)	3.6	23.7	−20.6	13.5			Khuzhir-Nuge
M 2002.455	Sea Gull	3.1	8.3	−20.7	5.4	35	13	Little Sea

[a] indicates samples that were previously published in Weber et al., 2002.

Sea are plotted on the right side of the graph, while four other perch from rivers are plotted on the left side of the graph. Sources of fish specimens include the Little Sea, a site south of the Little Sea on the shore of Lake Baikal called Bolshie Koty (abbreviated BK in Fig. 5, located just northeast of the Angara River), the Upper Lena river and various tributaries of the Angara River (indicated on Fig. 5 as "riverine"). The largest differences occur between areas of shallow water and areas of open water. As is evident in Fig. 5, there tends to

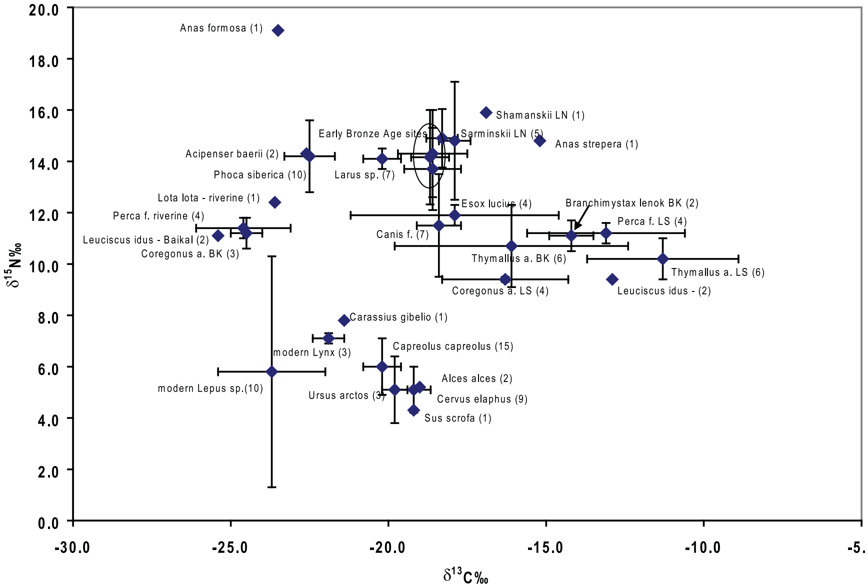

Fig. 5. Plot of δ^{13}C and δ^{15}N of faunal samples from Cis-Baikal. Fish, Lepus and Lynx are from modern contexts. All other fauna are from prehistoric contexts. Human remains from sites discussed in the text are also plotted.

be more variation in δ^{13}C than in δ^{15}N for the fish with more enriched δ^{13}C values. Perch (*Perca fluviatilis*) from riverine and Little Sea sources are plotted separately, as are ide (*Leuciscus idus*). Omul (*Coregonus autumnalis migratorius*) from Bolshie Koty are depleted in the heavier isotope of carbon relative to those from the Little Sea. Lenok (*Brachymystax lenok*) from the Upper Lena River (not plotted in Fig. 5, but presented in Table 4) have depleted δ^{13}C values (−26 to −27‰) while those from Lake Baikal are enriched in the heavier isotope, ^{13}C (−13.9 to −15.6‰). The difference in δ^{13}C between these groups of the same species is over 10‰. Fig. 6 is a plot of δ^{13}C and δ^{15}N values for all individual fish, illustrating the extreme range of values obtained from the region. Most of the fish with δ^{13}C less than −25‰ are from the Lena River and other rivers in the region.

Seagulls (*Larus* sp.) are included not as a food species, but because there are only two samples from waterfowl likely to be used for food (*Anas strepera*, the gray duck and *Anas formosa*, the Baikal teal). There are small marshlands just south of the Little Sea and further south at the source of the Angara River the water remains ice free year-round and is a gathering place for waterfowl. Numerous ethnographic accounts of northern hunter-gatherers report seasonal exploitation of waterfowl (Alekseenko, 1999; Anderson, 1999; Feit, 1999; Asch and Smith, 1999; Ziker, 2002). This may be another predictable food resource that people in the region relied on seasonally and that drew them to particular locations. Modified waterfowl (particularly *Cygnus*, *Grus*, and *Merganser* species) elements are relatively common burial accoutrements in some Baikal mortuary sites, particularly those on the Angara River and south Baikal. Waterfowl can be taken with nets (Bochenski et al., 2009) and eggs are easily collected. Both seagulls and ducks have high δ^{15}N values and the gray duck also has an elevated δ^{13}C value relative to other fauna.

3.4. Isotope results for human burials relative to fauna

The cluster of Early Bronze Age sites, including Kurma XI, are indicated in Fig. 5 by an oval since they are so close together. Fig. 7, plotted on a much smaller scale in order to separate the human groups somewhat, illustrates a lack of patterning with respect to the various temporal components and sites. One Early Neolithic burial from Khotoruk is within the range of variation of other sites for δ^{15}N, but is slightly enriched in the heavier isotope of carbon relative to the other burials. The two Early Neolithic burials from Shamanskii Mys fall close to burials from other sites. One Late Neolithic burial from Shamanskii Mys is within the range of one standard deviation of the other sites for δ^{15}N, but is slightly enriched in the heavier isotope of carbon relative to other burials. The other Late Neolithic site, Sarminskii Mys is similar in its isotope ratios to the Early Bronze Age burials from Shamanskii Mys and the western cluster of graves from Khuzhir-Nuge XIV. Other Early Bronze Age sites are tightly clustered with the exception of the east cluster of graves from Khuzhir-Nuge XIV. This is the group that is statistically significantly different from the other burial clusters from Khuzhir-Nuge XIV, as mentioned in section 3.2.

4. Discussion

4.1. IsoSource modeling

Given the complexity of isotope ratios among the potential foods in the region, the mixing model, IsoSource (Phillips and Gregg, 2003) was used to provide some guidance for interpreting the data. Mean stable isotope values from selected faunal bone data

Table 5
Comparison of prehistoric and modern species for stable carbon isotope ratios.

Species	Prehistoric			Modern			Δ prehistoric-modern
	n	mean δ13C‰	st. dev.	n	mean δ13C‰	st. dev.	
Alces alces (moose)	2	−19.1		6	−21.0		1.9
Capreolus capreolus (roe deer)	9	−20.2	0.6	30	−21.7	1.1	1.5
Cervus elaphus (red deer)	9	−19.2	0.3	21	−22.0	1.1	2.8
Phoca siberica (Baikal seal)	10	−22.5	0.8	9	−21.3	1.6	−1.2

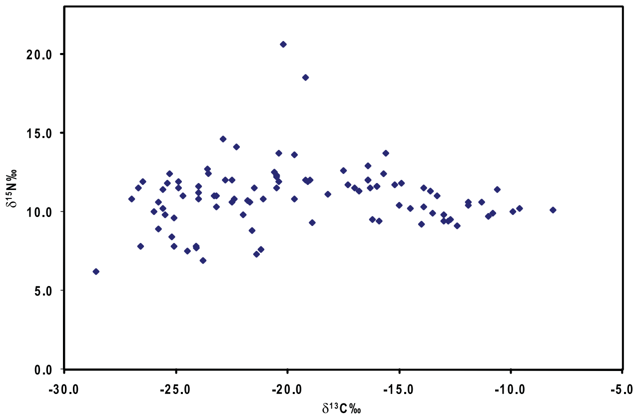

Fig. 6. Plot of δ^{13}C and δ^{15}N of individual fish specimens (from Table 4), showing the great amount of variation in δ^{13}C, and to a lesser extent, δ^{15}N values.

(prehistoric mammals, modern hare and modern fish) were adjusted for offsets between diet and tissue. The sources were selected to represent the range of stable isotope variation from the faunal species analyzed. Red and roe deer are similar to moose, which was, therefore, not included as a separate source. Hares are more depleted in the heavier isotope of carbon, but the mean value for δ^{15}N is only slightly greater than that of deer. Seals are isotopically distinctive, particularly with their high δ^{15}N values. A range of fish was included as sources to represent littoral and pelagic fish. Reference to the dispersion of isotope values shown in Fig. 6 illustrates the difficulty in isolating particular groups of fish. For littoral fish, mean values for δ^{13}C and δ^{15}N from four perch from the Little Sea were used. For grayling, the mean δ^{13}C and δ^{15}N values for all 20 specimens were used in order to represent a likely mix of open and shallow water fish for past diet. Mean stable isotope values for six whitefish (*Coregonus* sp.) from the Little Sea were used. These sources also represent other fauna not specifically labeled in the model. Birds were not included because we have only two waterfowl with quite distinctive isotope ratios. Plants were not included because they are thought to have been a constant though minor part of the diet. By including only animal sources, there is greater consistency in the amounts of carbon and nitrogen contained in each source. By excluding plants and ducks, we are not suggesting that they were not potential foods. The tolerance (0.5) and increment (2%) values are intentionally high because of the numerous uncertainties with respect to diet to tissue spacing and the large range of variation in the faunal isotope data. The δ^{13}C values of faunal species used in the model was determined as follows:

> Roe and red deer: mean δ^{13}C of collagen from prehistoric samples minus 3.7‰ [spacing from animal bone collagen to animal flesh, (Keegan and DeNiro, 1988)] plus 5‰ for the spacing from animal flesh to human bone collagen (Ambrose and Norr, 1993).
>
> Hares: mean δ^{13}C of collagen from modern samples minus 3.7‰ as above, plus 5‰ as above and plus an additional 1.3‰ to correct for the Suess effect (this is normally corrected by 1–1.2‰ however data presented in Table 5 suggest that it should be slightly greater for this sample).
>
> Fish: δ^{13}C of collagen from modern samples minus 3.7‰, plus 5‰ (as for roe and red deer). No adjustment was made for the Suess effect based on the fact that seals, the only aquatic animal for which we have both modern and prehistoric samples, do not exhibit the Suess effect (Table 5).
>
> For δ^{15}N, animal collagen and animal flesh were assumed to be the same; and 3‰ was added for the trophic shift from animal flesh to human bone collagen.

For each site there are thousands of feasible solutions (see Table 6). Presentation by percentiles (1, 50 and 99) shows the range, minus extreme outliers as well as the mid-point for each group (Phillips and Gregg, 2003; Newsome et al., 2004). The objective here is to provide some constraints on possible dietary composition and also to provide some suggestions for possible dietary shifts over time. The first percentiles indicate that with the exception of seals, other food sources may be entirely absent in some of the possible solutions. The 99th percentiles provide upper limits on the proportional representation of these food sources within the context of this particular model. Whitefish (*Coregonus* sp.) and other fish with similar isotope ratios provide the greatest potential source for all groups, followed by seals. Littoral fish, represented by

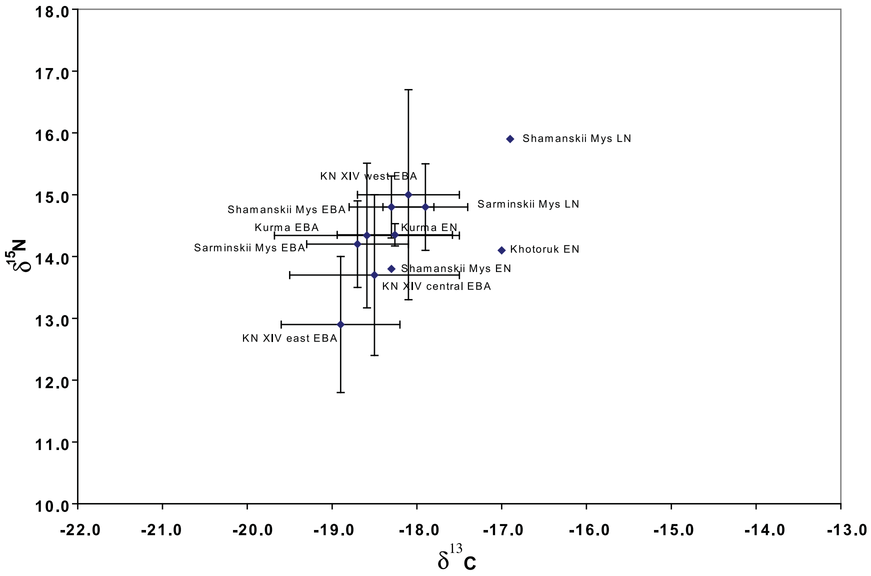

Fig. 7. Plot of δ^{13}C and δ^{15}N from human samples separated by time period. Note that the scale is much smaller than the scale in Fig. 5 so that it is possible to see the individual distributions.

Table 6
IsoSource potential solutions for a six source model for selected sites from the Little Sea region of Lake Baikal.

Sources[b]	Early Neolithic ($n = 3$)			Late Neolithic/Bronze Age ($n = 16$)[a]			Kurma XI			KN XIV west			KN XIV east		
	1%ile	50th %ile	99%ile	1%ile	50th %ile	99%ile	1%ile	50th%ile	99%ile	1%ile	50th %ile	99%ile	1%ile	50th %ile	99%ile
Red and Roe Deer	0	8	28	0	6	25	0	8	24	0	4	25	0	14	45
Hares	0	8	26	0	6	25	0	8	24	0	4	20	0	20	50
Seals	6	32	48	20	44	65	20	44	58	28	48	65	8	30	50
Grayling	0	14	42	0	14	45	0	10	34	0	14	45	0	8	35
Littoral perch	0	10	26	0	10	30	0	8	22	0	12	30	0	4	20
Whitefish	0	20	80	0	16	75	0	18	68	0	12	70	0	16	75
# feasible solutions	138,109			76,619			85,015			48,274			113,434		

Tolerance 0.5; Increment 2%.

[a] Individuals younger than 8 years of age were not included.

[b] Samples and offsets are explained in the text.

perch from the Little Sea and grayling, including those from the Little Sea, western shore near the Angara and from the Angara River (chosen to be more widely representative of potential catches) were significant food sources in the Early Neolithic and Late Neolithic/Early Bronze Age sites. Terrestrial herbivores (deer, hare and others with similar stable isotope ratios) appear to have made a smaller contribution to the diet with the exception of the east cluster of graves from Khuzhir-Nuge XIV.

Phillips and Gregg (2003), Fry (2006) and others caution individuals using IsoSource to focus on the ranges, not the averages. For the purpose of comparing sites and temporal components, we compare the proportional representation of each source at the 50th and 99th percentiles. The Late Bronze Age/Early Neolithic sites, including Kurma XI and the west cluster of Khuzhir-Nuge XIV are very similar, with greater representation of fish and seals and lower representation of terrestrial animals. The small sample of three burials from the Early Neolithic shows less proportional representation of seals and greater representation of fish as represented by the mean isotope ratios of *Coregonus* sp. The east cluster of graves at Khuzhir-Nuge XIV differs from all other groups with respect to the greater proportional representation of terrestrial herbivores.

4.2. *Other sources of dietary information*

Modeling results (Table 6) suggest that for the Early Neolithic Little Sea individuals, fish were the most important source of food, followed by seals. This supports the interpretation first put forward by Okladnikov (1959), which was based on the presence of fishing equipment in Early Neolithic graves. Late Neolithic and Early Bronze Age sites had similar diets, with a greater emphasis on seals and littoral fish (perch and grayling) and whitefish species of secondary importance. For the site of Kurma XI, there is a similar pattern with emphasis on seals, littoral fish and whitefish. At Khuzhir-Nuge XIV, as discussed in our earlier work (Katzenberg et al., 2009) variation in stable isotope data between east and west clusters is most likely due to greater emphasis on terrestrial mammals among individuals buried in the east cluster, but also greater emphasis on seals and littoral fish among individuals buried in the west cluster. This is supported by the results of the model.

For all Little Sea samples it appears that terrestrial mammals were an important component of the diet but not as important as fish and seals. This is consistent with the faunal record, which contains few terrestrial mammals in sites from the Little Sea shoreline during the Middle Holocene (Nomokonova et al., 2009). Zooarachaeological evidence for the Little Sea region from the sites, Ityrkhei (Losey et al., 2008; Nomokonova et al., 2009), and Ulan-Khada indicates considerable reliance on perch and whitefish (Salmonidae). Losey et al. (2008) provide evidence from analysis of fish remains for the use of nets or traps and they refer to evidence for use of nets and traps to capture small fauna such as hare, dating back to the Upper Paleolithic (citing Goebel, 2002:126 in Losey et al., 2008). Seals were an important source of food and were hunted seasonally, based on the faunal evidence (Weber et al., 1998; Nomokonova et al. (2010).

How much stable isotope variation is to be expected within a mortuary "population"? This will vary depending on the amount of variation in the dietary sources and on the length of time the cemetery was in use. Table 4 and Figs. 5 and 6 illustrate the wide range of stable isotope values for potential food sources around the Little Sea. A diet drawn from all terrestrial C_3 based sources will show little variation in bone collagen δ^{13}C values. A diet that includes fish will show greater variation in bone collagen δ^{13}C, based on the wide range of variation both within and between fish species. There is a great potential for variation in δ^{15}N values based on considerable variation between terrestrial and aquatic food webs and within the aquatic food web. If waterfowl meat or eggs are consumed, this introduces yet another source of variation with an isotopic signature more similar to aquatic foods, that is, enriched in the heavier isotope of nitrogen and variable for carbon. Shifting emphasis on fish from different parts of the lake, or variations in the relative consumption of terrestrial herbivores and fish will shift the isotope ratios. Cemeteries used over hundreds of years are likely to show such variation. It is also possible that the variation in stable carbon isotopes illustrates variation in fishing locations which may have been linked to specific human groups including families and lineages.

Burial 4 (KUR_2002.004) is unusual with respect to stable isotope values in comparison to other individuals from Kurma XI (Fig. 3) and from Khuzhir-Nuge XIV. The δ^{13}C from collagen is -15.0‰, the most enriched sample from both sites and the δ^{15}N of 17‰ is similarly the most enriched of all samples from both sites. The δ^{13}C value for apatite is almost the same as that of collagen (-15.1‰) resulting in a collagen-apatite spacing of -0.1, suggesting a diet especially high in lipids, which are depleted in the lighter isotope of carbon and which would be reflected in δ^{13}C of apatite (Lee-Thorp et al., 1989). The individual is an adult male (35–45 years old) from the Early Bronze Age and the grave contained two nephrite axes, 37 red deer canines and 141 bone/antler points (Metcalf, 2006). The isotope data suggest an individual who was consuming a large amount of littoral fish and/or waterfowl while the archaeological evidence from grave inclusions appears to emphasize hunting. While the high δ^{15}N value is consistent with seal consumption, the δ^{13}C would be more negative, thus foods enriched in the heavier isotope of both carbon and nitrogen must have been important in the diet of this individual, relative to others interred in the cemetery. The Early Neolithic site of Lokomotiv, near present day Irkutsk, on the Angara River included individuals with similarly high δ^{13}C values from collagen but not such high δ^{15}N. (Weber et al., 2002).

Overall, there is remarkably little variation over a considerable time span (Early Neolithic to Early Bronze Age) among individuals buried in the smaller mortuary sites around the Little Sea. For $\delta^{13}C$ from collagen the range of variation is only 2.6‰. It is slightly greater for $\delta^{13}C$ from apatite (5‰) and greatest for $\delta^{15}N$ (6.1‰). Adding in the larger site of Kurma XI, the range of variation is slightly greater for $\delta^{13}C$ from collagen (4.8‰) and similar for $\delta^{15}N$ (6.0‰). Contrary to expectations based on similarities in mortuary customs, the diets of individuals buried at Kurma XI are not most like those of individuals buried in the east cluster of graves at Khuzhir-Nuge XIV.

The overall lack of variation among Little Sea sites is not surprising in terms of the sources of stable isotope variation among potential food sources in the Little Sea. The greatest variation is found in the aquatic food web, both among fish species with varying diets and habitats and from seals, which are at the top of the food web among lake species. Seal hunting no doubt contributed to the elevated $\delta^{15}N$ values seen in humans and was likely a major reason for returning to the east coast of Olkhon Island. The special importance of seals may ultimately be tied to the creation of cemeteries in the region. Seals are a rich source of protein and fat, hunted from the east coast of the island, primarily in spring when they bask on the ice and thus are most vulnerable to human hunters, and corresponding in time to when terrestrial game is very lean. They also provide fur. Their predictable habits would encourage people to return to areas where they could be hunted on an annual basis. Among the dietary choices of terrestrial mammals, seals and fish, fish were the more dependable source of food over the annual cycle.

Ethnographic evidence from 1926 to 27 Polar Census among the Lake Yessei Yakuts (Argounova-Low, 2009) emphasizes fish as a reliable year-round resource with preservation by pickling – essentially by burying it in the ground until it ferments. Hunting and fishing were both important for this group in the 1920s, but hunting was preferred and individuals who ate only fish were usually the poor. This paper reinforces the notion of a seasonal round with food preferences but the reality of having to eat what is available.

5. Conclusions

Individuals buried at the site of Kurma XI exhibit stable isotope ratios that are consistent with those determined from individuals interred at the larger, contemporaneous, neighboring site of Khuzhir-Nuge XIV, but not with the east cluster of graves from that site. Within the region, there is some variation which can be tied to the wide variation in stable isotope ratios among aquatic species, and between aquatic and terrestrial species, suggesting variation in the use of specific food resources. The rich resources available within the Little Sea, and particularly the seasonal access to the Lake Baikal seal, undoubtedly led to the creation of mortuary sites in prominent locations revisited by people throughout the Neolithic and Bronze Age occupations of this region.

The distinctive differences in the stable carbon isotope ratios of some fish, depending on whether they were caught from the Little Sea, from the more open parts of the lake or from riverine habitats, provides a window into potential preferred fishing locations for people from these Neolithic and Early Bronze Age sites. The use of the mixing model, IsoSource, while providing many possible solutions, indicates that aquatic resources made up a greater proportion of the diet than did terrestrial mammals. The relative stability in diet over the long term is in contrast to other sources of evidence for genetic and cultural change over time.

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