Journal of Archaeological Science: Reports 67 (2025) 105395

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Continuation of hunter-gatherer weaning practices in middle/late Neolithic Latvia

Anna Batraga [a,*], Gunita Zariņa [a], Andrea Czermak [b], Rick J. Schulting [b]

[a] Institute of Latvian History, Faculty of Humanities, University of Latvia, Kalpaka bulvaris 4, Riga LV-1050, Latvia
[b] School of Archaeology, University of Oxford, 1 South Parks Road, Oxford OX1 3TG, UK

ARTICLE INFO

Keywords:
Weaning
Carbon and nitrogen isotopes
Neolithic
Agriculture
Diet

ABSTRACT

This paper provides information on early life histories from two Neolithic sites in Latvia, Kreiči and Abora I, reconstructed on the basis of stable nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) isotope values from dentine serial sections of nine individuals. With a single possible exception, most individuals were breastfed from birth, with breastmilk lessening as the main food source after the age of 0.6–0.9 years, although some were older. Complete weaning for all individuals had occurred by approximately age 4. These results seem more consistent with the hunter-gatherer tradition of longer weaning periods and older ages at weaning completion, rather than the 'Neolithic' pattern of earlier weaning often thought to have accompanied the spread of early agriculture. This paper also examines differences between child and adult diets within these communities. Higher $\delta^{15}N$ values for post-weaning age children suggest that they consumed more freshwater resources than adults. While there are hints of a slight decline in freshwater resources in the Late Neolithic at Abora I, this is less marked than in previously published Late Neolithic Corded Ware individuals from the site of Zvejnieki. This suggests that the process of Neolithisation was variable even within Latvia, with some communities more committed to farming and others maintaining a predominantly hunting and gathering subsistence economy.

1. Introduction

The Neolithic may be defined either technologically (e.g., by the adoption of pottery) or by the emergence and spread of agriculture. It is the onset of the Neolithic in the latter sense that is a particularly important subject of archaeological research, because this transformation ultimately promoted massive population increase and the development of complex sociopolitical systems, changing the world's landscape over the following millennia. At first, known as the "Neolithic Revolution" (Childe, 1936), much of the focus in archaeology has been on "origins" and the ways in which farming spread across Europe (e.g., Ammerman and Cavalli-Sforza, 1971; Bellwood and Renfrew, 2003; Bellwood, 2005; Bogaard, 2004). Over time, it has been understood that the elements of agriculture did not necessarily appear simultaneously across Europe, so the characteristics of the process and its regional variations are still an ongoing question. In the eastern Baltic region, the Neolithic spans from 5500 cal BC to 1800 cal BC, though here it is defined by the introduction of pottery rather than of farming (Rimantienė, 1992). The first signs of farming fall in the Late Neolithic period of the late 4th – early 3rd millenium cal BC with the arrival of Corded Ware cultural groups (CWC), but even then, it may have varied both locally and regionally (cf. Oras et al., 2023).

As a result, this period could be characterized by societal changes that are reflected in individuals' lives, including their diets. Until now, incremental dentine analysis in the region has only been conducted at the large Mesolithic/Neolithic cemetery of Zvejnieki in northern Latvia, which confirmed a dietary difference in CWC individuals, showing less use of aquatic resources than seen previously (Henderson et al., 2022). But this was based on a few individuals from a single site, leaving it unclear to what extent farming had spread. To address this, we explore the early life experiences of Middle/Late Neolithic individuals in eastern Latvia and compare them to those at Zvejnieki to determine whether dietary changes consistent with the adoption of domesticated resources are seen more widely in the region. Additionally, we compare childhood and adult diets to assess at what stage an 'adult' diet is adopted. This is important in terms both of reconstructing individual life histories, and of knowing the extent to which isotopic measurements on post-weaning-age dentine and bone can, or cannot, be used interchangeably.

* Corresponding author.
E-mail address: anna.batraga@lu.lv (A. Batraga).

https://doi.org/10.1016/j.jasrep.2025.105395
Received 26 March 2025; Received in revised form 5 September 2025; Accepted 7 September 2025
Available online 20 September 2025

1.1. Early farming in Stone age in territory of Latvia

The transition to agriculture in Latvia has long been a focus of research (Moora, 1952; Graudonis, 2001; Loze, 1997, 2000, 2015; Vasks, 2015; Legzdiņa and Zariņa, 2023). Previously it has been suggested that the first signs of early agriculture can be seen in the Middle Neolithic (3900–3000 calBC) to Late Neolithic (3000–1800 calBC), with the discovery of supposedly domestic faunal remains at several sites (Vasks, 2015). However, questions over their exact dates remain, and the small number of these finds suggests that the dependence on livestock was still minimal. For example, more recent studies in Lithuania have found no signs of domesticated animals or crops before the appearance of Neolithic Globular Amphora and Corded Ware cultures ca. 3200–2700 cal BC (Piličiauskas et al., 2017). Some evidence from present-day Estonia suggests that early domesticated animals (cattle, pig and sheep) were present in Late Neolithic period sites from ca. 2900–2700 cal BC (Lõugas et al., 2007), though recent radiocarbon AMS dates place the earliest domesticates here even later, ca. 2730–2490 cal BC (Oras et al., 2023). It is possible that in Latvia, early domesticated animals were present from around the same time.

A significant aspect of this research revolves around the extent to which migration influenced the shift to farming (cf. Jones et al., 2017; Saag et al., 2017). As noted above, the Corded Ware Culture (CWC) has been proposed as the group responsible for introducing agricultural practices in Latvia, and this has support from (some) stable isotope data for a dietary shift, the presence of domestic fauna, and ancient DNA, showing a major contribution of 'steppe ancestry' for some CWC individuals (Jones et al., 2017; Mittnik et al., 2018).

More recently, some researchers have suggested that, regardless of the timing of its introduction, farming did not come to dominate the diet until much later, in Late Bronze Age (1100–500 cal BC) (Vasks et al., 2021). This hypothesis is supported by stable isotope analysis and radiocarbon dating, although the sample size remains insufficient for definitive conclusions (Legzdiņa et al., 2020; Vasks et al., 2021).

1.2. Archaeological sites

The Kreiči settlement and cemetery are located in southeastern Latvia, about 400 m south of Great Ludza Lake, on the right bank of the Isnauda River (Fig. 1). The site was mainly investigated between 1955 and 1959 (Zagorskis, 1961). The area of the settlement was about 900 m^2, of which 760 m^2 were excavated. Kreiči settlement is one of the rare Stone Age settlements rich in finds, including pottery, flint, amber, stone and bone tools. The site is dated typologically from the second half of the Middle Neolithic into the Late Neolithic period, from ca. 3350 to 1750 BCE.

A total of 23 burials of various types were unearthed at Kreiči. Some were buried in an extended position on their backs, while others laid prone or in a flexed position on their sides. Three individuals were buried in a sitting position. There were single burials and double burials. The double burials include individuals positioned next to each other on their backs, individuals buried in diametrically opposite directions, and burials where the upper parts of the individuals were next to each other, but their lower parts were in different levels with intervening rocks and soil (Zagorskis, 1961). Due to the poor preservation state of the skeletons, sex could be determined for only five individuals from the site–-three females (graves 5, 14 and 16) and two males (graves 12 and 23).

The Abora I settlement, along with its cemetery, is located on the right bank of the Abora River, near its confluence with the Abaine River in the Lubāns Plain of eastern Latvia (Fig. 1). Major archaeological excavations at the site took place mainly from 1964 to 1965, again between 1970 and 1971, in 2008 (Loze, 1965, 1966, 1971, 1972, 2008), and most recently in the last couple of years (Legzdiņa et al., 2022; Haferberga et al., 2024). During these excavations, researchers explored an area of 1,311 m^2; however, estimates suggest that the entire settlement may have covered approximately 5,000 m^2. The excavations uncovered an array of nearly 22,000 artifacts, including tools made from stone, amber bone, antler, and flint, as well as wooden fish traps, though the majority (approximately 18,000 in total) are comprised of pottery sherds. Based on the artifacts and radiocarbon results, Abora I is mainly dated between ca. 3500 and 1900 cal BC, spanning the Middle Neolithic to the end of the Late Neolithic (Legzdiņa and Zariņa, 2023). As at Kreiči, there is also evidence indicating that the site was intermittently inhabited during the Bronze and Iron Ages.

The Abora I cemetery contains a total of 62 burials, and it is believed that both the cemetery and the settlement were used at the same time. The deceased were again buried in various positions: on their backs, in flexed positions laid on their sides and in two cases in sitting positions.

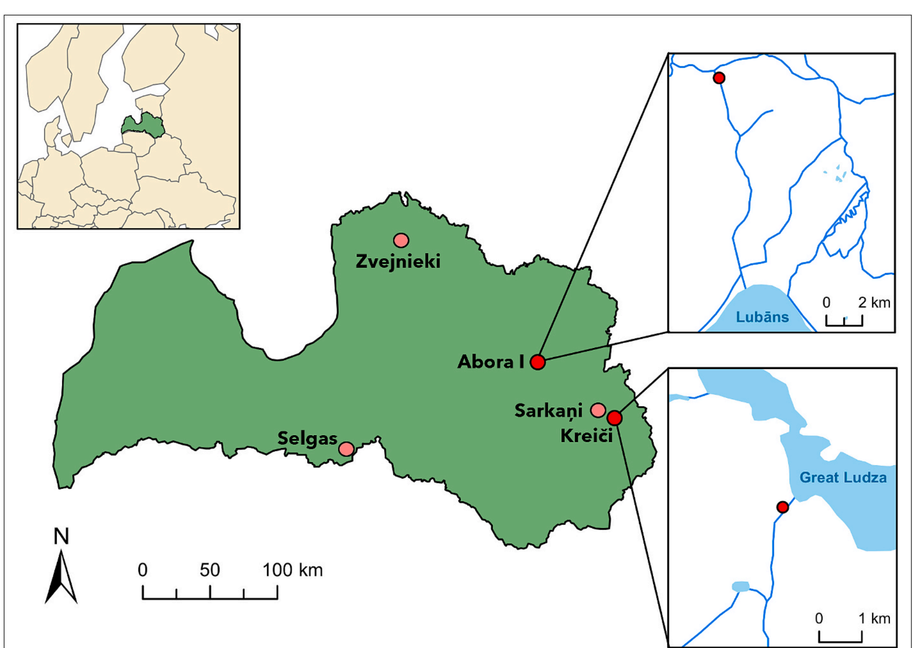

Fig. 1. Location of the Stone Age settlements and cemeteries mentioned and analysed in this study.

Single burials were the most prevalent, though there were some multiple graves containing two or three individuals. Grave goods were discovered in 22 of the burials, including pendants made from animal teeth, bone lunulae, and bone trapezoids, as well as amber ornaments and points crafted from bone and flint. Since the cemetery existed alongside the settlement, it explains why many of the burials had been somewhat disturbed (Legzdiņa and Zariņa, 2023).

Given the incomplete nature of the findings, researchers were able to determine the sex and age for only 32 of the 61 (ca. 52 %) documented burials. Additional anthropological information was obtained from isolated human bones discovered within the cultural layer, including cranial fragments, mandibles, and long bones, thus providing anthropological data for 72 individuals (Legzdiņa and Zariņa, 2023). Overall, there were 24 subadults, 20 adult females and 26 adult males, as well as two indeterminate adults. Of the 11 adult females with age-at-death estimates, five were under the age of 25. For males, however, the majority (eight of 12) had died between the ages of 30 and 50.

The nearby area of Lake Lubāns is known as the most densely populated Stone Age micro-region in Latvia. Studies have concluded that farming became increasingly prevalent in this area during the Late Neolithic, ultimately emerging as the primary subsistence strategy either during or shortly after the transition to the Bronze Age (Loze, 1997). Recent research shows that this might not be the case, at least in the Abora settlement. The stable isotope data from the Abora population indicates that the majority of individuals predominantly relied on freshwater resources supplemented by terrestrial plants, with minimal contributions from terrestrial animals. Interestingly, a few individuals exhibited a different subsistence approach, heavily utilizing terrestrial animal sources while also incorporating freshwater and plant resources. Notably, none of the individuals analysed showed isotopic evidence to suggest that agriculture played a significant role in their subsistence strategies (Legzdiņa and Zariņa, 2023).

1.3. Stable isotope analysis

The analysis of stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes have become an important method in archaeology for studying ancient diets and human interactions with animals. Major uses of $\delta^{13}C$ are to distinguish C_3 and C_4 plants, and foods from C_3 terrestrial and marine systems (Schoeninger et al., 1983). However, neither C_4 nor marine foods are relevant to the study area, where human diets relied on terrestrial C_3 and freshwater aquatic resources. Freshwater aquatic ecosystems can be quite variable (Dufour et al., 1999; Guiry, 2019; Katzenberg and Weber, 1999), though in the study area they appear to have been generally ^{13}C-depleted (Meadows et al., 2016; Meadows et al., 2018; Schmölcke et al., 2016). Conversely $\delta^{15}N$ values are expected to be higher on average for both marine and freshwater organisms compared to most terrestrial organisms, as a result of trophic level enrichment from the longer foodchains present in aquatic systems (Schoeninger and Deniro, 1984). Thus, $\delta^{13}C$ in conjunction with $\delta^{15}N$ measurements can usually identify the consumption of freshwater resources.

Measurements on collagen emphasise the contribution of dietary protein in both isotopes, to the effective exclusion of other macronurients in the case of $\delta^{15}N$, though the latter (i.e., lipids and carbohydrates) can contribute to the $\delta^{13}C$ signal (Jim et al., 2006). This would be the case particularly in low-protein diets, which are unlikely to characterise north-temperate envionments inhabited by prehistoric hunter-gatherers.

In contrast to bone, primary dentine does not remodel after its initial formation. Advances in analytical methods now allow for sequential sampling of isotopes from tooth dentine, providing detailed, high-resolution data on an individual's dietary patterns over time (Beaumont et al., 2013; Czermak et al., 2020; Eerkens et al., 2011). This approach is especially useful for studying childhood diet and weaning behaviours, as the structured formation of the permament dentition preserves a chronological record of dietary intake during different stages of early life.

1.4. Breastfeeding and weaning

Breastfeeding is critical for an infant's survival and health, as maternal milk not only provides essential nutrition but also fosters immunological tolerance, protecting the infant from various diseases (Cunningham et al., 1995; Silvia and Clements, 1997). When an infant reaches the age of approximately six months, complementary foods become necessary, because breastmilk will no longer provide all the necessary nutrients required for development (Dewey, 2013). This transition marks the initiation of weaning, the end of which sees the complete replacement of breast milk with solid food (Buikstra et al., 1986). As the infant undergoes these dietary changes, it is possible to see these weaning signals isotopically, which can be used in research into weaning practices in historic and prehistoric populations (Fogel et al., 1989; Katzenberg et al., 1993; Katzenberg et al., 1995).

The study of breastfeeding and weaning behaviours in archaeology has emerged as a pivotal focus within bioarchaeology, given its profound implications for individual life histories and their influence on the overall health of the examined population (e.g. Eerkens et al., 2011; Beaumont and Montgomery, 2016; King et al., 2018; Kaupová et al., 2023). As of late, researchers have utilized stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis of human tissues to effectively reconstruct historical breastfeeding and weaning practices. Typically, $\delta^{15}N$ values in exclusively breastfed infants are found to be approximately 2 to 3 ‰ higher than their mothers, attributed to a trophic level shift (Fogel et al., 1989; Fuller et al., 2006). When the weaning process starts, $\delta^{15}N$ values decrease, usually reaching similar values to those of adults. Trophic level shifts in $\delta^{13}C$ during weaning are far less pronounced, if seen at all, ranging from < 0.5 ‰ (Herrscher et al., 2017) to ca. 1 ‰ (Fuller et al., 2006). Generally, as complementary foods are introduced during weaning, isotopic values decline in both systems. What also need to be kept in mind are various factors that can obscure the weaning patterns, such as the presence of physiological stress, maternal dietary change during lactation, or weaning foods with similar values to those of breastmilk (Drtikolová Kaupová et al., 2024; Henderson et al., 2022).

Examining weaning patterns provides important insights into several aspects of a society's child-rearing practices (often referred to as parental investment), and the cultural factors that influence both the length of breastfeeding and the types of weaning foods introduced. Additionally, it sheds light on differences observed among various populations and potential biases in care based on the sex of infants. Understanding these dynamics is crucial for reconstructing historical human behaviors and health outcomes associated with breastfeeding practices across diverse contexts of culture, environment, economy, etc. (e.g. Tomori et al., 2017; Fildes et al., 2017; Jay, 2009).

2. Materials and methods

2.1. Samples

Human remains found at archaeological sites are stored in the Repository of Bioarchaeological Material at the Institute of Latvian History, University of Latvia, which has granted permission to use the material from Kreiči and Abora I for this study.

Individuals with the best preserved teeth and least worn crowns were selected. Because of the often poor state of preservation, not all of the individuals from Kreiči are kept in the Repository of Bioarchaeological Material at the Institute of Latvian History and only some of them were brought from the field. Only three individuals were suitable for inclusion in the present study: Burials 13, 14 (Fig. 2), and 23. From Abora, six individuals fit the criteria: Burials 3 (Fig. 2), 12, 22, 39, 40 and 54. The first molars of these nine individuals were selected for sampling (Kreiči n = 3, Abora I n = 6), representing the developmental period from

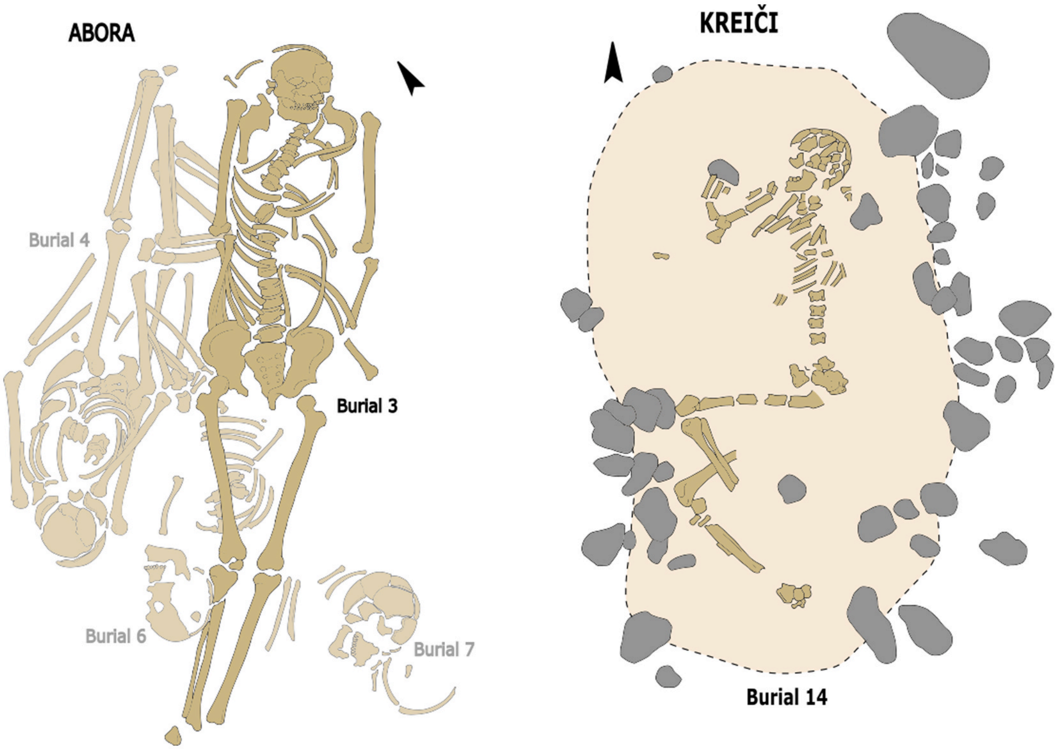

Fig. 2. Abora I Burial 3 and Kreiči Burial 14.

approximately 0 to 8 years. All the Abora I individuals included in this study had been previously analysed, providing data on age at death and sex, dating, and bone $\delta^{13}C$ and $\delta^{15}N$ values (Legzdiņa and Zariņa, 2023). To represent later childhood from approximately 8 to 14.5 years, the second molars of five individuals (Kreiči n = 3, Abora I n = 2) were also selected for analysis.

Two of the individuals were juveniles, while four were adults (>20 years), and one a child aged 8–9 years (A12). The sample includes three females and three males, while the sex of the remaining three individuals (K13, A12, A54) could not be determined due to poor preservation (Table 1).

Preparation of material for sequential dentine analysis was done following Czermak et al. (2020). Firstly, the teeth were photographed to document them before destructive analysis (supplementary material). They then underwent mechanical cleaning using air abrasion with aluminium oxide powder to remove any surface debris. Following this, the teeth were partially embedded in Herculite II, a gypsum moulding material, leaving the mesial or distal surface exposed to allow alignment of the cutting wheel. A Buehler IsoMet low speed saw with a diamond wafer blade was then utilized to section the teeth into approximately 2 mm thick longitudinal slices. Each slice was demineralized in 10 ml aliquots of 0.5 M HCl at a temperature of 4 °C for about two weeks. This was followed by treatment with 0.1 M NaOH for 30 min and another round of 0.5 M HCl for one hour at room temperature to remove any adsorbed carbon dioxide, with thorough rinsing with deionized MilliU water between each reagent application.

The demineralized tooth sections were then sampled sequentially from the crown to the root tip using a 1-mm-diameter KAI Medical biopsy punch equipped with a plunger, carefully avoiding secondary and tertiary dentine, including the pulp chamber and radicular channels, as well as any cementum on the outer root surface. The resulting dentine microsamples were labelled according to a numerical sequence corresponding to anatomical anatomical region, with their approximate ages assigned following guidelines established by AlQahtani et al. (2010). The dentine microsamples were then freeze dried and weighed into tin capsules and analysed using a Sercon 20/22 continuous flow isotope ratio mass spectrometer connected to an elemental analyser at the Research Laboratory for Archaeology and the History of Art, University of Oxford. The total uncertainty (cf. Szpak et al. 2017) varies between runs of different sample weights, but overall falls between ca. ± 0.1 ‰

Table 1
Radiocarbon dates and stable isotope values for individuals from Kreiči and Abora I.

Site	Individual	Age at death	Sex	Lab code	C/N	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	^{14}C BP	calBC (95,4%)	Period*	Source
Kreiči	K13	Juvenile	Indeterminate	Poz-184197		−22.9	12.8	4720 ± 35	3630–3374	MN	1
	K23	23–27	Male	Poz-184240		−25.3	14.2	4615 ± 30	3513–3342	MN	1
	K14	Adult	Female	Poz-184198		−25.4	14.3	4475 ± 30	3341–3029	MN/LN	1
Abora I	A3	19–21	Male	Poz-180142	3.2	−22.4	13.6	4470 ± 35	3341–3024	MN/LN	1
	A12	8–9	Indeterminate	OxA-39054	3.2	−21.0	14.7	4465 ± 21	3334–3027	MN/LN	2
	A54	13–15	Indeterminate	OxA-39058	3.2	−23.6	11.3	4333 ± 20	3011–2898	MN/LN	2
	A39	25–30	Female	OxA-39055	3.3	−25.2	9.4	4105 ± 21	2857–2574	LN	2
	A40	19–21	Female	OxA-39057	3.3	−22.4	12.5	4096 ± 21	2851–2573	LN	2
	A22	Adult	Male	OxA-39000	3.2	−24.8	12.1	3823 ± 20	2397–2151	LN/EBA	2

Period: MN – Middle Neolithic (3900 – 3000 cal BC), LN – Late Neolithic (3000 – 1800 cal BC), EBA – Early Bronze Age (1800 – 1100 cal BC).
Sources: 1) Project No. lzp-2021/1–0119; 2) Legzdiņa and Zariņa, 2023.
* The application of a freshwater reservoir effect would make the dates up to three centuries younger, reflected in the MN/LN and LN/EBA designations.

and 0.3 ‰ (1σ) for both $\delta^{13}C$ and $\delta^{15}N$.

The quality of collagen preservation was assessed according to standard criteria including collagen yield, atomic weight C:N ratio, and percentages of carbon (%C) and nitrogen (%N) (Ambrose, 1990; DeNiro, 1985; van Klinken, 1999). A more conservative C:N range of 2.9–3.4 was used, reflecting the fact that only single measurements are possible with the biopsy punch method (Czermak et al., 2019; Fernández-Crespo et al., 2018; Fernández-Crespo et al., 2020). In some cases, adjacent microsamples were combined to achieve the required weight. In the end, only samples weighing at least 0.35 mg were deemed reliable since lower weights can compromise mass spectrometer measurements (Burt and Amin, 2014).

Some of the selected teeth displayed little attrition, so the first microsample provides results for approximately the first 6 months of life. Most teeth were more worn, as is characteristic for hunter-gatherer diets that include coarse and gritty foods (Smith, 1984). Consequently, complete life histories for the 0 to 8 and 8 to 16 year age ranges were not obtainable in these instances. In cases where crown dentine was lost, the number of missing segments was estimated (Table 2).

3. Results

A total of 14 M, representing three individuals from Kreiči and six individuals from Abora, produced 181 microsamples. Stable isotope results for all samples fall within acceptable ranges for percentage of carbon, percentage of nitrogen, and atomic C/N ratios, although not every micro-sample contained sufficient collagen for analysis. Five microsamples did not attain the weight of 0.35 mg, so they were combined with an adjacent microsample. In four cases, the cusp of the tooth was lost due to tooth wear.

The dentine patterns observed in individual molars are shown along with dietary information from infancy and early childhood (up to ca. age 8 for M1) and late childhood (from post-weaning to ca. age 14.5 for M2) (Figs. 3 and 4). Isotopic profiles of all nine individuals, showing changes in stable light isotope ratios during the first ca. 8 years of life, as well as individuals who also had their M2 analysed, are shown in Fig. 3 (Kreiči) and 4 (Abora I). Comparison between dentine collagen nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) isotope profiles of M1 from Kreiči and Abora I is shown in Fig. 5. Given measurement uncertainty and normal biological variation, a minimum difference of ca. 0.5 ‰ is set as a notional threshhold for both isotopes for consideration as biologically meaningful.

3.1. Kreiči

For Kreiči 13 (Fig. 3A) (isotopically recognizable) weaning lasts from ca. 1.1 to ca. 4.2 years of age, providing the second longest duration among all individuals from both sites and also the oldest age at weaning completion (Table 2). There is a decline in $\delta^{15}N$ values from 16.9 ‰ to 12.9 ‰, while $\delta^{13}C$ values fluctuate between −21.1 ‰ and −24.1 ‰. This could potentially reflect seasonal changes in the foods that the mother consumed during breastfeeding. Post-weaning, the diet during early childhood fluctuates between 13.9 ‰ and 13.0 ‰ for $\delta^{15}N$ and between −24.5 ‰ and −23.3 ‰ for $\delta^{13}C$. In later childhood (M2), the individual shows a decrease in $\delta^{15}N$ values until ca. 9.7 years of age (lowest value of 11.4 ‰) before slowly increasing to 13.7 ‰. Similarly, the lowest value for $\delta^{13}C$ is seen at about 10 years of age (−25.7 ‰), with a small increase to −24.9 ‰.

For two other individuals Kreiči 14 (Fig. 3B) and Kreiči 23 (Fig. 3C) weaning signatures start at similar ages – 0.6 years for K14 and 0.7 years for K23 – but end at ages 4 and 2.5 years respectively. For K14 a decline in $\delta^{15}N$ values is seen from 19.9 ‰ to 14.9 ‰ at age 4, interrupted by sudden drop to 13.6 ‰ in one microsample at the age of ~ 1.3, corresponding with a sudden increase in $\delta^{13}C$ from −25.7 ‰ to −23.7 ‰. This could signal a change in the mother's diet, or an aborted attempt at the cessation of weaning. It could potentially be associated with an episode of physiological stress between ages 1—2 (e.g., Beaumont and Montgomery 2016; though see Discussion). For the remainder of the M1, $\delta^{15}N$ values range from 1.1 ‰ to 14.0 ‰, while $\delta^{13}C$ varies from −26.8 ‰ to −25.2 ‰. In late childhood (M2), little change is seen in $\delta^{15}N$ or $\delta^{13}C$ though both increase slightly in the last section, ca. age 14.

For K23 (Fig. 3C) a decline of 18.7 ‰ to 15.0 ‰ in $\delta^{15}N$ values marks the weaning process, similar to K14. Values for $\delta^{13}C$ are also similar to K14, changing from −25.3 ‰ at the beginning of weaning, to −26.3 ‰ at completed weaning. Similar values are also seen in rest of M1 for both $\delta^{15}N$ and $\delta^{13}C$, although the latter's highest value is −25.9 ‰. Values during later childhood also exhibit little variation, except right before age 9, where $\delta^{15}N$ rises from 13.9 ‰ to 14.5 ‰, and $\delta^{13}C$ value decreases from −25.6 ‰ to 26.4 ‰ and continues to decrease until the age of ca. 9.3.

Overall, these three individuals from Kreiči show rather high $\delta^{15}N$ values during breastfeeding. This reflects their mother's diet, which presumably included substantial amounts of freshwater fish and aquatic birds. Unfortunately, there are no faunal isotopic data for Kreiči as of yet, but values this high are only possible with the consumption of freshwater aquatic resources (given the site's distance from the lake, and the low $\delta^{13}C$ values). Freshwater fish from Neolithic contexts in the Lake Burtnieks catchment to the west show high $\delta^{15}N$ values but low $\delta^{13}C$ values relative to terrestrial fauna (Meadows et al., 2016; Meadows et al., 2018; Schmölcke et al., 2016).

3.2. Abora I

At Abora, the overall duration of exclusive breastfeeding was 0.6 ±

Table 2
Sampled teeth in this study.

Site	Individual	Period	Tooth	Dentine samples (n)	Comment
Kreiči	K13	MN	M1	14	
			M2	18	
	K23	MN	M1	14	Crown was worn, estimated age start at 0.50 years
			M2	13	Crown was worn, estimated age start at 3 years Tip of root is missing
	K14	MN/LN	M1	14	
			M2	5	First 9 segments did not meet the weight criteria
Abora I	A3A3	MN/LN	M1	16	Crown was worn, estimated age start at 0.50 years
			M2	18	Crown was worn, estimated age start at 3 years
	A12	MN/LN	M1	10	Tip of root is missing
	A54	MN/LN	M1	14	Crown was worn, estimated age start at 0.50 years
	A39	LN	M1	13	Tip of root is missing
	A40A40	LN	M1	10	Crown was worn, estimated age start at 0.50 years
			M2	11	Crown was worn, estimated age start at 3 years
	A22	LN/EBA	M1	11	

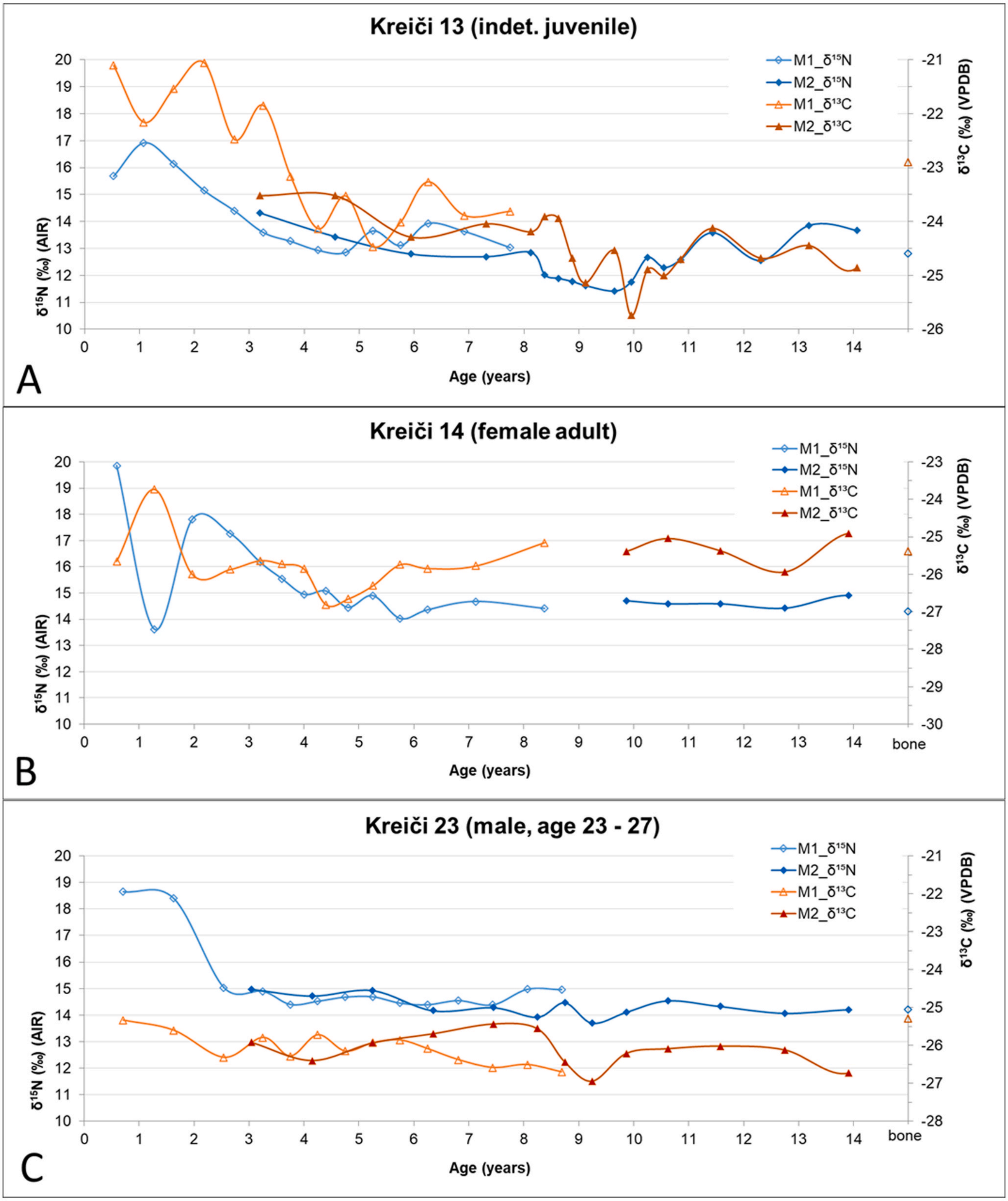

Fig. 3. Molar dentine profiles for Kreiči individuals. Data for the adult is shown on the edge of the plot.

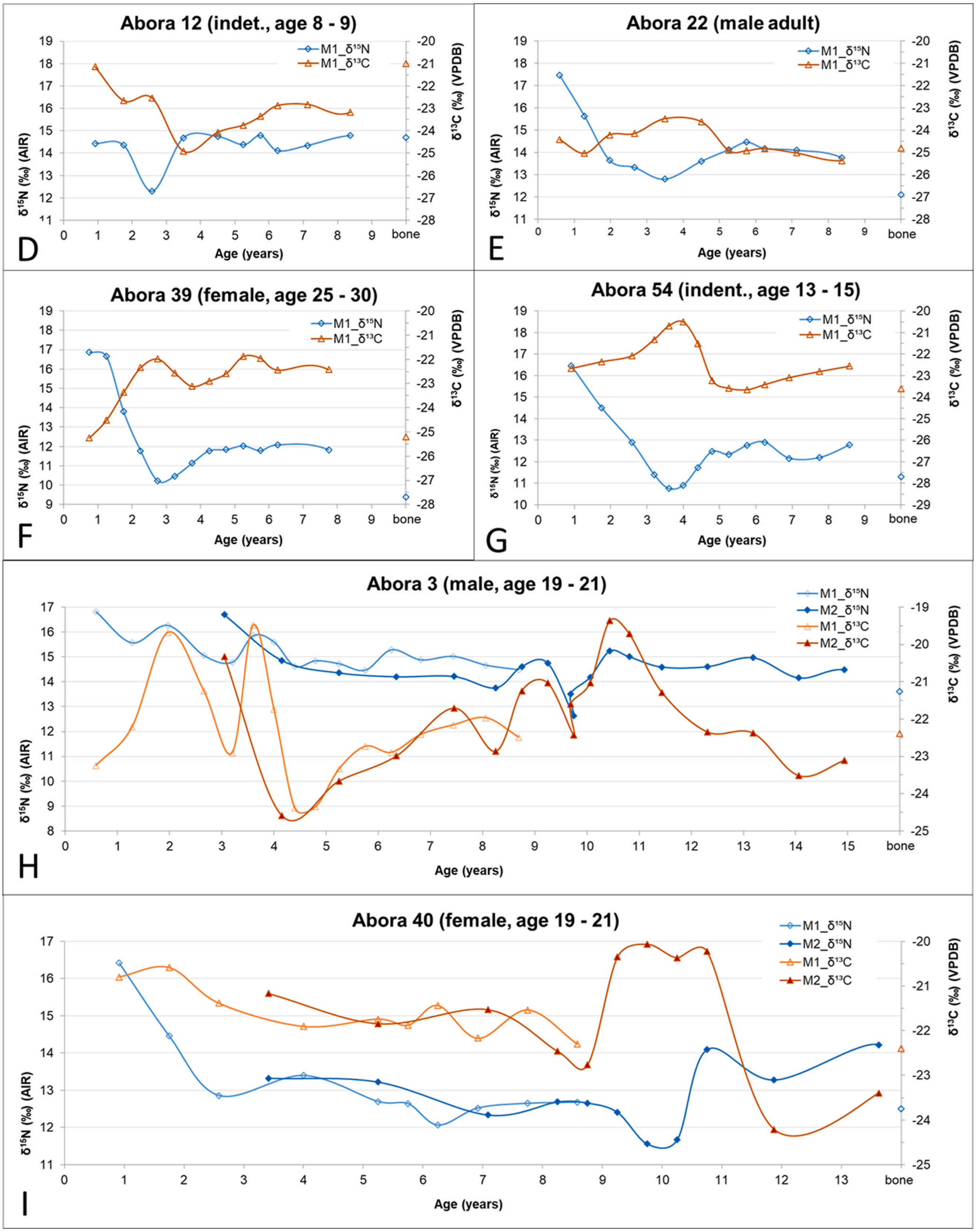

Fig. 4. Molar dentine profiles for Abora individuals. Data for the adult is shown on the edge of the plot.

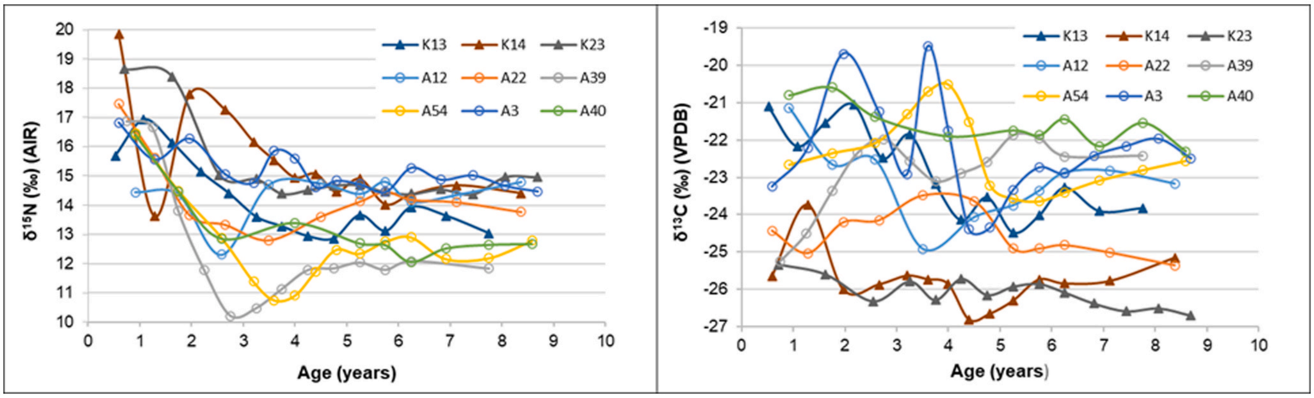

Fig. 5. Comparison of the nitrogen (δ15N) and carbon (δ13C) isotope profiles of the dentine collagen from Kreiči and Abora I from M1.

0.3 years (Table 2). The estimated duration of the weaning process differs individually from 1.7 to 2.9 years, which, in turn, affects the age at complete weaning (2.6 to 3.6 years of age). Overall, these results show no marked differences between individuals in weaning practices, though this could reflect the small sample size.

There are no clear differences between Middle Neolithic (graves 3, 12 and 54) and Late Neolithic (graves 39, 40 and 22) individuals regarding weaning patterns. The longest duration of weaning in the Middle Neolithic is seen in individuals from graves 3 and 54 with more than two years. In turn, they are the oldest when the weaning is completed (3.2 and 3.6 years of age). Regarding isotope values, these are variable between individuals. A54 (Fig. 4G) shows the greatest decrease in δ^{15}N during weaning (by 5.7 ‰) amongst other individuals, and also lowest δ^{15}N values after weaning, which range from 10.9 ‰ to 12.9 ‰. Meanwhile, δ^{13}C values increase from –22.7 ‰ to −20.7 ‰ during weaning and later ranges from −20.5 ‰ to –23.7 ‰. A similar range of δ^{13}C values after weaning is seen for A3 (Fig. 4H) as well. The range of δ^{15}N values is 14.5 ‰ to 15.9 ‰. There is also a sudden peak in δ^{13}C seen in A3 at the age of 2.7 years, which presumably tracks changes in their respective mother's diet and/or in their own diets. Results from the M2 show that δ^{15}N values are almost as high as when the individual started the weaning process. This could indicate that following weaning, the child's diet included considerable amounts of fish. The fluctuating δ^{13}C values in later childhood are rather puzzling, since δ^{15}N values remain relatively stable.

Individual A12 (Fig. 4D) shows a significant decrease in δ^{15}N values between the ages two and three. Then, it increases to values similar as before the drop. It is difficult to determine why this occurred. It is possible that the individual finished the process of weaning at the age of 2.6 years and then consumed food high in δ^{15}N, such as fish, which was an importatnt food source in Abora I. Alternatively, this individual may have been weaned early, or may not have been breastfed at all. One possible reason for this is that the mother may have passed away during childbirth or shortly thereafter. In later ages, this individual shows similar δ^{15}N values to A3. The δ^{13}C values are more or less in the same range with all the other individuals from Abora, except two M1, showing values lower than −24 ‰. It should also be noted that this individual died at the earliest age, between eight and nine years old, compared to others. This could indicate that the beginning of the child's life was rather strenuous, especially if the possibility that they were not breastfed is considered. Because of the uncertainty of A12, weaning patterns of this individual will not be analysed further.

While the duration of weaning is 2 years for A39 (Fig. 4F), for A40 (Fig. 4I) it is a slightly less–1.7 years. For these two individuals weaning ceased right before 3 years of age (2.6 to 2.8 years). Both A39 and A40 show comparatively low δ^{15}N values after weaning, ranging from 10.5 ‰ to 12.1 ‰ and 12.1 ‰ to 13.40 ‰. A40 show a sudden increase in δ^{13}C at age 9 which stays high until about the age of 11 when it decreases. This shows that there were significant dietary changes.

Individual 22 (Fig. 4E) showed the longest duration of weaning amongst Late Neolithic individuals – the duration is 2.9 years and is ceases at age 3.5. Further δ^{15}N values after weaning range from 13.6 ‰ to 1.5 ‰, comparable to those of A3.

Results for later childhood (M2) for both A3 and A40 show a peak δ^{13}C value around age 9–11 after which it declines in both individuals. While this could reflect diet change at a specific age, perhaps relating to roles, which could say something about the social structure in both Middle and Late Neolithic, the number of samples is too small for any robust conclusions.

4. Discussion

4.1. *Weaning patterns and diet structure*

Overall, a decrease in δ^{15}N values during the first years of life was observed in the majority of individuals, providing an indication of breastfeeding and the subsequent weaning process (Table 3). The first marked decrease in δ^{15}N values, which can be attributed to a contribution from complementary foods, occurred in most individuals ($n = 7$) at the age of 7–11 months. This is somewhat later than the current recommended time of six months for the introduction of complementary foods (WHO, 2003). This is not to say that ancient societies followed recommended modern practice, though it has a sound nutitional basis. However, stable isotopes will not necessarily track the introduction of small amounts of complementary foods, particularly if they are not clearly isotopically distinct from the mother's breastmilk. The matter is more complicated in hunter-gatherers than in farmers, since – in the absence of cereal gruel and animal milk – it is likely that a greater range of potential weaning foods were used by the former. The earliest evidence of dairy consumption in the region has been found in present-day Lithuania at the site of Nida (3300–2400 cal BC) (Heron et al., 2015). It can be assumed that dairying was practiced at this time in Latvia as well, considering the distance is not great. While the number of individuals in

Table 3
Weaning patterns of individuals from Kreiči and Abora.

Individual	Duration of (isotopically) exclusive breastfeeding (years)	Estimated duration of the weaning process (years)	Age at complete weaning (years)
K13	1.1	3.1	4.2
K14	0.6	3.4	4.0
K23	0.7	1.8	2.5
A3	0.6	2.6	3.2
A22	0.6	2.9	3.5
A39	0.8	2.0	2.8
A40	0.9	1.7	2.6
A54	0.9	2.7	3.6

this study is small, the age of complete weaning seems to broadly coincide between the two sites, suggesting similar weaning strategies. The three individuals from Kreiči completed weaning at the age of 2.5–4.2 years, while at Abora it was 2.6–3.6 years. Similar results are seen, for instance, in the Middle Neolithic site of Ajvide in Gotland (Pitted Ware culture), where the majority of infants continued breastfeeding into the third or fourth year of life (Howcroft et al., 2014). Meanwhile, in societies with agricultural subsistence strategies, weaning occurred slightly earlier than in hunter gatherers, although there were also variations (Howcroft, 2013). For example, in the Late Neolithic collective grave in Bronocice (Poland) most of the infants continued breastfeeding until three to four years of life (Cienkosz-Stepanczak et al., 2017). At Zvejnieki, however, weaning ceased at ca. 1.3 years for two Late Neolithic individuals (Henderson et al., 2022).

Regarding the post-weaning period, a decline in δ^{15}N values from time to time was observed in some individuals, followed by an increase. Changes in dietary habits, instances of malnutrition, and certain diseases have been recognized as potential factors that can lead to significant variations in δ^{15}N values and subsequently affect isotopic values in the human body (e.g. Kendall et al., 2020; Klaus, 2014). As a result, some isotopic patterns can be seen. One of these patterns is the opposing covariation, i.e., rising δ^{15}N and decreasing δ^{13}C values, seen in individuals K13, K14, K23, A12, A22, A39 and A54 (Fig. 3A–C; Fig. 4D–G). This has sometimes been interpreted as indicating nutritional or physiological stress, with the body catabolizing proteins and lipids (Beaumont and Montgomery, 2016; Craig-Atkins et al., 2018). However, many recent studies report contradictory results (e.g. Canterbury et al., 2020, Drtikolová Kaupová et al., 2021; Drtikolová Kaupová et al., 2022), which could be explained by individual differences of the phase of malnutrition and in the amount of body fat (Drtikolová Kaupová et al., 2024). The negative trend in A22, A39 and A54 (Fig. 4E–G) is visible for the entire molar, implying that these individuals suffered from malnutrition for many years, which seems implausible since two (A22 and A39) lived into adulthood, while the third died in early adolescence (age 13–15).

In any case, the more plausible interpretation for our study area is that opposing covariation in this context relates to the consumption of ^{13}C-depleted, high-trophic-level freshwater aquatic resources (cf. Henderson et al., 2022). The majority of individuals – K13, K14, A3, A22, A39, and A54 – show opposing covariation of decreasing δ^{15}N values and increasing δ^{13}C values. This pattern may be linked to variation in the consumption of freshwater and terrestrial resources, introduced to the infant directly or through changes in isotopic composition of mother's breastmilk (King et al., 2018). Previous studies have linked it to the use of C_4 foods as supplementary resources, but this is not feasible in the present study region. The vegetation here is predominately C_3, and the oldest evidence of C_4 millet has been found in the Late Bronze Age/Early Iron Age (1100–1 cal BC) Ķivutkalns settlement (Vasks and Zariņa, 2014), which is on par with dates from northern Germany and northern Poland where millet is dated a little earlier (Filipović et al., 2020).

The consumption of freshwater resources raises the possiblity of a freshwater reservoir effect (FRE), making the radiocarbon dates too old. Differences on the order of a few centuries were modelled at Zvejnieki (Meadows et al., 2016; Meadows et al., 2018), though freshwater systems are complex and may exhibit different FREs (Fernandes et al., 2015). Little detailed information is available for Lake Lubāns specifically, but an initial approximation of 284 ± 18 ^{14}C years has been proposed for the modern lake, based on a radiocarbon-dated pike (*Esox lucius*) caught in 2019 (Legzdiņa and Zariņa, 2023). While this may not reflect the ancient situation, it seems consistent with paired dates on human and aurochs' bone from grave 8 at Abora, resulting in a ^{14}C offset of 184 ± 20 BP (Legzdiņa and Zariņa, 2023), assuming that ca. 65 % of dietary protein was derived from freshwater resources, which seems reasonable given the stable isotope values.

Compared to Kreiči, Abora individuals show lower values for δ^{15}N and higher values for δ^{13}C, suggesting the possibility of different faunal baselines between the sites. Measurements on fish of the same species (in this case, pike, *Esox lucius*) differ by 1.4 ‰ in mean δ^{13}C values between Riņņukalns and Zvejnieki (two sites in northern Latvia located only few km from each other) (Eriksson et al., 2006; Schmölcke et al., 2015). To compare, pike from three Mesolithic to Neolithic sites in Lubāns wetland (Zvidze, Abora, Eiņi), that are located between 3 and 9 km from each other, resulted in a combined mean δ^{13}C value of −24.7 ± 0.6 ‰ (n = 7) (Legzdiņa, unpublished results). This value differs by −2.5 ‰ from that of Riņņukalns and by −1.1 ‰ from that of Zvejnieki. At the same time, δ^{15}N values suggest that the pike in Riņņukalns and Zvejnieki are on the same trophic level, with mean δ^{15}N values of 10.0 ‰ and 10.2 ‰, respectively. Meanwhile, the pikes in Lubāns wetland on average have a lower mean δ^{15}N value of 8.6 ± 0.5 ‰ (n = 7) (Legzdiņa, unpublished results), differing by 1.4 ‰ and 1.6 ‰ from Riņņukalns and Zvejnieki, respectively. Although there are too few samples from the Lubāns wetland to draw robust conclusions about sites individually, these results demonstrate that there are overall isotopic differences between sites in different parts of the region, sometimes even between nearby ones such as Riņņukalns and Zvejnieki. To interpret the human results, analysis of local isotope ecology needs to be undertaken at each site.

4.2. Signs of early farming

Archaeologist Ilze Loze has written that Stone Age people in the Lake Lubāns wetland area had turned to agriculture in the Late Neolithic, as seen from animal bone finds at Zvidze (Loze, 2000). Grinding stones, assumed to have been used for cereals, have also been found. The relatively elevated δ^{15}N values for the individuals in this study indicate a significant, albeit variable, intake of aquatic resources. For Abora, this is consistent with previous research on bone stable isotope values (Legzdiņa and Zariņa, 2023). Nevertheless, there are some hints of a decline in the use of aquatic resources for the post-weaning-age period (see below) between the Middle and Late Neolithic, with a mean δ^{15}N value of 14.5 ± 0.4 ‰ (n = 5) for the former, and 12.7 ± 0.9 ‰ (n = 4) for the latter. Despite the small sample size, the difference is statistically significant (Welch's *t*-test, $t = 3.67$, $p = 0.024$). The δ^{13}C values do not show a corresponding difference (*t*-test, $t = 1.66$, $p = 0.141$). In any case, the comparison is complicated by uncertainties over the freshwater reservoir correction that should be applied (and hence which individuals are Middle Neolithic, and which are Late), and the fact that most of the Middle Neolithic individuals (3/5) derive from Kreiči which may differ

Table 4
Weaning patterns in Zvejnieki, Abora and Kreiči (Zvejnieki data from Henderson et al., 2022).

		(Isotopically) exclusive breastfeeding (years)	Duration of the weaning process (years)	Age at complete weaning (years)
Zvejnieki	Mesolithic (n = 5)	<0.7	≥2.5	3.1
	Early-/Mid Neolithic (n = 9)	0.5	2.7	2.7
	Late Neolithic (CWC) (n = 3)	0.4	2.3	2.3
Abora	Middle Neolithic (n = 3)	1.1	2.0	3.1
	Late Neolithic (n = 3)	0.7	2.2	3.0
Kreiči	Middle Neolithic (n = 3)	0.8	2.9	4.0

in its isotopic environmental baseline. Because of these issues, we consider this evidence very tentative. Moreover, the decline is substantially less than seen in the CWC burials at Zvejnieki, with $\delta^{15}N$ values of ca. 10 ‰ suggesting predominantly terrestrial diets (Eriksson et al., 2006; Henderson et al., 2020; Meadows et al., 2018). This suggests that freshwater resources continued to form a substantial part of Late Neolithic diets at Abora I.

Neither Kreiči nor Abora show evidence for early weaning that might be considered as more characteristic of farming societies. Instead, they present similar weaning duration and age at completion to Mesolithic and Early/Middle Neolithic hunter-gatherers at Zvejnieki (Table 4). The isotopic values of individuals at Abora I are also rather more variable compared to the more homogenous values at Kreiči, which may relate to differing variability in the isotopic baselines; in their absence, this remains for future research to confirm.

The lack of clear isotopic evidence for substantial changes in diet and weaning practices in Late Neolithic Abora I suggests that some communities may have known about and used agriculture, while others chose not to. The clearest indications of this come from Zvejnieki, where individuals dated to the Late Neolithic exhibit lower $\delta^{15}N$ values and higher $\delta^{13}C$ values consistent with predominantly C_3 terrestrial resources, inferred to herald the appearance of mixed farmers. Moreover, ancient DNA confirms a high component ‘steppe ancestry’ for CWC burial 137 at Zvejnieki, consistent with many other sites across northern Europe (Jones et al., 2017). A similar trend of lower $\delta^{15}N$ values and higher $\delta^{13}C$ values can be seen with Late Neolithic CWC individuals from the sites of Sarkaņi and Selgas in present-day Latvia, with average values of 10.8 ‰ for $\delta^{15}N$ and −21.6 ‰ for $\delta^{13}C$ (n = 3) (Eriksson et al., 2003). Sarkaņi and Selgas are considered part of CWC thanks to grave offerings, while two Zvejnieki individuals were buried with CWC amphora pottery shards (burial 137) and one individual (burial 186) had bone plaques distinctive of the culture (Henderson et al., 2022). All were buried in crouched or supine positions with bent legs, a position that is often characteristic of this culture (e.g., Bourgeois et al., 2023). However, it is not sufficient to assign a burial to a given culture using body position alone. In Kreiči, both K13 and K14 were buried in flexed positions, but lacked grave offerings, while K23 had non-CWC pottery shards. Overall, there is no concrete evidence of a CWC presence at Kreiči. In Abora I, only A3 and A39 contained some grave offerings, but none that could be clearly attributed to the CWC. The small amount (ca. 1 %) presence of Corded Ware pottery at the site could easily be attributed to exchange rather than to the presence of a CWC population.

Our results emphasize that transitions to agriculture could be complex and locally variable, with some incoming farming communities coexisting alongside indigenous hunter-gatherers (cf. Fraser et al., 2018), with some local communities perhaps adopting the practice over time and others choosing not to, what Oras et al. (2023) have referred to as ‘parallel worlds’.

4.3. Comparison of childhood and adult diets

Since there are isotopic values of the same Abora I individuals as adults from previous studies, and Kreiči burials have also been analysed, it is possible to investigate whether there are differences in children and adult diets during the Middle and Late Neolithic (Table 5). The age range of 4 to 8 years was chosen for childhood diet because the beginning of this period marks the definitive end of weaning for all individuals. Adult isotopic values of the same individuals were obtained from cranial fragments, representing an average of foods consumed over the last decade or more of life (cf. Hedges et al., 2007).

Overall, there is a significant decrease in $\delta^{15}N$ values between childhood and adulthood, ranging from 0.2 to 2.5 ‰ (paired *t*-test, $t = 3.799$, $p = 0.007$, df = 7) (Table 5). This suggests higher consumption of freshwater resources, though it is not matched by corresponding differences in $\delta^{13}C$ values, which are similar for both children and adults (paired *t*-test, $t = 0.274$, $p = 0.792$, df = 7). Again, the absence of baseline fauna data makes further interpretation difficult. Nevertheless, we may provisionally propose that fish were consumed less often, and terrestrial game (and perhaps plant foods) correspondingly more often by individuals with “adult” status at both Kreiči and Abora I. At Zvejnieki, evidence suggests that hunters (showing slightly lower $\delta^{15}N$ values) may have held a higher status in the community, seen in the presence of animal tooth pendants as grave offerings, though there the lower $\delta^{15}N$ values are seen in both children and adults (Schulting et al., 2020; Henderson et al., 2022).

A comparable difference in $\delta^{15}N$ values to that noted for post-weaning-age between Middle (n = 4) and Late Neolithic (n = 4) individuals can also be observed in their adult bone collagen (Welch’s *t*-test, $t = 3.12$, $p = 0.031$). The same issues with interpretation of this small sample that were raised above apply here as well.

5. Conclusions

This study presents a sequential dentine $\delta^{13}C$ and $\delta^{15}N$ analysis of individuals from Kreiči and Abora I during the Middle and Late Neolithic. Stable carbon and nitrogen isotopic data from dentine serial sections of these 9 individuals suggest that most of them were breastfed for the better part of the first year. The process of weaning started at age 0.6 for the youngest and 1.1 years for the oldest, spanning from 1.7 to 3.4 years. While this is only a preliminary assessment of weaning patterns based on a small number of individuals, they do not conform to expectations of earlier weaning in farming communities, and instead continue to follow practices more typical of hunter-gatherers.

There are tentative indications of a decrease in the consumption of freshwater aquatic resources at Abora I, based on lower $\delta^{15}N$ values, but their interpretation is not straightforward. A larger sample size is required to address this possibility more fully, alongside a better

Table 5
Isotopic values during childhood, age 4 – 8 years, and adulthood.

Individual	calBC (95,4%)	Period*	Age at death	Sex	childhood, age 4 — 8 (‰)		adult (‰)	
					$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$
K13	3630–3374	MN	Juvenile	–	13.9	−24.1	12.8	–22.9
K23	3513–3342	MN	23–27	Male	14.6	−26.2	14.2	–25.3
K14	3341–3029	MN/LN	Adult	Female	14.6	−2.0	14.3	–25.4
A3	3341 – 3024	MN/LN	19–21	Male	14.9	−2.9	13.6	–22.4
A12	3334 – 3027	MN/LN	8–9	–	14.5	–23.3	–	–
A54	3011 – 2898	MN/LN	13–15	–	12.3	–22.7	11.3	–23.6
A39	2857 – 2574	LN	25–30	Female	11.9	−2.4	9.4	–25.2
A40	2851 – 2573	LN	19–21	Female	12.7	−21.9	12.5	–22.4
A22	2397 – 2151	LN/EBA	Adult	Male	14.0	−24.8	12.1	−24.8
				Mean	13.7	–23.8	12.5	−24.0
				SD	1.1	1.6	1.6	1.3

Period: MN – Middle Neolithic (3900 – 3000 calBC), LN – Late Neolithic (3000 – 1800 calBC), EBA – Early Bronze Age (1800 – 1100 calBC).
* The application of a freshwater reservoir effect would make the dates up to three centuries younger, reflected in the MN/LN and LN/EBA designations.

understanding of freshwater reservoir effects and the creation of a faunal isotopic baseline. Results from Late Neolithic individuals at the more studied Zvejnieki site do show some possible signs of early agriculture, which indicates that communities in this region were becoming aware of this new source of livelihood, but its full scope is yet to be understood.

Mean $\delta^{15}N$ values were lower in adults, which could mean that children received more freshwater resources – or less terrestrial game – in their diet. Possibly fish were more easily accessible and more frequently consumed in the base camp. Either way the diets vary between different individuals and different sites, showing variability in people's subsistence adaptions – 'parallel worlds' – in the eastern Baltic in the early 3rd millenium.

CRediT authorship contribution statement

Anna Batraga: Writing – original draft, Visualization, Investigation. **Gunita Zariņa:** Writing – review & editing, Resources. **Andrea Czermak:** Validation, Supervision, Methodology, Investigation. **Rick J. Schulting:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

Acknowledgement to the Baikal Archaeology Project for funding the first author's stay and work at the Research Laboratory for Archaeology and the History of Art, Oxford University. This research would not have been possible without the opportunity to work in this laboratory. Special thanks go to the staff of the laboratory, who provided invaluable expertise and practical advice on the work.

Also, an acknowledgement to Latvian Council of Science project No. lzp-2021/1-0119 "Skills in synergy, crafts in context: an integrated study of eastern Baltic Stone Age technologies" for permission to use the Kreiči date and isotopic data.

The preparation of this paper is funded by the Latvian Council of Science project No. lzp-2022/1-0300 "The environment and early farming of the Abora Neolithic settlement in lake Lubāns wetlands".

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2025.105395.

Data availability

Data will be made available on request.

References

AlQahtani, S., Hector, M., Liversidge, H., 2010. Brief communication: the London atlas of human tooth development and eruption. Am. J. Phys. Anthropol. 142, 481–490. https://doi.org/10.1002/ajpa.21258.

Ambrose, S.H., 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. J. Archaeol. Sci. 17, 431–451. https://doi.org/10.1016/0305-4403(90)90007-R.

Ammerman, A.J., Cavalli-Sforza, L.L., 1971. Measuring the rate of spread of early farming in Europe. Man 6 (4), 674–688. https://doi.org/10.2307/2799190.

Beaumont, J., Montgomery, J.M., 2016. The Great Irish Famine: Identifying starvation in the tissues of victims using stable isotope analysis of bone and incremental dentine collagen. PLoS One 11, e0160065. https://doi.org/10.1371/journal.pone.0160065.

Bellwood, P., 2005. First Farmers: the Origins of Agricultural Societies. Blackwell, Malden (MA).

Bellwood, P.S., Renfrew, C., 2003. Examining the Farming/ language Dispersal Hypothesis. McDonald Institute for Archaeological Research.

Bogaard, A., 2004. Neolithic Farming in Central Europe: An Archaeobotanical Study of Crop Husbandry Practices. Routledge, London.

Bourgeois, Q.P.J., Kroon, E.J., 2023. Emergent properties of the corded ware culture: an information approach. In: Kristiansen, K., Kroonen, G., Willerslev, E. (Eds.), The Indo-European Puzzle Revisited. Cambridge University Press, Cambridge.

Buikstra, J.E., Konigsberg, L.W., Bullington, J., 1986. Fertility and the development of agriculture in the prehistoric Midwest. Am. Antiq. 51, 528–546. https://doi.org/10.2307/281750.

Burt, N.M., Amin, M., 2014. A mini me? Exploring early childhood diet with stable isotope ratio analysis using primary teeth dentin. Arch. Oral Biol. 59 (11), 1226–1232. https://doi.org/10.1016/j.archoralbio.2014.07.014.

Canterbury, J.A., Beck, C.W., Dozier, C., Hoffmeister, K., Magaro, J., Perrotti, A.G., Wright, L.E., 2020. Bariatric surgery as a proxy for nutritional stress in stable isotope investigations of archaeological populations. J. Archaeol. Sci. Rep. 30, 102196. https://doi.org/10.1016/j.jasrep.2020.102196.

Childe, V.G., 1936. Man makes himself. Watts & Company, London.

Cienkosz-Stepanczak, B., Lisowska-Gaczorek, A., Haduch, E., Ellam, R., Cook, G., Kruk, J., Milisauskas, S., Koziel, S., Szostek, K., 2017. Nitrogen and strontium isotopes as tools for the reconstruction of breastfeeding practices and human behavior – a neolithic collective grave in Bronocice (Poland). Coll. Antropol. 41 (3), 191–199. https://hrcak.srce.hr/200341.

Craig-Atkins, E., Towers, J., Beaumont, J., 2018. The role of infant life histories in the construction of identities in death: an incremental isotope study of dietary and physiological status among children afforded differential burial. Am. J. Phys. Anthropol. 167 (3), 644–655. https://doi.org/10.1002/ajpa.23691.

Cunningham, A.S., 1995. Breast-feeding: Adaptive behavior for child health and longevity. In: Stuart-Macadam, P., Dettwyler, K.A. (Eds.), Breastfeeding: Biocultural Perspectives. Aldine de Gruyter, Hawthorne (NY), pp. 243–264.

Czermak, A., Fernández-Crespo, T., Ditchfield, P.W., Lee-Thorp, J.A., 2020. A guide for an anatomically sensitive dentine microsampling and age-alignment approach for human teeth isotopic sequences. Am. J. Phys. Anthropol. 173, 776–783. https://doi.org/10.1002/ajpa.24126.

Czermak, A., Schermelleh, L., Lee-Thorp, J.A., 2019. Fluorescence screening of collagen preservation in tooth dentine. Palaeogeogr. Palaeoclimatol. Palaeoecol. 532, 109249. https://doi.org/10.1016/j.palaeo.2019.109249.

DeNiro, M.J., 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. Nat 317, 806–809. https://doi.org/10.1038/317806a0.

Dewey, K.G., 2013. The challenge meeting nutrient needs of infants and young children during the period of complementary feeding: an evolutionary perspective. J. Nutr. 143, 2050–2054. https://doi.org/10.3945/jn.113.182527.

Drtikolová Kaupová, S., Brůžek, J., Hadrava, J., Mikšík, I., Morvan, M., Poláček, L., Půtová, L., Velemínský, P., 2024. Early life histories of Great Moravian children – carbon and nitrogen isotopic analysis of dentine serial sections from the Early medieval population of Mikulčice (9th-10th centuries AD, Czechia). Archaeol. Anthropol. Sci. 16 (1). https://doi.org/10.21203/rs.3.rs-1913554/v1.

Drtikolová Kaupová, S., Cvrček, J., Grossová, I., Hadrava, J., Půtová, L., Velemínský, P., 2021. The impact of pathological conditions on carbon and nitrogen isotopic values in the bone collagen of individuals with known biographic data and medical history. Int. J. Osteoarchaeol. 31 (6), 1105–1124. https://doi.org/10.1002/oa.3022.

Drtikolová Kaupová, S., Velemínský, P., Grossová, I., Půtová, L., Cvrček, J., 2022. Stable isotope values of carbon and nitrogen in hair compared to bone collagen from individuals with known medical histories (Bohemia, 19th–21st centuries). Int. J. Osteoarchaeol. 32 (5), 996–1010. https://doi.org/10.1002/oa.3125.

Dufour, E., Bocherens, H., Mariotti, A., 1999. Palaeodietary implications of isotopic variability in Eurasian lacustrine fish. J. Archaeol. Sci. 26, 617–627. https://doi.org/10.1006/jasc.1998.0379.

Eerkens, J.W., Berget, A.G., Bartelink, E.J., 2011. Estimating weaning and early childhood diet from serial micro-samples of dentin collagen. J. Archaeol. Sci. 38 (11), 3101–3111. https://doi.org/10.1016/j.jas.2011.07.010.

Eriksson, G., Lõugas, L., Zagorska, I., 2003. Stone Age hunter-fisher-gatherers at Zvejnieki, northen Latvia: radiocarbon, stable isotope and archaeozoology data. Before Farming 2, 1–25. https://doi.org/10.3828/bfarm.2003.1.2.

Eriksson, G., 2006. Stable isotope analysis of human and faunal remains from Zvejnieki. Back to the Origin: New Research in the Mesolithic-Neolithic Zvejnieki Cementery and Environment. In: Latvia, N., Larsson, L., Zagorska, I. (Eds.), Acta Archaeologica Lundensia 52. Almquist & Wiksell International, Stockholm, pp. 183–215.

Fernandes, R., Grootes, P.M., Nadeau, M.-J., Nehlich, O., 2015. Quantitative diet reconstruction of a Neolithic population using a Bayesian mixing model (FRUITS): the case study of Ostorf (Germany). Am. J. Phys. Anthropol. 158 (2), 325–340. https://doi.org/10.1002/ajpa.22788.

Fernández-Crespo, T., Czermak, A., Lee-Thorp, J.A., Schulting, R.J., 2018. Infant and childhood diet at the passage tomb of alto de la Huesera (north-Central Iberia) from bone collagen and sequential dentine isotope composition. Int. J. Osteoarchaeol. 28 (5), 542–551. https://doi.org/10.1002/oa.2659.

Fernández-Crespo, T., Snoeck, C., Ordoño, J., de Winter, N.J., Czermak, A., Mattielli, N., Lee-Thorp, J.A., Schulting, R.J., 2020. Multi-isotope evidence for the emergence of cultural alterity in late Neolithic Europe. Sci. Adv. 6 (4), eaay2169. https://doi.org/10.1126/sciadv.aay2169.

Fildes, V., 2017. The culture and biology of breastfeeding: an historical review of Western Europe. In: Stuart-Macadam, P., Dettwyler, K.A. (Eds.), Breastfeeding: Biocultural Perspectives. Routledge, New York, pp. 75–99.

Filipović, D., Meadows, J., Corso, M.D., Kirleis, W., Alsleben, A., Akeret, Ö., Bittmann, F., Bosi, G., Ciută, B., Dreslerová, D., Effenberger, H., Gyulai, F., Heiss, A.G., Hellmund, M., Jahns, S., Jakobitsch, T., Kapcia, M., Klooß, S., Kohler-Schneider, M., Kroll, H., Makarowicz, P., Marinova, E., Märkle, T., Medović, A., Mercuri, A.M., Mueller-Bieniek, A., Nisbet, R., Pashkevich, G., Perego, R., Pokorný, P., Pospieszny, Ł., Przybyła, M., Reed, K., Rennwanz, J., Stika, H.-P., Stobbe, A., Tolar, T., Wasylikowa, K., Wiethold, J., Zerl, T., 2020. New AMS 14C dates track the arrival and spread of broomcorn millet cultivation and agricultural change in prehistoric Europe. Sci. Rep. 10 (1), 13698. https://doi.org/10.1038/s41598-020-70495-z.

Fogel, M.L., Tuross, N., Owsley, D.W., 1989. Nitrogen isotope tracers of human lactation in modern and archaeological populations. Carnegie Institution of Washington Yearbook 88, 111–117.

Fraser, M., Sanchez-Quinto, F., Evans, J., Storå, J., Götherström, A., Wallin, P., Knutsson, K., Jakobsson, M., 2018. New insights on cultural dualism and population structure in the Middle Neolithic Funnel Beaker culture on the island of Gotland. J. Archaeol. Sci. Rep. 17, 325–334. https://doi.org/10.1016/j.jasrep.2017.09.002.

Fuller, B.T., Fuller, J.L., Harris, D.A., Hedges, R.E.M., 2006. Detection of breastfeeding and weaning in modern human infants with carbon and nitrogen stable isotope ratios. Am. J. Phys. Anthropol. 129 (2), 279–293. https://doi.org/10.1002/ajpa.20249.

Graudonis, J. 2001. Agro metālu periods. 1500. – 1. g. pr. Kr. In: Latvijas senākā vēsture, 9. g. t. pr. Kr. – 1200. g. Rīga: Latvijas vēstures institūta apgāds, 116.–185. lpp.

Guiry, E., 2019. Complexities of stable carbon and nitrogen isotope biogeochemistry in ancient freshwater ecosystems: implications for the study of past subsistence and environmental change. Front. Ecol. Evol. 7. https://doi.org/10.3389/fevo.2019.00313.

Haferberga, V., Čakare, A., Zariņa, G., Batraga, A., Kalniņš, M., Plankājs, E. 2024. Arheoloģiskās izpētes darbi Aboras I apmetnē 2023. gadā. In: Brūzis, R., Haferberga, V. (eds.). Arheologu pētījumi Latvijā 2022. un 2023. gadā.

Hedges, R.E.M., Clement, J.G., Thomas, C.D.L., O'Connell, T.C., 2007. Collagen turnover in the adult femoral mid-shaft: modeled from anthropogenic radiocarbon tracer measurements. Am. J. Phys. Anthropol. 133 (2), 808–816. https://doi.org/10.1002/ajpa.20598.

Henderson, R.C., Zariņa, G., Czermak, A., Schulting, R.J., Henderson, P.A., Legzdiņa, D., Zagorska, I., Lee-Thorp, J., 2022. Life histories at stone age Zvejnieki based on stable isotope profiles of tooth dentine. J. Archaeol. Sci. Rep. 44, 103496. https://doi.org/10.1016/j.jasrep.2022.103496.

Heron, C., Craig, O.E., Luquin, A., Steele, V.J., Thompson, A., Piličiauskas, G., 2015. Cooking fish and drinking milk? Patterns in pottery use in the southeastern Baltic, 3300–2400 cal BC. J. Archaeol. Sci. 63, 33–43. https://doi.org/10.1016/j.jas.2015.08.002.

Herrscher, E., Goude, G., Metz, L., 2017. Longitudinal study of stable isotope compositions of maternal milk and implications for the paleo-diet of infants. BMSAP 29 (3), 131–139. https://doi.org/10.1007/s13219-017-0190-4.

Howcroft, R., 2013. Weaned upon a time. Studies of the infant diet in prehistory. Stockholm University. Doctoral thesis.

Howcroft, R., Eriksson, G., Lidén, K., 2014. Infant feeding practices at the Pitted Ware Culture site of Ajvide. Gotland. J. Anthropol. Archaeol. 34, 42–53. https://doi.org/10.1016/j.jaa.2014.01.001.

Jay, M., 2009. Breastfeeding and weaning behaviour in archaeological populations: evidence from the isotopic analysis of skeletal materials. Child. Past 2, 163–178. https://doi.org/10.1179/cip.2009.2.1.163.

Jim, S., Jones, V., Ambrose, S.H., Evershed, R.P., 2006. Quantifying dietary macronutrient sources of carbon for bone collagen biosynthesis using natural abundance stable carbon isotope analysis. Br. J. Nutr. 95, 1055–1062. https://doi.org/10.1079/BJN20051685.

Jones, E.R., Zarina, G., Moiseyev, V., Lightfoot, E., Nigst, P.R., Manica, A., Pinhasi, R., Bradley, D.G., 2017. The Neolithic transition in the Baltic was not driven by admixture with early European farmers. Curr. Biol. 27 (4), 576–582. https://doi.org/10.1016/j.cub.2016.12.060.

Katzenberg, M.A., Pfeiffer, S., 1995. Nitrogen isotope evidence for weaning age in a nineteenth century Canadian skeletal sample. In: Grauer, A.L. (Ed.), Bodies of Evidence: Reconstructing History through Skeletal Analysis. Wiley-Liss, New York (NY), pp. 221–236.

Katzenberg, M.A., Saunders, S.R., Fitzgerald, W.R., 1993. Age differences in stable carbon and nitrogen isotopes ratios in a population of prehistoric maize horticulturalists. Am. J. Phys. Anthropol. 90, 267–281. https://doi.org/10.1002/ajpa.1330900302.

Katzenberg, M.A., Weber, A., 1999. Stable isotope ecology and palaeodiet in the Lake Baikal region of Siberia. J. Archaeol. Sci. 26 (6), 651–659. https://doi.org/10.1006/jasc.1998.0382.

Kaupová, S.L., Limburský, P., Vélová, L., 2023. Isotopic reconstruction of the early life experience of individuals from the early Bronze age Vliněves site (Czech Republic). J. Archaeol. Sci. Rep. 50, 104085. https://doi.org/10.1016/j.jasrep.2023.104085.

Kendall, E. J., Millard, A., Beaumont, J., Gowland, R., Gorton, M., & Gledhill, A. 2020. What Does not Kill You: Early Life Health and Nutrition in Early Anglo-Saxon East Anglia. In: Gowland, R., Halcrow, S. (Eds.) The Mother-Infant Nexus in Anthropology. Bioarchaeology and Social Theory. Springer.

Klaus, H.D., 2014. A probable case of acute childhood leukemia: skeletal involvement, differential diagnosis, and the bioarchaeology of cancer in South America. Int. J. Osteoarchaeol. 26 (2), 348–358. https://doi.org/10.1002/oa.2411.

Legzdiņa, D., unpublished results. Stable isotope analysis and local isotope ecology at the Lake Lubāns wetland, South-eastern Latvia.

Legzdiņa, D., Vasks, A., Plankājs, E., Zariņa, G., 2020. Re-evaluating the Bronze Age and Earliest Iron Age in Latvia: changes in Burial traditions in the light of ^{14}C dates. Radiocarbon 62, 1845–1868. https://doi.org/10.1017/RDC.2020.136.

Legzdiņa, D., Plankājs, E., Visocka, V., Zariņa, G. 2022. Arheoloģiskie izrakumi Aboras I apmetnē 2021. gadā. In: Urtāns, J., Brūzis, R. (eds.). Arheologu pētījumi Latvijā 2020.-2021. gadā.

Legzdiņa, D., Zariņa, G., 2023. Living on the climate edge suitable for early farming: the complex subsistence strategies of the late Neolithic people at the Abora site in Latvia. Proce. Latvian Academy of Sci. Section B 77 (1), 1–14. https://doi.org/10.2478/prolas-2023-0001.

Lõugas, L., Kriiska, A., Maldre, L., 2007. New dates for the late neolithic corded ware culture burials and early husbandry in the east Baltic region. Archaeofauna 16, 21–31.

Loze, I. 1965. Pārskats par Aboras I vēlā neolīta apmetnes arheoloģiskajiem izrakumiem 1964. gadā. VIAA:1340, LU LVI AMK.

Loze, I. 1966. Pārskats par Aboras I vēlā neolīta apmetnes arheoloģiskajiem izrakumiem 1965. gadā. VIAA:1341, LU LVI AMK.

Loze, I. 1971. Pārskats par Aboras vēlā neolīta apmetnes arheoloģiskajiem izrakumiem 1970. gadā. VIAA:779, LU LVI AMK.

Loze, I. 1972. Pārskats par arheoloģiskajiem izrakumiem Aboras I vēlajā neolīta apmetnē 1971. gadā. VIAA:780, LU LVI AMK.

Loze, I. 2008. Pārskats par arheoloģiskajiem izrakumiem Aboras vēlā neolīta apmetē. VIAA:1192, LU LVI AMK.

Loze, I.B. 1997. Zemkopības ieviešana Latvijas teritorijā (Lubāna ezera baseins). In: Arheoloģija un etnogrāfija, 19. Rīga, 25–41.

Loze, I.B., 2000. Stone Age settlements in the Lake Lubāns wetland in Latvia, and subsistence strategies of the population. Latvijas Zinātņu akadēmijas vēstis A 54, 109–122.

Loze, I.B. 2015. Lubāna mitrāja apdzīvotība akmens laikmetā. Rēzeknes augstskola.

Meadows, J., Bērziņš, V., Brinker, U., Lübke, H., Schmölcke, U., Staude, A., Zagorska, I., Zariņa, G., 2016. Dietary freshwater reservoir effects and the radiocarbon ages of prehistoric human bones from Zvejnieki. Latvia. J. Archaeol. Sci. Rep. 6, 678–689. https://doi.org/10.1016/j.jasrep.2015.10.024.

Meadows, J., Bērziņš, V., Legzdiņa, D., Lübke, H., Schmölcke, U., Zagorska, I., Zariņa, G., 2018. Stone-age subsistence strategies at Lake Burtnieks. Latvia. J. Archaeol. Sci. Rep. 17, 992–1006. https://doi.org/10.1016/j.jasrep.2016.03.042.

Mittnik, A., Wang, C.C., Pfrengle, S., Daubaras, M., Zariòa, G., Hallgren, F., Allmäe, R., Khartanovich, V., Moiseyev, V., Tõrv, M., et al., 2018. The genetic prehistory of the Baltic Sea region. Nat. Commun. 9, 442. https://doi.org/10.1038/s41467-018-02825-9.

Moora, H. 1952. Pirmatnējās kopienas iekārta un agrā feodālā sabiedrība Latvijas PSR teritorijā. Rīga: Latvijas Valsts izdevniecība.

Oras, E., Tõrv, M., Johanson, K., Rannamäe, E., Poska, A., Lõugas, L., Lucquin, A., Lundy, J., Brown, S., Chen, S., Varul, L., Haferberga, V., Legzdiņa, D., Zariņa, G., Cramp, L., Heyd, V., Reay, M., Pospieszny, Ł., Robson, H.K., Nordqvist, K., Heron, C., Craig, O.E., Kriiska, A., 2023. Parallel worlds and mixed economies: multi-proxy analysis reveals complex subsistence systems at the dawn of early farming in the northeast Baltic. R Soc. Open Sci. 10 (10), 230880. https://doi.org/10.1098/rsos.230880.

Piličiauskas, G., Kisieliene, D., Piličiauskienė, G., 2017. Deconstructing the concept of Subneolithic farming in the southeastern Baltic. Veg. Hist. Archaeobotany 26 (2), 183–193. https://doi.org/10.1007/s00334-016-0584-9.

Rimantienė, R., 1992. The Neolithic of the eastern Baltic. J. World Prehist. 6 (1), 97–143.

Saag, L., Varul, L., Scheib, C.L., Stenderup, J., Allentoft, M.E., Saag, L., Pagani, L., Reidla, M., Tambets, K., Metspalu, E., Kriiska, A., Willerslev, E., Kivisild, T., Metspalu, M., 2017. Extensive farming in Estonia started through a sex-biased migration from the steppe. Curr. Biol. 27 (14), 2185–2193. https://doi.org/10.1016/j.cub.2017.06.022.

Schmölcke, U., Meadows, J., Ritchie, K., Bērziņš, V., Lübke, H., Zagorska, I., 2016. Neolithic fish remains from the freshwater shell midden Riņņukalns in northern Latvia. Environ. Archaeol. 21 (4), 325–333. https://doi.org/10.1179/1749631415Y.0000000011.

Schoeninger, M.J., DeNiro, M.J., Tauber, H., 1983. Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. Science 220, 1381–1383. https://doi.org/10.1126/science.634421.

Schoeninger, M.J., DeNiro, M.J., 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. GCA 48, 625–639. https://doi.org/10.1016/0016-7037(84)90091-7.

Schulting, R.J., Henderson, R.C., Czermak, A., Zarina, G., Zagorska, I., Lee-Thorp, J. 2020. Unequal in death and in life? Linking burial rites with individual life histories. Moreau, L. (Ed). In: Social inequality before farming? Multidisciplinary approaches to the study of social organization in prehistoric and ethnographic hunter-gatherer-fisher societies, 279-291. DOI:10.17863/CAM.60636.

Silvia, R., Clements, K., 1997. Protein and nonprotein nitrogen components in human milk, bovine milk, and infant formula: quantitative and qualitative aspects in infant nutrition. JPGN 24, 328–344. https://doi.org/10.1002/j.1536-4801.1997.tb00433.x.

Smith, B.H., 1984. Patterns of molar wear in hunter-gatherers and agriculturalists. Am. J. Phys. Anthropol. 63 (1), 39–56. https://doi.org/10.1002/ajpa.1330630107.

Szpak, P., Metcalfe, J.Z., Macdonald, R.A., 2017. Best practices for calibrating and reporting stable isotope measurements in archaeology. J. Archaeol. Sci. Rep. 13, 609–616. https://doi.org/10.1016/j.jasrep.2017.05.007.

Tomori, C., Palmquist, A.E.L., Quinn, E.A. 2017. Breastfeeding: New anthropological approaches. Routledge, New York. doi: 10.4324/9781315145129.

van Klinken, G.J., 1999. Bone collagen quality indicators for palaeodietary and radiocarbon measurements. J. Archaeol. Sci. 26 (6), 687–695. https://doi.org/10.1006/jasc.1998.0385.

Vasks, A., 2015. No medniekiem un zvejniekiem līdz lopkopjiem un zemkopjiem. Latvijas aizvēstures senākais posms (10500. – 1. g. pr.Kr.) Rīga: Zinātne.

Vasks, A., Zariņa, G., 2014. Ķivutkalns Hill-fort and cemetery: new Data and new problems. J. Inst. Latv. Hist. 3 (92), 5–36.

Vasks, A., Zariņa, G., Legzdiņa, D., Plankajs, E., 2021. New data on funeral customs and burials of the Bronze Age Reznes cemetery in Latvia. Est. J. Archaeol. 25 (1), 3–31. https://doi.org/10.3176/arch.2021.1.01.

2003 WHO. 2003. Guiding principles for complementary feeding of the breastfed child. Geneva: World Health Organization. https://www.who.int/publications/i/item/9275124604 (accessed 21 July 2025).

Zagorskis, F. 1961. Kreiču neolīta kapulauks. Arheoloģija un Etnogrāfija, 3, 3–18.