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Stable isotopes in an unstable time: understanding diet and social organization at Plinkaigalis, Lithuania

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ABSTRACT

The Late Roman – Migration period (3rd–6th century CE) represents a time of significant, but understudied, sociopolitical change in Lithuania. While general dietary and cultural trends have been identified, more regionally specific data are needed. The focus of this research is to understand the lived experiences of individuals interred in the Late Roman – Migration period cemetery at Plinkaigalis, Lithuania based on isotopic assessments of diet. Analyses included assessments of stable carbon and nitrogen isotopes for bone and dental tissues of 192 individuals and 17 fauna. A MANOVA (Multivariate Analysis of Variance) was utilized to quantify dietary differences. The stable isotope analyses indicate a homogenous C_3 based diet (bone $\delta^{13}C_{coll}$ ranging from −21.6‰ to –19.8‰, bone $\delta^{15}N_{Coll}$ ranging from 7.5‰ to 9.5‰, dentin $\delta^{13}C_{coll}$ ranging from −22.1‰ to −18.9‰, dentin $\delta^{15}N_{Coll}$ ranging from 8.0‰ to 10.6‰) was present with insignificant variations across age, sex, and status groupings barring slight differences in male/female stable nitrogen and carbon isotope values when sex and age are considered simultaneously. Comparisons to contemporaneous Lithuanian sites and faunal data indicate a homogenous terrestrial diet was present across Lithuania with variations in freshwater fish consumption. In terms of lived experience, this suggests a strong degree of social cohesion and stability in Lithuanian dietary practices during a time of sociopolitical change. The consumption of fish/fishing and access to major waterways is suggested to indicate power centers and elite status. These findings necessitate further investigation of dietary protein intake, waterways, and status.

1. Introduction

The Late Roman – Migration period (3rd–6th century CE) in Lithuania saw significant cultural, social, and political changes including migrations, changes in settlement and long-distance contacts, trade route alterations, and increased conflict (Bliujienė, 2013; Bliujienė et al., 2017b; Jankauskas and Kozlovskaya, 1999; Kontny, 2020; Kurila, 2009; Kurila et al., 2021, 2025). Despite the sociocultural context, there is not a large body of knowledge pertaining to everyday life and diet in Lithuania in the Late Roman and Migration periods (Bliujienė et al., 2020; Simčenka et al., 2023; Skipitytė, 2022). This analysis will contribute to dietary and cultural information about the Late Roman – Migration period via stable isotopic analysis of individuals interred in the Plinkaigalis cemetery in Central Lithuania (Fig. 1). The main question driving this research is: What does the diet of individuals at Plinkaigalis indicate about their lived experience? Lived experience, in this

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context, refers to biocultural elements that contribute to the creation of one's individual and/or group identity(ies). In the dynamic milieu of the discussed period, variation and inequality in lived experience is expected given the high prevalence of skeletal trauma, social inequality evident in burial artifacts, supposed connection between social prowess and military prestige, and preliminary evidence for dietary variation in Lithuania at this time (Bliujienė et al., 2020; Simčenka et al., 2023). This question is addressed via stable isotopic analysis of human bone and tooth collagen for 192 human individuals from the Plinkaigalis cemetery and 17 faunal samples from sites in close temporal and spatial proximity. These data were also compared to isotopic studies from across Lithuania (Bliujienė et al., 2020; Simčenka et al., 2023; Skipitytė, 2022). To consider components of lived experience in relation to diet, six subquestions were identified:

- What are the components (C_3 or C_4) that made up the diet of these individuals?
- Does diet vary according to sex, age, or status?
- Were any community members likely to have similar lived experiences and means of constructing social identity based on their diet?
- How does the diet of Plinkaigalis compare to other regions in Lithuania?
- What does the diet of individuals at Plinkaigalis indicate about the social organization of the community or the broader region?
- Does the diet of individuals at Plinkaigalis change in response to sociopolitical unrest during the Late Roman and Migration periods?

These research questions will allow for isotopically derived conclusions regarding social relationships and dietary components within the population. There have been multiple isotopic studies focused on Lithuania from the Subneolithic, 13–18th centuries CE, and the modern day (Antanaitis-Jacobs and Ogrinc, 2000; Antanaitis-Jacobs et al., 2009; Brindzaitė et al., 2025; Page, 2014; Piličiauskas, 2016; Piličiauskas and Heron, 2015; Piličiauskas et al., 2017; Reitsema et al., 2014; Schotten, 2015; Simčenka et al., 2020; Skipitytė et al., 2020; Whitmore et al., 2019). The Late Roman – Migration period, however, is comparatively understudied. Bliujienė et al. (2020) found evidence for reliance on domesticated animals and a homogeneous C_3-based diet through the 1st millennium CE. Skipitytė (2022) evaluated stable carbon and nitrogen values for individuals from the 2–19th centuries CE and also found evidence for a homogeneous C_3-based diet in the early period with significant differences in male/female terrestrial protein consumption. Simčenka et al. (2023) reached similar conclusions but found regional variations in diet related to freshwater fish consumption. They also observed different nitrogen isotope values for males and females in the Migration period. While these studies suggest that diet was relatively homogenous in Lithuania during this time (barring small differences in males and females) this evidence is largely based on smaller sample sizes.

Zooarchaeological trends provide some additional dietary context during the Late Roman and Migration periods. In the broader Baltic region and Northern Europe cattle are the most prevalent domesticated animal (Bliujienė et al., 2017a; Maldre, 2007; Minkevičius et al., 2023; Nilsson Stutz, 2003; Piątkowska-Małecka, 2004; Tvauri, 2012). Horse and cattle are also commonly found in archaeological assemblages at western sites most abundantly followed by sheep, goats, and pigs (Daugnora et al., 2013; Vasks, 2011). In Eastern Lithuanian sites pig bones comprise the greatest portion of zooarchaeological assemblage with a marked decrease in the frequency of horse remains (Bliujienė et al., 2020; Simčenka et al., 2023). While these prior isotopic studies and zooarchaeological data have provided a broad understanding of isotopic variation in Lithuania during the Late Roman – Migration period, there are still significant gaps in our understanding of variation across and within the regional populations at the time. This study contributes significant dietary data for the North-Central region of Lithuania based on individuals interred in the Plinkaigalis cemetery.

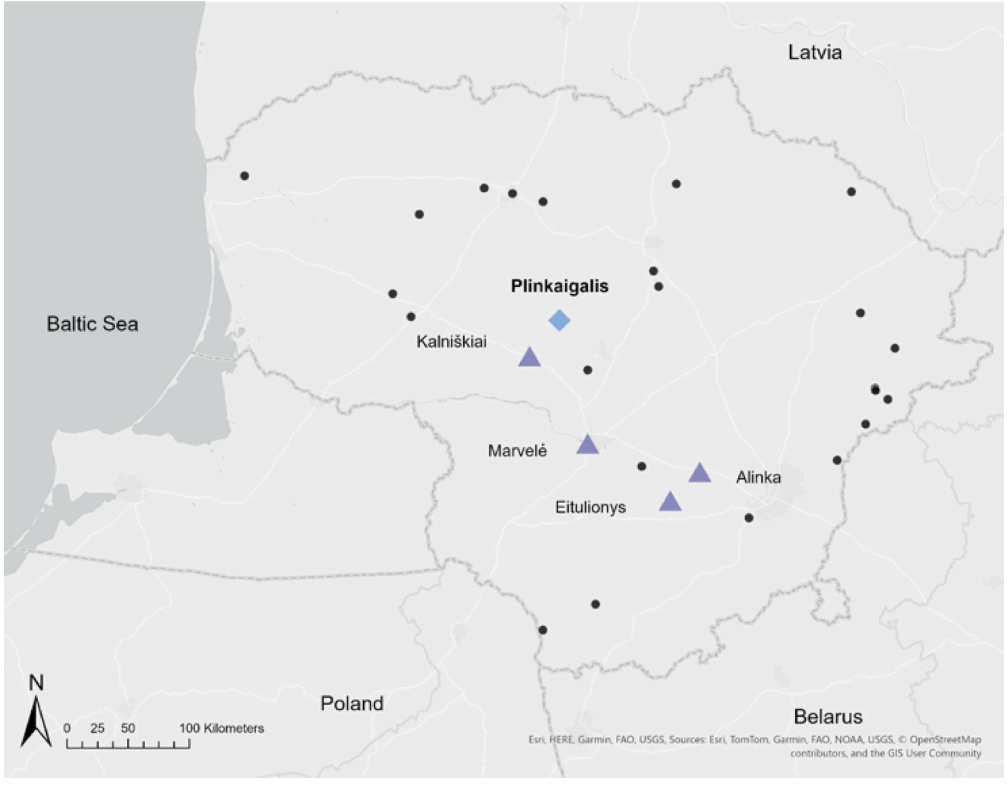

Fig. 1. Map showing the location of Plinkaigalis (blue diamond) and sites from the comparative studies (black circles and purple triangles). Notable comparative sites are represented by purple triangles.

1.1. Site overview

The Plinkaigalis cemetery is located in Krakės parish in the Kėdainiai district of Central Lithuania (5°24′51″N, 23°38′47″E) (Fig. 1). The site was nearly completely excavated between 1977 and 1984, revealing 364 human inhumations and eight cremations as well as four horse burials dating to the 3rd–6th century CE (Kazakevičius, 1993; Orozco et al., 2024). Excavations recovered many burial artifacts including silver and bronze crossbow brooches, neck-rings, pins, bracelets, buckles, glass and amber beads or amulets and other ornaments, swords, fighting knives, battle axes, spurs, and insignia of high status such as ornate drinking horns and shoulder straps (Bitner-Wróblewska, 2000; Kazakevičius, 1983; 1987; 1993; Kurila, 2024; Madyda-Legutko, 2006; Prassolow, 2013; 2018). Individuals at Plinkaigalis were buried with a range of these burial artifacts with some individuals evidently representing the social elite/high ranking military leaders and others buried without any grave goods (Kazakevičius, 1993).

During this time some males were buried with horses or horse body parts, equestrian equipment, weapons and ornaments made of precious metals, and other prestigious items displaying high status (Bitner-Wróblewska, 2000; Bliujienė and Butkus, 2009; Bliujienė and Steponaitis, 2009; Kazakevičius, 1983, 1987; Kontny, 2020; Prassolow, 2018). Female burials primarily contained weaving tools, sickles, and other household tools and ornaments (Kazakevičius, 1993). There is also osteometric evidence (stature and trace mineral concentrations) to suggest that there was some degree of social disparity among males and females at Plinkaigalis (Jankauskas and Kozlovskaya, 1999) and evidence for social stratification in (primarily Western) Lithuanian Late Roman and Migration Period burial artifacts (Banytė-Rowell et al., 2013; Banytė-Rowell, 2014).

Some of these burial artifacts from Plinkaigalis are imports or derivatives from different regions of Central and Northern Europe (Kazakevičius, 1983; 1987; 1993; Kurila, 2024; Madyda-Legutko, 2006). Brooches similar to those recovered in Lithuania have been found at Gräborg (a large Migration Period ring fort in Öland, Sweden), Altenerding in Germany, and Helgö on Lake Mälaren in Sweden (Bitner-Wróblewska, 2000; Magnus, 2004). These and other imported/derived artifacts suggest that the population at Plinkaigalis was engaged with the broader economy. The presence of items associated with varied social status further suggests that a social stratification system was in place. It can also be inferred that violent encounters were expected given the high prevalence of trauma and the inclusion of fighting knives, swords, and battle axes in burials (Kazakevičius, 1993; Kurila et al., 2021; Prassolow, 2018). Based on this evidence it is reasonable to expect that these differences in burial associated with social stratification will also be reflected in diet, and by extension social identity and lived experience.

2. Materials and methods

The sample represented 192 individuals and consisted of 57 females, 93 males, and 42 individuals of undetermined sex (mostly Non-adults). Of these, 39 were Non-adults, 86 Young adults, 52 Middle adults, 12 Old adults, and 3 individuals of unknown age. Taking into account grave inventories, 24 individuals were attributed to A status group, 71 individuals to B status group, 26 individuals to C status group, and 71 individuals to D status group. This sample represents approximately 53% of the cemetery population. Individuals were randomly selected for inclusion in this analysis and for paired samplings (a bone and a tooth sample were taken). Paired samples were taken to assess early and later life changes in stable carbon and nitrogen. The total number of individuals represented by a bone and a tooth sample is 45. All human bone samples collected for this research are from the first molars and femur to reflect the early and later stages of life, respectively (Smith, 1991). Femoral samples were obtained from the diaphysis using a cut off Dremel® wheel. Dental samples were maxillary or mandibular first molars, depending on availability.

It is important to note that all status, age, biological sex categories, and pathological assessments were previously ascribed by prior archaeologists and anthropologists investigating Plinkaigalis in the 1970–80s using standard skeletal criteria (Kazakevičius, 1993). Social status was determined qualitatively according to burial inventory count and artifact type (Adolfas Tautavičius, unpublished data). Status A refers to elite individuals (with the richest burial inventory), whereas status D refers to the lowest or unknown status individuals (those with a complete absence of burial artifacts and/or low status items). Age categories for this study were assigned using the following scale based on available age ranges for each individual: Young adults (20–40 years), Middle adults (41+ and younger than 50), and Old adults (51+) Each combination of subgroups is summarized in Table 1.

Twenty-one faunal samples (n = 17 after evaluating preservation) from Plinkaigalis, Žilionys (Roman to Medieval period), and Daučionys (Migration – Medieval period) were also analyzed (Table 2). Faunal samples were selected based on temporal and geographic proximity to Plinkaigalis. Additional faunal remains, barring four horses, are not available at Plinkaigalis necessitating the use of these sites as proxies. While most faunal remains were domesticated animals (cattle, pig, sheep/goat), two deer were sampled to provide a non-domesticated baseline for comparison. These faunal data were also compared to the larger baseline established by Simčenka et al. (2023) to consider the diet at Plinkaigalis within the broader region of Lithuania as this is the only study to report human and faunal stable isotope values from all major regions (Central, North-Central, Southern, Eastern, and Western). To compare dietary protein contributions from major food groups, the $\delta^{13}C_{Coll}$ and $\delta^{15}N_{Coll}$ ranges for each consumer group from Simčenka et al. (2023) were recalculated inclusive of the data from this study. For the purposes of comparison and consistency, the trophic level enrichment values utilized by Simčenka et al. (2023) were also applied in this study (1‰ for carbon and 4.5‰ for nitrogen).

2.1. Stable isotopes

Stable isotope analysis has been employed in bioarchaeological analyses of human and faunal diet since the 1970s (Katzenberg, 2008). The ratio of heavy and light stable carbon ($\delta^{13}C$) isotopes in human or animal bone/teeth reflects the different photosynthetic pathways used by plants to fix carbon as either a 3 or 4 carbon molecule (Katzenberg, 2008; Makarewicz and Sealy, 2015). These photosynthetic pathways differentiate plants into two major groups: C_3 (trees, herbaceous plants, wheat, rice, beans, tubers, nuts, cool-season grasses) and C_4 (maize, teosinte, amaranth, sugar cane, sorghum, and millet) plants (Chenery et al., 2010; DeNiro, 1987; Van der Merwe and Vogel, 1978; Vogel and Van der Merwe, 1977). The types of plants consumed by an organism also follow a known trend wherein C_3 plants have isotope values ranging from −20 to −35‰ and C_4 plants have values ranging from −9 to −14‰ (Deines, 1980). Approximately 75% of the carbon content in bone collagen is derived from amino acids in digested protein (Katzenberg, 2008; Sehrawat and Kaur, 2017), and as such, the resultant stable isotope values are a function of the protein portion of the diet. The

Table 1
Summary of age, sex and social status in the sample.

Sample Description (Human Remains)				
Biological Sex				
Male	Female	Indeterminate		
93	57	42		
Age Category				
Non-adult	Young Adult	Middle Adult	Old Adult	Indeterminate
39	86	52	12	3
Social Status				
A Status	B Status	C Status	D Status	
24	71	26	71	

Table 2
Summary of faunal remains sampled and associated sites. Age assessment for faunal samples were made by author Piličiauskienė.

Sample Breakdown (Faunal Remains)			
Sample Number	Species	Site	Age
A14	Red Deer (*Cervus elaphus*)	Daučionys	Adult
A14D2	Red Deer (*Cervus elaphus*) Duplicate of A14	Daučionys	Adult
A15	Pig (*Sus scrofa domesticus*)	Žilionys	>1 year
A16	Sheep/Goat (*Ovis aries/Capra aegagrus hircus*)	Žilionys	>1 year
A17	Roe Deer (*Capreolus capreolus*)	Daučionys	Adult
2J3	Horse *(Equus caballus)*	Plinkaigalis	4–5 years
3BJ1	Horse *(Equus caballus)*	Plinkaigalis	7–8 years
3AM2	Horse *(Equus caballus)*	Plinkaigalis	1.5–2 years
3AdP4	Horse *(Equus caballus)*	Plinkaigalis	1.5–2 years
A1	Pig *(Sus scrofa domesticus)*	Daučionys	2–3 years
A2	Pig *(Sus scrofa domesticus)*	Daučionys	1.5–2 years
A3	Cattle *(Bos taurus)*	Daučionys	Adult
A3D2	Cattle *(Bos taurus) Duplicate of A3*	Daučionys	Adult
A4	Cattle *(Bos taurus)*	Daučionys	Adult
A5	Sheep/Goat *(Ovis aries/Capra aegagrus hircus)*	Daučionys	<1.5–2 years
A6	Sheep/Goat *(Ovis aries/Capra aegagrus hircus)*	Daučionys	>2 years
A7	Horse *(Equus caballus)*	Daučionys	Adult
A8	Cattle *(Bos taurus)*	Žilionys	>3.5 years
A9	Cattle *(Bos taurus)*	Žilionys	<1 year
A10	Horse *(Equus caballus)*	Žilionys	Adult
A11	Horse *(Equus caballus)*	Žilionys	Adult
A12	Pig *(Sus scrofa domesticus)*	Žilionys	2–3 years
A13	Goat *(Capra aegagrus hircus)*	Žilionys	>2–3 years

remainder of the carbon content (25%) in bone is in hydroxyapatite (bioapatite) and is derived from carbohydrates, lipids, and protein representing whole diet (Katzenberg, 2008; Sehrawat and Kaur, 2017).

While carbon reflects plant based dietary components, nitrogen ($\delta^{15}N$) primarily reflects protein consumption (Brill, 1977; Katzenberg, 2008; Lee-Thorp, 2008). Protein intake is reflected in trophic level enrichment across consumer groups where there is an approximate 2-3‰ difference between the food source and tissue analyzed (Fuller et al., 2004; Katzenberg, 2008). Stable carbon and nitrogen can also be used to evaluate terrestrial vs. aquatic food sources (Chisholm et al., 1982; Dufour et al., 1999; Fuller et al., 2012; Katzenberg and Weber, 1999; Katzenberg et al., 2011; 2012; Schoeninger and DeNiro, 1984; Schoeninger et al., 1983), nutritional stress (Hobson and Clark, 1992; Hobson et al., 1993; Katzenberg and Lovell, 1999), pathology (Hill, 1998; Katzenberg and Lovell, 1999; Olsen, 2013; Orten and Neuhaus, 1982; White and Armelagos, 1997), pregnancy and weaning (Fogel et al., 1989; Fuller et al., 2004, 2005), and nitrogen enriching practices like the use of manure to fertilize crops (Bogaard et al., 2007; Fraser et al., 2011; Howcroft, 2013; Katzenberg and Lovell, 1999).

To facilitate an understanding of dietary variations over the course of a lifetime, teeth and bones can be analyzed to reflect the early and later stages of life, respectively. Stable isotopes are incorporated in bone throughout life as a function of bone remodeling (Fry and Arnold, 1982). In humans, bones begin to form *in utero* and remodeling of bone then takes place over the course of a lifetime (Allen and Burr, 2014; Katsimbri, 2017; Peacock, 2010; Robling et al., 2006). Turnover rates can vary by tissue and between trabecular and cortical bone (Ambrose, 1993; Klepinger, 1984). The rate of turnover for the femur is debated with some scholars proposing a rate greater than 10 years (Stenhouse and Baxter, 1979) and others suggesting that 10 years may be more accurate (Libby et al., 1964). This research will utilize the 10+ year turnover rate considering the findings of Hedges and Reynard (2007), which also suggest a turnover rate of at least 10 years, but likely longer, for femoral bone.

All collagen extraction procedures were conducted at the Laboratory for Bioarchaeological Sciences at the University of Central Florida based on modified methods described in Longin (1971). All samples were washed using deionized water in an Ultrasonicator. After washing, the samples were placed into a 60°C oven to dry (approximately 24 hours). Once dry, the samples were crushed to create small fragments of approximately even size (2–5 mm) using a mortar and pestle, and, in some cases, a hammer and adapted manual geological rock crusher were used to break down more dense samples. All samples were then weighed using a digital scale. The prepared samples were treated with 10 mL of a 2:1 chloroform–methanol solution to determine if lipids were present in the sample. The samples were then placed into the fume hood to dry. Once dry, the samples were demineralized using 10 mL of 0.5 M hydrochloric acid (HCL) per sample (Tuross et al., 1988). The samples were left in HCL until fully demineralized with the acid being refreshed as needed based on daily pH checks. After demineralization, the samples were washed until a pH of 2.5–3 was reached. Following this, 10 mL of 0.1 M sodium hydroxide (NaOH) was added to each sample to remove humic acids from the sample before rinsing again. After this process, the pH of each sample was checked to ensure pH levels were between 6 and 8. Finally, 10 mL of 0.25 M HCL was added and the samples were rinsed until a pH of 2.5–3 was obtained. The samples were then placed in glass beakers in a 90°C oven for 24 h to solubilize the collagen. After solubilizing, the remaining liquid was transferred into a new vial and placed back in the 90°C oven for 24–36 hours until dry. All samples were then weighed and final percent collagen yield was calculated. The collagen samples were then sent to the Light Stable Isotope Laboratory in the Department of Geological Sciences at the University of Florida for final analysis on a Thermo Delta V™ Advantage isotope ratio mass spectrometer with a ConFlo II™ interface that is attached to a Carlo Erba elemental analyzer. The resultant stable isotope ratios for collagen were then interpreted by comparing them to known standards to reconstruct diet and mobility at Plinkaigalis.

Collagen preservation was assessed based on percent collagen yield, the atomic C:N ratio, weight percent carbon, and weight percent nitrogen (Ambrose, 1990; DeNiro, 1985). Approximately 10% of the samples were analyzed as duplicate samples to evaluate accuracy. Accuracy was calculated by averaging the differences in stable isotope values for each run. Precision was reported by the University of Florida Laboratory.

2.2. Statistical Evaluation

While trends in stable isotope values can be ascertained visually it is also important to quantify the degree of difference, or lack thereof, in the sample. Statistical tests were conducted using IBM SPSS software to assess similarities and differences in the sample based on stable isotope values (carbon and nitrogen) for adult bone and dentin collagen across sex, age, and status groups using a MANOVA (Multivariate Analysis of Variance). A MANOVA was selected for analysis as it allows for multiple independent and dependent variables and combinations of variables while reducing the potential for type 1 errors (Hahs-Vaughn and Lomax, 2013; Warne, 2014). A Bonferroni MCP (Multiple Comparison Procedure) was selected as this is more conservative than other MCP's and because it allows for all pairwise comparisons to be made. The data were also tested for the standard assumptions of a MANOVA including normality, homogeneity of variance, independence of observations, covariance, and multicollinearity (Hahs-Vaughn and Lomax, 2013). The Non-adults and individuals of unknown sex (primarily Non-adults) were not included in the statistical analysis as Non-adult individuals are often enriched in nitrogen values as a function of the trophic level effect prior to weaning, which could create significant results when none are present beyond the expected 2-3‰ enrichment between trophic levels (Fuller et al., 2004).

2.3. Theory

This research is bounded within social identity theory and social

bioarchaeology to better understand the physical markers of culture within the population at Plinkaigalis and their means for constructing their social identity. Social identity theory uses group processes and belonging to explain thought and behavior based on the idea that the self, and by extension, one's identity, is constructed via belonging to social groups in society (Trepte, 2006). Social identity is then embodied and constructed through group membership, or the lack thereof, within a community (Hogg et al., 1995; Stets and Burke, 2000; Trepte, 2006). From these groups assumptions can then be made about both the individual and the greater population. It is also possible to make cultural inferences from biocultural evidence via social bioarchaeology wherein the skeleton is viewed as both cultural and biological, reflecting a culturally constructed organism (Agarwal and Glencross, 2011; Armelagos and Van Gerven, 2003; Armelagos et al., 1982; Joyce, 2005; Schutkowski, 2008; Sofaer, 2006). This connection between the biological and cultural elements of diet provides the basis for understanding social minutiae within the sample and a means for interpreting social identity within this cultural context from biological data. The social identities and experiences of each subgroup can then be considered in terms of the larger population and societal context.

3. Results

3.1. Precision and accuracy

The samples used for this research were processed in eight different batches on eight different dates. The precision for the equipment was monitored and reported by the University of Florida Laboratory (provided in supplemental materials). Accuracy was evaluated by comparing the stable isotope values for duplicate samples (10% of the total sample). The differences in stable isotope values for each run were taken and then averaged to assess the accuracy of the values (see supplemental materials). From these data it can be inferred that the data are both accurate and precise.

3.2. Collagen preservation

The majority of human samples fell within acceptable ranges for average weight percent carbon (%wtC), average weight percent nitrogen (%wtN), percent collagen yield (%collagen), and atomic C:N ratio (DeNiro, 1985; DeNiro and Weiner, 1988). The minimum acceptable collagen yield for this research is 2% following DeNiro and Weiner (1988) and the range for atomic C:N ratio is between 2.9 and 3.6 (DeNiro, 1985). All samples fell within acceptable ranges for atomic C:N ratio (values available in supplementary materials). One dentin sample was not preserved, K186T, due to a low collagen yield of 0% and was removed from the study.

In terms of bone collagen percent weight carbon, 17 individuals had values above the 47% threshold. Sixteen of these individuals exhibited values less than 1% greater than the 47% threshold and were included in this study as the departure from the standard is minimal. However, individual K170 had a weight percent carbon value of 48.5% and was removed from further analysis. Eleven individuals had bone collagen weight percent nitrogen values slightly above the 17% threshold, but all individuals were within 1% of the standard. In terms of dentin collagen weight percent carbon, only one individual had a value above 47% (K286) and four individuals had weight percent nitrogen values greater than 17%. All departures from the discipline standard are less than 1% for dentin collagen results.

All sampled faunal teeth were well preserved with marginal departures from the standards for weight percent carbon and weight percent nitrogen (less than 1% difference). Four faunal bone samples fell outside of acceptable ranges for preservation, and these samples (A2, A5, A7, and A13) were removed from the study. The total number of faunal samples included in this study is 17 after removing all poorly preserved samples.

3.3. MANOVA

A MANOVA was utilized to assess the significance of difference in stable isotope values in the sample. The assumption of normality was met for all collagen distributions based on a Shapiro Wilk's test, Q-Q plot assessment, skewness, kurtosis, and a Levene's test (Table 3). Covariance was evaluated based on the Box's M test statistic (Table 4). The assumption of multicollinearity was violated, however, this was expected considering the experimental design wherein two tissues were evaluated using the same two stable isotopes, which introduces a multicollinear relationship.

The MANOVA indicated that for bone $\delta^{15}N_{Coll}$ and bone $\delta^{13}C_{coll}$ significant differences are present in the sample with a low effect size. Effect size refers to the strength of the difference between variables where low effect size indicates that a statistical relationship is subtle (Hahs-Vaughn and Lomax, 2013). There were no significant main interactions for dentin stable isotope values. Males and females differed significantly in terms of $\delta^{15}N_{Coll}$ values and Young/Old and Middle/Old adults differed significantly in terms of $\delta^{13}C_{Coll}$ when sex and age were considered together. A difference in the bone $\delta^{13}C_{Col}$ values between the A/C status groups was not present in the main interaction, but a significant difference was noted after the MCP was applied. The low effect size of all significant results indicates that there are no statistically relevant differences in the stable isotope values (Table 5).

3.4. Stable isotope results

Based on the overall stable isotope values, a high degree of clustering and homogenous C_3-based diet was observed in all datasets (Fig. 2) (full datasets and summary statistics for each subgroup are provided in the supplementary materials). Collagen stable isotope values from dentin show only slight variations (dentin $\delta^{13}C_{coll}$ −22.1‰ to −18.9‰, dentin $\delta^{15}N_{Coll}$ 8.0‰ to 10.6‰) as compared to bone (bone $\delta^{13}C_{coll}$ −21.6‰ to −19.8‰, bone $\delta^{15}N_{Coll}$ 7.5‰ to 9.5‰) when the sample is viewed holistically (including paired samples and non-paired samples). When assessing only the individuals with paired samples (bone and tooth) there were no significant differences in values derived from bone versus teeth for bone and dentin collagen stable $\delta^{13}C$ isotopes.

In terms of $\delta^{15}N_{Coll}$, only two individuals, K331 and K337, are significantly depleted (2‰) from early (tooth value) to later life (bone value) (Fig. 3). Individual K331 was a 20–40-year-old (young adult) male of B status and individual K337 was a 20–40-year-old (young adult) female of D status. Both individuals had no evidence of trauma or pathology. A decrease in their $\delta^{15}N_{Coll}$ values could suggest reduced protein intake from animal sources/freshwater fish based on the lack of pathological conditions or trauma (Petzke et al., 2005). The higher $\delta^{15}N_{Coll}$ values earlier in life could also be explained by protein, water, or other stress resulting from crop failure and famine (536 CE), the Plague of Justinian (541–544 CE), or general social unrest during the Migration period (Bliujienė, 2013; Kurila, 2009). The modeled radiocarbon dates for this cemetery (Orozco et al., 2024), however, suggests that most of these individuals likely lived and died in the Late Roman or Early Migration period, in years predating known potential stressors such as the Plague of Justinian and known crop failure/famine.

Prolonged stress due to general sociopolitical unrest during the Migration period can be excluded as a possibility based on the trends noted by Orten and Neuhaus (1982) and Hobson et al. (1993) wherein nitrogen is enriched, rather than depleted, when an individual is exposed to prolonged protein and nutritional stress. It is more likely that these differences simply reflect weaning from early to later life in both individuals (Fuller et al., 2004, 2006; Petzke et al., 2005). This is further supported by the differences in bone and tooth $\delta^{13}C_{coll}$ values for these individuals where K331 has a difference of 0.86‰ and K337 has a difference of 1.71‰. As other studies have reported (de Luca et al., 2012; Fuller et al., 2006) an approximate 1‰ difference in $\delta^{13}C_{coll}$ values from early to later life reflecting weaning it is reasonable to suggest weaning

Table 3
Summary of the normality test results.

Tissue	Shapiro Wilk's Sig.	Q-Q Plot	Skewness	Kurtosis	Levene's Sig.	Overall Normality
Bone Collagen Carbon	0.222	Linear	0.193	0.457	0.733	Yes
Bone Collagen Nitrogen	0.810	Linear	−0.110	0.640	0.385	Yes
Dentin Collagen Carbon	0.199	Linear	0.500	1.051	0.093	Yes
Dentin Collagen Nitrogen	0.265	Linear	0.309	−0.215	0.308	Yes

Table 4
Summary of the covariance analysis.

Dataset	Box's M Sig.	Assumption Violated?
Bone $\delta^{13}C_{Coll}$/Bone $\delta^{15}N_{Coll}$	0.355	No
Dentin $\delta^{13}C_{Coll}$/Dentin $\delta^{15}N_{Coll}$	0.194	No

Table 5
Summary of between subject's effects from the MANOVA.

Main Interaction	Between Subjects Interaction	P-Value	Effect Size (Partial Eta^2)	MCP Sig.
Male versus Female: Bone Collagen Carbon or Nitrogen	Bone $\delta^{13}C_{Coll}$	0.847	0.000	N/A
	Bone $\delta^{15}N_{Coll}$	<0.001	0.091	N/A
Sex and Age: Bone Collagen Carbon or Nitrogen	Bone $\delta^{13}C_{Coll}$	0.006	0.081	Young/Old p = 0.006 Middle/Old p = 0.004 A/C status p = 0.002
	Bone $\delta^{15}N_{Coll}$	0.274	0.21	Young/ Middle p = 0.031

is the most likely explanation for this shift in stable carbon and nitrogen from early to later life. Additional data inclusive of more Non-adults would be needed to fully evaluate these trends in the population as only two individuals displayed this difference in $\delta^{13}C_{coll}$ and $\delta^{15}N_{coll}$ values. There were no additional differences in stable isotope values (Figs. 4-6).

Individuals were also considered as elite (status groups A and B combined) and commoners (status groups C and D combined) to determine if larger status groupings would illuminate any potential differences. However, there were no notable differences in diet across these larger status groups despite differences in grave goods being observed (Bitner-Wróblewska, 2000; Kazakevičius, 1993) (Fig. 7). The general lack of difference, beyond individuals K331 and K337, in paired stable isotope values and when the sample is viewed holistically suggests that there are no isotopically significant changes in diet from early to later life and that all sampled individuals are likely local to the area of Plinkaigalis.

3.5. Faunal baseline comparison

The faunal isotope values for individuals included in this study indicate that the fauna clearly consumed C_3 plants ($\delta^{13}C_{coll}$ −20.6‰ to –22.7‰, bone $\delta^{15}N_{Coll}$ 5.2‰ to 7.2‰, $\delta^{13}C_{coll}$ −21.6‰ to –23.6‰, dentin $\delta^{15}N_{Coll}$ 5.4‰ to 8.3‰) (Fig. 8). The deer samples were within range of the stable isotope values for domesticated animals. This suggests that the domesticated animals may have grazed locally or been fed locally gathered fodder. The lack of difference between early and later life tissues in the faunal data indicates that animals used for subsistence were likely local and kept within local grazing areas during their lifetime.

In this dataset there is an approximately 2‰ difference between the human and terrestrial herbivore stable nitrogen values, which suggests an omnivorous diet is present in humans. The isotope values from this study were also added to the baseline established by Simčenka et al. (2023) for a broader comparison (Fig. 9). There was no major shift in the consumer expectancy ranges when the data from this study were added.

3.6. Contextualization and comparison between sites

To place this research within the larger context of the Lithuanian Late Roman and Migration periods, comparisons were made to adult individuals from three other studies (Bliujienė et al., 2020; Simčenka et al., 2023; Skipitytė, 2022) based on bone collagen stable isotope values from sites across Lithuania. Studies were selected from available literature based on closest proximity and temporal agreement, when possible. Importantly, while Skipitytė (2022) reports isotopic values from the 2–19th centuries CE only the values from the 2–7th century CE were included in this study.

The stable carbon and nitrogen isotope values from Plinkaigalis are

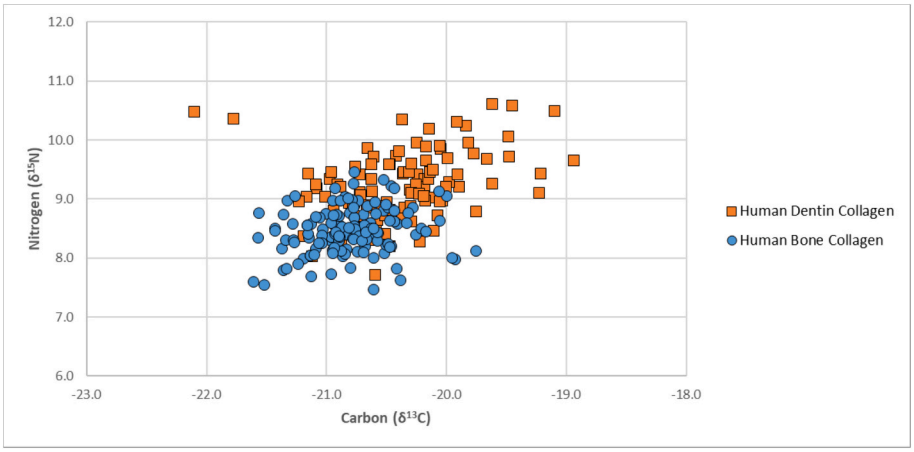

Fig. 2. Graph of the stable carbon and nitrogen values from bone and teeth.

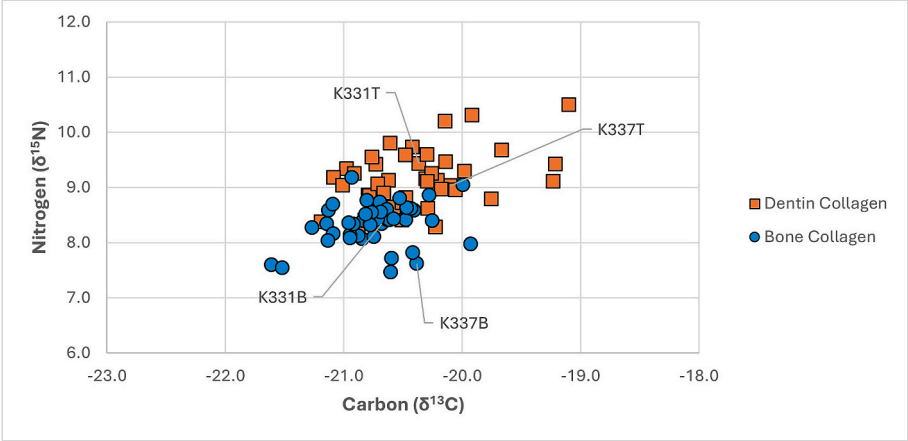

Fig. 3. Graph showing the stable isotope values of individuals with paired samples (bone and tooth). The two individuals (K337 and K331) with isotopically significant differences in their bone and tooth values are indicated on the graph. 'B' after the sample number refers to bone while 'T' refers to tooth.

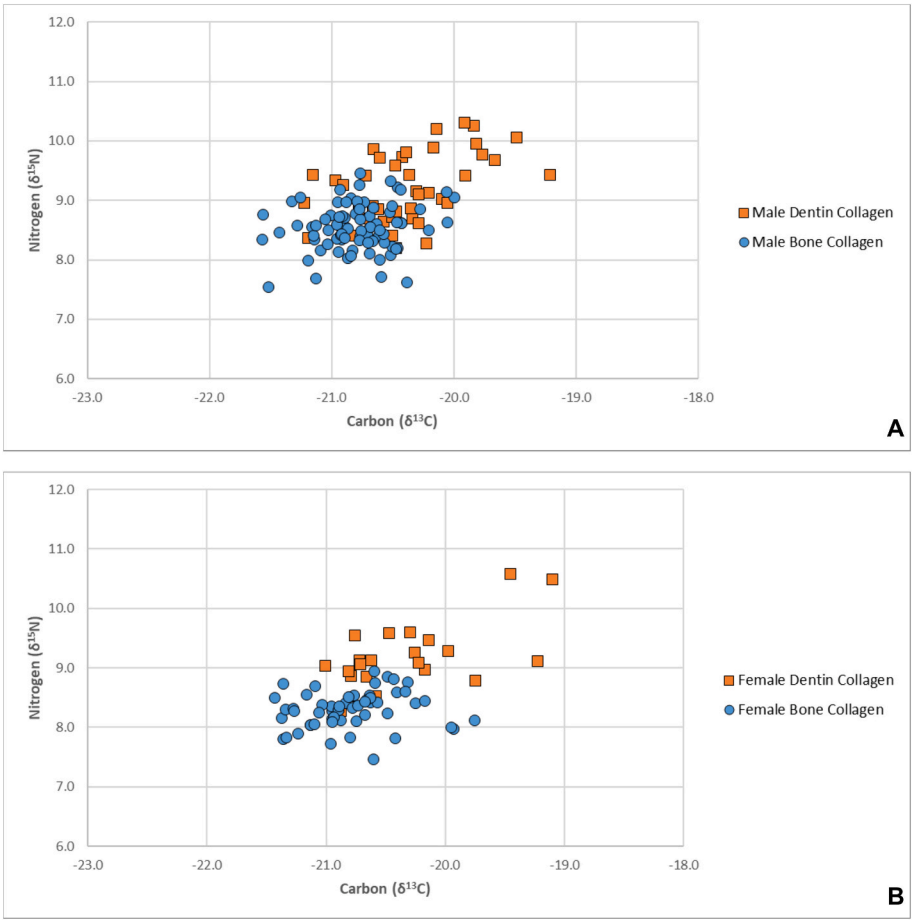

Fig. 4. Graph of the male (A) and female (B) stable carbon and nitrogen values.

slightly lower, but very similar to the values reported by all available comparative studies (Bliujienė et al., 2020; Simčenka et al., 2023; Skipitytė, 2022) (Fig. 10). Similar to this study, none of the comparative studies noted any differences in stable isotope values based on age, sex, or social status barring slight differences in male and female nitrogen values by Skipitytė (2022) and Simčenka et al. (2023). This difference in nitrogen values noted by Skipitytė (2022) is attributed to the 2–13th centuries CE broadly, however, and should be cautiously interpreted as evidence for this disparity in the Migration period. While the data from Simčenka et al. (2023) overlaps in temporal proximity more closely, the small effect size makes it unclear if this potential difference in protein consumption is meaningfully significant.

Simčenka et al., 2023 also found that one female (burial K115) from Plinkaigalis had an elevated nitrogen value ($\delta^{15}N_{Coll}$ = 10.5‰) compared to other individuals in Central Lithuania. In contrast, this study found a $\delta^{15}N_{Coll}$ value of 7.8‰ for the same individual, which was similar to other adults in this study. This disparity is likely due to differences in the turnover rate of the femur and occipital bone where the

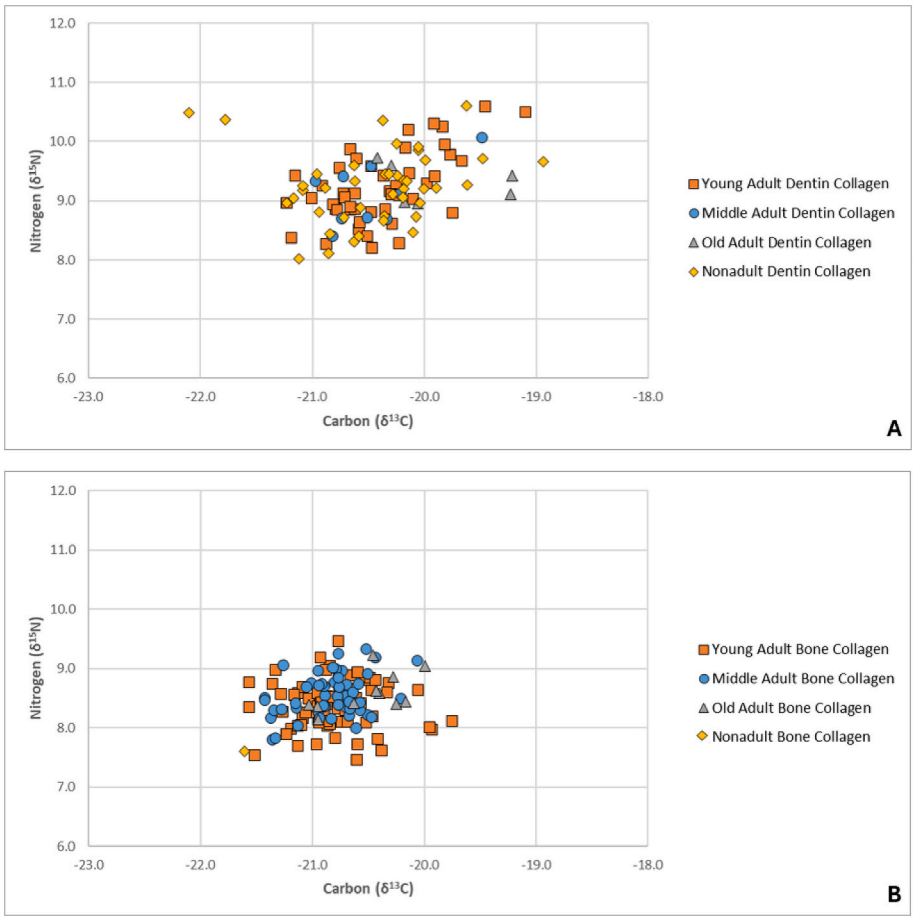

Fig. 5. Graph of the bone collagen carbon and nitrogen values by age group for teeth (A) and bone (B).

increased range represented by stable isotope values from the occipital bone likely reflects migration based on the trends noted by Simčenka et al. (2023). A lab error is also possible, but unlikely given the well preserved data in both studies. As the occipital represents the slowest rate of bone turnover (Fahy et al., 2017) it is most likely the higher $\delta^{15}N_{Coll}$ value reported by Simčenka et al. (2023) simply represents an increase in terrestrial protein, freshwater fish, and/or illness at some point in the individual's life outside the range of turnover captured by the femoral bone used in this study (greater than 10 years). This individual was considered elite (A status) and was buried with many artifacts, including jewelry, being the richest female in the whole cemetery (Kazakevičius, 1993). It is also believed that this individual is a non-local based on stable isotopic analysis of strontium for burial K115 by Kurila et al. (2025). Stable isotope values derived from bioapatite (unpublished data) for individual K115 indicate there is a 0.98‰ increase in stable nitrogen from tooth (early life) and bone (later life) values further supporting a non-local origin and increased fish intake for this individual. These combined data suggest that this elite young woman was likely non-local and at some point in her later life had increased access to terrestrial protein and/or freshwater fish. This could suggest that fish consumption and non-local origin is linked to elite status. Other elites in the cemetery at Plinkaigalis, however, do not have higher nitrogen values.

There are also two individuals in the comparative studies from Eitulionys (Barrow 4, burial 1) and Alinka (Barrow 9, burial 1) with higher bone $\delta^{15}N_{Coll}$ values (2‰ higher than the Plinkaigalis median or more) (Bliujienė et al., 2020). The elevation in these values is likely explained by increased freshwater fish intake, access to terrestrial protein, or breastfeeding. Eitulionys is located near two freshwater lakes (0.5–1 km away) while Alinka is not located near any major rivers or lakes (the Elektrėnai Reservoir was excluded as a water source as it was not constructed until the 1960s). It should be noted that the associated settlement site for individuals buried at Eitulionys is not known, but it is reasonable to suggest that the settlement and burial sites would be near each other. The two individuals with higher stable nitrogen values are a 2–3-year-old and a 16–18-year-old of unknown biological sex. Increased protein intake from terrestrial or freshwater sources is a plausible explanation for the 16–18 year old. Considering that this individual was buried at Eitulionys with greater access to water, freshwater fish may be driving this disparity. However, this is less likely to explain the higher nitrogen value observed in the 2–3-year-old from Alinka. Instead, this likely indicates that this individual was still relying on breastmilk as part of their diet. These comparisons indicate that protein access, local/non–local origins, and access to water all play a part in the consumption of fish/terrestrial protein and the construction of the elite diet.

4. Discussion

- What are the components (C_3 or C_4) that made up the diet of these individuals?

The stable isotope analysis of individuals interred in the Plinkaigalis cemetery suggests that their diet was homogenous and consisted of C_3 plants and terrestrial protein. Archaeobotanical studies suggest that available C_3 plants from the Late Bronze Age into the Migration Period in Lithuania would have included barley (*Hordeum vulgare* var. *vulgare* and *Hordeum vulgare* var. *nudum*), wheat (*Triticum dicoccon*, *Triticum spelta*, and *Triticum aestivum/durum*), broad beans (*Vicia faba*), peas (*Pisum sativum*), lentils (*Lens culinaris*), false flax (*Camelina sativa*), oat (*Avena sativa*), and rye (*Secale cereale*) (Antanaitis-Jacobs et al., 2009;

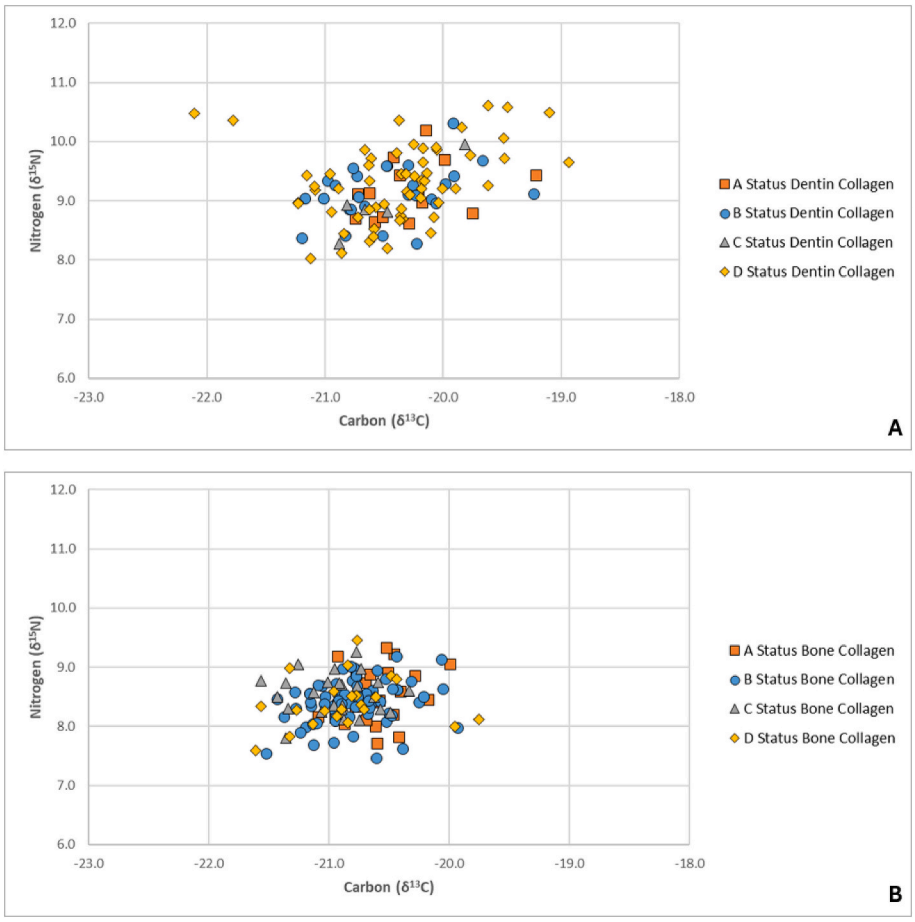

Fig. 6. Graph of the bone collagen carbon and nitrogen values by status group for teeth (A) and bone (B).

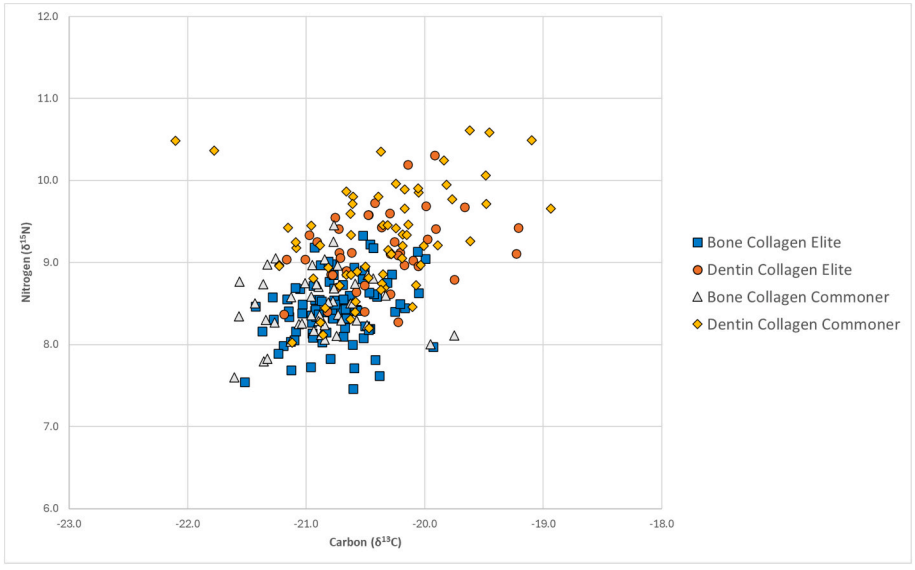

Fig. 7. Graph of the stable carbon and nitrogen values from bone/dentin for elites and commoners. Elites are individuals of A and B status originally and commoners are individuals of C and D status.

Bliujienė et al., 2020; Lideikytė-Šopauskienė, 1935; Michelbertas, 1986; Minkevičius, 2019; Minkevičius et al., 2020; Pollmann, 2014; Salatkienė and Grigas, 2017). As there is no archaeobotanical evidence directly associated with Plinkaigalis it is not possible to identify more specific trends in the consumption of particular C_3 plants at this time.

The nearby hillfort (located on the bank of the Šušvė river) likely represents the settlement site for individuals interred at Plinkaigalis but is not possible to know their husbandry practices specifically as it has not been excavated. The tentative association of the hillfort with individuals interred in the cemetery is based on geographic proximity and

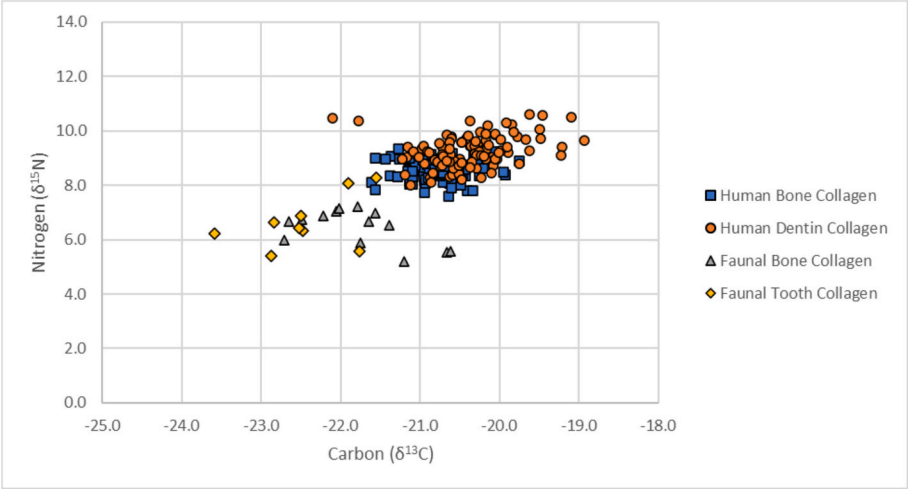

Fig. 8. Comparison of stable isotope values derived from bone and dentin collagen for human and faunal remains from this study.

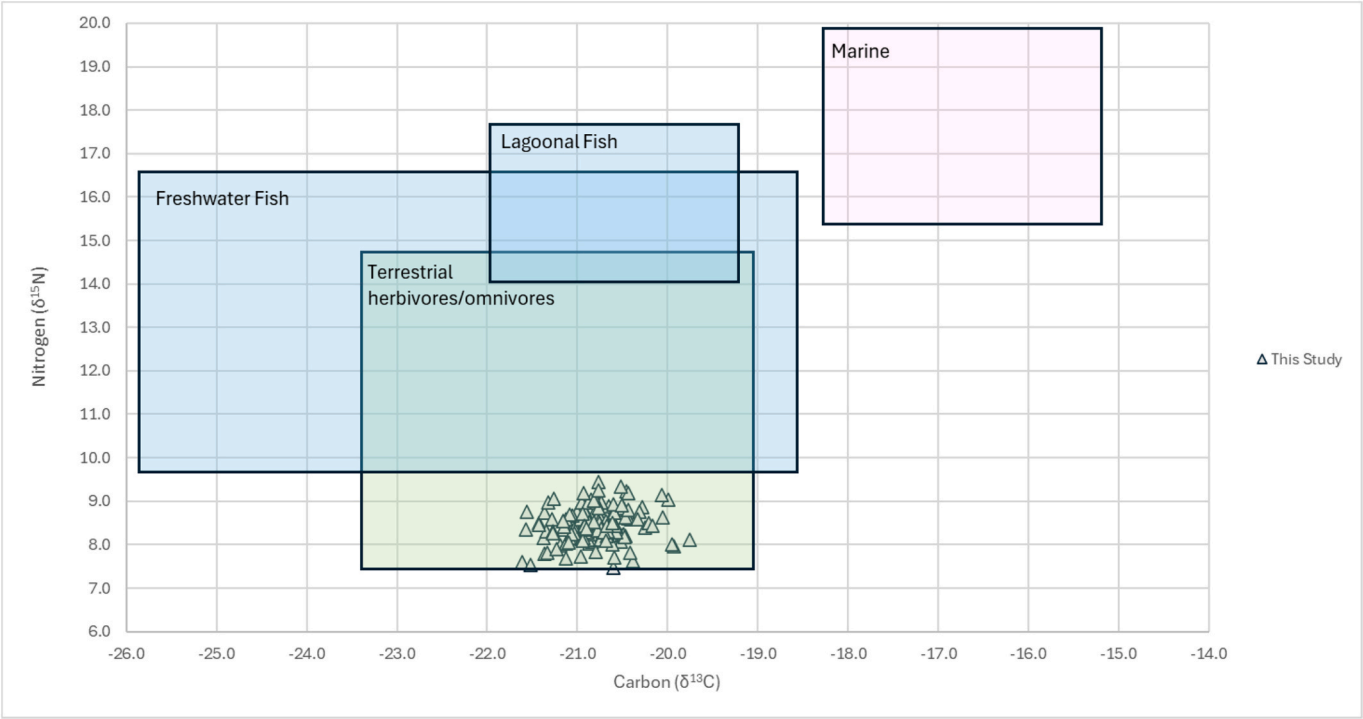

Fig. 9. Graph showing the human stable isotope values from this study and the expected ranges (recalculated inclusive of the faunal samples in this study and data from Simčenka et al., 2020) for each consumer group.

the general shape of the hillfort, which allows the authors to roughly date the structure to the 1–2nd millennium CE. While it is not possible to rule out other settlement sites, the individuals interred at Plinkaigalis would have lived in the general area of the hillfort with access to similar food resources. Therefore, some suggestions regarding fodder can be made based on stable isotope values from faunal remains. The wild deer samples were within range of the stable isotope values for domesticated animals. A possible explanation for this could be that domesticated animals were fed using locally gathered food resources or that they grazed locally. It is also possible that the higher $\delta^{15}N_{Coll}$ values are being driven by the use of fodder wherein fodder grown on fields fertilized with manure would have higher $\delta^{15}N_{Coll}$ values which could account for an elevation in values up to 9‰ (Bogaard et al., 2007; Fraser et al., 2011). However, soil fertilization with manure was unlikely at this time as this practice is only known in Lithuania from the Late Medieval period onward (Brindzaitė et al., 2025). Feeding domesticated animals with locally gathered resources or local grazing are most likely considering the trends in manured fertilization practices in Lithuania.

- Does diet vary according to sex, age, or status?
- Were any community members likely to have similar lived experiences and means of constructing social identity based on their diet?

Significant differences in diet based on age, sex, or social status were not present with large effect sizes in the data from this study barring a slight increase in male bone collagen nitrogen values compared to females and minimal differences in $\delta^{13}C_{Coll}$ values across age groups when sex and age were considered in tandem. Skipitytė (2022) reported a small difference in male and female nitrogen values, but these data are attributed to the 2–13th centuries CE. This could suggest that over time

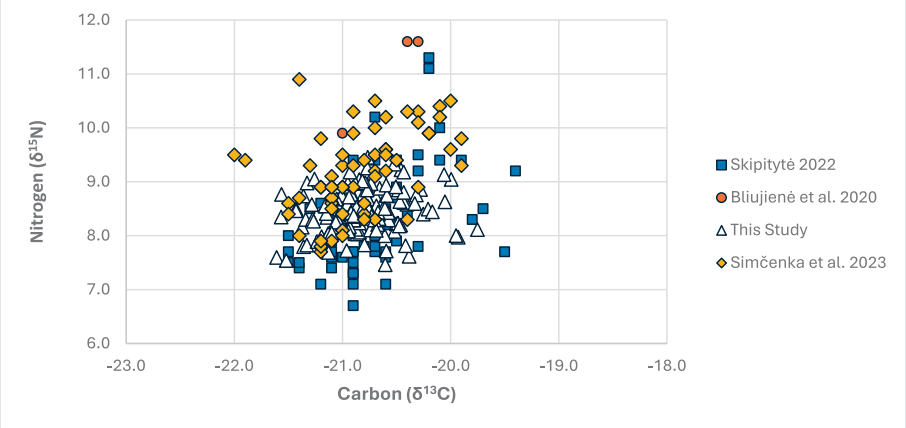

Fig. 10. Comparison of current bone collagen isotope data to data published by Bliujienė et al., 2020, Simčenka et al., 2023, and Skipitytė, 2022.

dietary differences in males and females increased with regard to protein intake. Additional study across time periods with larger sample sizes within each represented group would be needed to fully evaluate this trend. Simčenka et al. (2023) also reported a male/female protein intake disparity, but the significance of this difference is contested. The lower p-value observed in this study ($p < 0.001$) as compared to Simčenka et al. (2023) ($p = 0.027$) suggests that difference in male and female nitrogen values becomes more apparent when more data are added. However, the low effect size indicates that this difference, while present, is minimal despite the larger sample size. Considering the low effect size and high degree of clustering in the sample overall, it is suggested that any differences in male and female protein consumption are negligible. This suggests that males and females ate similar diets and that while differences in grave goods exist between the sexes (Bitner-Wróblewska, 2000; Kazakevičius, 1993) these differences are not overtly present in diet. The lack of meaningful differences across subgroups (sex, age, and social status) further indicates that diet and the construction of identity through belonging to these groups is not reflected in dietary practices. It is possible that variation was present, but not detectable if all available food sources were C_3 plants and terrestrial protein.

- How does the diet of Plinkaigalis compare to other regions in Lithuania?
- What does the diet of individuals at Plinkaigalis indicate about the social organization of the community or the broader region?

The homogeneity in diet noted in this study is similar to findings across Northern Europe in the Roman and Migration periods wherein a diet based on C_3 plants, terrestrial protein, and low marine input were common (Bliujienė et al., 2020; Knipper et al., 2013; Reitsema et al., 2014; Simčenka et al., 2023; Skipitytė, 2022; Vytlačil et al., 2018). The similarity across regions, time periods, and subgroupings could indicate that a broader Baltic social identity, as evidenced by stable dietary practices, was well established at this time. The results of this study also support trends noted by Simčenka et al. (2023) where North-Central Lithuanian diet is characterized by lower/no freshwater fish consumption and greater reliance on terrestrial protein as compared to more Central and coastal sites.

This disparity in freshwater fish consumption between North-Central (Kalniškiai, Plinkaigalis) and Central sites (Marvelė) is interesting considering that Kalniškiai, Plinkaigalis, and Marvelė are all located near freshwater water sources. The reduced consumption of freshwater fish at Plinkaigalis has been previously attributed to the feasibility of using the Šušvė river for subsistence given its smaller size compared to the Nemunas and Neris rivers near Marvelė (Simčenka et al., 2023). A social component, however, cannot be ruled out given that many individuals with elevated nitrogen values at both Plinkaigalis and Marvelė were most likely of high status and humans can be reasonably expected to exploit all available resources. The number of buried humans and horses (1591 human inhumations/cremations and 236 horse burials) (Bertašius, 2005) suggests that Marvelė was a larger population center than Plinkaigalis with greater access to resources, including freshwater fish and horses, but Marvelė was in use for a longer time span than Plinkaigalis which explains the difference in cemetery size and complicates direct comparison. Historically, fish (Piličiauskienė and Blaževičius, 2019; Skipitytė et al., 2020) and horses (Banytė-Rowell et al., 2013; Bliujienė and Butkus, 2009; Bliujienė and Steponaitis, 2009; Piličiauskienė et al., 2022) are correlated with high status at different time periods in Lithuania. It is important to note, however, that the relationship between fish and elite diets was noted only in samples from the 13–18th centuries CE in the existing literature. The lack of correlation between fish and elite diet in earlier periods is due to the paucity of current research in this area. If fish are presumed to also be associated with elite diet as suggested by this study and Simčenka et al. (2023), individuals at Plinkaigalis may have been considered lower status as compared to larger population centers like Marvelė. The higher $\delta^{15}N_{Coll}$ value for individual K115 at Plinkaigalis (included in both this study and (Kurila et al., 2025) further supports this correlation between freshwater fish and high status. As this individual is likely a non-local (Kurila et al., 2025) high status is also likely impacted by local/non-local origins. This interpretation is based on the smaller population size, low freshwater fish contributions, and comparatively small number of horses present at Plinkaigalis. It is also possible that this difference simply reflects regional cultural variation not linked to status.

If social status and protein consumption are linked in this way, this would indicate that Plinkaigalis would have been viewed as having lower status than other regional groups and therefore would have consumed less freshwater fish despite having access to a nearby river. This could indicate that fishing may have been viewed as an elite activity/controlled by the elite or possibly a leisure activity as compared to farming/animal husbandry for subsistence. The cultural acceptability of this activity would provide a social explanation for why individuals living near a river would not exploit it for freshwater resources. It is also important to note that not all elite individuals at Plinkaigalis are considered non-local (Kurila et al., 2025) and some elites have lower nitrogen values suggesting greater consumption of terrestrial protein. These trends merit further investigation to fully understand the relationship between fish/protein consumption, waterways, local/non-local origins, and social status in the Late Roman – Migration periods. Future analysis of individuals at Plinkaigalis should also include re-sampling from the occipital to determine if higher nitrogen values are observed in more individuals when a bone with a lower turnover rate is analyzed.

Apart from these small variations, the consistency in diet at Plinkaigalis and across regions suggests that dietary habits remained stable

across Lithuania for many centuries. This stability in dietary components indicates that trade and interactions with other groups during this tumultuous time took place in the local area, in areas with isotopically similar food resources, or that deviations in dietary practices during periods of movement (for trade, warfare, etc.) cannot be isotopically differentiated from periods of rest. Given the evidence for trade activity based on artifacts (Banytė-Rowell et al., 2013; Banytė-Rowell, 2014; Bliujienė, 2013; Kačkutė, 2015) engaging in only localized trade can be removed as a singular explanation. Trade likely occurred with many groups across Europe and the Baltic region, but the food base was either similar or only consumed for a short period of time resulting in similar isotope values at Plinkaigalis for centuries despite contacts with other groups. It is also possible that food products were not major trade items and that the local Balts were engaged more in the supply of goods for trade rather than engaging in trade activities themselves.

- Does the diet of individuals at Plinkaigalis change in response to sociopolitical unrest during the Late Roman and Migration periods?

In terms of lived experience at the societal level, individuals at Plinkaigalis and across Lithuania likely lived in societies with a high degree of social cohesion based on the stability observed in dietary practices across multiple centuries. Some studies on the impact of warfare on social cohesion suggest that violence and warfare can reduce trust and social cohesion as a result of a "security dilemma" created through repeated trust violations (Gilligan et al., 2014; Posen, 1993; Walter and Snyder, 1999). Other studies suggest that social cohesion and trust can actually increase in times of warfare and violence as "collective coping" mechanisms develop in response to violent events resulting in greater social cohesion (Fiedler, 2023; Gilligan et al., 2014; Lyons et al., 1998; Pennebaker and Harber, 1993). Some scholars further argue that humans are evolutionarily predisposed to be more cooperative and altruistic in response to stressors (Bellows and Miguel, 2009; Blattman, 2009; Bowles, 2008; Voors et al., 2012). Given the stability in foodways and the lengthy use of the cemetery from the 3–7th centuries CE, which would not have been possible if social cohesion was relatively low, it is reasonable to infer that any social unrest during the Migration period increased social cohesion at Plinkaigalis. Alternatively, it is possible that the lack of dietary variation is simply due to the consistency in availability of the same foods over time and unrelated to broader social structures. Future analysis of stable oxygen values is expected to further illuminate the degree of cohesion and mobility at Plinkaigalis.

5. Conclusion

The isotopic data indicates that a homogenous C_3 diet reliant on terrestrial protein was observed at Plinkaigalis. This is similar to broader trends across Lithuania and Europe, but there is regional variation in freshwater fish consumption that could potentially be linked to local/non-local origins, population size/power, and social status. This population was clearly impacted by the events of the Late Roman and Migration period (as evidenced by significant skeletal trauma and evidence of foreign trade) while maintaining homogenous dietary practices. Based on the stability of dietary practices and prolonged use of the cemetery at Plinkaigalis, it is suggested that individuals at Plinkaigalis experienced a greater degree of social cohesion during the Late Roman and Migration period despite social unrest. There is, however, a significantly smaller population at Plinkaigalis, and reduced consumption of freshwater fish compared to Central Lithuanian sites. This is cautiously interpreted as potential evidence that Plinkaigalis was not a major population/power center as compared to sites near major waterways.

While this study contributed significant dietary information about diet in Central Lithuania, it is unclear from the comparison of these data to contemporaneous studies if freshwater fish was consumed at all at Plinkaigalis and if there is a meaningful difference in male and female protein consumption. Future directions will include assessments of stable nitrogen isotopes based on the occipital to evaluate nitrogen differences between males and females at Plinkaigalis, considerations of local/non-local origins, and spatial evaluations of population centers to better understand migration and regional relationships during the Late Roman – Migration period in Lithuania.

CRediT authorship contribution statement

Alexandria R. Orozco: Writing – review & editing, Writing – original draft, Project administration, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Tosha Dupras:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Laurynas Kurila:** Writing – review & editing. **Giedrė Piličiauskienė:** Writing – review & editing, Resources. **Rūta Brindzaitė:** Writing – review & editing, Resources. **John Schultz:** Writing – review & editing, Supervision, Investigation, Conceptualization. **Jovita Kadikinaitė:** Writing – review & editing, Resources. **Emily Zavodny:** Writing – review & editing, Formal analysis. **Rimantas Jankauskas:** Writing – review & editing, Resources, Formal analysis, Data curation. **Scott Branting:** Writing – review & editing, Supervision.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2026.106136.

Data availability

Data is provided in supplementary materials section. Additional information is available upon request.

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