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Continuity and change in subsistence at Tell Barri, NE Syria

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Abstract:

The history of the Fertile Crescent is well documented through archaeology and epigraphy. However, contrary to adjacent regions in the Mediterranean and Middle East, the reconstruction of diet and food ways through isotope analysis is limited for Mesopotamia and, consequently, matters of subsistence change are not well understood. To address this, collagen carbon and nitrogen isotopic ratios of human (N=84) and animal (N=8) samples from Tell Barri, Syria, predominantly ranging from the Early Bronze Age to Roman/Parthian times, were analysed to ascertain diachronic dietary patterns as well as gender- and age-related differences.

Only in the early occupation periods is there evidence of gender-related diet, while the later phases do not display significant differences between males and females. In the early phases of occupation, subsistence is based on a terrestrial C_3 diet, but changes towards the inclusion of more C_4 based foodstuffs in later phases. This trend is unaffected by the clear historic reference to periods when increased pastoralism alternates with settled agricultural farming.

Keywords: light stable isotopes; diet; Northern Mesopotamia; Bronze Age; agriculture; herding

1. Introduction

Analysis of stable carbon and nitrogen isotopes in human and animal tissues from archaeological contexts has become an established method for the reconstruction of diet and subsistence in past human populations (Katzenberg, 2008; Lee-Thorp, 2008). Studies on dietary variation within and between populations (e.g., Le Huray and Schutkowski, 2005; Knipper *et al.*, 2013) as well as overarching questions about diachronic change (e.g., Grupe *et al.*, 2013; Müldner *et al.*, 2014) have produced an increasingly fine-grained appreciation of past subsistence regimes and dietary behaviour. While this includes the Eastern Mediterranean, Anatolia and adjacent regions (e.g., Budd *et al.*, 2013; Gregoricka and Sheridan, 2013; Pearson *et al.*, 2013; Schutkowski and Richards, 2014), there is still little understanding of subsistence change in Mesopotamia, and sporadic attempts to address this so far were either confined or met with limited success (Batey, 2011; Hornig, 2010; Schutkowski, 2012). The site of Tell Barri, which is representative of the dry farming zone in the central part of the Fertile Crescent, and which was continuously inhabited from the beginning of the Early Bronze Age until the Roman/Parthian period (Pierobon Benoit, 2008), offers a rare opportunity to explore this in diachronic detail.

After agriculture had been invented in that area in the 9th millennium BCE, the subsistence of local human populations was based on plant cultivation and animal husbandry. The two most common cereals were wheat and barley, and legumes and vegetables supplemented the local diet (Riehl, 2009; cf. Ellison, 1978, 1984), all of them belonging to the C_3 pathway. There is only marginal evidence of millet, which is a C_4 cereal, during the Pre-Pottery Neolithic (Hunt *et al.*, 2008), but it was re-introduced together with sorghum in the 1st millennium BCE; however, it never became a very important crop (cf. Nesbitt and Summers, 1988). The most common domestic animals were ovicaprids, cattle, and pigs (Miller, 2013; Arbuckle, 2014), some of which were kept close to the human settlements, but especially ovicaprids may have been fed in more distant pastures on the dry steppe, which could not have been used for plant cultivation because of insufficient precipitation.

Throughout the history of Mesopotamia farmers interacted with herders. In most periods these two groups co-operated; for example the Middle Bronze Age archives from Mari (modern Tell Hariri) in the middle Euphrates region indicate that both groups not only exchanged their products, but were also linked with each other by a close network of social and kinship ties, a constellation termed dimorphic society by modern scholars (Rowton, 1977). However, any deterioration of environmental conditions (as e.g. prolonged drought) disrupted the balance between the two subsistence strategies and sometimes, when dry steppes became too dry for feeding ovicaprids, pastoralists invaded areas suitable for plant cultivation and contributed to the fall of early states that were economically based on cereal crops (Neumann and Parpola, 1987). In the history of ancient Mesopotamia, two major periods of increased mobility of herders were recorded in historical documents and there is evidence that this social instability was induced by climatic change and periods of prolonged drought (e.g. Riehl *et al.*, 2012).

The first period, the transition from the Early Bronze Age (EBA) to the Middle Bronze Age (MBA), started c. 2250 BCE and ended c. 1950 BCE (Cullen *et al.*, 2000; Wossink, 2009). The beginning of this event was contemporary to the fall of the Akkadian empire and there has been a vivid discussion among archaeologists and environmentalists whether a volcanic eruption or a bolide impact triggered this period of drought and contributed to the abandonment of some settlements in Northern Mesopotamia (cf. Cullen *et al.*, 2000; Koliński, 2011). Although the central authority (i.e. the 3rd dynasty from Ur) recovered in Southern Mesopotamia at the turn of the 21st century BCE (Van de Mieroop, 2007), herders known as Amorites kept migrating from the North to the South, and finally their leaders took control over all Sumerian cities c. 2000 BCE (Van de Mieroop, 2007). Amorites quickly adapted to the urban civilization, and in the early 2nd millennium BCE the strict co-operation between farmers and herders was restored (cf. Rowton, 1977).

The second period of social instability, caused by climatic change that increased mobility of herders, lasted from c.

1200 BCE to c. 850 BCE, the transition from the Late Bronze Age (LBA) to the Early Iron Age (EIA) (Neumann and Parpola, 1987; Issar and Zohar, 2007; Langgut et al., 2013). During that time, all LBA states (Egypt, Assyria, Babylonia, Hatti) collapsed or at least entered into a period of social upheaval, and pastoral populations, especially Arameans in Mesopotamia, dominate the historical record (Sader, 2000). Unlike a millennium earlier, Arameans did not readily adapt to urban civilization and their tribes in Northern Mesopotamia were gradually conquered by the expanding Neo-Assyrian empire in the 9th–8th centuries BCE (Liverani, 2014).

The available textual evidence does not refer directly to the area of Tell Barri, which was the second-ranked town in the Early Bronze Age, then the capital city of the kingdom of Kahat in the Middle Bronze Age, and finally, after c. 850 BCE, the garrison city in the time of empires (Pecorella, 2008; Pierobon Benoit, 2013). However, it is clear that the periods of instability recorded in Babylonia and Assyria must have affected also the north-western part of Mesopotamia. Using samples of human and animal calcified tissues representing several millennia of human settlement at Tell Barri, it should be possible to ascertain whether and how instability at the transition between EBA and MBA and between LBA and EIA affected diet and subsistence of human populations in this region. We hypothesize that the relative proportion of animal-derived food is higher in times when mobile herders dominate and the size of the sedentary agricultural population decreases, and that during the periods of social and economic instability some alternative resources must have been occasionally exploited and thus the diet became more variable. Moreover, some C_4 grasses and reeds are present in the dry steppe and in the valleys of permanent rivers and wadis (Nesbitt, 2006); therefore changes in the exploitation of these areas by herders may influence $\delta^{13}C$ values. All of these effects should register in changes of isotope ratios.

2. Biogeochemistry of dietary reconstruction

The principles underpinning the reconstruction of dietary patterns and the inference on underlying subsistence activities in past populations are well-established and have been described in considerable detail (e.g. Schwarcz and Schoeninger, 1991; Katzenberg, 2008; Lee-Thorp, 2008; Richards and Hedges 2008). The ratios of carbon and nitrogen isotopes, ($\delta^{13}C$ and $\delta^{15}N$) of various food sources are reflected in the ratios of consumer tissues (Ambrose, 1993; DeNiro and Epstein, 1978, 1981; Schoeninger and DeNiro, 1984, Tiezsen and Fagre, 1983). When measured from bone collagen, carbon and nitrogen stable isotopes largely represent protein intake accumulated over about ten years prior to the death of an individual (Hedges *et al*., 2007). Fractionation, the systematic alteration of isotopic ratios along the food chain and in the passage from one tissue to another, is used to infer trophic position of consumers relative to other individuals and those organisms that supply the food web.

Fractionation for carbon typically amounts to 1-3‰, relative to the baseline ratio of marine bicarbonate in the PeeDee Belemnite formation (Vienna PeeDee Belemnite standard, VPDB), and for nitrogen to 3-5‰, measured against the ratio for nitrogen in air (Ambient Inhalable Reservoir, AIR). In addition to fractionation, origin of foodstuffs and biochemical properties are responsible for further isotopic differentiation of dietary intake.

Depending on the photosynthetic pathway, the vast majority of plants divide into C_3 (Hatch-Slack cycle) or C_4 plants (Calvin-Benson cycle). C_4 plants are more enriched in ^{13}C carbon than C_3 plants, which results in an isotopic separation of these two groups when compared against the reference standard (Smith and Epstein, 1971). Carbon isotope signatures therefore permit distinction between groups of plants and the identification of relative amounts of major plant groups contributing to human diet. C_3 plants grow in temperate climates and comprise common cultivars, including wheat, rye or barley and most vegetables. C_4 plants originate from more arid environments. Maize, millet and sorghum belong into this group, but also some native grasses and chenopods.

As a result of fractionation, carbon derived from animal protein is isotopically different from plants of the same habitat and human $\delta^{13}C$ values will be less negative when domestic or wild animals are contributing to the diet in measurable quantities (De Niro and Epstein, 1978). Nitrogen isotopic ratios of bone collagen essentially reflect intake of animal protein (De Niro and Epstein, 1981; Hedges and Reynard, 2007), and thus, for the reconstruction of human food ways, allow the detection of trophic level effects caused by the consumption of meat or animal products .

Carbon and nitrogen isotope ratios have also been used to assess the timing of weaning, as the introduction of solid foods marks the transition from exclusive breastfeeding to the consumption of an omnivorous human diet. This process is reflected in trophic level changes of isotope ratios from younger to older children (e.g. Fogel *et al*., 1989; Richards *et al*., 2002; Fuller *et al*., 2006, Bourbou *et al*., 2013). The protein from breast milk is incorporated into the child's body tissues with elevated carbon and nitrogen values and therefore the collagen isotope ratios of infants not yet weaned can be up to 3‰ higher than those of their mothers, as well as most adults at a site (Schurr, 1997; Herring *et al*., 1998). During and after weaning, children's bones will have a mix of collagen laid down during breastfeeding with high carbon and nitrogen values, and collagen laid down from consuming a diet similar to that of adults with lower carbon and nitrogen values (Millard, 2000). Over time, bone collagen isotope ratios will change to levels typical of adults at the site.

3. Materials

Tell Barri, with its maximum size of 34 hectares and a height of more than 30 meters above the surrounding plain, is one of most prominent archaeological sites in the Khabour drainage. It has been excavated since 1980 by the Italian expedition from the universities of Florence and Naples, first under direction of Paolo Emilio Pecorella (Florence), then of Raffaella Pierobon Benoit (Naples) (Pecorella, 2008; Pierobon Benoit, 2013).

In the course of more than 30 seasons of excavations, the stratigraphy of the site has been well recognised, particularly due to the large trench G at the south-eastern slope of the site, where the Early Bronze Age I settlement (c. 2900 BCE) was found on virgin soil. The site was occupied continuously from the Bronze Age through the Iron Age to the Parthian/Roman period, with some traces of settlement also dated to later times (Pierobon Benoit, 2013). No regular cemetery has been found, but several human skeletons and a few isolated human bones were retrieved from domestic contexts. The total number of individuals in primary and secondary burials amounts to 117 (Sołtysiak, 2008;

2010). The state of preservation is variable, but skeletons found in the trenches G and J had been usually retrieved from deep strata and therefore most of them were only slightly affected by taphonomic factors.

Bone samples were taken from all human skeletons excavated at Tell Barri that were not heavily weathered and could be dated by their archaeological context and stratigraphy. In total, 84 samples were available, covering a chronological range from the Early Bronze Age to the Modern cemetery of the 19th and early 20th century at the top of the site (**Table 1**). No systematic archaeozoological study has been conducted so far, but teeth of ten animals (four pigs, four ovicaprids and two canids) were collected for analysis and dentin samples were used to establish a limited isotopic foodweb background. All available animal tooth samples represent relatively late periods of occupation at Tell Barri, i.e. Neo-Assyrian and Achaemenian periods. For comparative purposes, the NISP (number of identifiable specimens) frequencies of taxa in animal bone assemblages at Tell Arbid are used to check the possible impact of changes in animal husbandry on isotopic data. This site is located in the same ecological zone only some 15 kilometers north-west of Tell Barri (Bieliński, 2013). Especially the proportion of pigs at Tell Arbid decreased clearly between the Middle and Late Bronze Age, ranging between 40% and 45% in the EBA and MBA assemblages and 15-25% during the LBA and the Hellenistic period (Piątkowska-Małecka and Koliński, 2006; Piątkowska-Małecka and Smogorzewska, 2010); this decrease was accompanied by growth of the ovicaprid proportion.

4. Methods

Duplicate samples were taken from cortical human bone and dentin from terrestrial animal specimens. Surfaces were cleaned using air abrasion with an aluminium oxide powder to remove adhering soil particles, and then subjected to a modified Longin method (Brown *et al*., 1988) for collagen extraction: samples are demineralised in 0.5M HCl at 2-5°C and then gelatinised at 72°C for 48h in deionised water adjusted to pH 3, with 0.5M Hcl. This process typically took as long as 14 days, but occasionally, extraction times were extended depending on the actual size of the specimen. The extraction mix was filtered using Ezee filter separators (Elkay Laboratory Products, Basingstoke) to remove insoluble materials and then was purified again using Amicon Ultra-4 centrifugal filters (Millipore) to remove contaminants lower than 30,000 nominal molecular weight limit (Brown *et al*., 1988). The resulting solutions were lyophilised, a sub-sample of 0.4±0.1mg combusted and analysed by Isotope Ratio Mass Spectrometry (Finnigan Delta Plus XL).

Methionine standard reference material, with known both ^{13}C (-26.6‰) and ^{15}N (-3.0‰) values (Elemental Microanalysis, Devon, UK) was measured at regular intervals in tandem with samples of bone collagen to examine the accuracy and precision of analytical methods, together with internal and external certified laboratory standards (e.g. IAEA standards, bovine liver, fish gel etc.). Collagen yield, the percentages of carbon and nitrogen, and the C/N ratio were recorded to control for possible effects of diagenetic processes (Ambrose, 1993). In conjunction with the sample preparation method employed here (Brown *et al*., 1988), collagen yields as low as 0.5% are deemed acceptable (van Klinken, 1999), however, usually only yields of 1% and higher are considered sufficient to indicate preservation of authentic collagen. For this study, samples that yielded between 0.5 and 1% collagen were considered suspect and any samples with collagen yields below 0.5% were discarded from the analysis to take account of local sediment conditions that could have potentially impaired collagen preservation. Samples not having a C/N ratio between 2.9 and 3.6 (the range known for native bone collagen) (Ambrose, 1993) were omitted.

As the sample size was small in most cases, non-parametric tests were used, i.e. Kruskal-Wallis ANOVA to compare three and more samples, with post-hoc multiple comparison, and Mann-Whitney U test for differences between distributions of two samples. Correlations were explored using both Pearson’s correlation coefficient and Spearman’s rank order correlation. All statistics were calculated using Statistica 10 software.

5. Results

In total, 71 out of 84 human bone samples (86%) and eight out of ten animal dentin samples contained acceptable amounts of collagen and met the established quality standard criteria (van Klinken *et al.* 1999) (see **Table 2). Table 3** presents data for the animal samples and **Table 4** contains descriptive stastistics for all samples analysed.

The spread of isotope ratios for the overall human sample is considerable, amounting to about two trophic levels for carbon (δ^{13}C -20.3‰ to -17.6‰) and to about three trophic levels for nitrogen values (δ^{15}N 6.1‰ to 15.3‰). Even if adults and sub-adults are taken into account separately, the picture principally does not change (adults: δ^{13}C -20.3‰ to -18.3‰, δ^{15}N 6.1‰ to 14.2‰; sub-adults: δ^{13}C -20.3‰ to -17.5‰, δ^{15}N 7.8‰ to 15.3‰). Overall, the results and their spread suggest a terrestrial diet based largely on C_3 plants and varying input from animal-derived foodstuffs.

In the sub-adult sample, overall, children and adolescents are generally within the range of adults for both carbon and nitrogen ratios. Infants (0-2 years of age) display a much more diverse pattern. About half of them (eight out of fourteen; see **Figure 2**) cluster closely within the adult range, whereas the smaller subset is clearly separated by elevated nitrogen ratios as well as slightly more positive carbon values. This suggests that those young children with nitrogen ratios above 11.5‰ to 12‰ represent individuals that died while they were still entirely or largely breast-fed. Among them are one neonate and five infants ranging from 0.75 to 1.75 years of age. Those with nitrogen values below 11.5‰ were neonates or infants who died a few months after birth (six individuals) and older infants who had been weaned already as indicated by their values within the adolescent and adult distribution (two individuals approximately 1.5 and 2 years old). Since all children between the age of 2.5 and 7 lack these elevated ratios, it can be assumed that they had been completely weaned.

Due to small sample sizes, the differences in δ^{13}C and δ^{15}N between four defined age groups (infants 0-2 years old, young children 2.5-7.5 years old, older children 8-15 years old, adults and adolescents) were tested for the whole sample, without division into chronological subsets (**Figure 2**). The Kruskal-Wallis test results are statistically significant both for δ^{13}C (H=8.82, p=0.0318) and for δ^{15}N (H=14.52, p=0.0023) and this significance is related only to differences between infants and all other age categories. For nitrogen, all multiple comparisons between infants and other age groups produced $p<0.05$ and for carbon only the difference between infants and adults has $p<0.05$. Since all pairwise p-values for the three post-weaning age groups equal 1.0, only infants will be excluded from the subsequent analyses of temporal trends assuming that in 2-2.5 year old children the weaning process was already completed.

For all individuals older than 2.5 years, the sample size is small in case of all temporal subsets, so although the Kruskal-Wallis test is statistically significant for δ^{13}C (H=14.52, p=0.043), for all pairwise comparisons p>0.05. However, some difference between early (i.e., EBA, EMB and MBA) and later (i.e., LBA, NAS, ACH, PAR and MOD) samples may be observed, with mean δ^{13}C ratios shifting from -19.7‰ to -19.3‰ towards -19.1‰ to -18.9‰ (**Figure 3**). This difference is very small, but quite clear, so this general division between earlier and later samples will be used in further analyses. There are no significant differences between subsets in the δ^{15}N values (H=9.10, p=0.25) and there is no clear temporal pattern (**Figure 4**). Apart from some differences in mean δ^{13}C values between the chronological subsets, variance also seems to be slightly higher in later periods, and especially NAS and EMB values are more scattered than EBA values (**Table 4**).

For all subsets with six or more individuals, the correlation between δ^{13}C and δ^{15}N values was tested using both parametric and non-parametric methods (**Table 4**). The correlation is rather weak (although statistically significant) in the whole sample, but there are striking differences between subsets: both values were strongly correlated in the EBA, moderately correlated in the MBA and weakly or not correlated in the EMB, NAS and ACH subsets. The correlation for all early subsets is moderate (N=26, Pearson r=0.48, p<0.05; Spearman r_s=0.39, p<0.05) and absent for all late subsets (N=31, r=-0.02; r_s=0.22, both values are not significant)

Non-parametric analysis of variance in the whole dataset of the early and late subsets of humans together with three animal taxa confirmed significant differences between the early and late subsets, both in case of δ^{13}C (Kruskal-Wallis H=17.35, p<0.002) and for δ^{15}N (H=18.13, p<0.002) (**Figure 5**). There are no significant differences between the early human subset and pigs, but differences between the late human subset and pigs are significant both for carbon and for nitrogen (**Table 5**). This effect is paralleled by the clear decrease in the number of pigs at Tell Arbid between MBA and LBA.

The pattern of differences between males and females changed between the early and late phases of occupation. In the early periods, males exhibit both elevated carbon (Mann-Whitney U test, Z=2.21, p<0.03) and to some extent also nitrogen values (Z=1.64, p=0.10) compared to females. On the other hand, in the late periods values for males are more scattered, but there is no statistically significant difference between the sexes in either δ^{13}C or δ^{15}N (**Figure 7**).

6. Discussion

In general, most individuals from all periods at Tell Barri fall into a relatively narrow range of δ^{13}C values between -20‰ and -18.5‰, which indicates a diet based almost exclusively on C_3 plants. Such a result was expected taking into account the observation that since the very beginning of agriculture the main crops in Northern Mesopotamia were C_3 cereals like wheat and barley (Riehl, 2009). In contrast, δ^{15}N values are more variable, although largely ranging between 8 and 11, which may indicate relatively broad spectrum of omnivorous diets.

For both carbon and nitrogen several outliers were detected, and most of them represent individuals that date to the Neo-Assyrian and Achaemenian periods. Of the three individuals with highest $\delta^{15}N$ values two were males (NAS and EMB) and one individual yielded no reliable sex assessment (ACH). Relatively more negative $\delta^{13}C$ values in all these individuals suggest a diet abundant in proteins of animals fed almost exclusively on C_3 plant resources. On the other hand, two female individuals with lowest $\delta^{15}N$ values, even below the level of herbivores, and also low $\delta^{13}C$ values, were dated to the EBA and MBA periods. One individual with the highest $\delta^{13}C$ value in the analysed sample, close to -17.5‰, was an 8-year old child (NAS).

The most interesting difference between the earlier and later samples is a small but clear shift towards higher $\delta^{13}C$ ratios in later periods, with a threshold at the transition from the MBA to the LBA. Whilst a detailed analysis of animal remains from Tell Barri is not yet available, a comparison with nearby Tell Arbid as the closest possible proxy suggests that the observed change in isotopic values may be correlated with some shift in animal husbandry: pigs were much more important in the earlier Bronze Age periods than in the LBA and later (Zeder, 1998; Piątkowska-Małecka and Koliński, 2006). As pigs at Tell Barri, which the present study shows, were fed exclusively on C_3 plants (most likely from surplus of plant cultivation), a diet based mainly on cereals and even a greater share of pig meat should be characterised by low and less variable $\delta^{13}C$ values in the early phases of occupation.

Data of the ovicaprids from Tell Barri exhibit clearly higher $\delta^{13}C$ values than the pigs and are associated with later phases of occupation. Whilst the elevated average human $\delta^{13}C$ in later periods can partly be explained by higher relative consumption of lamb meat or dairy products, the positive correlation between $\delta^{13}C$ and $\delta^{15}N$ in the EBA and – to a lesser extent – in the MBA may indicate that in the earlier period animals other than pigs fed partially on C_4 plants. It is possible that some distant pastures in the dry steppe with several C_4 grasses such as *Chloridoideae* or *Panicoideae* (cf. Nesbitt, 2006) or wetlands along Wadi Jaghjagh and other streams with *Phragmites* (Al-Jassem *et al*., 2010) were used for pasture in these earlier periods in a more systematic way than in later periods, when at least ovicaprids fed almost exclusively on C_3 plants. Unfortunately, no ovicaprid tooth samples from the early periods were available in the present study, so this pattern cannot be directly corroborated.

Another factor contributing to the temporal change in $\delta^{13}C$ values may be related to climate. It has been observed that water stress in C_3 cereals like barley results in higher absorption of ^{13}C and this effect may be higher than the shift of 0.5‰ observed here (Ferrio *et al*., 2005). Indeed, research on barley grains from several Syrian sites dated to the Bronze Age has shown that $\delta^{13}C$ values ranged from 13.5‰ to 19‰ and there were quite clear temporal trends that may be correlated with known periods of aridification (Riehl, 2008). However, the major shift towards higher water stress in barley was noted between EBA and MBA and it is consistent with other proxy data suggesting a climatic change during that time. On the other hand, arid conditions continue from MBA to LBA and there is no major difference at the transition between these periods (Riehl, 2008). Therefore, it is not likely that water stress in C_3 cereals was a factor in the pattern observed here, although this effect may have contributed to the overall variability of $\delta^{13}C$ values in the human remains.

In general, the higher average δ^{13}C value in later periods seems to be the consequence of at least two processes: a much smaller share of pigs in the livestock, and higher variability of subsistence in general, combined with the possible introduction of some C_4 cereals, for example millet, which has been recorded in large quantities in the Neo-Assyrian stratum at Tille Höyük, a site located on the upper middle Euphrates (Nesbitt and Summers, 1988) and depicted, together with sorghum, another C_4 crop, in Sennacherib's palace in Nineveh, dating back to c. 700 BCE (Vinall *et al.*, 1936). These cereals were absent in earlier periods, so even if their share in cereal production of the later period was small, they could contribute to the observed shift in δ^{13}C values.

Another difference in the ratios of stable carbon and nitrogen isotopes between the earlier and later periods concerns dietary differences between the sexes. Males and females from the early subset (EBA to MBA) are relatively well differentiated. Male values suggest a diet more abundant in animal protein and also more shifted towards the consumption of C_4 food items, which again may be the consequence of herding some animal taxa in places more abundant in C_4 grasses. In contrast, males from later periods (LBA to MOD) differ from females mainly because their δ^{13}C and especially δ^{15}N values are more dispersed. Some correlation between isotopic ratios of both elements is noted here (especially when an outlier with a very high δ^{15}N value is omitted), but the overall pattern is clearly different in the two compared temporal subsets.

The most unexpected outcome of the present analysis is the lack of a clear isotopic signal that would indicate increased pastoralism in the transitional periods between EBA and MBA and between LBA and NAS/ACH. It should be expected that mobile herders who, according to historical sources, dominated the region in both these “dark ages” (EBA\MBA: Wossink, 2009; LBA\EIA: Younger, 2007) relied more on animal-related food and, moreover, fed their flocks in areas more abundant in C_4 plants. Therefore, higher average values of both δ^{13}C and δ^{15}N should be expected. In fact, the only peculiarity of the transitional periods is a higher dispersion of individual values, with no clear differences in average values in relation to preceding and following periods. This is especially well visible in the Neo-Assyrian period, which, in case of Tell Barri, means 9th century BCE, the very end of a “dark age”.

Actually, the observed pattern may be much more comprehensible when interpreted from the perspective of Tell Barri itself and not from the general regional perspective. For most of its history, Tell Barri was an urban centre of primary or secondary rank with a population of several hundred or thousand people feeding particularly on local resources. During the “dark ages” it may have been less densely populated, but still was not the place where mobile pastoralists lived. So, the dispersal of individual isotopic signatures may reflect the need of searching for alternative food resources in these periods where the city was to some extent isolated from its hinterland, but throughout all periods individuals buried at Tell Barri represented the local population of farmers.

Surprisingly, the clearest transition in diet and subsistence at Tell Barri occurred between the Middle and Late Bronze Age, when some continuity was expected, if we follow the historical sources. In that time, the area was under control of the Mitanni state, with a most prominent Hurrian ethnic background, but probably Indo-European ruling elites, as suggested by onomastic evidence (Cancik-Kirschbaum and Eidem, 2014). In roughly the same time, nomadic pastoralists called *aḫlamû* became visible especially at the borders of the Syrian Desert and after the fall of the Mitanni state they transformed into Arameans known from Assyrian sources (Lipiński, 2000; Sader, 2014). It is possible that an increasing independence of herders was the major factor contributing to the observed shift in diet and subsistence.

During the Early and Middle Bronze Age, Northern Mesopotamia was likely a place of strict co-operation between plant cultivators and herders, whether forced by central state administration or out of free will. The exchange of resources was well organised and the system was profitable for both sides, as herders led their flocks outside agricultural areas during the winter when dry steppes flourished due to abundant precipitation, and moved to the arable fields after the harvest, when flocks fed on the stubbles and manured the fields (Wossink, 2009). This so-called dimorphic society is well described in the archives from Mari on the Euphrates River and dated to the MBA (Rowton, 1974, Pitard, 1996, Fleming, 2009), but such a system was likely present also in the earlier period and in the Khabour drainage. Even the "dark age" during the transition between EBA and MBA temporarily disturbed but did not change the system, as the herders known as Amorites quickly adapted to Mesopotamian urban civilisation (Liverani, 1973; Schwartz, 2013). The correlation between δ^{13}C and δ^{15}N in earlier periods at Tell Barri and the low variability in individual isotopic values suggests that during that time the site was inhabited by a society with stable subsistence and diet standardised by efficient administration.

Although archaeological and epigraphical sources for the economy of later periods are very scarce, it is possible to propose a consistent interpretation of observed changes in isotopic values. When herders became more independent during the Late Bronze Age, the subsistence of the city must have been adapted to this new situation. Pigs became less popular, as they provided meat, but no secondary products like milk or wool (cf. Zeder, 1998). When distant pastures were occupied by *aḫlamû* and thus no longer available for the urban population (cf. Hole, 2007), only local plant resources may have been used for fodder. It is possible, then, that pigs must have given way for more ubiquitous ovicaprids or cattle. Also the introduction of new crops in the Neo-Assyrian period may be related to the cultivation of lands that were too arid for barley or wheat, but still suitable for drought-resistant millet and sorghum (Rostamza *et al.*, 2013), which may have become the alternative source of grain and fodder. All this re-orientation of subsistence appeared to be permanent and the separation of mobile herders and settled plant cultivators remained stable throughout all later periods, as suggested also by increased δ^{13}C values at Tell Barri.

7. Conclusion

Whilst only a relatively small number of skeletons were found during the past 30 years of excavations at Tell Barri, their temporal distribution enables some insight into changes in diet and subsistence of the local settled human population through several millennia. The most important shift happened between the Middle and Late Bronze Age when the average δ^{13}C values significantly increased, and the correlation between δ^{13}C and δ^{15}N disappeared. Also the differences between sexes in isotopic ratios of both elements were no longer present. This shift in isotopic signatures was paralleled by a clear decrease of pigs among the livestock and the small-scale introduction of more drought resistant cereals such as sorghum and millet. It is possible that this change in subsistence was the result of increased relative isolation between plant cultivators and herders operating in dry steppes, which forced the settled population to adapt their economy to higher direct exploitation of ovicaprids and to wider use of more arid areas for agriculture.

It is interesting that two major episodes of prolonged drought, which were documented both by paleoenvironmental proxies and by historical and archaeological evidence, did not change the general subsistence modes, and contributed only to a greater dispersal of food acquisition strategies in the context of already existing practices. On the other hand, the only observed small but significant and irreversible shift in subsistence occurred in the period when the climate was rather stable and it is likely that this was the effect of social and economic and not environmental factors.

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Tables

Table 1: Defined chronological subsets with their age-at-death and sex profiles.

	Period	Abbrev.	Dating	0-2	2.5-7.5	8-15	Adults			Total
							M	?	F	
Early subsets	Early Bronze Age	EBA	c. 2800-2200 BCE		1	1	2	2	4	10
	Early/Middle Bronze Age	EMB	c. 2200-2000 BCE	2	2	1	1	2		8
	Middle Bronze Age	MBA	c. 2000-1500 BCE	8	2	1	2	1	3	17
Late subsets	Late Bronze Age	LBA	c. 1500-1200 BCE	2	1		1	2		6
	Neo-Assyrian period	NAS	c. 900-800 BCE	1	1	2	4		1	9
	Achaemenian period	ACH	c. 500-300 BCE	1	2		4	4	4	15
	Parthian period	PAR	c. 100-300 CE					2		2
	Modern cemetery	MOD	c. 1850-1950 CE					4		4
	Total			14	9	5	14	17	12	71

Table 2: Carbon and nitrogen stable isotopic ratios for human bones.

Id	Chronology	Age category	Sex	$\delta^{13}C$	$\delta^{15}N$	C/N ratio	Coll. yield %
TB122	EBA	young child		-19.3	10.3	3.30	1.5
TB1142	EBA	adult	F	-19.4	9.9	3.28	1.1
TB1267	EBA	adult		-19.7	9.2	3.30	2.9
TB1295	EBA	adult		-19.8	9.8	3.40	1.6
TB1302	EBA	adult	F	-19.7	9.1	3.46	2.0
TB1307	EBA	adult	M	-19.5	10.9	3.37	2.8
TB1515	EBA	adult	M	-19.9	8.9	3.30	0.6
TB1526	EBA	adult	F	-20.3	6.5	3.22	3.3
TB1527	EBA	older child		-19.9	7.8	3.26	3.5
TB1554	EBA	adult	F	-20.0	7.5	3.22	5.8
TB763	EMB	young child		-18.9	10.7	3.18	5.4
TB813	EMB	older child		-20.3	8.6	3.20	5.1
TB1065	EMB	young child		-19.7	8.4	3.28	1.1
TB1097	EMB	adult		-19.3	8.2	3.21	3.5
TB1148	EMB	adult	M	-19.5	12.3	3.28	1.4
TB1298	EMB	infant		-18.9	9.4	3.22	2.4
TB1422	EMB	infant		-19.1	10.9	3.24	3.3
TB1440	EMB	adult		-19.2	8.1	3.21	4.3

Id	Chronology	Age category	Sex	$\delta^{13}C$	$\delta^{15}N$	C/N ratio	Coll. yield %
TB60	MBA	adult	F	-20.0	8.9	3.24	2.5
TB573	MBA	adult	M	-18.8	11.3	3.24	1.8
TB574	MBA	adult		-19.7	8.7	3.27	1.1
TB575/1	MBA	infant		-19.2	12.1	3.19	7.5
TB575/2	MBA	infant		-19.1	9.6	3.36	0.9
TB580	MBA	adult	F	-19.9	9.7	3.19	9.2
TB584	MBA	infant		-19.3	11.1	3.21	5.8
TB593	MBA	adult	F	-19.9	6.1	3.39	6.2
TB637	MBA	young child		-19.2	8.3	3.18	4.7
TB640	MBA	older child		-19.2	8.3	3.20	8.5
TB779	MBA	infant		-19.1	9.2	3.16	6.5
TB891	MBA	adult	M	-19.3	8.0	3.44	0.1
TB954	MBA	infant		-18.8	10.1	3.19	7.6
TB964	MBA	infant		-18.5	15.3	3.21	3.6
TB992	MBA	young child		-19.8	9.0	3.38	0.8
TB999	MBA	adult	M	-19.1	9.8	3.25	5.5
TB1043	MBA	infant		-18.7	10.3	3.26	1.4
TB1743	MBA	infant		-19.3	12.0	3.14	12.1
TB613	LBA	infant		-19.1	10.9	3.21	3.4
TB1094	LBA	adult		-19.7	8.0	3.18	5.3
TB1134	LBA	adult	M	-18.4	11.0	3.20	6.0
TB1368	LBA	infant		-18.4	11.5	3.23	7.7
TB1424	LBA	adult		-18.8	9.7	3.21	7.6
TB1744	LBA	young child		-18.9	8.7	3.16	6.5
TB592	NAS	adult	M	-19.7	13.3	3.20	2.7
TB774	NAS	adult	M	-19.3	10.8	3.21	12.7
TB835	NAS	older child		-17.5	10.5	3.17	8.3
TB836	NAS	adult	M	-19.5	9.3	3.19	6.4
TB838	NAS	older child		-19.0	10.7	3.20	2.2
TB877	NAS	adult	M	-19.4	8.8	3.28	5.1
TB962	NAS	infant		-18.4	13.4	3.19	9.3
TB991	NAS	young child		-19.9	9.4	3.22	5.2
TB1037	NAS	adult	F	-18.3	10.9	3.28	2.4
TB33	ACH	young child		-18.9	8.8	3.22	2.0
TB83	ACH	young child		-18.9	10.1	3.25	2.6
TB127	ACH	adult		-19.3	8.4	3.17	6.1
TB193	ACH	adult		-20.0	14.2	3.23	1.2
TB255	ACH	adult	F	-19.2	9.2	3.19	7.2

Id	Chronology	Age category	Sex	$\delta^{13}C$	$\delta^{15}N$	C/N ratio	Coll. yield %
TB256	ACH	adult	F	-19.0	9.3	3.19	5.2
TB266	ACH	adult	M	-18.2	11.6	3.19	2.3
TB267	ACH	adult	F	-19.0	9.9	3.18	4.0
TB270	ACH	adult		-18.5	9.7	3.18	6.6
TB288	ACH	adult	M	-19.0	10.1	3.17	3.0
TB296	ACH	adult	M	-18.9	10.0	3.16	3.8
TB300	ACH	infant		-18.3	13.1	3.18	9.6
TB312	ACH	adult	F	-19.5	8.8	3.28	2.7
TB316	ACH	adult	M	-20.0	8.7	3.17	9.2
TB678	ACH	adult		-19.7	11.1	3.17	7.1
TB103	PAR	adult		-19.5	9.3	3.36	0.8
TB1573	PAR	adult		-19.1	9.0	3.17	5.8
A	MOD	adult		-18.8	8.9	3.19	
B	MOD	adult		-18.3	9.5	3.20	
C	MOD	adult		-19.2	8.2	3.21	
D	MOD	adult		-19.3	8.7	3.20	

Table 3: Carbon and nitrogen stable isotopic ratios for animal dentin.

Id	Chronology	Taxon	$\delta^{13}C$	$\delta^{15}N$	C/N ratio	Coll. yield %
TB310	ACH	Canid	-19.2	7.0	3.35	5.1
TB310	ACH	Canid	-18.9	7.5	3.20	8.1
TB102	NAS	Pig	-20.6	7.9	3.21	26.5
TB331	ACH	Pig	-20.1	8.0	3.24	13.6
TB1424	LBA	Pig	-19.9	5.5	3.32	8.5
TB774	NAS	Ovicaprid	-18.8	8.7	3.19	10.7
TB835	NAS	Ovicaprid	-19.4	7.3	3.26	5.5
TB1424	LBA	Ovicaprid	-19.9	8.5	3.27	10.4

Table 4: Basic statistics for δ^{13}C and δ^{15}N in chronological subsets and correlations between δ^{13}C and δ^{15}N (only post-weaning individuals). Correlations with $p<0.05$ are in bold face.

Subset	**N***	**δ^{13}C**					**δ^{15}N**					**δ^{13}C and δ^{15}N correl.**		
		min	**max**	**mean**	**sd**	**med**	**min**	**max**	**mean**	**sd**	**med**	**n***	**r**	**r_s**
EBA	10	-20.4	-19.3	-19.74	0.30	-19.7	6.5	10.9	8.98	1.36	9.1	10	**0.89**	**0.92**
EMB	8	-20.3	-18.9	-19.36	0.47	-19.3	8.1	12.3	9.58	1.56	9.0	6	0.24	-0.14
MBA	17	-20.0	-18.5	-19.27	0.44	-19.2	6.1	15.3	9.98	2.02	9.7	9	0.54	0.42
LBA	6	-19.7	-18.4	-18.89	0.48	-18.9	8.0	11.5	9.96	1.38	10.3			
NAS	9	-19.9	-17.5	-19.00	0.77	-19.3	8.8	13.4	10.77	1.64	10.7	8	0.02	0.19
ACH	15	-20.0	-18.2	-19.08	0.55	-19.0	8.4	14.2	10.20	1.66	9.9	14	-0.14	0.16
PAR	2	-19.5	-19.1				9.0	9.3						
MOD	4	-19.3	-18.3	-18.93	0.45	-19.0	8.2	9.5	8.84	0.54	8.8			
early	35	-20.4	-18.5	-19.43	0.45	-19.3	6.1	15.3	9.61	1.76	9.4	26	**0.46**	**0.39**
late	36	-20.0	-17.5	-19.07	0.51	-19.0	8.0	14.2	10.09	1.56	9.7	31	-0.02	0.22
all humans	71	-20.4	-17.5	-19.22	0.55	-19.2	6.5	15.3	9.85	1.66	9.6	57	**0.28**	**0.34**
pigs	3	-20.6	-19.9	-20.23	0.33	-20.1	5.5	8.0	7.15	1.41	7.9			
ovicaprids	3	-19.9	-18.8	-19.36	0.56	-19.4	7.3	8.7	8.17	0.74	8.5			
canids	2	-19.2	-18.9				7.0	7.5						

*N – total number of individuals; n – number of post-weaning individuals.

Table 5: Multiple comparisons p-values for Kruskal-Wallis test of differences in δ^{13}C (below the diagonal) and δ^{15}N values (above the diagonal). Early and late subsets for human bones compared with three animal taxa. Values below 0.05 are in bold face.

		δ^{15}N p-values				
		Humans early	**Humans late**	**Pigs**	**Ovicaprids**	**Canids**
δ^{13}C p-values	**Humans early**		0.408	0.405	1.000	0.649
	Humans late	**0.022**		**0.030**	0.340	0.092
	Pigs	0.697	**0.015**		1.000	1.000
	Ovicaprids	1.000	1.000	0.574		1.000
	Canids	1.000	1.000	0.142	1.000	

Figures

Figure 1: Map showing the location of Tell Barri.

Figure 2: Distribution of $\delta^{13}C$ and $\delta^{15}N$ in four defined age-at-death classes.

Figure 3: Temporal trends in $\delta^{13}C$ at Tell Barri, only post-weaning individuals.

Figure 4: Temporal trends in $\delta^{15}N$ at Tell Barri, only post-weaning individuals.

Figure 5: Distribution of $\delta^{13}C$ and $\delta^{15}N$ in early (EBA to MBA) and late subsets, only post-weaning individuals, and in animal dentin samples.

Figure 6: Distribution of $\delta^{13}C$ and $\delta^{15}N$ for males and females in early (a) and late (b) subsets.

Figure 1

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Figure 2

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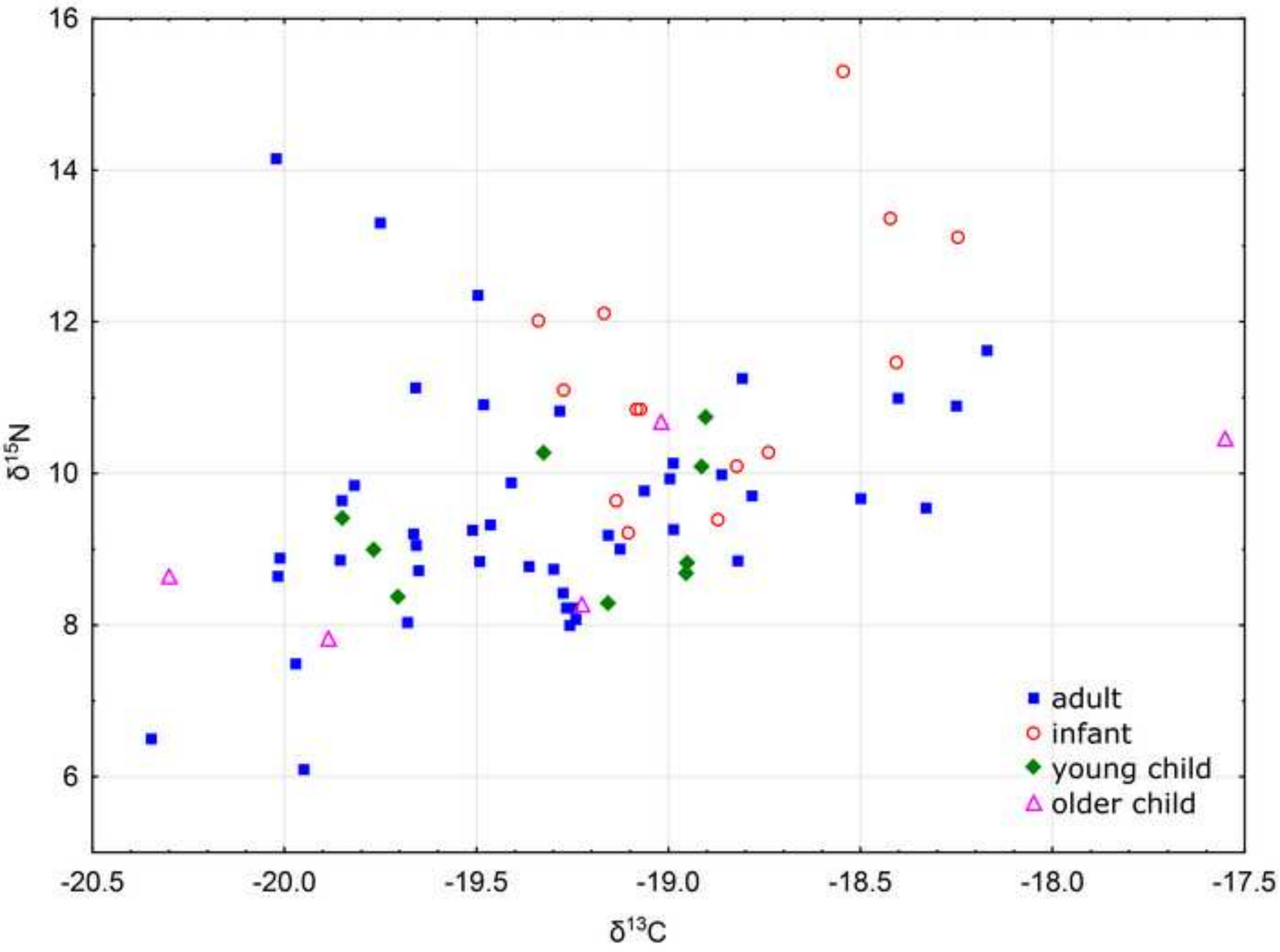

Figure 3

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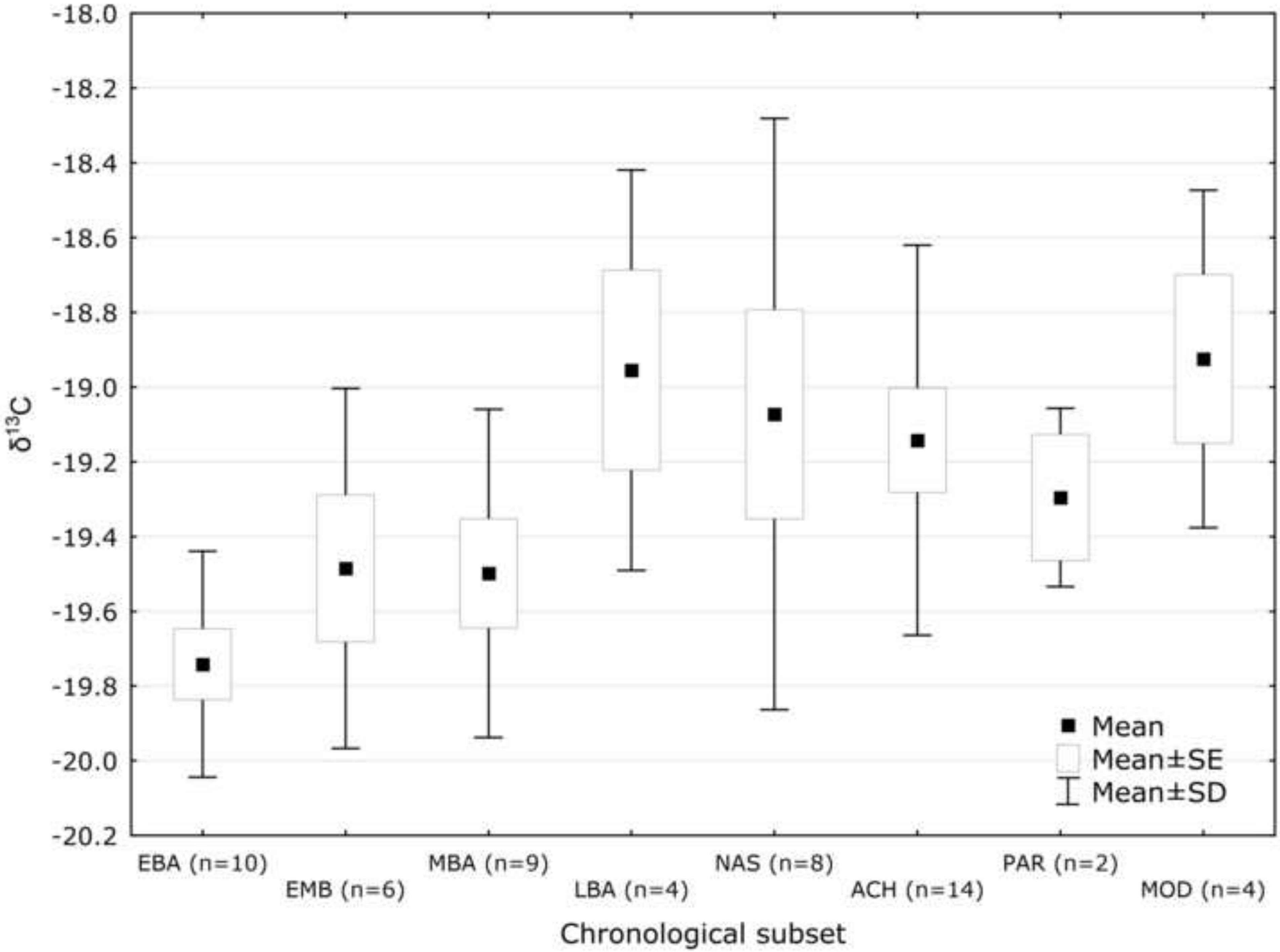

Figure 4

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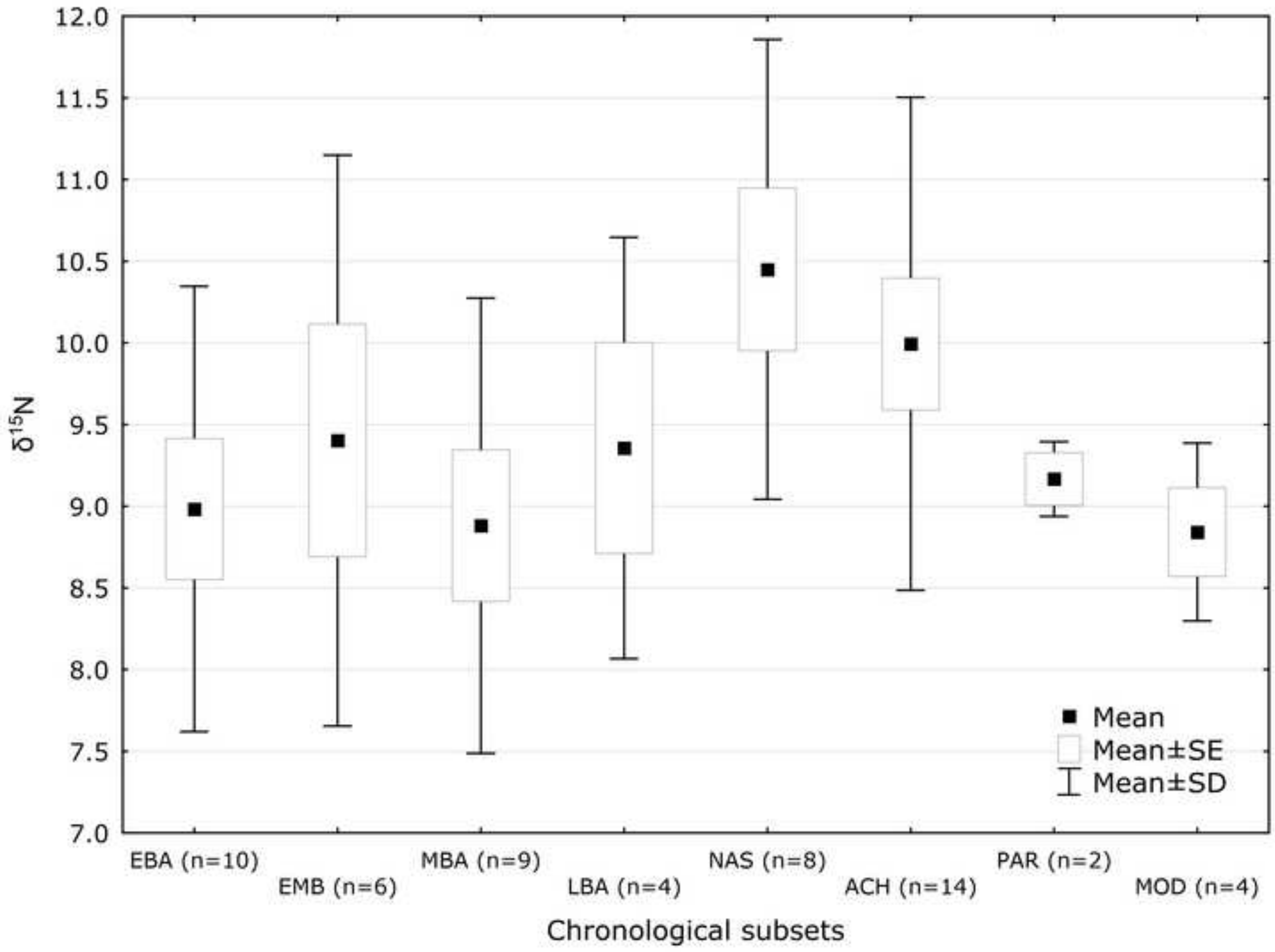

Figure 5

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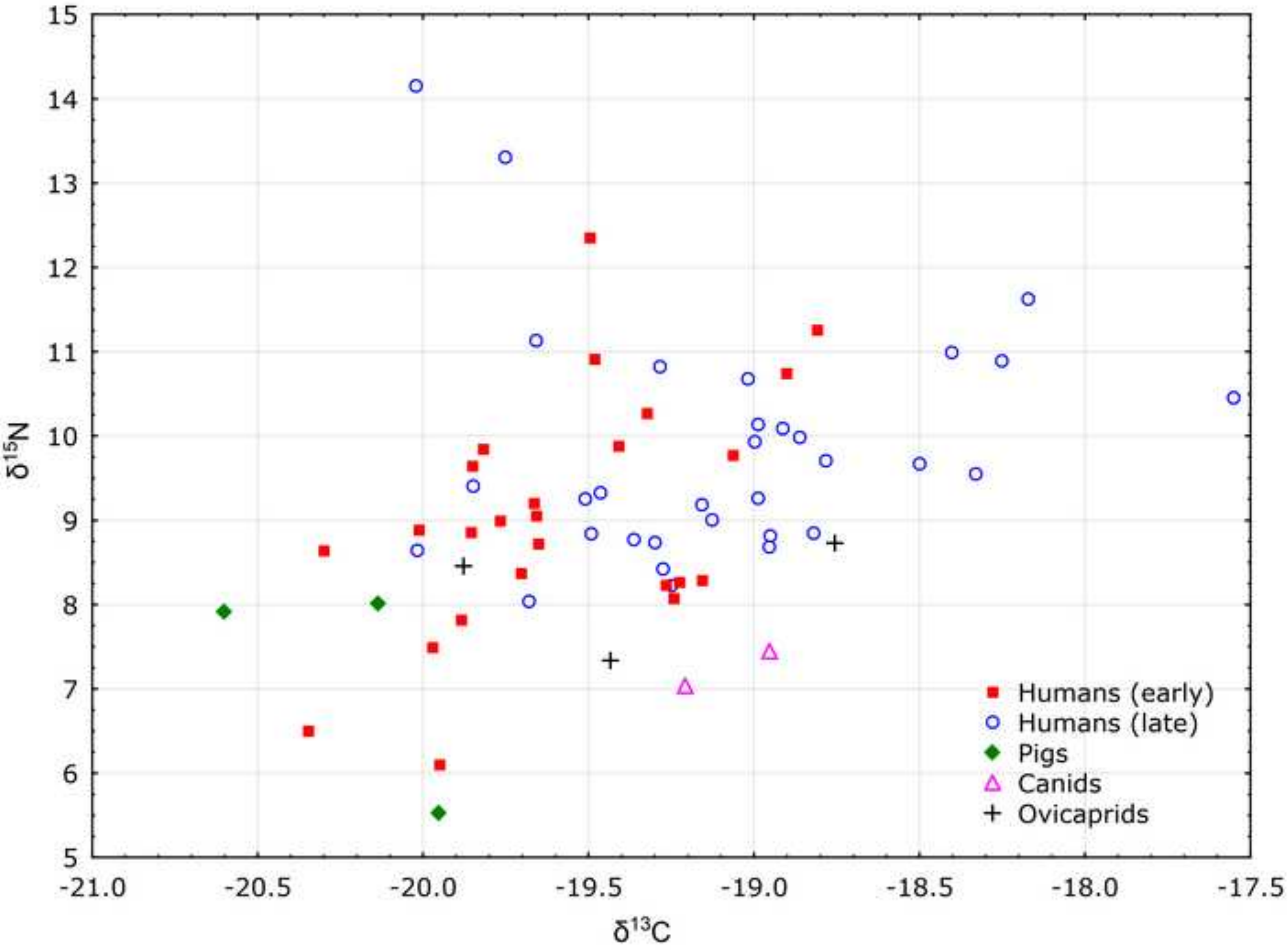

Figure 6a

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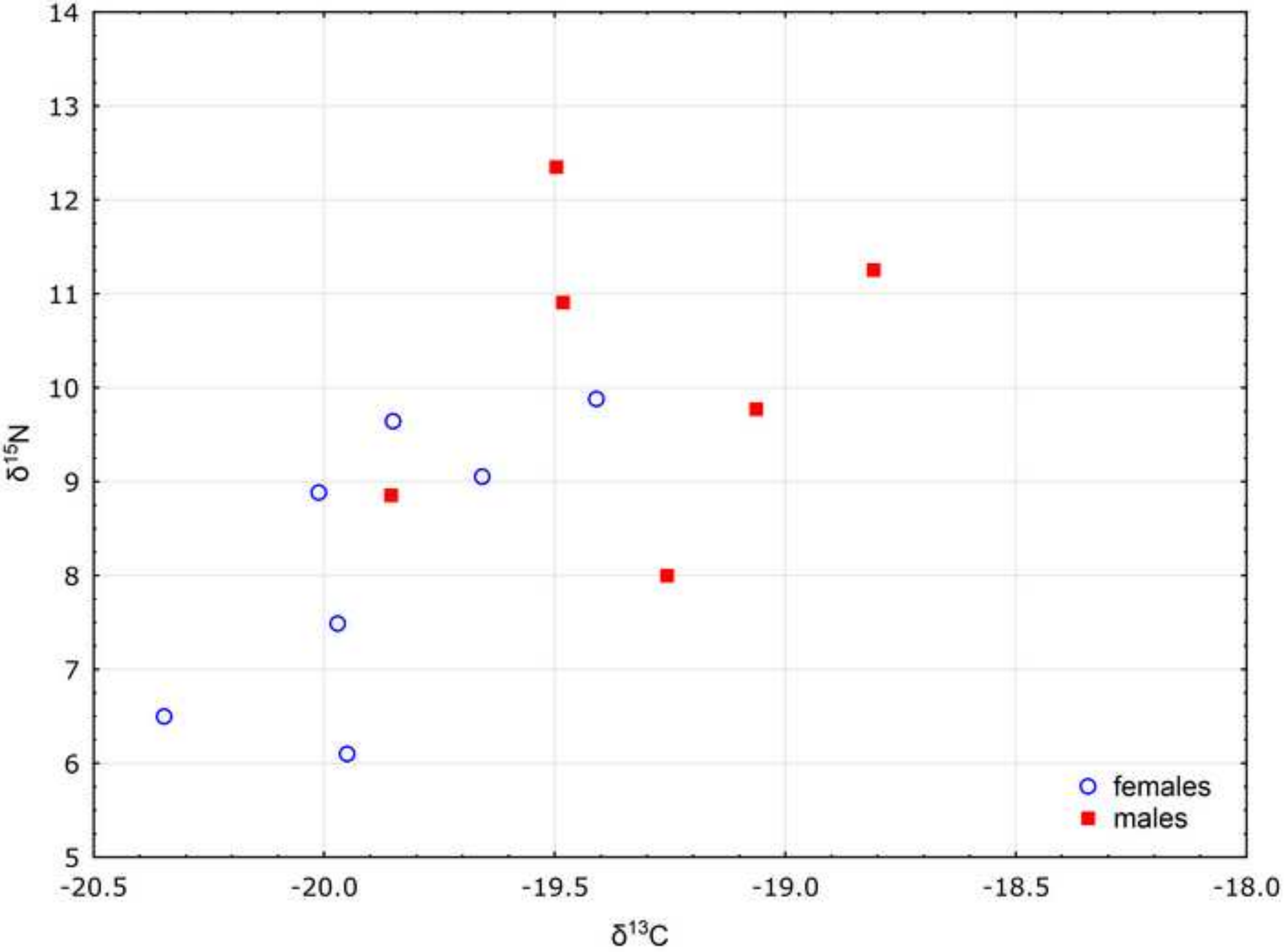

Figure 6b

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