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Abstract

The West Eurasian steppes during the Eneolithic, the Early and Middle Bronze and the Iron Age were largely inhabited by communities believed to show an elevated level of spatial mobility, often linked to their subsistence economy. In this doctoral thesis, questions concerning the mobility and migration as well as the diet and economy of these, in some sense mobile communities were approached by applying isotope analyses, particularly $^{87}Sr/^{86}Sr$, $\delta^{18}O$, $\delta^{15}N$ and $\delta^{13}C$ analyses. Adapting these methods to a study area of extremely large spatial and chronological dimensions and to a proportionally undersized sample set certainly tested the limits of the methods, but it also allowed a wide variety of questions to be answered.

Mobility and Diet; Isotope Analysis; West Eurasian Steppes; Eneolithic; Early and Middle Bronze Age; Iron Age.

Die westeurasische Steppenzone wurde im Äneolithikum, in der Früh- und Mittelbronzezeit und der Eisenzeit von Gemeinschaften besiedelt, für die ein gewisser Grad an räumlicher Mobilität, zumeist in Zusammenhang mit ihrer Subsistenzwirtschaft, angenommen wird. In einer Promotionsstudie wurden Fragen nach Mobilität und Migration sowie Ernährung und Wirtschaftsweise dieser in unterschiedlichem Maß mobilen Gemeinschaften mittels Isotopenanalysen, genauer $^{87}Sr/^{86}Sr$-, $\delta^{18}O$-, $\delta^{15}N$- und $\delta^{13}C$-Analysen, nachgegangen. Die Anwendung dieser Methoden auf einen räumlich und zeitlich sehr weitgefassten Untersuchungsrahmen und auf eine in Relation dazu sehr geringe Datengrundlage stieß hier zwar sicherlich an ihre Grenzen, ermöglichte aber ebenso die Beantwortung einer Vielzahl an Fragestellungen.

Mobilität und Ernährung; Isotopenanalysen; westliche Eurasische Steppe; Äneolithikum; frühe und mittlere Bronzezeit; Eisenzeit.

1 Introduction

Archaeological research frequently focuses on questions concerning the mobility, migration, subsistence strategies and diet of prehistoric communities. In this respect the communities that inhabited the West Eurasian steppes in the 4th, 3rd and 1st millennia BC are of special interest and were the subject of a doctoral dissertation[1] which is summarized in this article.

The wide dispersion of homogeneous burial traditions and cultural remains as well as the numerical mismatch between settlement structures and burials have led researchers to regard Late Eneolithic and particularly Early Bronze Age steppe communities as leading a mobile form of life that is often described as semi nomadic or pastoralist. Animal bone assemblages from excavated settlements dating to the Early Bronze Age support this idea by providing evidence of a change to a subsistence economy based on predominant cattle husbandry.[2] This might be interpreted as an adjustment to changes in climate, since climate modeling suggests that an aridisation process began to occur approximately contemporaneously.[3] The emergence of wagon (part) depositions in burial contexts suggests a potential correlation between this period's spatially effective innovations such as specialized mobile herding and the use of wagons and draught animals and a measurable increase

1 This PhD thesis entitled 'Prehistoric Mobility and Palaeodiet in Western Eurasia. Stable Isotope Analysis of Human Populations and Domesticated Animals between 3500 and 300 BC' was written within research group A II of the Excellence Cluster Topoi, which investigated the spatial effects of technological innovations and changing ways of life, and was defended on July 18th, 2012, Gerling 2012. It will be published entitled 'Prehistoric Mobility and Diet in the West Eurasian Steppes 3500 to 300 BC – An Isotopic Approach', Gerling (in press).

2 Cf. e. g., Čenych, Antipina, and Lebedeva 1998, 244; Kaiser 2012, fig. 83–85.

3 Körper, Wagner, and Cubasch (in press); cf. also Weninger et al. 2009, esp. 34–50.

in mobility. In general, it can be assumed that the mobility level is most restricted in settled communities, while it gradually increases in semi-nomadic societies and peaks in mainly nomadic people such as the mounted nomads of the Scythian period. In addition to regular movements due to specialized herding practices, there is evidence suggesting that migrations into the Carpathian-Balkan regions occurred among the Early Bronze Age steppe people. Due to the fact that archaeological approaches have not yielded satisfactory answers to questions regarding the lifestyle, economy, interregional interactions and potential migrations of steppe communities, stable isotope analysis was applied so that answers could be found by scientific means.

2 Research Objectives and Data Sources

Key objectives were to reconstruct potential mobility and dietary patterns for each study site as well as to compare the data obtained from isotopic analysis at a regional and supra-regional level. Furthermore, the isotopic data from the periods before and after approximately 3000 BC were compared in order to identify changes connected with the introduction of specialized stockbreeding, the early deposition of wagons in burial contexts and an incipient aridisation process. All these might be reasons for lifestyle shifts potentially implying an increased level of mobility. A basis of comparison for the Eneolithic, Early and Middle Bronze Age[4] data was provided by samples dating to the Iron Age. Since the emergence of fully-fledged nomadism and mounted warfare are closely linked to the Scythian communities, (at least parts of) these populations can be considered highly mobile.[5] Finally, the applied methods were tested to determine their potential and their limitations.

In this context almost 400 samples, including tooth enamel samples and references, deriving from 27 sites (Fig. 1) were selected for $^{87}Sr/^{86}Sr$, $\delta^{18}O$, $\delta^{15}N$ and $\delta^{13}C$ analyses. The study covers a vast area, which was subdivided into sub-regions or single sites; Bulgaria and Hungary in the Carpathian-Balkan region, Central and Eastern Ukraine in the North Pontic region, the Kuban region, the northwest Caspian steppes and the Middle and Lower Volga region in Russia, and the Altai Mountains in Kazakhstan. The studied sites predominantly date to four different time periods: the late Eneolithic period in the second half of the 4th millennium BC, the Early and Middle Bronze Age with the Yamnaya culture, which thrived mainly in the first half of the 3rd millennium BC, and the Early and Developed Catacomb culture in the late first and the second half of the 3rd millennium BC, and finally, the Iron Age with the Scythian period corresponding to the 1st millennium BC. Altogether, 142 human specimens were selected for strontium and oxygen isotope analyses. Such analyses are frequently used in mobility studies and are commonly performed on tooth enamel, which is relatively stable against diagenetic alteration.[6] Depending on the choice of tooth, enamel mineralization occurs over a period of several months to years and remains mostly unchanged in its chemical composition.[7] Both primary and secondary dentition develops during childhood; therefore it reflects the isotopic signal of infancy and early youth.[8] Furthermore, this means the isotopic signals of later stages in life cannot be determined by analyzing tooth enamel.

4 Following the Russian terminology the Yamnaya culture belongs to an early and the Catacomb culture to a subsequent phase of the Bronze Age.
5 E. g., Khazanov 1984, 19–21.
6 Hillson 1996, 181, 224; Tütken, Vennemann, and Pfretzschner 2004, 92.
7 Hillson 1996, 148–149.
8 Lowenstam and Weiner 1989, 147; Sealy, Armstrong, and Schirre 1995, 290.

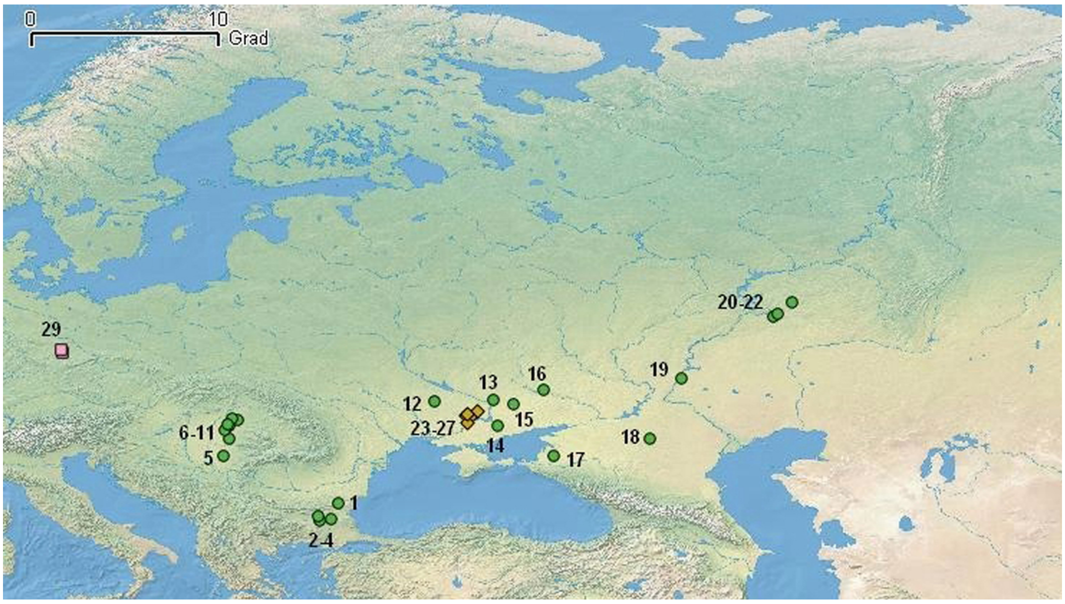

Fig. 1 | Map of sites: 1 Smyadovo, 2 Benkovski, 3 Ovchartsi, 4 Boyanovo, 6 Balmazújváros, 7 Debrecen, 8 Püspökladány, 9 Sárrétudvari, 10 Dévaványa, 11 Kétegyháza, 12 Kirovograd, 13 Peshtchanka, 14 Vinogradnoe, 15 Shakhta Stepnaya, 16 Nevskoe, 17 Olennii, 18 Sukhaya Termista II, 19 Politotdelskoe, 20 Nikolaevka, 21 Podlesnyi, 22 Kalinovka (all 4th/3rd Millennium BC), 23 Alexandropol, 24 Babina Mogila, 25 Drana Kokhta, 26 Ordzhonikidze, 27 Zolotaya Balka, 28 Berel (all 1st Millennium BC), 29 Zauschwitz (Globular Amphora Culture, 4th/3rd Millennium BC). – 5 Uivar was investigated in another context.

51 human specimens[9] were chosen for supplemental carbon and nitrogen isotope analysis. This type of analysis is used in dietary studies and is mainly applied to the collagen fraction of bone and tooth dentine. Unlike tooth enamel, bone reflects the last years and decades of an individual's lifetime,[10] which is why the results of the mobility and dietary studies can only be tentatively compared.

In sampling, the principle of gaining representative chronological and chorological cross sections was observed. However the statistical relevance of sample sizes per site and sampled region, and the numerical consistency of sex, age and chronological groups, were unfortunately not taken into consideration. These factors complicated data evaluation significantly.

3 Archaeological Background

The earliest sampled skeletons date to the late Eneolithic period, which – in this area – covers the second half of the 4th millennium BC. During this period, a variety of heterogeneous burial traditions were distributed throughout the East European steppes. It is a matter of debate, however, whether these traditions equal cultural groups and/or anthropological identities.[11] In adapting to local ecological conditions, Late Eneolithic steppe communities are thought to have adopted different economy types such as hunting, farming and animal herding, and an economy based on mobile animal herding is proposed for some of these groups.[12] Wide ranging cultural interactions in the areas west

9 Results were obtained from 51 bones and 7 teeth deriving from 51 human individuals.
10 Knipper 2004, 611–615 including a detailed discussion on the turnover rate of bone.
11 Rassamakin 1999, Rassamakin 2004.
12 Rassamakin 1999, 147–151; Bunyatyan 2003, 272; Anthony 2007, 269.

of the North Pontic steppes and the Caucasus are in evidence, and migrations associated with the gradual decline of the Tripolye culture have been discussed.[13]

Despite burial mounds being present as early as the second half of the 4th millennium BC in the context of several Eneolithic steppe cultures, they did not become the predominant form of burial construction until the time of the Yamnaya or Pit Grave culture (dating to the late 4th to the middle or later 3rd millennium BC).[14] The homogeneous burial tradition of the Yamnaya culture is widely distributed across the West Eurasian steppes from the southern Ural Mountains and into the Carpathian-Balkan region. Supra-regional characteristics include supine burials with crouched legs or crouched burials, laid out in rectangular or oval pits and covered by burial mounds (kurgans). Burial pits may also be covered by wood or stone coverings. Ochre coloring, the addition of ceramics and bone pins, the deposition of wagon (parts) and the general scarcity of burial objects are further cultural elements common to the Yamnaya culture.[15] Despite these unifying characteristics, regional variants can be distinguished. Although the economic basis of the Yamnaya communities is a subject of controversy, it is mainly considered to be based on mobile animal husbandry.[16] Scant evidence of settlements and the distribution of burial mounds in the open steppes are also seen as indicators of an increased degree of mobility.[17]

An early phase of the Catacomb culture emerges in the first half of the 3rd millennium BC in the Northeast Pontic region and coexists with the Yamnaya culture for several centuries. Later, a developed form of the Catacomb culture spread across large parts of the North Pontic region between the lower and middle Volga and the Caspian Sea in the East and the Prut River and the mouth of the Danube in the West.[18] Evidence of the kind of wide-ranging cultural interactions known to have taken place in the preceding period is mostly missing.[19] Although there are a variety of distinct regional variants, particularly in the developed phase of the Catacomb culture, a number of general characteristics can be distinguished. Burials, ranging from supine positions on the back to tightly crouched ones, are executed in catacomb constructions underneath recently erected or already existing burial mounds. Burial objects vary regionally and are generally modest and uniform, although the number of objects increases in comparison to the preceding Yamnaya culture.[20] The most common objects are ceramic vessels and bone adornment such as hammer-headed pins in the early phase of the Catacomb culture. The entrances to the burial chambers may be blocked by stones or wood and chambers may be furnished with organic material. In some regional variants burial elements such as metal objects, wagon (part) depositions, ochre coloring and clay-modeled skulls occur.[21]

Five North Pontic necropolises of the 1st millennium BC were additionally selected for isotopic analysis, since a high mobility level among the Scythians is suggested by archaeological and specifically by written sources.[22]

13 Rassamakin 2004, 184–185.
14 E. g., Kohl 2007, 264 [adapted from Trifonov (2001), 75 table 1 (in Russian)]; Rassamakin and Nikolova 2008, 67.
15 E. g., Kaiser 2011; cf. Shishlina 2008, 43–86 for Yamnaya characteristics in the Caspian Steppes.
16 E. g., Rassamakin 1999, 151–154; Bunyatyan 2003, 274–276; Shishlina 2008, 244.
17 Cf. Kohl 2007, 144.
18 Kaiser 2003, 2.
19 Lichardus and Lichardus-Itten 1995, 53; Kaiser 2003, 273–332.
20 Kaiser 2011, 204–205.
21 Ślusarska 2006, 46; Shishlina 2008, 132–134; Otroschenko 2010, 32.
22 E. g., Parzinger 2004, 25–28 including ancient authors; Parzinger 2009, 17; Scoryi 2010, 70.

4 Mobility and Migration

4.1 Fundamentals and Methods

Strontium and oxygen isotope analyses were applied to investigate mobility patterns. Strontium isotope analysis is based on differences in underlying geology, or more precisely, in the isotope ratios in rocks and associated sediments, which vary according to their age and composition.[23] Younger, rubidium-poor rocks result in lower $^{87}Sr/^{86}Sr$ ratios, while older rocks with higher rubidium concentrations yield higher $^{87}Sr/^{86}Sr$ ratios. Through weathering processes the $^{87}Sr/^{86}Sr$ signature of rocks reaches the soil and ground water, where it is taken up by plants. Without undergoing significant fractionation, the $^{87}Sr/^{86}Sr$ ratio enters animals and humans primarily through food, but also through drinking water and air, and is incorporated in hard tissues such as tooth and bone.[24]

Oxygen isotope analysis, by contrast, depends on local variations in ratios of ^{18}O to ^{16}O in water that are caused by the following: distance from the ocean, temperature, precipitation and geographic location.[25] Through drinking water, and to a much lesser extent food and air, the oxygen isotope ratio of local precipitation water is taken up by animals and humans, and in contrast to strontium undergoes considerable fractionation in the process.[26]

The $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ ratios of humans and animals are best determined by analyzing tooth enamel, due to its relatively high resistance to diagenetic alteration.[27] Comparing the strontium and oxygen isotope ratios in tooth enamel which represent the childhood with the expected and measured levels in the burial places enables differentiations to be made between 'local' and 'non-local' or migrated individuals. For this purpose an isotopic characterization of the surroundings of the burial mounds is needed. The expected regional oxygen isotope ranges in the study area were modeled on the basis of the Online Isotopes in Precipitation Calculator[28] and the modern precipitation data published by the International Atomic Energy Agency[29]. Because of temporal climatic differences these values are not entirely equivalent to prehistoric values, which is why they were compared to the mean values measured in human and faunal tooth enamel and discussed with respect to their reliability. The large size of the study area made an initial area-covering modeling of expected values possible. The estimation of the 'local' $^{87}Sr/^{86}Sr$ range is more easily determined. An initial approximation of expected strontium isotope ratios is obtained by consulting a geological map[30]. However, the underlying geology does not necessarily indicate the amount of biologically available strontium in the vicinity of the burial place.[31] For this reason additional soil samples, plants and faunal remains as well as human dentine and bone samples were collected. A combination of a variety of references proved to be the most suitable basis for establishing the 'local' $^{87}Sr/^{86}Sr$ range, although not every site exhibited this kind of diversity. Site-specific $^{87}Sr/^{86}Sr$ ranges were calculated based on the means of all the references, taking into consideration double standard variations and excluding outliers that may have been contaminated.

Finally, maps of expected values were created for each study region on the basis of the estimated 'local' strontium and oxygen isotope ranges.

23 Faure 1977; Ericson 1985.
24 E. g., Knipper 2004; Bentley 2006.
25 Sharp 2007, 80–86.
26 Hoefs 1997, 3–18.
27 Tütken, Vennemann, and Pfretzschner 2004, 92.
28 http://wateriso.utah.edu/waterisotopes/pages/data_access/oipc.html (visited on 02/06/2012); Bowen 2010.
29 http://www-naweb.iaea.org/napc/ih/index.html (visited on 12/14/2011).
30 Asch 2005.
31 Cf. Price, Burton, and Bentley 2002; Bentley 2006; Evans et al. 2010.

4.2 Results

Although theories of mobility are frequently mentioned in archaeological isotope studies, they are rarely effectively applied to these studies. While familiar theories of mobility and migration are summarized in this study, their application to the data is relatively complicated since the cultural groups under investigation are associated with a number of elements of uncertainty: The boundaries of the Eneolithic steppe cultures as well as the regional variants of the Bronze Age Yamnaya and Catacomb cultures are only vaguely defined and discussed in Russian and Ukrainian research. Furthermore, the economic basics are much debated and are described as implying some kind of increased mobility level,[32] without the level being specified. The ranges and directions of mobility remain a subject of speculation. This is mainly due to the scarcity of camps and permanent settlements and the infrequency of archaeological investigations on the subject. Multiple temporary stays are often indicated, for example in the northwest Caspian region,[33] but multi-phase long-lasting settlements also occur, such as Mikhailovka in southern central Ukraine.[34] However detailed references for potential migration cycles, such as circular or resource-related cycles, do not exist. Furthermore, a mobile community's last place of residence does not necessarily coincide with its burial places. The latter issue calls into question the validity of collecting reference samples for use in establishing 'local' isotopic signatures in the kurgan environment.

As mentioned previously, $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses depend on a variety of factors; while a human specimen's $^{87}Sr/^{86}Sr$ ratio basically depends on that of the underlying geology, the $\delta^{18}O$ ratio is relative to various factors like temperature, precipitation, altitude, latitude, and distance from the ocean. A combination of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses allowed very good results to be obtained and enabled isotopic distinctions to be made for the majority of the sampled regions and the identification of outlier specimens (Fig. 2).[35]

At the site level, strontium isotope analysis revealed clear tendencies. However, comparisons at the intra- and inter-regional levels were complicated by frequent differences in the number of sites per study region and the sample sizes per site. Sites with consistent $^{87}Sr/^{86}Sr$ values could be distinguished from those that showed higher variability in their strontium isotope values. These patterns were not necessarily repeated in the $\delta^{18}O$ values, and sample populations characterized by relatively homogeneous $^{87}Sr/^{86}Sr$ values were repeatedly combined with more variable $\delta^{18}O$ values, whilst sites with more varying $^{87}Sr/^{86}Sr$ values were often characterized by less varied $\delta^{18}O$ values (Fig. 3).

The combination of the results of both $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses enabled a distinction to be drawn between different mobility patterns. However the question must remain open whether these differences are related to larger mobility ranges, to differences in social organization or to varying data sets. Homogenous isotopic results are repeatedly associated with the use of the kurgans during just one cultural period, perhaps equivalent to one single community, while widely distributed isotopic results often correlate to a diachronic use of the burial mounds. Nevertheless, there are also examples that prove the opposite. Expected strontium and oxygen values for the North Pontic region were modeled based on a geological map. The results suggest short-range mobility within regions of varying strontium but similar oxygen isotope ratios, e. g. for Kirovograd, while long-range mobility is suggested between regions of similar strontium but varying oxygen isotope

32 Koryakova and Epimakhov 2007, 215–216; Frachetti 2008, 20, 44; Kaiser 2010a, 195.
33 Shishlina, Gak, and Borisov 2008.
34 Anthony 2007, 320–321.
35 In this paper measured $\delta^{18}O_{carbonate}$ values were converted to $\delta^{18}O_{(drinking)water}$ values following the equation by Longinelli 1984. The equation by Chenery et al. 2012 will be used in the publication of the PhD thesis Gerling (in press).

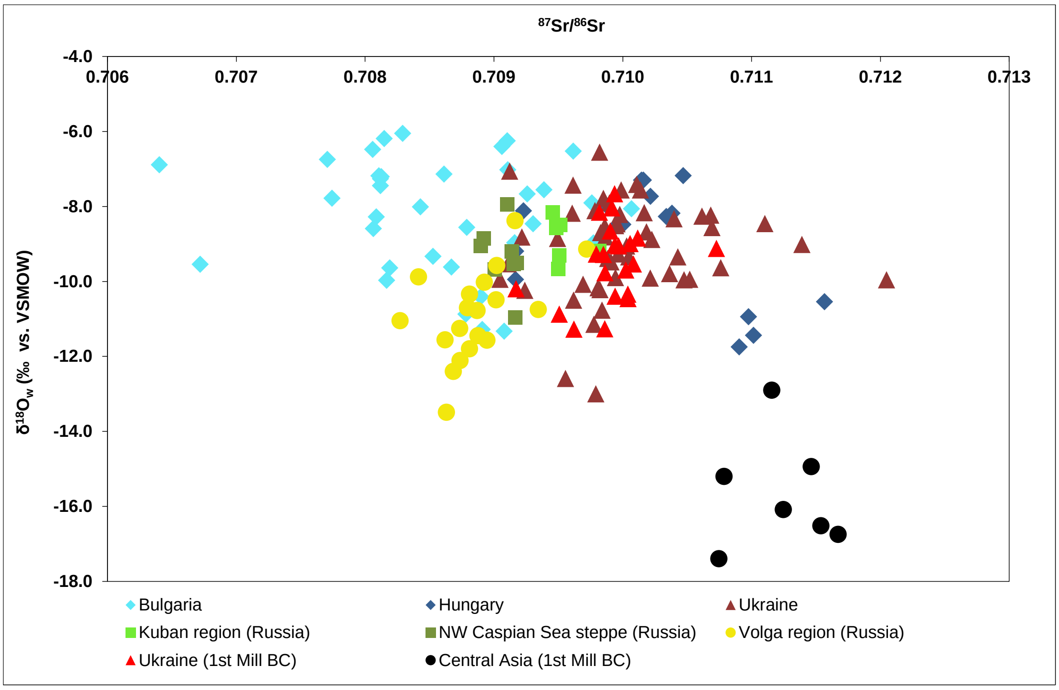

Fig. 2 | $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{water}$ values of all tooth enamel samples with main clusters encircled by similar colors according to regions: Bulgaria (turquoise), Hungary (blue), Ukraine (dark red), Russia: Northwest Caspian Steppes (dark green), Kuban region (green), Volga region (yellow), Iron Age Ukraine (light red) and Iron Age Central Asia (black, humans only).

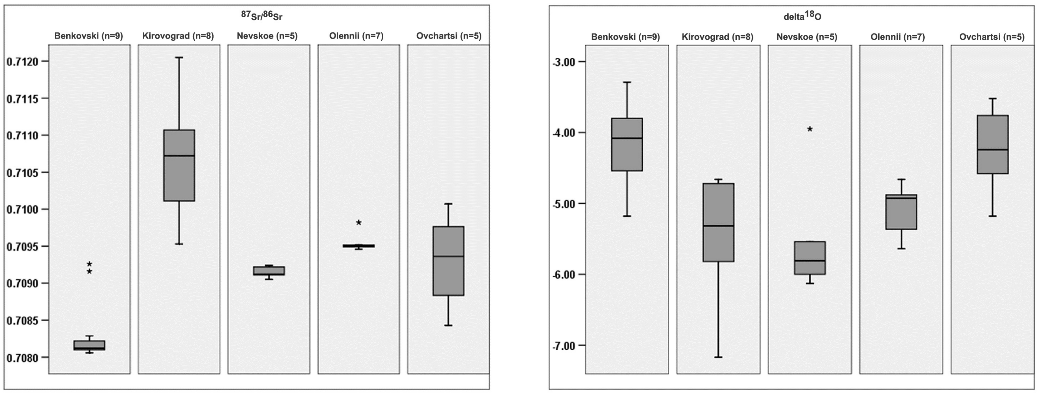

Fig. 3 | Box plots featuring sites with stable $^{87}Sr/^{86}Sr$ but varying $\delta^{18}O_{carbonate}$ values (e. g., Benkovski, Nevskoe, Olennii) or non-uniform $^{87}Sr/^{86}Sr$ and varying or uniform $\delta^{18}O_{carbonate}$ values (e. g., Kirovograd, Ovchartsi).

ratios, e. g. for Vinogradnoe. However, the results for Vinogradnoe might be influenced by the 1 to 2 increase in $\delta^{18}O$ values in those teeth that mineralize during breastfeeding.[36]

Intra- and inter-regional comparisons were complicated by diverse strategies in reference sampling. Without taking into account the fact that some reference samples are more reliable than others, it can be suggested that the data for the Eneolithic and the Yamnaya period is the most widely distributed, particularly in the Carpathian-Balkan region and especially in $^{87}Sr/^{86}Sr$ (Fig. 4). By contrast, only limited distributions are attested for the Early (and Developed) Catacomb culture. The presence of chronological differences

36 Wright and Schwarcz 1998.

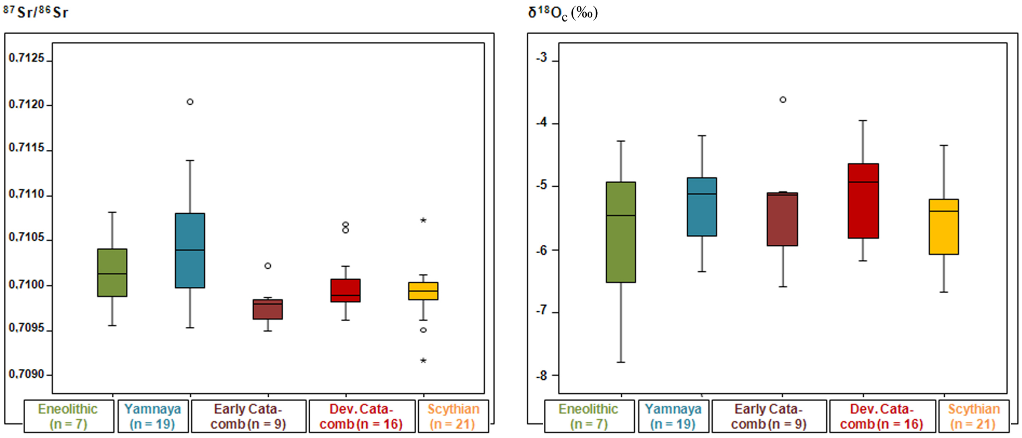

Fig. 4 | Box plots of the $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{carbonate}$ variability of the North Pontic samples by chronological period. Differences might also depend on the varying geographic locations of the sites.

seems to indicate a minor shift in isotope patterns[37] at the end of the 4th millennium BC, which might be associated with climatic change and/or the appearance of partly mobile pastoralism. The shift in the oxygen isotope ratios to less negative values from the Yamnaya period onwards can potentially be explained by discrepancies in the sampling strategy. The relatively restricted ranges of isotope values obtained from the Scythian samples in the North Pontic region[38] can be interpreted as evidence that mobility was either limited or resistant to isotope analysis due to the presence of wide-ranging homogenous isotope ratios in this region. The geographic dispersion of the sites and the presence of isotopic variations within the sites argue against their comprising a single residence community.

Faunal mobility was investigated in two case studies: In one case sequential strontium and oxygen isotope analyses were conducted on a triple cattle deposition from Zauschwitz, Germany, which is affiliated with the Globular Amphora culture that is chronologically parallel to the Yamnaya culture, in another, analyses were conducted on five horses from the Scythian period site of Berel in the Kazakh Altai Mountains. For Berel the results of the analysis suggest that some humans and horses originated in regions that significantly differ in respect to both geology and climate. An interpretation of regular mobility, possibly in seasonal cycles, was strengthened by the results of $^{87}Sr/^{86}Sr$ laser ablation measurements. Although changes of location due to trade or warfare cannot be excluded, the most probable interpretation attributes regular patterns to movements connected with transhumance.

Migration is one distinct type of mobility. In the context of the Early Bronze Age Yamnaya culture migration, movements between the North Pontic steppes and the East European steppe-like regions to the west are a subject of debate. The core zone of the regional variants of the Yamnaya culture is located between the Ural Mountains and the lower Danube, but the burials in the Yamnaya tradition are distributed not only in these regions but also in some areas of the Carpathian-Balkan region.[39] The cultural similarities imply intensive cultural interactions, probably associated with human migration.

37 $^{87}Sr/^{86}Sr$ values according to chronological groups vary significantly [One-way ANOVA: $p < 0.01$ (all samples), $p = 0.002$ (North Pontic)]. A post hoc test (Tukey HSD) revealed that only Yamnaya and Developed Catacomb culture vary on a 5 % level of significance. This is also true for the Eneolithic and Yamnaya samples.

38 No statistically significant difference between the samples of the Iron Age period and those of the preceding periods (T-test: $\delta^{18}O$: $t = 1.19$, $p = 0.238$; $^{87}Sr/^{86}Sr$: $t = 1.65$, $p = 0.104$).

39 Heyd 2011, 530–531.

David W. Anthony argues that the cultural contacts between the North Pontic steppes and the Carpathian-Balkan region in the Eneolithic but especially in the Early Bronze Age are a prime example of a migration.[40] According to Anthony, a migration can be initiated by push and pull factors.[41] In the case of the Yamnaya cultural communities, these are factors like climatic changes in the steppes or the search for new pastures in the Carpathian Basin or raw material deposits in the Carpathians. Anthony's migration model includes several phases:[42] In the first, 'leapfrogging' phase, 'scouts' leave their region of origin and collect information on potential migration regions. In the next phase one or several groups of migrants follow the 'scouts' to the region of choice. According to Anthony these migration movements were associated with the collapse of the settled communities in the Northwest and West Pontic regions. In these phases archaeological records take the form of isolated import finds which occur along the migration routes and in the migration area, while a mixture of cultural elements begins only in the subsequent phase of 'establishment' in the migration area. In a potential phase of 'return migration' culturally mixed elements as well as the cultural remains of other local groups or cultures are sometimes taken back to the region of origin. Anthony's model provides a substantial basis for further considerations, although a number of facts such as new ^{14}C dates, for example, make Anthony's version of a Yamnaya migration highly improbable.[43]

However, a number of complications occur when migration models are applied to this study: Firstly, an individual's isotope signature does not change abruptly when the place of residence changes, but only gradually in association with a longer journey, thus leading to a mixed isotopic signal. Since tooth enamel mineralizes mainly during childhood, the isotopic signature of an individual who migrated later in life should only reflect the isotopic signal of the North Pontic or North West Pontic region. Migrations that occur at some stage in the childhood during the period of tooth enamel mineralization, in contrast, should result in mixed isotopic signals. However, due to unknown migration routes these mixed isotopic signals are hard to detect. Migration routes along the Danube River or across the Carpathian Mountain passes into the Carpathian Basin, for example, might result in similar or identical mixed isotopic signals.

Secondly, 'non-local' isotope ratios do not always agree with the archaeological evidence. Ideally, an individual who has migrated exhibits differences in the burial tradition as well as 'non-local' strontium and oxygen isotope ratios. The best conditions for identifying migration arise when an individual leaves the distribution area of the archaeological culture as well as its original strontium and oxygen isotope regions.[44] Burials from the Carpathian-Balkan region dating to the Eneolithic and Bronze Age are a good illustration of this. Most of the Bulgarian and Hungarian specimens conform to the 'local' isotope ranges, while only a few deviate from the expected isotope ranges for these regions (Fig. 5).

Most of the human specimens from the Eneolithic cemetery of Smyadovo, Bulgaria deviate from the 'local' ranges in respect to either their $\delta^{18}O$ or their $^{87}Sr/^{86}Sr$ ratios. Consideration could be given to whether the much depleted oxygen isotope ratios can be attributed to the individuals' originating from further Northeast, to their having any connection with the nearby Balkan Mountains, such as the consumption of drinking water from rivers originating in the mountains, or to climatic differences between the Eneolithic and the Early Bronze Age.

Half of the human specimens at the Hungarian site Sárrétudvari-Őrhalom are significant outliers in respect to both isotopic systems. Four of them fit the Hungarian site's

40 Cf. Anthony 1990; Anthony 1997.
41 Anthony 1990, 899; Anthony 1997, 22.
42 Cf. Anthony 1990, 902–904.
43 Kaiser 2010b.
44 Cf. model as in Tütken 2010, 45 fig. 6.

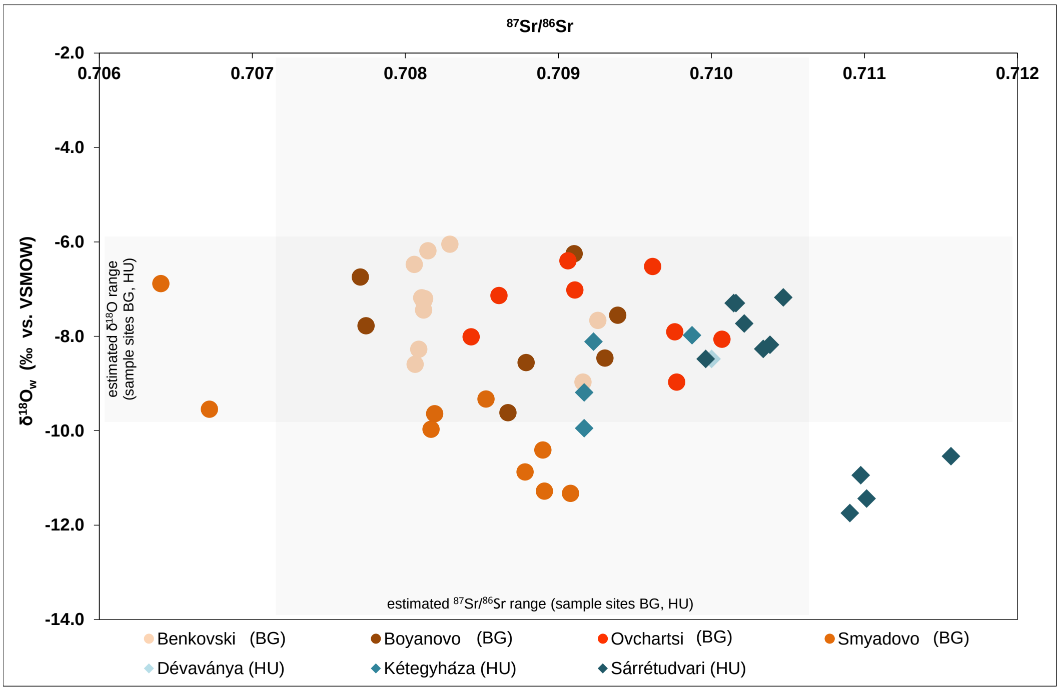

Fig. 5 | $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{water}$ values of human individuals from the Carpathian-Balkan sample sites. Most samples fall within the expected local isotopic ranges.

profile, while four others are statistically significant outliers. The archaeological evidence, the *Lockenringe* and foreign types of copper axes and copper daggers, additionally indicate that the individuals either immigrated or spent time away from their local residence in childhood. The combination of more radiogenic strontium and more negative oxygen isotope ratios points to regions with older geology and lower temperatures, like mountains or regions further east. Further, parallels to the ceramic inventories of the Transylvanian Livezile cultural group[45] may imply a connection to the Carpathians, potentially involving transhumance practices.[46]

5 Paleodiet

5.1 Fundamentals and Methods

True to the motto 'You are what you eat', stable isotope analysis facilitates the reconstruction not only of mobility but also of dietary patterns. Carbon and nitrogen isotope analysis is usually applied in exploring diet and subsistence in ancient communities.[47] Since an economy based on specialized cattle husbandry is suggested for both the Yamnaya and Catacomb culture communities, an isotopic investigation of the proportions of terrestrial and other food components was attempted.

Carbon isotope analysis helps to distinguish between food webs based on two different photosynthesis cycles:[48] C_3 plants and their consumers are characterized by depleted carbon isotope ratios while nutrition based on C_4 plants results in less depleted ones. Higher values are also characteristic for consumers of a diet based on marine food, whereas

45 Cf. Kulcsár 2009; Ciugudean 2011.
46 Gerling, Heyd, et al. 2012; Gerling, Bánffy, et al. 2012.
47 Cf. Katzenberg 2008 for a detailed overview.
48 Sharp 2007, 153–157.

freshwater resources result in rather depleted but highly variable isotope ratios. In addition, temperature and precipitation, elevation above sea level and the seasonal growing periods of the plants are factors influencing the body's carbon content.[49]

Nitrogen isotope analysis, in addition, enables distinctions to be drawn between individual consumers' levels within a food web.[50] Plants are on the lowest level of the food web and show nitrogen values of about 3 ‰, while the nitrogen values of herbivores on the second trophic level and carnivores on the succeeding level are enriched by 3 to 5 ‰ each.[51] Since aquatic food webs include more trophic levels, consumers of freshwater and marine resources have on average even higher nitrogen isotope ratios. In addition to the position in the food web additional factors like differences in metabolism, geographic position of and climatic conditions at the sites as well as nursing periods influence a consumer's $\delta^{15}N$ value.[52]

Since carbon and nitrogen isotope values depend on diet, it can be assumed that different economic systems correlate with variations in the stable isotope patterns of the consumers. It has been shown in previous studies that farming communities generally exhibit lower $\delta^{13}C$ and $\delta^{15}N$ values[53] than typically isotopically enriched individuals in hunter-gatherer societies.[54] Therefore, if Early Bronze Age steppe communities did in fact change to a subsistence economy based on mobile cattle herding, as the archaeological evidence suggests, this might be detectable by stable isotope analysis. Such a change would lead to increased consumption of meat (and milk products), thus resulting in elevated $\delta^{15}N$ ratios, and possibly even elevated $\delta^{13}C$ values, due to the consumption of uncultivated C_4 steppe grasses. There are a number of unknowns, such as the proportions of C_3 and C_4 plants in the study region and the possible occurrence of climatic changes that would also lead to elevated $\delta^{15}N$ ratios. Based on investigations of the paleosoil in burial mounds and several pollen analysis studies, it has been suggested that an aridisation process took place in the 3rd millennium BC in the East European steppes.[55]

5.2 Results

The paleodietary study was conducted on the remains of human individuals from three sites in modern Bulgaria, four sites in the Ukraine and one site in the Kuban region in modern Russia. In summary, it can be stated that the diet was mainly site- and region-specific (Fig. 6). A positive correlation existed between the $\delta^{13}C$ and $\delta^{15}N$ values. Furthermore, a strong correlation was established between nitrogen isotope ratios and geographical locations, especially with regard to longitude, pointing to an east-west gradient in the nitrogen isotope ratios and spatially varying climatic conditions.

However, deeper insight into the diet of Eneolithic and Early and Middle Bronze Age humans in the investigated regions requires an increase in both human and animal sample sizes and the establishment of a reconstructed food web, which would further provide the basis for the development of 'mixing models' with two or more 'end member' food components. Nevertheless, it can be hypothesized that the diet of all West Pontic individuals was based on C_3 plants, C_3 plant consumers[56] and products derived from them. Analysis of specimens from the Eneolithic site Smyadovo show isotopic values that

49 Bentley and Knipper 2005, 632.
50 E. g., Schoeninger and DeNiro 1984.
51 Hedges and Reynard 2007, 1241.
52 Ambrose 1991.
53 E. g., Dürrwächter et al. 2006; Nehlich et al. 2009 on the Neolithic Linearbandkeramik societies.
54 E. g., Drucker and Bocherens 2004; Stevens, Jacobi, and Higham 2010 on Paleolithic humans.
55 Shishlina, Sevastyanov, and Hedges 2012, 187 fig. 5, 6 with further literature.
56 Mean values fauna (mainly deriving from other studies in the same study region): $\delta^{13}C$ -19.94 ‰, $\delta^{15}N$ 5.58 ‰.

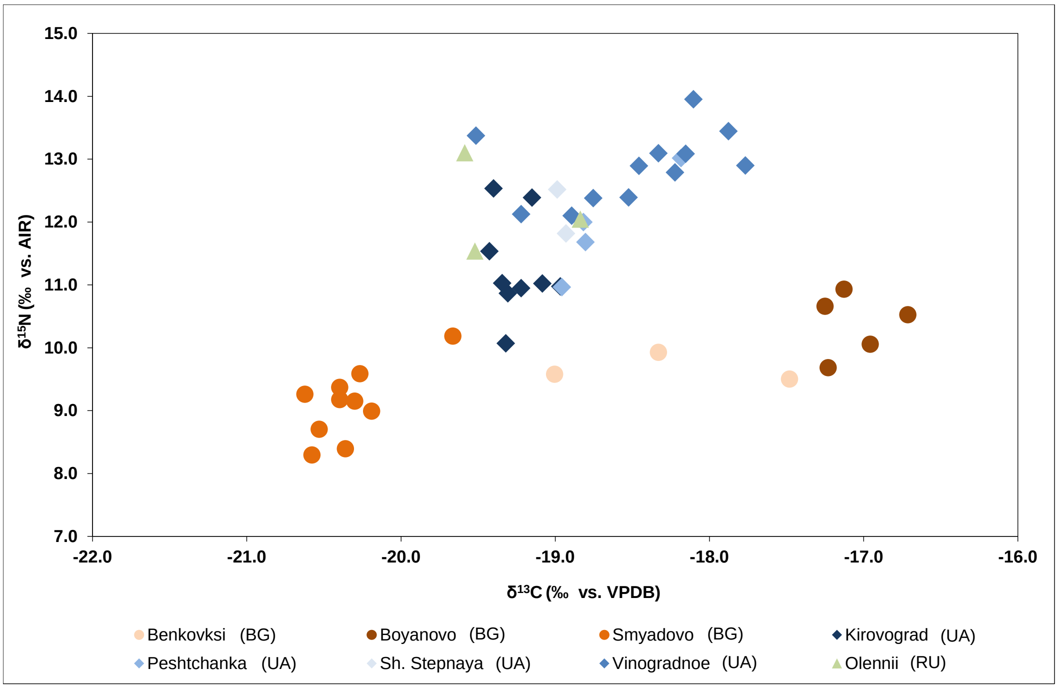

Fig. 6 | Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) values of the sampled human specimen from the study sites in the West Pontic (Bulgaria, circles), the North Pontic (Ukraine, diamonds) and the Kuban region (Russia, triangles).

are typical for societies living on agriculture and livestock farming, whereas those from the other two Bronze Age sites show that C_4 plants exerted increased influence. This can potentially be attributed to dietary changes or changes in agricultural activities, e. g. the cultivation of C_4 plants such as millet. Due to the geographic location of the sites the addition of marine elements to a diet based on C_3 and C_4 plants is rather improbable.

C_3 plants and C_3 herbivores also comprise the predominant dietary component for North Pontic individuals, with C_4 plants exerting moderate influence. The shift in $\delta^{15}N$ ratios between the human individuals in the West Pontic and those in the North Pontic and South Russia can be explained by a combination of reasons: The small sample of herbivores subjected to $\delta^{13}C$ and $\delta^{15}N$ analysis in this study and those examined in further studies in the same region revealed enriched $\delta^{15}N$ values due to drier climatic conditions.[57] Since the shift is smaller for herbivores than for humans, varying climatic conditions cannot be the only reason for the prevalence of significantly higher $\delta^{15}N$ values among humans from the North Pontic region and Southern Russia in comparison to Bulgaria. It is likely that a significant proportion of freshwater fauna like fish was added to the diet of populations from the North Pontic and the Kuban region during the Eneolithic and Bronze Age. On the basis of earlier light stable isotope studies in the Ukrainian and south Russian steppes,[58] it can be argued that fishing was a major subsistence activity during these periods.

Statistical tests with strong limitations were applied, since group sample sizes were mostly too small. However, chronological variations have been statistically confirmed

57 The North Pontic fauna exhibits only a mild degree of enrichment, but a significant difference can be found in Southern Russia. Means fauna (this study and further studies in the same study regions): North Pontic $\delta^{13}C$ -20.54 ‰, $\delta^{15}N$ 5.8 ‰, South Russia $\delta^{13}C$ -19.4 ‰, $\delta^{15}N$ 8.9 ‰. In addition to drier climatic conditions grazing on salt marshes might provide an explanation.

58 E. g., Lillie, Budd, and Potekhina 2011 (with older literature); Privat 2004; Shishlina 2008; Shishlina, Gak, and Borisov 2008; Shishlina, Sevastyanov, and Hedges 2012.

despite the absence of a decisive chronological trend.[59] Furthermore, no variations associated with differences in sex could be detected.[60] Minor variations existed between children and adults, which might be indicators of a meat- or fish-enriched diet in adulthood, but the differences are very small.[61]

6 Conclusions

The degree of mobility and hence of economic change is difficult to detect in non- or semi-sedentary communities where mobility patterns and ranges are unknown and few settlements have been found. Vague cultural borders and economic bases, as well as uncertainty regarding whether burial and residence places are identical, make it difficult to adopt theories and hypotheses. Nevertheless, the combination of strontium and oxygen isotope analysis enabled an isotopic characterization of each site and region and the identification of outliers, often in agreement with the archaeological evidence. Differences in space and time became apparent; between the West and the North Pontic in respect to chorology and between the Eneolithic/Yamnaya and Catacomb culture in respect to chronology. No higher degree of mobility was identified isotopically in respect to exceptional graves like wagon burials or age, sex and (social) status. The data obtained from $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analysis neither entirely confirms nor decisively rules out the possibility that migrations occurred into the regions southwest of the distribution areas of the Eneolithic steppe cultures and the Early Bronze Age cultures of the North Pontic region. Although some specimens certainly deviate from the 'local' isotope ranges and therefore indicate the presence of migrants, a conclusion that is often further supported by archaeological evidence, there is no certain connection with the North Pontic region.

The diet of the Eneolithic and Early Bronze Age communities in the study region shows large regional differences, although it is generally dominated by C_3 plants and C_3 herbivores. Moreover, C_4 plants and aquatic resources also exert an influence. A potential change in the Early Bronze Age subsistence economy cannot be conclusively determined based on this data.

This study explores an extremely large area and focuses on a region which has formerly only been investigated by individual, small-scale studies. It became apparent that the sampling of such a vast study area is extremely complicated, and sampling strategies certainly need to follow the same standards as those used when investigating single sites. Statistically relevant sample sizes for human specimens as well as food and water sources and the isotopic characterization of the more immediate surroundings are required to enable distinct conclusions to be drawn. It could be shown that the study area is isotopically distinguishable, however, which would provide a sound basis for future studies in the same area involving isotope analyses. Although questions about the mobility and dietary patterns and migrations of the Eneolithic, Early and Middle Bronze Age and Iron Age individuals in the West Eurasian steppes have been given preliminary rather than conclusive answers, this study represents an excellent starting point for further isotope work.

59 Significant difference in $\delta^{15}N$ between the chronological groups in the North Pontic (Kruskal-Wallis test: $p = 0.003$). Samples from all chronological periods are only represented from Vinogradnoe and show significant chronological differences (One-way ANOVA: $\delta^{13}C$: $p < 0.001$; $\delta^{15}N$: $p = 0.01$).

60 Sex determination only done for North Pontic specimens (One-way ANOVA: $\delta^{15}N$: $p = 0.51$; $\delta^{13}C$: $p = 0.19$).

61 Differences between the age groups were not statistically significant (One-way ANOVA: $\delta^{15}N$: $p = 0.72$; $\delta^{13}C$: $p = 0.46$).

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