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Subsistence and social change in central Eurasia: stable isotope analysis of populations spanning the Bronze Age transition

Alicia Ventresca Miller [a,b,*], Emma Usmanova [c], Viktor Logvin [d], Saule Kalieva [d], Irina Shevnina [e], Andrei Logvin [e], Alina Kolbina [f], Aleksander Suslov [g], Karen Privat [h], Katherine Haas [a], Michael Rosenmeier [i,j]

[a] University of Pittsburgh, Department of Anthropology, 3302 WWPH, Pittsburgh, PA 15260, USA
[b] Christian-Albrechts-Universität zu Kiel, Human Development in Landscapes, Institute for Prehistoric and Protohistoric Archaeology, Stable Isotope Laboratory, Johanna-Mestorf-Straße 2-6, 24118 Kiel, Germany
[c] Karaganda State University, Saryarka Archaeological Institute, University Street 28, 100012 Karaganda, Kazakhstan
[d] Department of History and Archaeology, Surgut Governmental University, Lenin Prospect 1, 628412 Surgut, Russian Federation
[e] Kostanai State University, A. Baitursynova Street 47, 110000 Kostanai, Kazakhstan
[f] Kostanai Regional History Museum, 115 Altynsarina, 110000 Kostanai, Kazakhstan
[g] Lisakovsk Museum of the History and Culture of the Upper Tobol Region, Microregion 11, House 11, 111200 Lisakovsk, Kazakhstan
[h] University of New South Wales, Electron Microscope Unit, Mark Wainwright Analytical Centre, Kensington, NSW 2052, Australia
[i] University of Pittsburgh, Department of Geology and Planetary Science, 24107 O'Hara St, Pittsburgh, PA 15260, USA
[j] Paul C. Rizzo Associates, Inc., 500 Penn Center Boulevard, Suite 100, Pittsburgh, PA 15235, USA

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A B S T R A C T

At the transition from the Middle (2100–1700 BC) to Late Bronze Age (1700–1400 BC) in the central Eurasian steppe, significant changes occurred in patterns of settlement and mortuary practice. Traditional interpretations link these changes to shifts from semi-settled agro-pastoral communities to more mobile forms of pastoralism. However, correlations between subsistence strategies and shifts in social and ritual practices have been infrequently tested. This paper explores the nature of subsistence economies in two populations from the sites of Bestamak (MBA) and Lisakovsk (LBA) in northern Kazakhstan. Carbon and nitrogen stable isotope analysis of bone collagen was undertaken to understand dietary intake. The close clustering of isotope values indicates homogeneity in subsistence practices for these two communities spanning the transition. Therefore, while changes occurred in social and ritual practice, subsistence regimes stayed relatively uniform at the transition. Results of this research add to previous literature, revealing that dietary intake of pastoral populations in the Eurasian steppe are much more intricate than previously believed.

1. Introduction

While pastoral societies have varied economies, social systems, and mobilities, only recently have scholars began to integrate the variable lifeways of pastoral communities (e.g. Frachetti, 2008a, 2008b; Frachetti et al., 2010; Murphy et al., 2013; Spengler et al., 2013a). In the case of central Eurasia (e.g. northern Kazakhstan, southern Urals) a great deal of attention has focused on sweeping changes that occurred from the Middle (2100–1700 BC) to Late Bronze Age (1700–1400 BC). During the Middle Bronze Age (Sintashta, Petrovka) a combination of nucleated settlements and large populations, of approximately 200–700 individuals, highlight the more sedentary nature of these communities (Gening et al., 1992; Grigor'yev 2000a; Anthony, 2007; Kohl, 2007; Koryakova and Epimakhov, 2007; Hanks, 2009). In contrast, subsequent Late Bronze Age (Andronovo) settlements more commonly consist of smaller communities with similar cultural materials dispersed over a vast area. Numerous authors have interpreted this pattern as evidence of increased interaction and mobility (Evdokimov, 1983;

* Corresponding author. Christian-Albrechts-Universität zu Kiel, Human Development in Landscapes, Institute for Prehistoric and Protohistoric Archaeology, Stable Isotope Laboratory, Johanna-Mestorf-Straße 2-6, 24118 Kiel, Germany.
E-mail address: aventrescamiller@gshdl.uni-kiel.de (A. Ventresca Miller).

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Potemkina, 1983; Habdulina and Zdanovich, 1984; Kuz'mina, 2007; Koryakova and Epimakhov, 2007). Explaining the shift from aggregated to dispersed communities is challenging because the subsistence economies of local communities remain undetermined. This has resulted in models that equate aggregated communities with agro-pastoralism, and the dispersal of these groups as a move towards nomadic pastoralism.

Comparative research on pastoral societies has demonstrated that communities are highly variable in terms of subsistence economies and herding strategies (Khazanov 1978; Cribb, 1991; Chang and Koster, 1994; Leonard and Crawford, 2002; Frachetti, 2008a; Frachetti et al., 2010; Murphy et al., 2013; Spengler et al., 2013a). Furthermore, assumptions that pastoral societies are highly mobile and therefore possess low levels of social complexity have been challenged through the identification of institutionalized social stratification and ranking (Palumbo, 1987; McIntosh, 1999; Di Cosmo, 2002; Kradin, 2002; Chang, 2008). Rather than assume subsistence regimes are predictably related to shifts in mobility and social practice, the nature of subsistence should be treated as one variable among many in reconstructing pastoral societies. Therefore, this paper examines dietary intake at intra- and inter-cemetery scales to investigate if changes in settlement and mortuary practices corresponded with a transition in practices of consumption.

While pastoral societies are now considered in discussions of social complexity, comparative anthropological studies have previously assigned complex social developments only to sedentary agricultural societies with a range of hierarchical forms of social organization. The emergence of social complexity in pastoral groups has subsequently been tied to a reliance on agricultural products or interactions with settled societies (Khazanov 1978, 1984; Dyson-Hudson, 1980; Barfield, 1981). While pastoralists are often defined as those who undertake animal herding as their primary form of subsistence procurement, a number of other strategies linked to variability of within group mobility and agro-pastoralist orientations have been identified (Khazanov 1978; Barfield, 1981, 1993; Cribb, 1991; Chang and Koster, 1994; Frachetti, 2008a). Middle Bronze Age (MBA) sites in the central Eurasian steppe, by virtue of their aggregated nature and seemingly more complex mortuary remains, are posited to have been agro-pastoral (Zdanovich, 1997: 15; Zdanovich and Zdanovich, 2002). The seemingly stable and settled nature of these communities in conjunction with the recovery of sickles has led some researchers to suggest that MBA sites were undertaking horticultural or agricultural subsistence practices as part of a mixed agro-pastoral lifeway (Zdanovich, 1997: 15; Zdanovich and Zdanovich, 2002). In contrast, as communities became more dispersed during the Late Bronze Age (LBA), others have hypothesized that there was a switch to increased mobile pastoralism (Tkacheva, 1999). Yet the relationship between dispersed communities and possible changes in mobility, herd size, and composition is yet another branch of the prehistoric economy that is not well understood (Morales-Muniz and Antipina, 2003; Bendrey, 2011). Improved comprehension of individual and community dietary intake is therefore critical to a better understanding of the broader social and economic processes within central Eurasia.

This paper examines the diet and subsistence practices of two Bronze Age cemetery populations from northern Kazakhstan through stable carbon and nitrogen isotope analyses. The Bestamak (MBA) and Lisakovsk (LBA) sites have sufficient sample sizes and offer an opportunity to compare these contiguous periods and archaeological culture groups within the central Eurasian steppe (Fig. 1). As variability has been suggested for pastoral subsistence regimes, the current study provides direct evidence for prehistoric diet in two communities that span a ritual and social transformation. This approach offers both a micro-regional context (encapsulating several communities), as well as a broader regional context for understanding possible relationships between subsistence strategies and social change in the central Eurasian steppe. Furthermore, differences in the carbon and nitrogen isotopic composition ($\delta^{13}C$ and $\delta^{15}N$) of bone collagen provide a useful technique for determining the dietary practices of humans and animals. This is especially true concerning the roles that terrestrial and freshwater resources, as well as wild and cultivated plants, may have played in consumption practices.

2. Archaeological context

2.1. The cemeteries

The site of Bestamak is located in northern Kazakhstan within Kostanai oblast' (administrative region), and is situated on the right

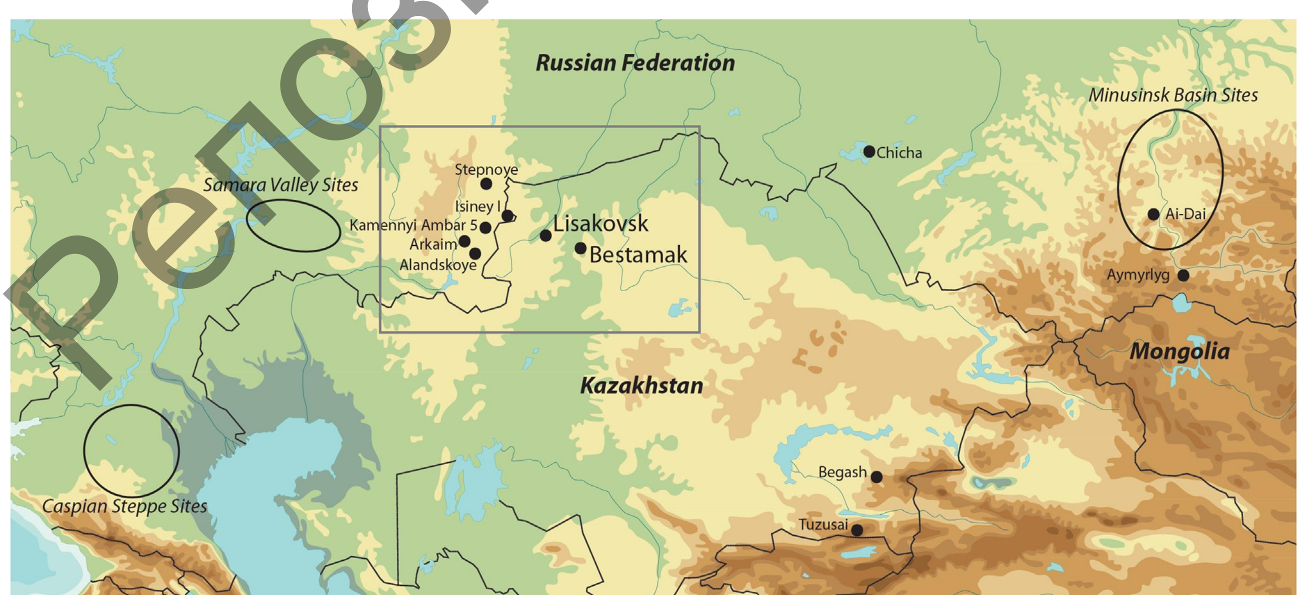

Fig. 1. Location of Eurasian steppe sites and macro-regions discussed in this paper with rectangle indicating the Central Eurasian Steppe.

bank of the Buruktal River (Figs. 2 and 3). The Buruktal is a small tributary of the Ubagan River, which is in turn a tributary of the more substantial Tobol River. The Bestamak site consists of both a settlement and a cemetery which span several periods that indicate occupation from the Neolithic to Middle Ages. Several studies of the mortuary site have been published, which include discussions of status, gender, and the lives of children (Logvin, 2002; Shevnina, 2003; Logvin and Shevnina, 2004, 2008; Kalieva and Logvin, 2009; Logvin et al., 2009; Shevnina and Boroshilova, 2009). However, settlement data for Bestamak has never been officially published, and little information is publicly available. Recent radiocarbon (^{14}C) dating of the site indicates that burials used in this study range in age from approximately 2032–1640 cal BC (Logvin and Ševnina, 2013). Most of the nearly 170 burials excavated at Bestamak have been assigned relative ages based on associated cultural material. Only 60 burials have been linked to the MBA and used in this analysis. These burials include both flat and kurgan (earthen mound) burials (Kalieva and Logvin, 2009) (Fig. 4).

The Lisakovsk site is similarly located in Kostanai oblast' in northern Kazakhstan, approximately 100 km to the west of Bestamak (Fig. 2). Lisakovsk is comprised of a cluster of seven cemeteries (designated as Lisakovsk 1 through 7) and a settlement aligned along a 12 km stretch of the Tobol River floodplain (Usmanova and Logvin, 1998; Usmanova, 2005; Usmanova et al., 2005; Usmanova, 2010). Cemeteries 2 through 5 at Lisakovsk are located on the left bank of the Tobol River. In contrast, cemeteries 1, 6, and 7, as well as the settlement, are located on the Tobol's right bank (Fig. 5). Each of the seven cemeteries is composed of several types of burial construction including kurgans with ditches, stone covered or enclosed burials, and flat burials which lacked stone or earthen markers (Fig. 6). Radiocarbon ages, dendrochronological analysis of burial timbers, and cultural material associations suggest that the cemeteries date to the LBA (Panyushkina et al., 2008). Lisakovsk 1, 3, and 4 have been dated to: 1860–1770 cal BC, 1800–1700 cal BC, and 1770–1680 cal BC (Panyushkina et al., 2008: 465). Settlement excavation data for Lisakovsk has not been published, although a group of pithouses (∼6) were previously excavated (Usmanova pers. comm.). Faunal research for the LBA site of Lisakovsk was undertaken at both the cemetery and settlement (based on NISP) (Outram et al., 2010). At the settlement, the dominant remains are cattle ($n = 1474$, 66%), with sheep/goat also prominent ($n = 625$, 28%), and only a few horse ($n = 89$, 4%). In contrast, within cemetery contexts, there is an abundance of cattle ($n = 223$, 42%), sheep/goat ($n = 160$, 30%), and horse ($n = 133$, 25%), as well as some dog remains ($n = 21$, 4%) (Outram et al., 2010: 121–2). As soil flotation was not used as a recovery method at the Lisakovsk site, the remains of fish bones or wild grains/cereals have yet to be identified.

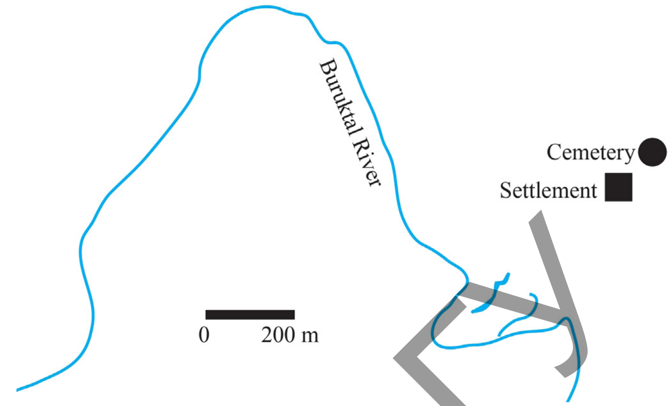

Fig. 3. Location of the Bestamak cemetery and settlement (52°10′N, 64°32′E).

2.2. Previous research of Bronze Age economies and diet

Previous research on subsistence and dietary intake in central Eurasia (Fig. 1) has focused on the examination of faunal materials, the study of botanical evidence, the analysis of dental wear and pathologies, chemical analyses of bone collagen, and the chemical analysis of lipids found in vessels. This section discusses previous research in the region as a comparative measure for the current

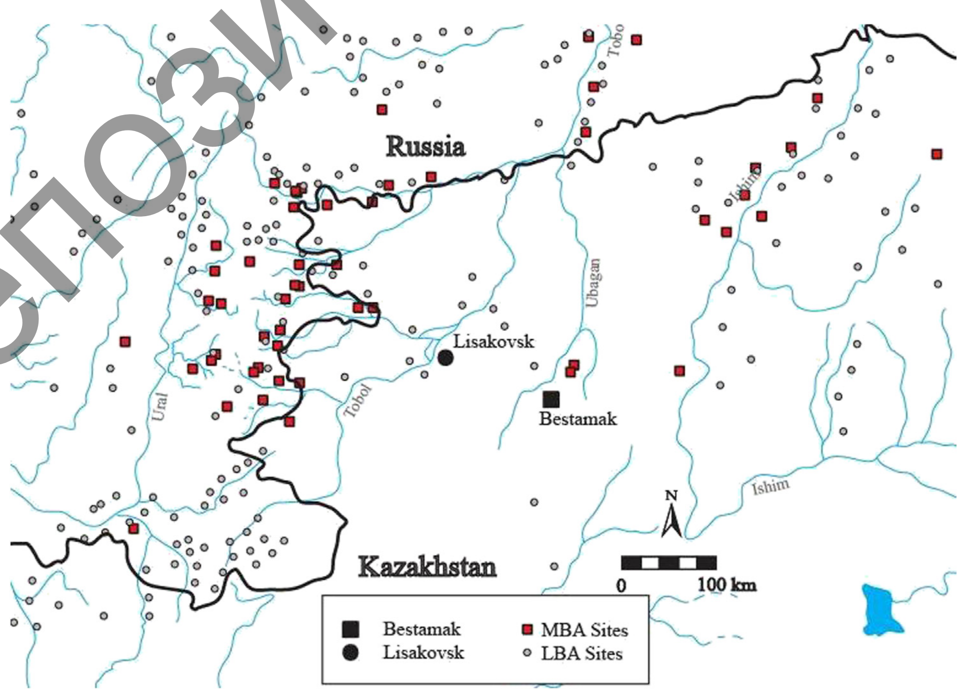

Fig. 2. Middle to Late Bronze Age Settlement Transition in central Eurasia.

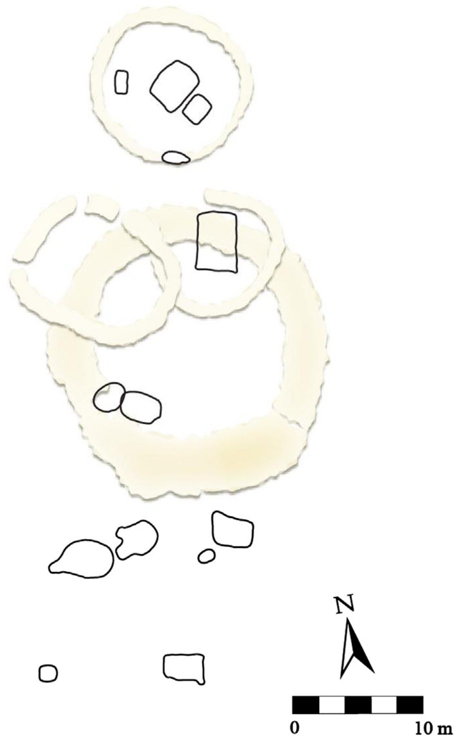

Fig. 4. Examples of kurgans (mounds) from the Bestamak cemetery.

project. Archaeological evidence reveals that Bronze Age societies in the Eurasian steppe maintained livestock, and nearly all scholars agree that meat and milk products formed a major component of their subsistence economy (Khazanov 1984; Cribb, 1991; Kosintsev, 2000, 2003; Frachetti, 2002; Outram et al., 2009). The vast majority of faunal remains recovered from Bronze Age settlements reveal the primary use of cattle and sheep/goat, with somewhat lesser use of horse (Kosintsev, 2000; Gayduchenko, 2002, 2005, 2010; Bachura, 2009; Kosintsev and Gasilin, 2009; Kosintsev, 2010). However, many researchers have posited that MBA societies had mixed agro-pastoral lifeways or horticulture (Zdanovich, 1997: 15; Zdanovich and Zdanovich, 2002).

Botanical analyses at the site of Kamennyi Ambar (MBA) have revealed fragments of *Chenopodium album* and *Vicia cracca* seed; indications of the use of wild plants that were natural to this region and time period (Hanks and Doonan, 2013). In a separate study, charred legumes (*Fabaceae*) were recovered in two thirds of the test pits at the Kamennyi Ambar settlement, whether they were used for human or animal consumption is still unknown (Krause et al., 2010: 119–120). At present, no domesticated plants have been recovered from the Kamennyi Ambar settlement, although excavations and soil flotation are currently underway (Krause and Fornasier, 2013). At the MBA sites of Alandskoe and Arkaim, trace amounts of botanical remains were identified as wild forms of millet (*Panicum*), wheat (*Triticum*), and barley (*Hordeum*) (Gayduchenko, 2002: 403–406). These botanical remains were recovered from house floors or the interior of ceramic vessels; however these particular cereals are wild and reportedly grow locally. Indirect evidence for agriculture or horticulture includes implements such as stone pestles and sickles. However, stone pestles could have been used for the processing of wild grains (Epimakhov, 2010), may have been related to mining activities, or utilized in the processing of medicinal plants or minerals. In addition, sickles can have a variety of functional and ritual uses including cutting fodder for animals, plants for medicinal purposes, or wild cereals for human consumption. In addition, research into human dentition at MBA sites reveal few dental caries and little tooth wear on individuals at Kamennyi Ambar 5 (Judd et al., 2009) or Kurgan 25 at the Bol'shchyekaraganskogo cemetery near the settlement of Arkaim (Lindstrom, 2002). A combination of few dental caries, a paucity of tooth wear, and high prevalence of calculus deposits is often associated with a high protein diet (i.e. a diet that lacks carbohydrates and coarse foodstuffs) (Hillson, 1979, 1996; Lillie, 1996).

Isotopic studies in the Eurasian steppe have become more common over the past decade. In northern Kazakhstan and the southern Urals, one of the first isotopic studies was undertaken at the MBA Bol'shchyekaraganskogo cemetery in the southern Urals (Privat, 2002). This study analyzed 14 individuals and indicated a diet primarily focused on animal protein rather than plants. Nitrogen isotope values provided evidence for human consumption of meat and milk products from cattle and ovicaprids, rather than from horses (Privat, 2002). Pilot studies at two MBA sites located nearby were posited to have evidence of freshwater fish consumption by humans, based on elevated $\delta^{15}N$ values (Privat, 2004). Isotopic values of individuals from Bestamak had average $\delta^{15}N$ values ranging from 10.5 to 13.6‰, while Kamennyi Ambar 5 had average $\delta^{15}N$ values ranging from 11.3 to 14.8‰ (Privat, 2004). Privat suggests that these sites were populated by individuals with dietary consumption patterns including both terrestrial animals and freshwater fish (2004: 75–76). Furthermore, at the Late Bronze Age (Alakul') site of Isiney I, average $\delta^{15}N$ values ranging from 10.5 to 11.9‰, and their dietary intake was proposed to consist mainly of terrestrial herbivores and few fish (Privat, 2004).

These previously analyzed datasets from the Bronze Age in central Eurasia provide clear evidence that dietary variability is

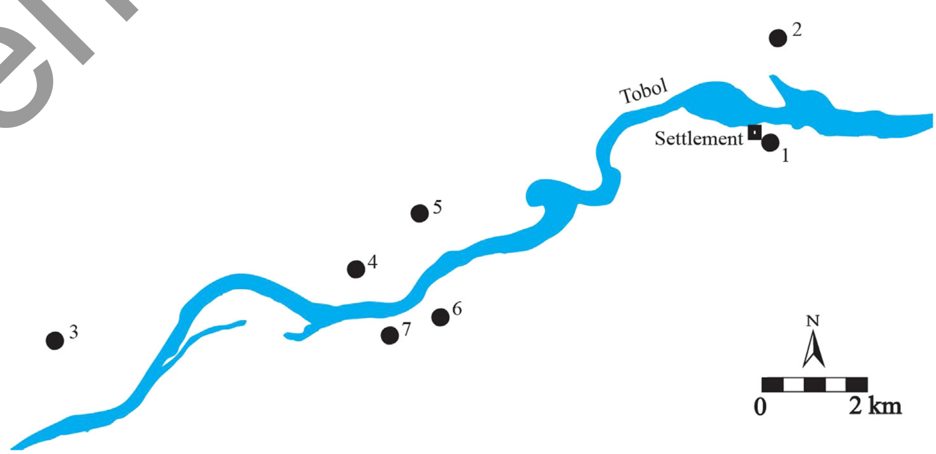

Fig. 5. Location of the Lisakovsk settlement and cemeteries 1 through 7 (52°32′N, 62°23′E).

Fig. 6. Examples of kurgans (mounds) and enclosures from the Lisakovsk cemetery.

present between (and possibly within) communities and locales over time. More recently, it has been suggested that the remains of fish have factored strongly in the diet of many prehistoric steppe communities while evidence for use of agricultural items is lacking (Privat et al., 2002; Anthony et al., 2005; Privat et al., 2005; Schulting and Richards, in press). These isotopic results are supported by the recovery of a diverse collection of fish from fortified settlements of the MBA (Gayduchenko, 2002, 2010; Hanks and Doonan, 2013; Stobbe et al., 2013). Remains of wild fauna including rabbit, deer, elk, wild pig, and saiga have also been recovered in cultural contexts at a number of Bronze Age pastoral sites (Frachetti and Benecke, 2009; Gayduchenko, 2002: 410). A renewed interest in the diverse nature of pastoral economies therefore highlights the need to re-examine dietary intake among these groups in relation to social organization (Chang and Koster, 1994).

At several LBA sites, including the Lisakovsk site, the chemical analysis of lipids from ceramic vessels was undertaken, and revealed a different outlook on foodways during the Bronze Age (Outram et al., 2010). Chemical analysis undertaken on sherds from both the cemetery and the settlement of Lisakovsk separated lipids into ruminant dairy, ruminant adipose, and horse adipose tissues (Outram et al., 2010: 124). In funerary and settlement contexts few containers held equine fat and ruminant adipose/fat, instead the dominant lipids were those related to ruminant dairy tissues (Outram et al., 2010: 124–5). From this data, it would seem that individuals at the Lisakovsk site were consuming mostly cattle, sheep, and goat, as well as the occasional horse. However, there was a lack of evidence for freshwater fish being found in the containers examined (Outram et al., 2010: 121,124). While detailed data on the differential use of containers at cemeteries as well as a few settlements allows for more thorough reconstructions of mortuary and household rituals, stable isotopic data of human remains from the Lisakovsk site should reveal a more intimate picture of individual and community dietary intake.

2.3. Previous isotopic research in the Eurasian steppe

In the broader Eurasian steppe, numerous isotopic studies have focused on the dietary intake of pastoral groups (Katzenberg and Weber 1999; Lillie and Richards, 2000; O'Connell et al., 2003; Iacumin et al., 2004; Privat, 2004; Shishlina et al., 2007; Katzenberg et al., 2009; Shishlina et al., 2009; Lillie et al., 2011; Katzenberg et al., 2012; Shishlina et al., 2012; Murphy et al., 2013; Svyatko et al., 2013; Schulting and Richards, in press). This research has greatly impacted the study of pastoralism in Eurasia and the variability evident between local communities. In the nearby Samara valley, samples from Neolithic to Late Bronze Age individuals ($n = 59$) indicate shifts in diet from the Eneolithic and Bronze Age (Schulting and Richards, in press). Over time there was a decrease in, yet not an abandonment of, the consumption of freshwater fish and other resources. However, at the MBA to LBA transition, there was no evidence for any dietary change, nor is there evidence for the consumption of millet (Schulting and Richards, in press). During the Bronze Age, average δ^{15}N values are depleted (11.5‰) from the preceding Eneolithic (14.3‰), while average δ^{13}C values are elevated for the Bronze Age (−19.0‰) in comparison to the Eneolithic (−21.5) (Schulting and Richards, in press). Average isotopic values of Bronze Age individuals are very similar to those found at the sites under study.

Recent research in Siberia compares several periods of time in the Minusinsk basin and indicates that C_4 plants only became an important component of the diet in the LBA Karasuk culture (1500–900 BC) and Early Iron Age (EIA) Tagar culture (900 BC-400 AD) (Svyatko et al., 2013). Each of these culture groups was interpreted as having a diet that included freshwater fish. The Andronovo component (19th-15th cent. cal BC) of this research is directly comparable to datasets found in this paper. Andronovo individuals ($n = 22$) had average δ^{13}C values of −19.2‰ and average δ^{15}N values of 11.2‰ (Svyatko et al., 2013). These isotopic values are interpreted by the authors as a diet focused on the consumption of terrestrial animal protein with a varying use of freshwater fish (Svyatko et al., 2013). Another project in southwestern Siberia evaluated individuals at two Iron Age sites identified as nomadic pastoralist societies (Murphy et al., 2013). At the sites of Ai-Dai and Aymyrlyg average δ^{13}C values were −15.1‰ and −15.3‰ respectively. These values are interpreted as a departure from a pure C_3 system and authors conclude that this is evidence of millet consumption (Murphy et al., 2013). Average δ^{15}N values are 10.6‰ for Ai Dai and 13.2‰ for Aymyrlyg. While the values for Ai Dai fall within the normal range for the consumption of terrestrial animal protein, those for Aymyrlyg are higher which therefore includes the possibility that this community was consuming freshwater fish or that it was located in an area of increased aridity/salinity (Murphy et al., 2013).

Diachronic analyses of groups from the Caspian steppe indicate that Bronze Age groups had δ^{13}C ranges of −22.2‰ to −15.3‰ and extreme variation in δ^{15}N values from 8.9‰ to 18.4‰ (Shishlina et al., 2012). Overall, these results were interpreted as evidence of three dietary groups which are modeled based on the differential consumption of herbivore protein, wild C_3 plants, freshwater resources, or marine products. Average isotopic values for Model 2 (−19.9‰; 13.3‰) indicate dietary patterns similar to those at the sites under study. These values are interpreted as the result of a diet based in herbivore protein, freshwater resources as well as C_3 plants (Shishlina et al., 2012).

3. Materials and methods

3.1. Stable carbon and nitrogen isotopes

Carbon and nitrogen stable isotopes have routinely been used to reconstruct human and animal diets (DeNiro and Epstein, 1978; Balasse et al., 2000; White et al., 2001; Privat et al., 2002; Ambrose and Krigbaum 2003; Privat et al., 2005). The study of dietary intake is rooted in the basic principles of the food chain, as consumption patterns are incorporated into animal tissue. Bone collagen has a turnover rate of years, and thus reflects the average isotopic composition, and dietary intake, of an individual (Ambrose, 1993; Wild et al., 2000). Bone samples analyzed as part of this project were obtained from three institutions: *Karaganda State University (in the name of E. A. Buketov), Lisakovsk Museum of History and Culture of the Upper Tobol Region*, and the *Kostanai Regional History Museum* with permission of the archaeological and anthropological researchers. All human and faunal samples used in isotopic analysis were collected from adult individuals. Adult humans were considered those individuals above 18 years of age based on physical analysis. Juvenile individuals were not selected for this analysis, as they could be influenced by the effects of weaning, or have a mixture of weaning and post weaning isotopic values (Mays et al., 2002; Durrwachter et al., 2006). The skeletal remains of individuals from the cemeteries were analyzed for age-at-death and biological sex determinations using standard methods (Scott, 1979; Powell, 1985; Milner, 1992; Buikstra and Ubelaker, 1994). Sample sizes for each cemetery were computed in order to have confidence levels between 90 and 95%. The Bestamak site has a total skeletal sample size of 45, therefore, for stable isotope analysis, a total of 22 adults were chosen for analysis. The Lisakovsk site has a total sample size of 138 individuals, therefore samples of 29 adults were chosen for analysis. Individuals from Bestamak and Lisakovsk were sampled for carbon and nitrogen stable isotopes, as well as C:N analyses.

Bone samples were prepared following similar methods described in Richards and Hedges (1999) with some modifications (see also Privat et al., 2002). Approximately 0.5–1.0 g of bone was obtained from each individual using a handsaw. Bones treated with glue or marked with ink were not sampled. The surface of the bone was cleaned with a Dremmel® tool and grinding attachment at low speed in order to remove any surface contaminants and cancelous (i.e. 'spongy') bone. Samples were cleaned ultrasonically in deionized water and then broken into smaller fragments with a percussion mallet, but not powdered, as this may affect protein retention (Schoeninger et al., 1989). Bone fragments were then soaked in a 1.0 M HCl solution overnight, rinsed with deionized water, and gelatinized at 95 C overnight in 10^{-3} M HCl solution (pH 3). A porosity C (25–50 μm) fritted disk was used to isolate the liquid fraction by filtration. The liquid fraction was then evaporated to 5 ml and freeze-dried to make the final collagen product. Carbon and nitrogen isotope and C:N (atomic) ratio values were measured on 0.5–1 mg of collagen using a GV Instruments, Ltd. (now Isoprime, Ltd., a subsidiary of Elementar Analysensysteme) Isoprime™ stable isotope ratio mass spectrometer and coupled EuroVector high temperature elemental analyzer with a diluter kit for sequential isotope analyses. By international standards, nitrogen isotope values are expressed in conventional delta (δ) notation as the permil (‰) deviation from air. Carbon isotope values are similarly expressed in conventional delta (δ) notation as the permil (‰) deviation from the Vienna PeeDee Belemnite (VPDB).

3.2. Isotopic baselines

Several underlying factors are important for constructing baselines as part of the interpretation of stable carbon and nitrogen isotopic values. This includes the investigation and analysis of prehistoric and modern animal remains, plants, the local environment, and climate when possible. Local environmental variability is one of the main factors affecting stable carbon and nitrogen isotopic values of animals and humans (Iacumin et al., 2004; Rubenstein and Hobson, 2004; Hollund et al., 2010). Therefore, in order to deal with the effects of environmental differentiation, isotopic values of animal remains have been used to construct a baseline comparative measure to evaluate the human samples. A baseline of animal isotopic values was created for each prehistoric community to compare with remains recovered from burial contexts. This baseline allows for the comparison of isotopic values of prehistoric animals and humans from the same environmental locale and period of time. This study utilizes existing δ^{13}C and δ^{15}N values of faunal remains from the site of Bestamak (Privat, 2004) and new measurement data from faunal remains recovered from the site of Lisakovsk (Ventresca Miller, 2013). Specifically, the dataset from Bestamak includes δ^{13}C and δ^{15}N values from *Bos taurus* ($n = 1$), *Ovis aries* ($n = 1$), *Canis familiaris* ($n = 2$), and *Equus caballus* ($n = 1$) (Privat, 2004). The Lisakovsk dataset includes δ^{13}C and δ^{15}N values from *B. taurus* ($n = 1$), *O. aries* ($n = 3$), *C. familiaris* ($n = 1$), and *Equus* ($n = 1$) (Ventresca Miller, 2013).

In terms of freshwater fish, several species have been recovered from MBA sites such as Kamennyi Ambar and Stepnoye. These include *Cyprinidae* sp. (Carp), *Perca fluviatilis* (European perch), and *Esox lucius* (Northern pike), yet none of these have been analyzed isotopically (Stobbe et al., 2013). As no archaeological samples of freshwater fish were available from nearby sites for analysis, δ^{13}C and δ^{15}N values for modern Eurasian riverine fish from the southwestern Siberian site of Chicha (Privat, 2004) were used to provide an estimate for the likely range of isotopic values for consumed fish. These samples are from riverine contexts that are similar to those found in northern Kazakhstan. In lieu of the collection of modern samples from the two sites under study, fish isotopic values from Chicha are the closest corollary available for central Eurasia.

While clear distinctions between the human consumption of terrestrial versus aquatic animals is evident (O'Connell et al., 2003), diversity in animal diet cannot be discounted as a factor in human dietary change. While freshwater fish is one possibility for differential human diet, changes in grazing behavior and location may also be a factor. Different herbivores are known to have varied isotopic signatures based on variation in grazing behaviors, such as the differences between horses and cattle/ovicaprids (Privat, 2004; Hollund et al., 2010; Lillie et al., 2011). Recent research has identified differences between herbivores based on environmental niches, with higher nitrogen and carbon isotopic values characteristic of animals grazed in marshy areas (Britton et al., 2008). Elevated nitrogen isotope values are often related to saline (Heaton, 1987) or arid environments (Heaton et al., 1986). Fermented animal milk has also been discussed as a potential source of elevated nitrogen values. However, the work of Privat discounted fermented milk as a source of higher δ^{15}N values, as the fermentation process was shown to not significantly alter the nitrogen isotopic values of milk (2004: 98–101).

Several other baseline datasets were used in this comparative analysis in order to examine all possible dietary inputs, including issues related to wild and domesticated plants. There is currently great discussion over the use of wild versus domesticated plant species during the Bronze and Iron Ages in the Eurasian steppe. While there is no available prehistoric plant data from northern Kazakhstan during these periods, there is limited data from the southern Urals and southeastern Kazakhstan. During the MBA in the southern Urals, wild plants including *Chenopodiaceae* (Chenopodium), *Fabaceae* (legume, pea, or bean family), *Polygonaceae* (knotweed), *Poaceae* (grasses) and *Fragaria viridis* (strawberry) have been identified through floatation and paleobotanical analyses at the sites of Kamennyi Ambar 5/Ol'gino and at Stepnoye (Krause et al., 2010; Hanks and Doonan, 2013; Ng, 2013; Rühl et al., 2013). There are published reports of wild forms of *Panicum* sp. and *Triticum* sp. from the MBA sites of Arkaim and Alandskoe (Gayduchenko, 2002), however these lack full species identification, morphological analyses, and chronology (Frachetti et al., 2010). Furthermore, these findings contrast greatly with current understandings of plant species identified in the southern Urals region during the MBA. In southeastern Kazakhstan, domesticated broomcorn millet (*Perca miliaceum*) and wheat (*Triticum aestivum* or *T. turgidum*) were identified in burial contexts at the site of Begash and dated to the Bronze Age (2460–1950 cal BC) (Frachetti et al., 2010). Similar findings for the Iron Age site of Tuzasai in southeastern Kazakhstan include the recovery of phytoliths for foxtail millet, barley, wheat, and rice (Chang et al., 2003; Spengler et al., 2013b). While the findings in southeastern Kazakhstan are interesting and reveal some of the earliest evidence of millet and wheat in the central Eurasian steppe, it is still up for debate whether these items were being grown, consumed, or traded in the north. At this moment, there is little evidence for the use of domesticated cereals in northern Kazakhstan or the southern Urals during the Bronze Age.

Baseline datasets are also greatly affected by local environmental inputs including issues of salinity and climate data. While stable carbon and nitrogen isotopic studies are tied to the local environment, no local plant species were sampled as part of isotopic analyses for this project. Therefore, local environmental differentiation and climate are discussed from the perspective of previous research in the region. The Kostanai oblast (administrative region) located in north central Kazakhstan consists of two broadly defined vegetation subprovinces, the northern Kazakhstan forest-steppe and the Trans-Ural/Turgay steppe (Rachkovskaya and Bragina, 2012: 124–5). Only a small section of the northeastern part of Kostanai oblast is defined as forest-steppe as it includes *Betula*, and mixed *Populus* and *Betula* forests, interspersed with meadow steppes, rich forb, and feather grass steppes (Rachkovaskaya and Bragina, 2012: 126). In certain depressions there are also small sections of vegetation comprising sedge marshes and willow brushwoods. The majority of the oblast is part of the Trans-Ural – Turgay subprovince which includes a full range of steppe vegetation communities such as steppes of rich forb, feather grass and forb, and feather grass in the north, with fescue and feather grass steppes on the slopes on low hills near rivers (Rachkovskaya and Bragina, 2012: 126–7). In addition, small vegetation communities of sagebrush, bunch grass and other xerophytic forbs, fescues, and feather grasses are present nearby. Relic pine forests are also interspersed with meadow communities and complex steppes on lake terraces (Rachkovskaya and Bragina, 2012: 127). The archaeological sites under study are both located within open steppe, yet they differ because Bestamak is found along a tributary river dotted with small salt marsh ponds, while Lisakovsk is located on the high banks of the Tobol River.

The climate is relevant to isotopic baselines, as it affects water and vegetation which is consumed by animals and humans. Yet the prehistoric climate is not well understood in northern Kazakhstan or the southern Urals during the Bronze Age, as few detailed studies have been undertaken. Research into climatic change in central Eurasia is complicated because scholars disagree on the climatic conditions during the Bronze Age with differing theories on whether the climate has been stable, become more arid, or increased in humidity (Demkin and Demkina 2002; Matveev et al., 2002; Anthony et al., 2005; Koryakova and Epimakhov, 2007; Anthony, 2007). As research programs have started to focus on micro-regional approaches to climate, we are beginning to understand local temperature fluctuations in prehistory (Demkin and Demkina 2002; Matveev et al., 2002). In northern Kazakhstan, several broad trends in vegetational history are evident based on lake cores undertaken at Mokhovoe Lake within Kostanai oblast (Kremenetski et al., 1997). This lake is relatively close to the archaeological sites under study, and located between the Tobol and Ubagan Rivers. Sedimentation at the lake started circa 6000 years BP, with a hiatus around 4500 to 2900 years BP (Kremenetski et al., 1997). At the early stage (6000–4500 BP) vegetation was forest-steppe and grass-steppe with some patches of birch forest. The authors interpret these findings as a long period of favorable climatic conditions when vegetation groups expanded and the herb cover of the steppe was more mesophytic, containing plants that needed a regular source of water (Kremenetski et al., 1997: 403). After this period there was a hiatus (4500–2900 BP) which was characterized by the authors as a drier period with a more continental climate and decreased forest area (Kremenetski et al., 1997: 403). However, a lack of sedimentation does not preserve pollen, and therefore vegetation and climate inferences are difficult to discern. As the sites of Bestamak and Lisakovsk were occupied during this hiatus, the extent of variation in climate and local environment continue to be unclear. Until climatic data is collected and analyzed in multiple local communities this data should not be used as a basis for making claims about the Bronze Age in central Eurasia.

4. Results

4.1. Stable carbon and nitrogen isotopes

The validity of isotopic data as a dietary measure is based on the assumption that contamination of the collagen has not occurred post-mortem. For collagen, C:N ratios are the most commonly used measure of diagenesis and its potential impact on $\delta^{13}C$ and $\delta^{15}N$ values. Bone collagen with a C:N ratio that falls outside the range of 2.9–3.7 is considered to have been affected by post-mortem alteration (DeNiro, 1985; Schoeninger et al., 1989; Ambrose and Norr, 1993). For this research, 49 of 51 human bone samples (96%) and 6 of 6 animal bone samples (100%) had atomic C:N ratios between 3.0 and 3.6 (Tables 1 and 2). These ratios fall within the range of 2.9–3.7, indicating that collagen was not contaminated or degraded (DeNiro, 1985; Schoeninger et al., 1989; Ambrose and Norr, 1993). The two samples that fell outside of the acceptable range for C:N ratios (3.70 and 3.76 respectively) were not used in this study. Tables 1 and 2 present the results of stable isotope analysis for each cemetery with unacceptable ratios shaded (samples 3503 and 3176).

Table 1
Bestamak isotopic results (shaded samples fell outside of acceptable range and were not used in this study).

Sample I.D.	Period	Corr. $\delta^{13}C$	Corr. $\delta^{15}N$	C:N (atomic)	Age	Sex	Bone sampled
B3501	MBA	−19.42	11.56	3.5	24–35	Indet.	*R. Tibia*
B3503	MBA	−18.50	11.79	3.7	Adult	Indet.	Long bone
B3507	MBA	−19.17	11.60	3.4	20–30	Female	*L. Femur*
B3508	MBA	−19.22	11.10	3.5	20–30	Female	*R. Femur*
B3512	MBA	−19.42	11.40	3.5	35–50	Male	*Long Bone*
B3513	MBA	−19.37	12.15	3.5	19–24	Female	*L. Femur*
B3515	MBA	−19.58	11.27	3.5	35–50	Indet.	*L. Femur*
B3518	MBA	−18.80	11.94	3.5	18–22	Indet.	*R. Femur*
B3520	MBA	−19.24	11.28	3.4	23+	Indet.	*R. Femur*
B3523	MBA	−18.75	12.63	3.5	18–24	Indet.	*R. Femur*
B3531	MBA	−18.62	12.51	3.4	18–24	Female	*L. Femur*
B3532	MBA	−19.51	11.04	3.5	30–55	Indet.	*R. Femur*
B3534	MBA	−18.99	09.53	3.5	24–60	Female	*L. Femur*
B3538	MBA	−19.24	11.09	3.4	30–60	Female	*L. Femur*
B3540	MBA	−17.63	14.08	3.5	18–24	Indet.	*R. Femur*
B3542	MBA	−19.01	11.13	3.6	Adult	Indet.	*R. Femur*
B3545	MBA	−18.74	11.52	3.4	18–30	Male	*R. Tibia*
B3547	MBA	−19.25	12.13	3.5	25–30	Male	*L. Tibia*
B3550	MBA	−19.37	11.96	3.5	Adult	Indet.	*R. Femur*
B3558	MBA	−18.30	13.98	3.6	18–50	Female	*R. Femur*
B3566	MBA	−18.67	11.90	3.6	30–55	Male	*Fibula*
B3575	MBA	−18.92	11.18	3.5	20–44	Male	*L. Humerus*

Table 2
Lisakovsk isotopic results (shaded samples fell outside of acceptable range and were not used in this study).

Sample I.D.	Period	Corr. $\delta^{13}C$	Corr. $\delta^{15}N$	C:N (atomic)	Age	Sex	Bone sampled
L3001	LBA	−18.76	11.53	3.4	35+	Indet.	Rib
L3004	LBA	−18.95	11.64	3.3	Adult	Indet.	*R. Femur*
L3013	LBA	−18.85	12.45	3.5	Adult	Indet.	*R. Femur*
L3016	LBA	−18.94	09.91	3.4	Adult	Indet.	*L. Tibia*
L3036	LBA	−18.55	12.03	3.3	Adult	Indet.	*R. Femur*
L3070	LBA	−18.70	12.05	3.3	20–30	Indet.	R. 3rd Metatarsal
L3071	LBA	−18.62	13.88	3.3	40–50	Indet.	*Ulna*
L3081	LBA	−18.86	12.08	3.3	30–50	Indet.	*L. Tibia*
L3093	LBA	−19.40	11.54	3.3	22–30	Indet.	*L. Tibia*
L3102	LBA	−18.67	12.37	3.3	20–30	Indet.	L. 5th Metatarsal
L3105	LBA	−19.02	11.97	3.4	Adult	Indet.	*R. Femur*
L3110	LBA	−19.29	11.21	3.4	35–50+	Indet.	*L. Femur*
L3112	LBA	−18.82	13.48	3.4	20–35	Female	R. 1st Metatarsal
L3130	LBA	−18.87	12.82	3.4	35–50+	Male	*Parietal*
L3137	LBA	−17.49	14.35	3.3	45–59	Male	*R. Femur*
L3139	LBA	−19.03	12.45	3.4	24–40	Female	*R. Humerus*
L3142	LBA	−19.03	11.23	3.4	24–40	Indet.	*L. Radius*
L3150	LBA	−18.96	11.93	3.4	30–39	Female	*R. Tibia*
L3155	LBA	−17.62	13.14	3.0	Adult	Indet.	*L. Femur*
L3160	LBA	−18.50	12.54	3.4	17–25	Female	*L. Femur*
L3161	LBA	−18.56	10.87	3.4	35–44	Indet.	*L. Tibia*
L3165	LBA	−18.77	11.27	3.5	35–44	Male	*R. Femur*
L3167	LBA	−18.33	12.20	3.3	30–45	Female	*L. Femur*
L3168	LBA	−18.98	11.68	3.3	Adult	Indet.	R. 4th Metatarsal
L3170	LBA	−19.08	12.04	3.4	40–50	Male	*R. Femur*
L3173	LBA	−18.83	12.03	3.4	35–45	Male	*R. Femur*
L3176	LBA	−18.94	12.07	3.8	30–39	Male	R. Femur
L3178	LBA	−19.68	09.95	3.5	20–30	Indet.	*L. Ulna*
L3184	LBA	−18.67	11.87	3.3	Adult	Indet.	Rib
L3023	LBA	−18.96	08.32	3.5	Adult	Indet.	–
L3067	LBA	−20.16	04.61	3.5	Adult	Indet.	–
L3159	LBA	−18.75	07.09	3.5	Adult	Indet.	–
L3177	LBA	−19.40	05.98	3.4	Adult	Indet.	–
L-DOG	LBA	−18.80	08.75	3.5	Adult	Indet.	–
L-SG	LBA	−19.36	07.36	3.6	Adult	Indet.	–

Nitrogen isotopic values of bone collagen for individuals at Bestamak ranged from 9.5‰ to 14.1‰, with an average of 11.8‰ (Table 1). The average $\delta^{15}N$ value for individuals at Lisakovsk was 12.0‰, with values ranging from 9.9 to 14.4‰ (Table 2). Average $\delta^{15}N$ values of individuals at both sites are elevated relative to average values reported for cattle (8.4‰), sheep/goat (7.1‰), and horse (5.4‰), allowing for the possibility that some of the individuals with higher values were consuming fish species with average $\delta^{15}N$ values reported for fish (10.5‰). High nitrogen isotopic values for human bone collagen suggest that human dietary intake cannot solely be explained by the consumption of herbivore meat and milk. Freshwater fish, which have high $\delta^{15}N$ values compared to terrestrial herbivores, may be one possible source. While high $\delta^{15}N$ values of animal bone collagen might also be at play due to foddering or differential consumption of plant species, the average isotope values for animal collagen at each of these sites fits well within the expected norms for the region (Privat, 2004).

The range of $\delta^{13}C$ values for human bone collagen at Bestamak is minimal (−19.6‰ to −17.6‰) with an average value of −19.0‰. Individuals from Lisakovsk had $\delta^{13}C$ isotopic values ranging from −19.7 to −17.6‰, and an average value of −18.8‰. Differences between average human $\delta^{13}C$ values at the two sites are significant ($p = 0.0868$). These varying values could be influenced by multiple factors including water stress (Tieszen, 1991), the consumption of waterfowl (Richards et al., 2001), and plant consumption. These values fall between the isotopic range for C_3 and C_4 plant consumption. The range of isotopic values for C_4 plants such as millet often varies from −12 to −16‰, with an average of 14‰, while C_3 plants exhibit approximate $\delta^{13}C$ values of −21 to −35‰, with an average isotopic value of −28‰ (O'Leary, 1988; Hoppe et al., 2004).

Generally, human consumers relying on terrestrial C_3 systems have bone collagen $\delta^{13}C$ values of approximately −21‰, while those relying on purely C_4 systems have values as high as approximately −8‰. Mixed carbon isotopic values should not be considered unusual, as these sites are located in an area of mixed C_3/C_4 plant zones identified as steppe bordering forest-steppe with subzone moderate moisture (Sokolov, 1968; Cerling and Quade, 1993). Furthermore, herbivores recovered from Bestamak and Lisakovsk exhibit bone collagen $\delta^{13}C$ values ranging from −17.7 to −20.0‰ and from −18.8 to −20.2‰ respectively. If the human populations were eating freshwater fish, then it would be expected that their bone collagen $\delta^{13}C$ values would be closer to those of freshwater fish consumers which range from −25.3 to −15.9‰ (Privat, 2004: 70). It is important to note that the study of collagen alone, without comparison to apatite, can be problematic as collagen tends to reflect primarily protein in the diet rather than whole diet. When foods low in protein are consumed in small amounts, they may not be reflected in the stable isotope values of collagen (Harrison and Katzenberg, 2003).

Local environments surrounding these two sites are only slightly different, with Bestamak located in a more marshy area than Lisakovsk. This is supported by a significant difference in animal $\delta^{15}N$ average values between these two locales ($p = 0.144$). The average $\delta^{15}N$ isotope value of animals at Bestamak was 9.7‰ and at Lisakovsk was 7.0‰, however the sample sizes were very small, $n = 5$ and $n = 6$ respectively. There is extensive evidence that a negative relationship exists between water availability and $\delta^{15}N$ isotope values for herbivores (Murphy and Bowman, 2006). It has also been shown that $\delta^{15}N$ isotopic values are higher in saline and arid environments (Heaton et al., 1986; Heaton, 1987) and that the consumption of marsh plants by herbivores elevates their nitrogen values from +1.6 to 3.5‰ (Britton et al., 2008). Therefore, further analyses of marsh plant isotopic values must be undertaken in order to understand the relationship between $\delta^{15}N$ values, water availability, and herbivore consumption in these locales. Average human $\delta^{15}N$ values between the two sites are not significantly different, or the number of individuals sampled is too small for significance testing. However, $\delta^{13}C$ values in human remains at Lisakovsk were significantly elevated in comparison with those at Bestamak ($p = 0.0868$). Differences in $\delta^{13}C$ isotopic values at the two sites could be influenced by multitude of factors including water stress or the consumption of waterfowl. In particular, waterfowl could be indicated by lower $\delta^{13}C$ isotopic values, without inherent elevated $\delta^{15}N$ isotopic values (Richards et al., 2001). This slight change may also be due to local environmental differences or diachronic climatic shifts. Although $\delta^{13}C$ isotopic values between humans are significant, they are only slightly different and therefore need to be evaluated with further research comparing them to plant and animal species present in these locales.

5. Discussion

5.1. Stable carbon and nitrogen isotopes: inter-cemetery comparison

This approach to dietary reconstruction relies on the assessment of the relative dietary dependence of humans upon three main food types: terrestrial herbivores, freshwater fish, and plants (Fig. 7). Human $\delta^{15}N$ values are typically enriched by 3–5‰ relative to consumed foods. Existing studies indicate that human bone

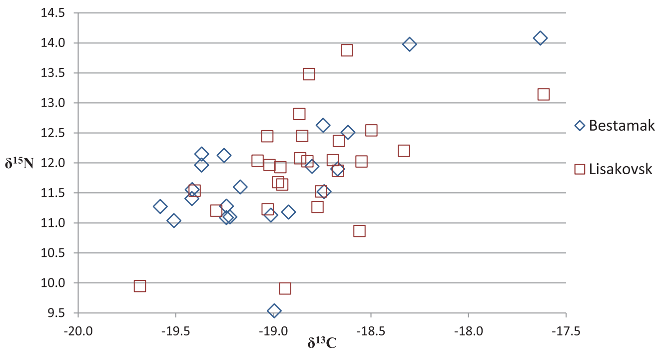

Fig. 7. Comparison of carbon and nitrogen isotopic values for humans at Bestamak (MBA) and Lisakovsk (LBA).

collagen $\delta^{13}C$ values have a broader range and are typically 0–5‰ higher than consumed foods (Schoeninger and DeNiro, 1984). Consumption practices of pastoral groups continue to be heavily debated, especially the degree to which freshwater fish or wild plant materials contributed to the human diet during the Bronze Age. Several different species of fish have been recovered from the MBA site of Kamennyi Ambar 5 the southern Urals: *Cyprinidae sp.* (Carp), *P. fluviatilis* (European perch), and *E. lucius* (Northern pike) (Stobbe et al., 2013). To date, no stable isotopic analyses of modern or prehistoric fish remains have been undertaken from the sites under study or nearby. However, stable isotopic values of modern fish from the site of Chicha, in southwestern Siberia, are available and include similar species of fish from a steppe context (Privat, 2004). The species of fish from Chicha include *Carassius carassius* (family *Cyprinidae*), *P. fluviatilis*, and *E. lucius*, which exhibit $\delta^{13}C$ and $\delta^{15}N$ values ranging from −25.3 to −15.9‰ and 8.4–13.8‰ respectively (Privat, 2004; Privat et al., 2005) (Fig. 8) (Table 3).

Wild plants such as *Chenopodiaceae* (Chenopodium), *Fabaceae* (legume, pea, or bean family), *Polygonaceae* (knotweed), *Poaceae* (grasses) and *Fragaria viridis* (strawberry) were present in the central Eurasian steppe during the Bronze Age (Krause et al., 2010; Hanks and Doonan, 2013; Ng, 2013; Rühl et al., 2013) and may also have served as a food source for Bronze Age populations at Bestamak and Lisakovsk. As the isotopic signatures of these plant materials are currently unknown for the Central Eurasian steppe, proxies from adjacent areas in the Central Asia must be used as a comparative measure. The remains of prehistoric plants have been tested in the Caspian steppe, revealing average $\delta^{13}C$ values of −26‰ for C_3 plants, and −12‰ for C_4 plants (Shishlina et al., 2012). Some of these plants, such as reeds and grasses, were characterized by very high $\delta^{15}N$ values (Shishlina et al., 2012). Isotopic values of plants recovered from Uzbekistan, Turkmenistan, and Mongolia while in different climatic zones, can be examined as part of a general comparative dataset. Carbon isotopic values were recorded for the following species found in Central Asia: *Chenopodiaceae Atripliceae* (−13.0 to −13.9‰), *Poaceae Andropogonae* (−12.3 to −16.2‰), and *Polygonaceae* (−12.7 to −12.9‰) (Toderich et al., 2007: 39–42). Unpublished plant data from Mongolia indicates that $\delta^{13}C$ values ranged from −23.4 and −28.3‰ for C_3 photosynthetic pathways, while two C_4 plants had $\delta^{13}C$ values of −14.4 and −14.7‰ (Sikora, 2007; Stacy, 2008).

As Chenopodium has been identified through charred seeds at several MBA sites we know that this plant was available for consumption, yet these prehistoric remains have not been isotopically tested (Krause et al., 2010; Hanks and Doonan, 2013). The average $\delta^{13}C$ value for *Chenopodium* is −26‰ for modern samples (Smith and Epstein, 1971; Schwarcz et al., 1985) while samples of prehistoric *Chenopodium sp.* (New Mexico, United States) had average $\delta^{13}C$ values of −26‰ and average $\delta^{15}N$ value of 7.4‰ (Schoeninger et al., 1989: 52). However, when we examine average $\delta^{13}C$ values for members of the *Chenopodium* genus, there is great variation between species, some of which are characterized as C_3 and some as C_4 plants (Smith and Epstein, 1971; Schwarcz et al., 1985; Akhani et al., 1997). The spectrum of carbon isotope values for species of Chenopodiaceae from the Old World reveal two separate groups with $\delta^{13}C$ values ranging from −15.5‰ to −9.27‰ and −31.99‰ and −20.77‰ (Akhani et al., 1997). The plotting of these species reveal that the Eurasian steppe lies at the border zone between locations where 75% of *Chenopodiaceae* are C_4, and where 75% of *Chenopodiaceae* are C_3 plants (Akhani et al., 1997: 188).

Herbivore (cattle, sheep, goat, horse) $\delta^{13}C$ values at the Bestamak and Lisakovsk sites suggest a mixed C_3 and C_4 plant diet for Bronze Age animal populations. Furthermore, relatively high $\delta^{15}N$ values in the herbivore population indicate a dietary source enriched in $\delta^{15}N$, which may have included plants from wetland, marshy, or saline environments. Recent research has shown that herbivores that consume marsh plants tend to have $\delta^{15}N$ values

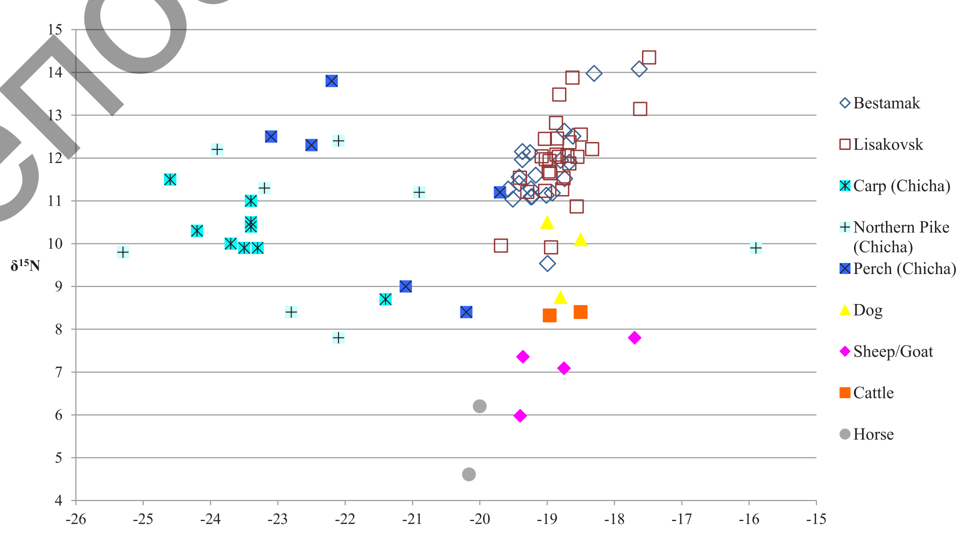

Fig. 8. Comparative isotopic baseline values of faunal materials from Bestamak, Lisakovsk, and Chicha.

Table 3
Isotopic results of fishes from the site of Chicha.

Sample	Species	Site	Corr. $\delta^{13}C$	Corr. $\delta^{15}N$
BES3	*Bos taurus*	Bestamak	−18.5	8.4
BES 5	*Canis familiaris*	Bestamak	−19.0	10.5
BES 4	*Canis familiaris*	Bestamak	−18.5	10.1
BES 1	*Equus caballus*	Bestamak	−20.0	6.2
BES 2	*Ovis aries*	Bestamak	−17.7	7.8
CHA28	*Carassius carassius*	Chicha	−24.6	11.5
CHA29	*Carassius carassius*	Chicha	−24.2	10.3
CHA59	*Carassius carassius*	Chicha	−23.7	10.0
CHA61	*Carassius carassius*	Chicha	−23.5	9.9
CHA26	*Carassius carassius*	Chicha	−23.4	11.0
CHA30	*Carassius carassius*	Chicha	−23.4	10.4
CHA27	*Carassius carassius*	Chicha	−23.4	10.5
CHA31	*Carassius carassius*	Chicha	−23.3	9.9
CHA9	*Carassius carassius*	Chicha	−21.4	8.7
CHA25	*Esox lucius*	Chicha	−25.3	9.8
CHA21	*Esox lucius*	Chicha	−23.9	12.2
CHA23	*Esox lucius*	Chicha	−23.2	11.3
CHA7c	*Esox lucius*	Chicha	−22.8	8.4
CHA24	*Esox lucius*	Chicha	−22.1	12.4
CHA7b	*Esox lucius*	Chicha	−22.1	7.8
CHA22	*Esox lucius*	Chicha	−20.9	11.2
CHA7a	*Esox lucius*	Chicha	−15.9	9.9
CHA20	*Perca fluviatilis*	Chicha	−23.1	12.5
CHA19	*Perca fluviatilis*	Chicha	−22.5	12.3
CHA18	*Perca fluviatilis*	Chicha	−22.2	13.8
CHA8a	*Perca fluviatilis*	Chicha	−21.1	9.0
CHA8c	*Perca fluviatilis*	Chicha	−20.2	8.4
CHA8b	*Perca fluviatilis*	Chicha	−19.7	11.2

that are elevated by +1.6–3.5‰ compared to non-saline terrestrial environments (Britton et al., 2008). In addition, elevated $\delta^{15}N$ values are found in conjunction with elevated $\delta^{13}C$ values (Britton et al., 2008). Nitrogen isotopic values of herbivores at both the Bestamak and Lisakovsk sites are elevated to a range that corresponds to diets that include high numbers of marsh or wetland plants, and carbon isotope values are also elevated, following this pattern. Variability in animal dietary intake may be dependent upon grazing location, or may be a factor related to environmental shifts over time.

5.2. Comparative intra-cemetery bioarchaeological research

In addition to diachronic investigations of overall dietary trends, the results of the $\delta^{13}C$ and $\delta^{15}N$ analysis of human collagen also allow for discussions of differentiation between individuals based on dietary intake. Isotopic results were comparatively tested against social, biological and ritual factors at both cemeteries. However, only a sample of individuals from each site were used in isotopic analyses (Bestamak $n = 22$; Lisakovsk $n = 29$), which may have affected the outcomes of comparative studies. There was no association between isotopic values and the age or sex of individuals, although only adults were used in this study. Furthermore, biodistance analysis of dentition, and the hypothetical kinship groups constructed, did not correlate with isotopic groupings of individuals under study. However, individuals who were outliers in terms of isotopic values did sometimes correlate with certain mortuary rituals, grave goods or spatial location in the cemeteries, as discussed below.

At Bestamak, two individuals have elevated $\delta^{13}C$ and $\delta^{15}N$ values in relation to the rest of the community (Fig. 9). These individuals (samples B3540 and B3558) have $\delta^{13}C$ values of −17.6‰ and −18.3‰ respectively, and $\delta^{15}N$ values of 14.1‰ and 13.9‰. At Bestamak as a whole, the average $\delta^{13}C$ value is −19.0‰ and the average $\delta^{15}N$ value is 11.8‰. Two tailed *T*-tests separately comparing $\delta^{13}C$ and $\delta^{15}N$ values of these individuals with the rest of the community reveal that at 95% confidence the difference

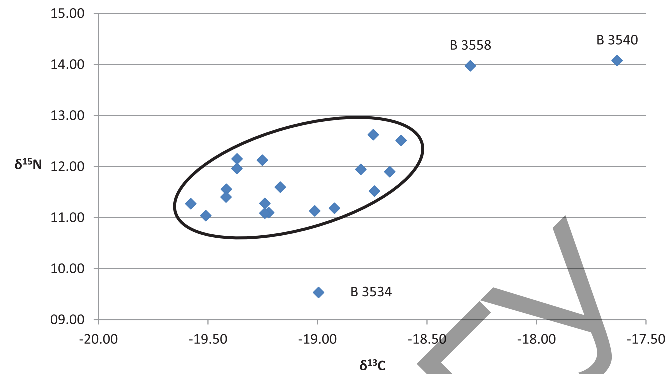

Fig. 9. Isotopic values for individuals at Bestamak (with numbered outliers).

between these individuals and the community is significant ($p < 0.001$). While elevated $\delta^{15}N$ values may indicate greater consumption of fish by these individuals, $\delta^{13}C$ values near −18‰ could indicate the consumption of C_4 plants. Due to their significantly different collagen isotopic values, these individuals are posited as having a slightly different diet than the other members of the community. Of these individuals, one was determined to be female, while the other was indeterminate in regards to biological sex. They were buried with groundstone slabs and pestles, which were only recovered from a total of five burials at Bestamak. As these individuals had a slightly different diet and unique items, they may have had a social status related to the processing and consumption of plants or medicinal items. One individual (sample B3534) had a very low $\delta^{15}N$ value which may have been due to increased consumption of horse protein or plant materials which generally have lower nitrogen values.

When considering human remains at the Lisakovsk cemetery, several individuals seem to be outliers in terms of dietary intake (Fig. 10). The average $\delta^{15}N$ value for individuals at Lisakovsk was 12.0‰. Two individuals have comparatively low $\delta^{15}N$ values: samples L3178 (10.0‰) and L3016 (9.9‰). A two-tailed *T*-test between individuals with low $\delta^{15}N$ values and the rest of the individuals tested indicates that at 95% confidence the difference between these two groups is very significant ($p = 0.0008$). Several other individuals exhibited comparatively elevated $\delta^{15}N$ values, including samples L3112 (13.5‰), L3071 (13.9‰), L3155 (13.1‰), and L3137 (14.4‰). However, a two-tailed *T*-test of individuals with elevated $\delta^{15}N$ values and the rest of the individuals indicates that at 95% confidence the difference between these groups is not significant ($p = 5.124$). Finally, two individuals were characterized by elevated $\delta^{13}C$ values when compared to the rest of the group,

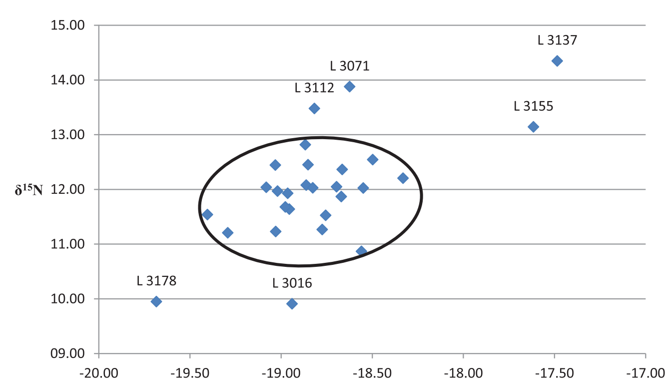

Fig. 10. Isotopic values for individuals at Lisakovsk (with numbered outliers).

namely samples L3137 (−17.5‰) and L3155 (−17.6‰). However, a two-tailed *T*-test between these individuals and the rest of the community indicates that the difference between them is not significant ($p = 1.0713$). Therefore, only individuals with low δ^{15}N values are significantly different from the rest of the population (samples L3178 and L3106). Depleted δ^{15}N values may be due to a slightly different diet including a lack of fish consumption, or a focus on more horse meat and milk which has relatively low δ^{15}N values (5.5‰). Of the two individuals with comparatively low δ^{15}N values, one cannot be linked to a specific grave assemblage and the other was buried with only a single ceramic vessel. However this second individual (L3178) was buried in a ditch, an unusual placement for this cemetery. This may be evidence that this person was of low status due to the low number of associated burial goods, inconspicuous placement, and differential diet.

5.3. Conclusions

Carbon and nitrogen stable isotope data suggest that the primary dietary intake of individuals at both Bestamak and Lisakovsk was terrestrial animal protein, likely in the form of milk and meat. The animals most often found at MBA sites are cattle and sheep/goat, which at Bestamak have an average δ^{15}N value of 8.1‰. Therefore, humans subsisting primarily on these animals (assuming a 3–5‰ trophic level increase) would have δ^{15}N values ranging from 11.1 to 13.1‰, which is relatively close to actual Bestamak human bone collagen δ^{15}N values which range from 9.5 to 14.1‰. Similarly, at Lisakovsk δ^{15}N values of humans range from 9.9 to 14.4‰ and the average for cattle and sheep/goat is 7.2‰. Humans subsisting primarily on cattle and sheep/goat (assuming a 3–5‰ trophic level increase) would have δ^{15}N values ranging from 10.2 to 12.2‰, which is very close to the actual range of δ^{15}N values for Lisakovsk human bone collagen. The slightly elevated δ^{15}N values for some Bestamak and Lisakovsk humans may reflect supplemental fish consumption, whereas individuals with lower bone collagen δ^{15}N values may indicate increased consumption of horse meat and milk.

The comparative analysis of these two cemeteries indicates that general patterns of dietary intake were relatively uniform from the MBA to LBA transition in the central Eurasian steppe. The differences between the sites of Bestamak and Lisakovsk in terms of δ^{15}N values is not statistically significant (Student's $t = 0.895$, $p = 0.376$). Slight differences may be due to environmental variation, as δ^{15}N isotopic values are elevated in arid or saline environments (Heaton et al., 1986; Heaton, 1987; Murphy and Bowman, 2006). However, the site of Bestamak is in a more marshy and saline environment than Lisakovsk, and δ^{15}N values of individuals at the former site are depleted rather than elevated. While climatic change may be a factor, it is currently difficult to determine how broad environmental shifts affected these local communities. Therefore, individuals with elevated δ^{15}N values at both sites may have consumed freshwater fish, while those with depleted δ^{15}N values may have consumed horse protein. There also is a strong possibility that differential δ^{15}N values are the result of a diet with similar diversity of foodstuffs, with proportionally lower or higher intake of specific items.

Differences between the average of δ^{13}C values for human bone collagen at the sites of Bestamak (−19.0‰) and Lisakovsk (−18.8‰) were significant (Student's $t = 1.75$, $p = 0.0868$). Variation in δ^{13}C values could be dependent upon multiple factors including water stress, the consumption of waterfowl or freshwater fish, as well as plant consumption practices (Tieszen, 1991; Richards et al., 2001). Carbon isotopic values for humans fall between the normal range for C_3 and C_4 plants, which often fall into two groups. C_4 plant species recovered from Central Asia (including Chenopodaciae, Poaceae, and Polygonaceae) have carbon isotopic values that range from −12.3 to −16.2‰, while C_3 plants (such as *Chenopodium album*) recovered from other regions have a range of values from −26 to −33.6‰ (Toderich et al., 2007: 39–42; Hart et al., 2007; Schulenberg, 2002: 104; Akhani et al., 1997: 194; Schoeninger et al., 1989: 52). If humans were consuming plant materials, they would have human bone collagen δ^{13}C values that were elevated by approximately 0–5‰. The δ^{13}C values of Bestamak and Lisakovsk reveal a range of values, suggesting that individual dietary intake did vary. This variation could be the result of different diets, but it could also be due to a proportionally lower or higher intake of the same dietary sources. While δ^{13}C values of human bone collagen at these sites do not indicate the consumption of large amounts of C_4 plant materials it is possible that a small portion of the population, or overall diet, included these items. Pastoralists have a diet that focuses primarily on terrestrial animal protein, but they also consumed gathered plant materials as a dietary supplement or for medicinal purposes. Wild plant consumption may thus be important to dietary reconstructions which are not highlighted by isotopic values of bone collagen (Harrison and Katzenberg, 2003). The examination of the mineral portion of bones and teeth from these and other sites in the future will add valuable information regarding the carbohydrate component of the human diet.

There also are several interesting correlations at the intra-cemetery scale between isotope values and mortuary practices. At Bestamak, two individuals with elevated δ^{13}C and δ^{15}N values were buried with different items than the rest of the community. These individuals were buried with groundstone pestles and slabs, and may have had a special social status related to the processing and consumption of plants and medicinal items. At the site of Lisakovsk, two individuals had significantly depleted δ^{15}N values compared to the rest of the population. These individuals may have consumed more horse meat and milk than other protein sources. One of these individuals was buried in the ditch surrounding a kurgan (mound). While the consumption of horse might normally be attributed to a high status individual, this person had few burial goods, an inconspicuous placement and a differential diet, which may be evidence of the low status of this individual.

This approach includes the correlation of multiple datasets, providing a more nuanced context for understanding relationships between subsistence regimes and social change. The dietary intake of pastoral groups during the Bronze Age seems to have stayed relatively stable over a period of great transition in social and ritual institutions. However, this has currently only been tested for a few cemeteries spanning the transition, and future research may reveal significant variation between local communities. Among pastoral groups, subsistence regimes can no longer be predictably related to the consumption of only animal products. Instead, the nature of subsistence economies should be treated as an important variable in understanding and reconstructing pastoral societies. While evidence seems to point to a focus around ruminant domesticates, there is variability in diet between individuals, indicating a supplementation of the diet with a range of alternate foods, including wild resources such as fish and plants, as well as horse. Therefore, in the case of the central Eurasian steppe, dietary intake had a foundation in the consumption of meat and milk, with a secondary dependence on wild seeds and grains, as well as freshwater fish. As these additional items were all locally available, it is not surprising that they were being consumed when they could be obtained. Furthermore, these secondary products were differentially used by individuals within each community, revealing intra-community diversity in consumption practices. Future studies need to continue to investigate dietary intake both within and between communities in order to understand correlations between social change and consumption practices.

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References

Akhani, H., Trimborn, P., Ziegler, H., 1997. Photosynthetic pathways in Chenopodiaceae from Africa, Asia and Europe with their ecological, phytogeographical and taxonomical importance. Plant Syst. Evol. 206, 187–221.
Ambrose, S.H., 1993. Isotopic analyses of paleodiets: methodological and interpretive considerations. In: Sanford, M.K. (Ed.), Investigations of Ancient Human Tissue: Chemical Analyses in Anthropology. Gordon and Breach Science Publishers, Amsterdam, pp. 59–130.
Ambrose, S.H., Norr, L., 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: Lambert, J.B., Grupe, G. (Eds.), Prehistoric Human Bone: Archaeology at the Molecular Level. Springer-Verlag, Berlin, pp. 1–37.
Ambrose, S.H., Krigbaum, J., 2003. Bone chemistry and bioarchaeology. J. Anthropol. Archaeol 22, 193–199.
Anthony, D., 2007. The Horse, the Wheel, and Language. Princeton University Press, New Jersey.
Anthony, D., Brown, D., Brown, E., Goodman, A., Kokhlov, A., Kosintsev, P., Kuznetsov, P., Mochalov, O., Murphy, E., Peterson, D., Pike-Tay, A., Popova, L., Rosen, A., Russel, N., Weisskopf, A., 2005. The Samara valley project: Late Bronze Age economy and ritual in the Russian steppes. Eurasia Antiq. 11, 395–417.
Bachura, O.P., 2009. Determination of the season and age of slaughter of animals for the recording of the structure of the Ust'e settlement. In: Tairov, A.D., Ivanova, N.O. (Eds.), Ethnic Interactions in the Southern Urals: Collection of Scientific Papers. Russia, Chelyabinsk, pp. 31–33 (in Russian).
Balasse, M., Ambrose, S.H., Smith, A.B., Price, T.D., 2000. The seasonal mobility model for prehistoric herders in the south-western Cape of South Africa assessed by isotopic analysis of sheep tooth enamel. J. Archaeol. Sci. 29, 917–932.
Barfield, T.J., 1981. The Central Asian Arabs of Afghanistan: Pastoral Nomadism in Transition. University of Texas Press, Austin.
Barfield, T.J., 1993. The Nomadic Alternative. Prentice Hall, Englewood Cliffs.
Bendrey, R., 2011. Some like it hot: environmental determinism and the pastoral economies of the later prehistoric Eurasian steppe. Res. Policy Pract. 1, 8.
Britton, K., Muldner, G., Bell, M., 2008. Stable isotope evidence for salt-marsh grazing in the Bronze Age Severn Estuary, UK: implications for palaeodietary analysis at coastal sites. J. Archaeol. Sci. 35, 2111–2118.
Buikstra, J.E., Ubelaker, D.H., 1994. Standards: for data collection from human skeletal remains. In: Arkansas Archaeological Research Survey Series No. 44Arkansas Archaeological Survey, Fayetteville, pp. 217–231.
Cerling, T.E., Quade, J., 1993. Stable carbon and oxygen isotopes in soil carbonates. Climate change in continental isotopic records. Geophys. Monogr. 78, 217–231.
Chang, C., 2008. Mobility and sedentism of the Iron Age Agropastoralists of Southeast Kazakhstan. In: Barnard, H., Wendrich, W. (Eds.), The Archaeology of Mobility: Old World and New World Nomadism. University of California, Los Angeles, pp. 329–342.
Chang, C., Koster, H.A. (Eds.), 1994. Pastoralists at the Periphery: Herders in a Capitalist World. University of Arizona Press, Tuscon.
Chang, C., Benecke, N., Grigoriev, F.P., Rosen, A.M., Tourtellotte, P.A., 2003. Iron Age society and chronology in South-east Kazakhstan. Antiquity 77 (296), 298–312.
Cribb, R., 1991. Nomads in Archaeology. Cambridge University Press, New York.
Demkin, V.A., Demkina, T.A., 2002. Paleoecological crises and optima in the Eurasian steppes in ancient times and the middle ages. In: Jones-Bley, K., Zdanovich, D.G. (Eds.), Complex Societies of Central Eurasia from the 3rd to 1st Millennium BC, Vol IIInstitute for the Study of Man, Washington, DC, pp. 389–399.
DeNiro, M.J., 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature 317, 806–809.
DeNiro, M.J., Epstein, S., 1978. Influence of diet on the distribution of carbon isotopes in animals. Geochim. Cosmochim. Acta 42 (5), 495–506.
Di Cosmo, N., 2002. Ancient China and its Enemies: the Rise of Nomadic Power in East Asian History. Cambridge University Press, Cambridge.
Durrwachter, C., Craig, O.E., Collins, M.J., Burger, J., Alt, K.W., 2006. Beyond the grave: variability in Neolithic diets in Southern Germany. J. Archaeol. Sci. 33, 39–48.
Dyson-Hudson, R., 1980. Toward a general theory of pastoralism and social stratification. Nomadic Peoples 7, 1–7.
Epimakhov, A.V., 2010. On Sintashta agriculture: Bronze Age of the southern Urals. J. Archaeol. Anthropol. Ethnogr. 2 (13), 36–41 (in Russian).
Evdokimov, V.V., 1983. Chronology and periodization of monuments of the Bronze Age of Kostanai near the Tobol. In: Bronze Age Steppe Region between the Rivers Ural-Irtish. Bashkirskii Gosuniversitet, Chelyabinsk (in Russian).
Frachetti, M.D., 2002. Bronze Age exploitation and political dynamics of the Eastern Eurasian steppe zone. In: Boyle, K., Renfrew, A.C., Levine, M. (Eds.), Ancient Interactions: East and West in Eurasia, McDonald Institute Monographs, pp. 161–170 (Cambridge).
Frachetti, M.D., 2008a. Variability and dynamic landscapes of mobile pastoralism in ethnography and prehistory. In: Barnard, H., Wendrich, W. (Eds.), The Archaeology of Mobility: Old World and New World Nomadism. University of California, Los Angeles, pp. 366–396.
Frachetii, M.D., 2008b. Pastoralist Landscapes and Social Interaction in Bronze Age Eurasia. University of California Press, Berkeley.
Frachetti, M.D., Spengler, R.N., Fritz, G.J., Mar'yashev, A.N., 2010. Earliest direct evidence for broomcorn millet and wheat in the Central Eurasian steppe region. Antiquity 84, 993–1010.
Frachetti, M., Benecke, N., 2009. From sheep to (some) horses: 4500 years of herd structure at the pastoralist settlement of Begash (south-eastern Kazakhstan). Antiquity 83, 1023–1037.
Gayduchenko, L.L., 2002. The biological remains from the fortified settlements of the country of towns of the south Trans-Urals. In: Jones-Bley, K., Zdanovich, D.G. (Eds.), Complex Societies of Central Eurasia from the 3^{rd} to 1^{st} Millenium BC: Regional Specifics in Light of Global Models. Institute for the Study of Man, Washington, pp. 400–416.
Gayduchenko, L.L., 2005. Types of fauna from the Petrovka culture settlement Semiozornoe 2 in the southern Urals. In: The Third Inter-regional Scientific-practical Conference "Zyranovski Reading". Russia, Kurgan (in Russian).
Gayduchenko, L.L., 2010. Biological remains of the fortified settlements 'Country of Towns' south Trans-Urals. In: Tairov, A.D. (Ed.), Arkaim-Sintashta: Ancient Heritage of the Southern Urals (On the 70^{th} Birthday of G. B. Zdanovich). Chelyabinsk State University, Chelyabinsk (in Russian).
Gening, V.F., Zdanovich, G.B., Gening, V.V., 1992. Sintashta: Archaeological Sites of Aryan Tribes of the Ural-Kazakh Steppes. Russian Academy of Sciences, Chelyabinsk (in Russian).
Grigor'yev, S.A., 2000. Bronze Age: Ancient History of the Southern Trans-Urals. Southern Urals State University, Chelyabinsk (in Russian).
Habdulina, M.K., Zdanovich, G.B., 1984. Landscape-climate fluctuations and questions of culture-history situation in northern Kazakhstan. In: Bronze Age of the Region between the Rivers Ural-Irtysh. Russia, Chelyabinsk (in Russian).
Hanks, B.K., 2009. Late prehistoric mining, metallurgy, and social organization in north central Eurasia. In: Hanks, B.K., Linduff, K.M. (Eds.), Social Complexity in Prehistoric Eurasia: Monuments, Metals and Mobility. Cambridge University Press, Cambridge, pp. 146–167.
Hanks, B.K., Doonan, R., 2013. Research results from 2007–2012 by the Sintashta collaborative archaeology research project at the fortified settlements of Stepnoye and Ust'ye. In: The Environment and Cultural Development during the Bronze Age in the Southern Urals, Conference Held March 7–9, 2013, Frankfurt, Germany.
Harrison, R.G., Katzenberg, M.A., 2003. Paleodiet studies using stable carbon isotopes from bone apatite and collagen: examples from Southern Ontario and San Nicholas Island, California. J. Anthropol. Arch. 22, 227–244.
Heaton, T.H.E., 1987. The $^{15}N/^{14}N$ ratios of plants in South Africa and Namibia: relationship to climate and coastal/saline environments. Oecologia 74, 236–246.
Heaton, T.H.E., Vogel, J.C., von la Chevallerie, G., Collett, G., 1986. Climatic influence on the isotopic composition of bone nitrogen. Nature 322, 822–823.
Hart, J.P., Lovis, W.A., Schulenberg, J.K., Urquhart, G.R., 2007. Paleodietary implications from stable carbon isotope analysis of experimental cooking residues. J. Archaeol. Sci. 34, 804–813.
Hillson, S.W., 1979. Diet and dental disease. World Archaeol. 11 (2), 147–162.
Hillson, S.W., 1996. Dental Anthropology. Cambridge University Press, Cambridge.
Hollund, H.I., Higham, T., Belinskij, A., Korenevskij, S., 2010. Investigation of palaeodiet in the North Caucasus (South Russia) Bronze Age using stable isotope analysis and AMS dating of human and animal bones. J. Archaeol. Sci. 37 (12), 2971–2983.
Hoppe, K.A., Amundson, R., Vavra, M., McClaran, M.P., Anderson, D.L., 2004. Isotopic Analysis of tooth enamel carbonate from modern North American feral horses: implications for paleoenvironmental reconstructions. Palaeogeogr. Palaeoclimatol. Palaeoecol 203, 299–311.
Iacumin, P., Nikolaev, V., Genoni, L., Ramigni, M., Ryskov, Ya.G., Longinelli, A., 2004. Stable isotope analyses of mammal skeletal remains of Holocene age from European Russia: a way to trace dietary and environmental changes. Geobios 37, 37–47.
Judd, M.A., Kovacik, M.E., Hanks, B.K., Rajev, D., Epimakhov, A.V., 2009. Mining the steppes: community health during the Sintashta period. In: Paper Given at the Seventy-eighth Annual Meeting of the American Association of Physical Anthropologists.

Kalieva, S.S., Logvin, V.N., 2009. Cemetery of the settlement of Bestamak: preliminary report. J. Archaeol. Anthropol. Ethnogr. 9, 32–58. Russia, Tyumen (in Russian).

Katzenberg, A.M., Goriunova, O.I., Weber, A., 2009. Paleodiet reconstruction of Bronze Age Siberians from the mortuary site of Khuzhir-Nuge XIV, Lake Baikal. J. Archaeol. Sci. 36, 663–674.

Katzenberg, A.M., McKenzie, H.G., Losey, R.J., Goriunova, O.I., Weber, A., 2012. Prehistoric dietary adaptations among hunter-fisher-gatherers from the Little Sea of Lake Baikal, Siberia, Russian Federation. J. Archaeol. Sci. 39, 2612–2626.

Katzenberg, A.M., Weber, A., 1999. Stable Isotope Ecology and Palaeodiet in the Lake Baikal Region of Siberia. J. Archaeol. Sci. 26, 651–659.

Khazanov, A.M., 1978. Characteristic features of nomadic communities in the Eurasian steppes. In: Weissleder, W. (Ed.), The Nomadic Alternative: Modes and Models of Interaction in the African-Asian Deserts and Steppes. Mouton Publishers, The Hague/Paris.

Khazanov, A.M., 1984. Nomads and the Outside World. The University of Wisconsin Press, Madison.

Kohl, P.L., 2007. The Making of Bronze Age Eurasia. Cambridge University Press, Cambridge.

Koryakova, L., Epimakhov, A., 2007. The Urals and Western Siberia in the Bronze and Iron Ages. Cambridge University Press, Cambridge.

Kosintsev, P.A., 2000. Bone remains of animals from the fortified settlement of Arkaim. In: Zdanovich, G.B., Zdanovich, S.Ya. (Eds.), Archaeological Sources and Models for Ancient Technologies: Work of the Museum-reserve Arkaim, Chelyabinsk (in Russian).

Kosintsev, P.A., 2003. Typology of archaeozoological complexes and animal models of ancient populations in southwestern Siberia. In: The Latest Archaeozoological Research in Russia: on the Centenary Birthday of V. I. Tsalkina. Languages of Slavic Culture, Moscow (in Russian).

Kosintsev, P.A., 2010. Problems of studying the economy of the Sintashta culture. In: Tairov, A.D. (Ed.), Arkaim-Sintashta: Ancient Heritage of the Southern Urals (On the 70th Birthday of G. B. Zdanovich). Chelyabinsk State University, Chelyabinsk (in Russian).

Kosintsev, P.A., Gasilin, V.V., 2009. Bone complexes at the Sintashta Site. In: Tairov, A.D., Ivanova, N.O. (Eds.), Ethnic Interactions in the Southern Urals: Collection of Scientific Papers. Chelyabinsk (in Russian).

Kradin, N.N., 2002. Nomadism, evolution and world-systems: pastoral societies in theories of historical development. J. World-Syst. Res. VII (III), 368–388.

Krause, R., Koryakova, L.N., Fornasier, J., Sharapova, S.V., Epimakhov, A.V., Panteleeva, S.E., Berseneva, N.A., Molchanov, I.V., Kalis, A.J., Stobbe, A., Thiemeyer, H., Wittig, R., König, A., 2010. Befestigte Siedlungen der Bronzezeitlichen Sintasta-Kultur in Transural, Westsibirien (Russische Föderation). Fortified settlements of the Bronze Age Sintashta culture in the Transurals, Western Siberia (Russian Federation). Eurasia Antiq. 16, 97–129 (in German).

Krause, R., Fornasier, J., 2013. New research in the Karagaily Ayat region. In: The Environment and Cultural Development during the Bronze Age in the Southern Urals, Conference Held March 7-9, 2013, Frankfurt, Germany.

Kremenetski, C.V., Tarasov, P.E., Cherkinsky, A.E., 1997. Postglacial Development of Kazakhstan Pine Forests. In: Géographie physique et Quaternaire, 51 (3), pp. 391–404.

Kuz'mina, E.E., 2007. The Origin of the Indo-Iranians. Koninklijke Brill NV, Leiden.

Leonard, W.R., Crawford, M.H., 2002. The Human Biology of Pastoral Populations. Cambridge University Press, Cambridge.

Lillie, M.C., 1996. Mesolithic and Neolithic populations of Ukraine: indications of diet from dental pathology. Curr. Anthropol. 37 (1), 135–142.

Lillie, M.C., Richards, M.P., 2000. Stable isotope analysis and dental evidence of diet at the Mesolithic-Neolithic transition in Ukraine. J. Archaeol. Sci. 27, 965–972.

Lillie, M.C., Budd, C., Potekhina, I., 2011. Stable isotope analysis of prehistoric populations from the cemeteries of the Middle and Lower Dnieper Basin, Ukraine. J. Archaeol. Sci. 38, 57–68.

Lindstrom, R.W., 2002. Anthropological characteristics of the population of the Bolshekaraganski cemetery, kurgan 25. In: Arkaim: Necropolis: By the Material of Mound 25 Bolshekaraganskogo Burial: Book 1 (Chelyabinsk).

Logvin, A.V., Shevnina, I.V., 2004. Research of the Bestamak cemetery in the field season 2003. In: Akhizhanovskie Chteniya – 2004. Almaty (in Russian).

Logvin, A.V., Shevnina, I.V., 2008. Elite Burial of the Sintashta-Petrovka Period in the Cemetery of Bestmak. Kostanai Governmental University, Kostanai (in Russian).

Logvin, A., Sevnina, I., 2013. The cemetery of Bestamak. In: Stöllner, T., Samašev, Z. (Eds.), Unknown Kazakhstan: Archaeology in the Heart of Asia, Catalog of the Exhibition of the German Mining Museum, vol. I. Bochum (in German).

Logvin, A.V., Shevnina, I.V., Kolbina, A.V., 2009. Burial of elderly women in the Bestamak cemetery: study of historical and cultural heritage of Central Asia. In: Collection of Material from the International Scientific Conference 'Margulanovskie Reading – 2008', Karaganda (in Russian).

Logvin, V.N., 2002. The cemetery of Bestamak and the structure of the community. In: Jones- Bley, K., Zdanovich, D.G. (Eds.), Complex Societies of Central Eurasia from the 3rd to 1st Millenium BC: Regional Specifics in Light of Global Models. Institute for the Study of Man, Washington, pp. 189–201.

Matveev, A.V., Ryabogina, N.E., Semochkina, T.G., Larin, S.I., 2002. Materials on the Paleogeographic Description of the Andronovo Age in the Trans-Urals Forest-Steppe. In: Jones-Bley, K., Zdanovich, D.G. (Eds.), Complex Societies of Central Eurasia from the 3rd to 1st Millennium BC, Vol IIInstitute for the Study of Man, Washington, D.C, pp. 443–454.

Mays, S.A., Richards, M.P., Fuller, B.T., 2002. Bone stable isotope evidence for infant feeding in Mediaeval England. Antiquity 76, 654–656.

Pathways to complexity: an African perspective. In: McIntosh, S.K. (Ed.), Beyond Chiefdoms: Pathways to Complexity in Africa. Cambridge University Press, Cambridge, pp. 1–30.

Milner, G.R., 1992. Determination of Skeletal Age and Sex: a Manual Prepared for the Dickinson Mounds Reburial Team (Manuscript on file). Dickson Mounds Museum, Lewiston, Illinois.

Morales-Muniz, A., Antipina, E., 2003. Srubnaya fauna and beyond: a critical assessment of the archaeozoological information from the East European Steppe. In: Levine, M., Renfrew, C., Boyle, K. (Eds.), Prehistoric Steppe Adaptation and the Horse. McDonald Institute for Archaeological Research, Cambridge, pp. 329–351.

Murphy, B.P., Bowman, D.M.J.S., 2006. Kangaroo metabolism does not cause the relationship between bone collagen δ^{15}N and water availability. Funct. Ecol 20, 1062–1069.

Murphy, E.M., Shulting, R., Beer, N., Chistov, Y., Kasparov, A., Pschentsyna, M., 2013. Iron Age pastoral nomadism and agriculture in the eastern Eurasian steppe: Implications from dental paleopathology and stable carbon and nitrogen isotopes. J. Archaeol. Sci. 40, 2547–2560.

Ng, C.Y., 2013. Archaeobotanical evidence for Bronze Age subsistence economy and social complexity (2100-1750 BCE)at the Stepnoye settlement, Russia. In: European Association of Archaeologists Annual Meeting 2013, Plzen, Czech Republic.

O'Connell, T.C., Levine, M.A., Hedges, R.E.M., 2003. The Importance of fish in the diet of central Eurasian peoples from the mesolithic to the early iron age. In: Levine, M.A., Renfrew, A.C., Boyle, K. (Eds.), Prehistoric Steppe Adaptation and the Horse, McDonald Institute Monograph. McDonald Institute for Archaeological Research, Cambridge, pp. 253–268.

O'Leary, M.H., 1988. Carbon isotopes in photosynthesis. BioScience 38 (5), 328–336.

Outram, A.K., Stear, N.A., Bendrey, R., Olsen, S., Kasparov, A., Zaibert, V., Thorpe, N., Evershed, R.P., 2009. The earliest horse harnessing and milking. Science 323, 1332–1335.

Outram, A.K., Stear, N.A., Kasparov, A., Usmanova, E., Varfolomeev, V., Evershed, R.P., 2010. Horses for the dead: funerary foodways in Bronze Age Kazakhstan. Antiquity 85, 116–128.

Palumbo, G., 1987. "Egalitarian" or "Stratified" Society? Some notes on mortuary practices and social structure at Jericho in EB IV. Bull. Am. Sch. Orient. Res. 267, 43–59.

Panyushkina, I.P., Mills, B.J., Usmanova, E.R., Cheng, L., 2008. Calendar age of Lisakovsky timbers attributed to Andronovo community of Bronze Age in Eurasia. Radiocarbon 50 (3), 459–469.

Potemkina, T.M., 1983. On the origins of the Alakul' culture in the Tobol region. In: Bronze Age Steppe Region between the Rivers Ural-Irtish. Bashkir State University, Chelyabinsk (in Russian).

Powell, M.L., 1985. The analysis of dental wear and caries for dietary reconstruction. In: Gilbert Jr., R.I., Mielke, J.H. (Eds.), The Analysis of Prehistoric Diets. Academic Press, Orlando.

Privat, K., 2002. Preliminary report of palaeodietary analysis of human and faunal remains from Bolshekaragansky kurgan 25. In: Arkaim: Necropolis (By the Material of Mound 25 Bolshekaraganskogo Burial: Book 1) (Chelyabinsk).

Privat, K., 2004. Investigation of the Diet of Eurasian Bronze and Iron Age Populations, Focusing on Terrestrial versus Freshwater Resources (Unpublished Doctoral dissertation). University of Oxford.

Privat, K., O'Connell, T.C., Richards, M.P., 2002. Stable isotope analysis of human and faunal remains from the Anglo-Saxon cemetery at Berinsfield, Oxfordshire: dietary and social implications. J. Archaeol. Sci. 29, 779–790.

Privat, K., Schneeweib, J., Benecke, N., Vasil'ev, S.K., O'Connell, T., Hedges, R., Craig, O., 2005. Economy and diet at the Late Bronze Age-Iron Age site of Čiča: artefactual, archaeozoological and biochemical analyses. Eurasia Antiq. 11, 419–448.

Rachkovskaya, E.I., Bragina, T.M., 2012. Steppes of Kazakhstan: Diversity and present state. In: Werger, M.J.A., van Staalduinen, M.A. (Eds.), Eurasian Steppes, Ecological Problems and Livelihoods in a Changing World, Plant and Vegetation, vol. 6, pp. 103–148.

Richards, M.P., Hedges, R.E.M., 1999. Stable isotope evidence for similarities in the types of marine foods used by Late Mesolithic humans at sites along the Atlantic coast of Europe. J. Archaeol. Sci. 26, 717–722.

Richards, M.P., Pettitt, P.B., Stiner, M.C., Trinkaus, E., 2001. Stable isotope evidence for increasing dietary breadth in the European mid-Upper Paleolithic. Proc. Nat. Acad. Sci. 98 (11), 6528–6532.

Rühl, L., Herbig, C., Stobbe, A., 2013. Food, fodder, and timber: plant use in the fortified Bronze Age settlement of Kamennyj Ambar in the Transurals-Steppe (Russia) Plant macro-remains and charcoal analyses. In: Poster Presented at the 16th IWGP Conference in Thessaloniki.

Rubenstein, D.R., Hobson, K.A., 2004. From birds to butterflies: animal movement patterns and stable isotopes. Trends Ecol. Evol. 19 (5), 256–263.

Schoeninger, M.J., DeNiro, M.J., 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. Geochim. Cosmochim. Acta 48, 625–639.

Schoeninger, M.J., Moore, K.M., Murray, M.L., Kingston, J.D., 1989. Detection of bone preservation in archaeological fossil samples. Appl. Geochem. 4, 281–292.

Schulenberg, J.K., 2002. The Point Peninsula to Owasco Transition in Central New York (Unpublished PhD dissertation). Department of Anthropology, The Pennsylvania State University, University Park, Pennsylvania.

Schulting, R.J., Richards, M.P., 2013. Stable isotope analysis of Neolithic to Late Bronze Age populations in Samara valley. In: Anthony, D.W., Brown, D.R., Khokhlov, A.A., Kuznetsov, P.F., Mochalov, O.D. (Eds.), The Samara Valley Project: a Bronze Age Landscape in the Russian Steppes (in press).

Scott, E.C., 1979. Dental wear scoring technique. Am. J. Phys. Anthropol. 51, 213–218.

Schwarcz, H.P., Melbye, J., Katzenberg, M.A., 1985. Stable isotopes in human skeletons of southern Ontario: reconstructing paleodiet. J. Archaeol. Sci. 12, 187–206.

Shevnina, I.V., 2003. Monuments of the Sintashta-Petrovka type. In: Akhatov, G.A., Bermagambetov, A.Zh., Loshakova, T.N. (Eds.), Akhinzhanovskie Readings – 2002. Almaty (in Russian).

Shevnina, I.V., Boroshilova, S.A., 2009. Child burials of the advanced bronze age: based on materials from Bestamak. In: Tairov, A.D., Ivanova, N.O. (Eds.), Ethnic Interactions in the Southern Urals. Publishing Center YuUrGU, Chelyabinsk (in Russian).

Shishlina, N.I., Zazovskaya, E.P., van der Plicht, J., Hedges, R.E.M., Sevanstyanova, V.S., Chicagova, O.A., 2009. Paleoecology, subsistence, and ^{14}C chronology of the Eurasian Caspian steppe bronze age. Radiocarbon 51 (2), 491–499.

Shishlina, N.I., van der Plicht, J., Hedges, R.E.M., Zazovskaya, E.P., Sevanstyanov, V.S., Chicagova, O.A., 2007. The Catacomb cultures of the North-west Caspian steppe: ^{14}C chronology, reservoir effect, and paleodiet. Radiocarbon 49 (2), 713–726.

Shishlina, N.I., Sevastyanov, V., Hedges, R.E.M., 2012. Isotope ratio study of Bronze Age samples from the Eurasian Caspian Steppes. In: Kaiser, E., Burger, J., Schier, W. (Eds.), Population Dynamics in Prehistory and Early History. New Approaches by Using Stable Isotopes and Genetics, de Gruyter, pp. 177–197.

Sikora, M., 2007. The Oxygen and Carbon Isotopic Compositions of Modern and Archaeological Horse (Equid) Teeth from North Kazakhstan (M.A. thesis). University of Pittsburgh, Department of Geology and Planetary Sciences and University Honors College.

Smith, B.N., Epstein, S., 1971. Two categories of 13C/12C ratios for higher plants. Plant Physiol. 47, 380–384.

Sokolov, A., 1968. Agrochemical Characteristics of Soils of the USSR – Kazakhstan and Chelyabinsk Regions. Science, Moscow (in Russian).

Spengler, R.N., Frachetti, M.D., Fritz, G.J., 2013a. Ecotopes and herd foraging practices in the Steppe/Mountain ecotone of central Asia during the Bronze and Iron Ages. J. Ethnobiol. 33 (1), 125–147.

Spengler, R.N., Chang, C., Tourtellotte, P.A., 2013b. Agricultural production in the Central Asian mountains: Tuzusai, Kazakhstan (410-150 B.C.). J. Field Archaeol. 38 (1), 68–85.

Stacy, E., 2008. Stable Isotopic Analyses of Equid (Horse) Teeth from Mongolia (B.A. thesis). University of Pittsburgh, Department of Geology and Planetary Sciences and University Honors College.

Stobbe, A., Rühl, L., Nekrasov, A.E., Kosintsev, P.A., 2013. Fish - an important dietary component in the settlement of Kamennyi Ambar (Siberia). In: Krause, R., Koryakova, L. (Eds.), Multidisciplinary Investigations of the Bronze Age Settlements in the Southern Transurals (Russia), Frankfurter Archäologische Schriften, p. 23 (Bonn).

Svyatko, S.V., Schulting, R.J., Mallory, J.P., Murphy, E.M., Reimer, P.J., Khartanovich, V.I., Chistov, Y.K., Sablin, M.V., 2013. Stable isotope dietary analysis of prehistoric populations from the Minusinsk Basin, Southern Siberia, Russia: a new chronological framework for the introduction of millet to the eastern Eurasian steppe. J. Archaeol. Sci. 40, 3936–3945.

Tkacheva, N.A., 1999. Dynamics and character in the development of Bronze Age settlement complexes in the upper Irish. J. Archaeol. Anthropol. Ethnogr. 2. Russia, Tyumen (In Russian).

Tieszen, L.L., 1991. Natural Variations in the carbon isotope values of plants: implications for Archaeology, Ecology, and Paleoecology. J. Archaeol. Sci. 18, 227–248.

Toderich, K., Black, C.C., Juylova, E., Kozan, O., Mukimov, T., Matsuo, N., 2007. C3/C4 plants in the vegetation of Central Asia, geographical distribution and environmental adaptation in relation to climate. In: Lal, R., Suleimenov, M., Stewart, B.A., Hansen, D.O., Doraiswamy, P. (Eds.), Climate Change and Terrestrial Carbon-Sequestration in Central Asia. Taylor and Francis, London, pp. 33–64.

Usmanova, E.R., 2005. Lisakovsk Burials I: Facts and Parallels. Karaganada State University in Honor of E.A. Buketov, Lisakovsk Museum of the History and Culture of the Tobol River, Kazakhstan, Karaganda-Lisakovsk (in Russian).

Usmanova, E.R., 2010. Womens Costumes during the Bronze Age in Kazakhstan: an experience in reconstruction. Kazakhstan, Karaganda-Lisakovsk (in Russian).

Usmanova, E.R., Logvin, V.H., 1998. Women's Decorations of Kazakhstan: Bronze Age. Karaganada State University in Honor of E.A. Buketov, Kostanai State University in Honor of A. Baitursinova, Lisakovsk Museum of the History and Culture of the Tobol River, Kazakhstan, Karaganda-Lisakovsk (in Russian).

Usmanova, E.R., Merts, V.K., Kolbina, A.V., Ventresca, A., 2005. On the Subject of 'Text' in Funeral Ceremonies during the Bronze Age. In: The Study of Archaeological Monuments in the Pavlodar along the Irtish. Pavlodar Governmental University in Honor of S. Toraigirov, Kazakhstan, Pavlodar (in Russian).

Ventresca Miller, A.R., 2013. Social Organization and Interaction in Bronze Age Eurasia: a Bioarchaeological and Statistical Approach to the Study of Communities (Unpublished dissertation). Department of Anthropology, Pittsburgh, Pennsylvania.

White, C.D., Pendergast, D.M., Longstaffe, F.J., Law, K.R., 2001. Social complexity and food systems at Altun Ha, Belize: the isotopic evidence. Latin Am. Antiq. 12 (4), 371–393.

Wild, E.M., Arlamovsky, K.A., Gosler, R., Kutschera, W., Piler, A., Puchegger, S., 2000. ^{14}C dating with bomb peak: an application for forensic medicine. Nucl. Instrum. Methods Phys. Res. B 172 (1–4), 944–950.

Zdanovich, D.G., 1997. Sintashta Society: The Social Foundations of 'Quasi-city' Culture in the Southern Urals during the Bronze Age. Chelyabinsk State University, Chelyabinsk (in Russian).

Zdanovich, G.B., Zdanovich, D.G., 2002. The "Country of Towns" of southern transurals and some aspects of steppe assimilation in the Bronze Age. In: Boyle, K., Renfrew, A.C., Levine, M. (Eds.), Ancient Interactions: East and West in Eurasia, McDonald Institute Monographs, pp. 249–264 (Cambridge).