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RESEARCH ARTICLE

Chronological considerations for the use of the Late Roman–Migration period Cemetery at Plinkaigalis, Lithuania

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Abstract

This study presents new (n=32) and previously published (n=35) human bone ^{14}C AMS dates from 54 individuals interred in 50 burials in the Plinkaigalis cemetery (3rd–7th century AD, Lithuania). The aim of this study is to establish duration of use and identify temporal subgroups within the cemetery. Individuals in group burials were assessed for temporal agreement across individuals and the dates for individuals with multiple dates were combined using OxCal. The Sum command, Interval command, and two Bayesian models (overlapping and abutting periods of use) were used to approximate the use of the site over time and evaluate the chronology of dated burials. An IDW (inverse distance weighted) model was employed to visualize median radiocarbon dates across the cemetery for comparison to earlier IDW interpolations of time at Plinkaigalis. While the two models cannot be distinguished at this time, it can be determined that the site was likely in continuous use from 200–600 cal AD (Sum), 230–560 cal AD (Model 1), 220–550 cal AD (Model 2), or cal 283–508 AD (IDW). The area of the cemetery associated with earliest use shifted east when the IDW model was compared to original data. There was also poor agreement in some group burials and burials with multiple dates. The models generally agree on assignment of burials to phases, but disparate phase assignment was noted across the IDW and Bayesian models. Temporal subgroups cannot be confidently reclassified beyond early/later periods of use based on these models without additional sampling and refinement of the IDW modeling method.

Introduction

The Plinkaigalis cemetery in central Lithuania presents a unique context from which to examine sociocultural changes within the context of the Late Roman–Migration period of the Northeastern European *Barbaricum* given its extended period of use and large assemblage of diverse grave goods. Due to being one of the best preserved and most extensively excavated cemeteries of the 1st millennium AD in Lithuania and the whole East Baltic region, Plinkaigalis plays a substantial role in research on this period of the cemetery's chronology, dating it to around the later phase of the Roman period and the Migration period (Bliujienė 2013; Kazakevičius 1993). Continued refinement of the cemetery's use can be achieved through the use of radiocarbon dating techniques. This will not only aid a great deal in the ongoing research of this site and the community that left it (Jankauskas and Kozlovskaya 1999; Švelniūtė 2005), but also contribute to more precise artifact chronology of the larger region.

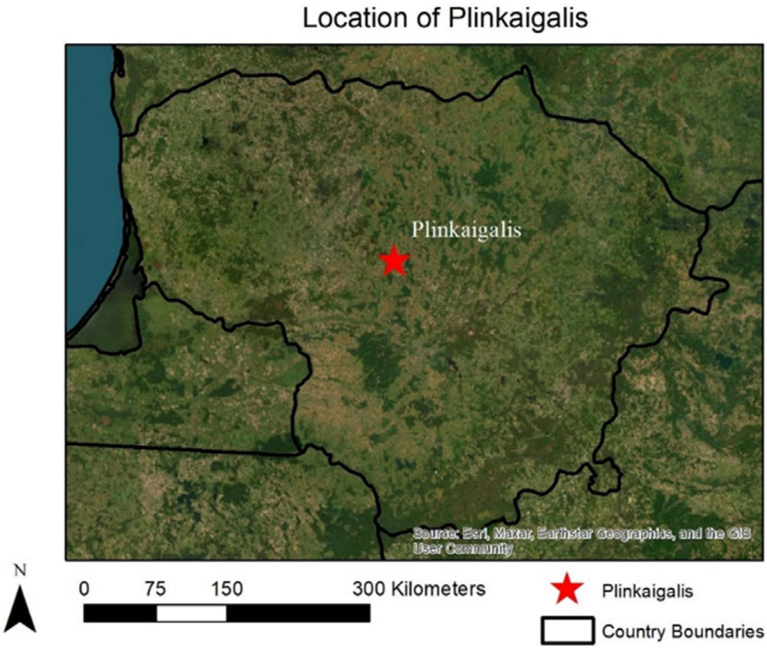

Figure 1. *Location of the Plinkaigalis cemetery.*

The purpose of this study is to evaluate the use of the Plinkaigalis cemetery over time and attempt to identify temporal subgroupings within the cemetery based on radiocarbon dates and the generation of two Bayesian models representing overlapping and abutting periods of use. Additionally, an inverse distance weighted (IDW) model based on median carbon dates was generated for the purposes of comparing the Bayesian models and the initial temporal subgroups (ascribed by the first Principal Investigators at Plinkaigalis: Eugenijus Jovaiša and Vytautas Kazakevičius) against the temporal distribution of graves as derived from the radiocarbon dates. This facilitates more directed interpretations of the relationships and lived experiences of individuals at Plinkaigalis over time by targeting future analysis according to temporal subgroup.

Site and period background

Plinkaigalis was a cemetery, a part of a complex including a hillfort and two adjacent cemeteries (Figure 1), on the left bank of the Šušvė river in Krakės parish of the Kėdainiai district (55°24'51''N, 23°38'47''E). It was completely excavated in 1977–1984 by archaeologists Eugenijus Jovaiša and Vytautas Kazakevičius. The excavations yielded 372 human burials, of which 8 were cremated (Kazakevičius, 1993). The site was initially dated to the Migration period (5th–6th centuries AD) with some burials dated to the 3rd–4th centuries AD and cremations to the 7th century AD (Kazakevičius, 1993). By the early 20th century, the nearby Pašušvys cemetery had already been totally demolished. Its use during the middle and second part of the 1st millennium AD is demonstrated by artifacts that remain. Excavations at Plinkaigalis have recovered grave goods including silver and bronze crossbow brooches, neck-rings, bracelets, pins, glass, amber and metal beads, amulets and other ornaments, silver, bronze and iron buckles and other parts of belts and shoulder-straps, leather sheaths, battle axes, fighting knives and swords, spurs and other equestrian equipment, luxurious drinking horns, sickles, spindle-whorls, and other tools (Bitner-Wróblewska 1991, 2000; Bliujienė 2002; Kazakevičius 1983, 1987, 1993; Kurila 2024; Prassolow 2013, 2018). The richness of burials varies from those lacking any grave goods

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to those given exclusive sets of items, which probably demonstrates variability in social status. Results from an osteometric study of individuals at Plinkaigalis (Jankauskas and Kozlovskaya 1999) also suggest that social stratification may have been present. The wide range of grave goods and initial dating assessments necessitated the use of radiocarbon dating to better understand the site's use over time.

In the Late Roman and Migration periods, Lithuania and the East Baltic region can be seen as a part of the unrest that raged throughout the European *Barbaricum* wherein movement of people, sociopolitical unrest, and changes in economy and material culture were common across Europe (Bitner-Wróblewska 2001; Bliujienė 2013; Curta 2021; Hedeager 2000; Kazanski 2009; Kurila 2009; Mączyńska 2020; Šimėnas 2006; Tvauri 2012). There are notable trends in Late Roman and Migration period burial broadly, including male burial with horses and equestrian equipment (Bliujienė and Butkus 2009; Bliujienė and Steponaitis 2009; Piličiauskienė et al. 2022b), the presence of imports, crossbow brooches, neck-rings, buckles and other ornaments made of silver or gilded silver in burials, inclusion of prestigious weapons, such as fighting knives and swords, other insignia of high status (Bitner-Wroblewska 2001; Bliujienė 2013; Bliujienė et al. 2017; Bliujienė and Curta 2011; Kazakevičius, 1983, 1987; Prassolow 2018; Šimėnas 2006), and increased evidence of warfare and violence (Kurila et al. 2021). Burial of males with horses/horse offerings and equestrian equipment is found primarily in East and West Lithuania. The burial position and associated artifacts vary by burial, but the practice was relatively widespread and could have been associated with high-ranking military leaders (Bliujienė and Butkus 2009). The presence and distribution of crossbow brooches and other prestigious items has been suggested to indicate intermarriage, gift-giving, spoil of raids, migration, and/or the transmission of cultural objects and ideas (Bitner-Wróblewska 2000; Bliujienė and Steponaitis 2009; Magnus 2004).

These burial practices and items deposited as grave goods suggest that individuals in the Late Roman and Migration period in Lithuania were in contact with other populations, potentially moving across the landscape, and that some social stratification was present in the community at Plinkaigalis. It is proposed that these social differences and stratification would also be reflected in burial practice. Given the wide range and potential outside impacts to grave goods, the use of Bayesian and spatial modeling of radiocarbon dates is employed to add clarity to the temporal use and social groups in the cemetery. It is expected that the models will refine the burial chronology in the cemetery allowing for burial location and proximity to be interpreted as a proxy for similar social groups in life.

Material and methods

This project included the radiocarbon dating of 32 unburnt human femoral bone samples from Plinkaigalis, Lithuania. Previously published dates (n=35 dates) for Plinkaigalis (Kurila 2024; Kurila et al. 2021, 2023) were included in this analysis to provide the most comprehensive assessment of available radiocarbon dates from Plinkaigalis representing 54 individuals (n=67 dates) from 50 burials (Table 1). Dates from Kurila (Kurila 2024; Kurila et al. 2021, 2023) were sampled from the occipital or parietal bones, as available. As bone collagen turnover rate can vary by tissue and type of bone, it is important to consider the impact of bone collagen offsets on this analysis (Ambrose 1993; Klepinger 1984). The rate of turnover for bone 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). It is important to note that due to these turnover rates, the radiocarbon dates do not represent the exact date of death of the individuals, but rather a range of years representing the last decade or more of life. Minimal impact on the interpretation of radiocarbon dates due to bone collagen offsets is expected as 10–25 years is a relatively small offset in comparison to the long temporal use of the Plinkaigalis cemetery. Interpretation of the radiocarbon dates can also be impacted by aquatic dietary components, which impact carbon reservoirs (Chisholm et al. 1982, 1983; Tauber 1981). Preliminary analysis of the stable carbon and nitrogen values (unpublished) and the central location of the cemetery near a river

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Table 1. *Summary of radiocarbon dates and biological information from this study, Kurila et al. (2021, 2023) and Kurila (2024). Samples with weight percent carbon, weight percent nitrogen, atomic ratio, and/or percent collagen values outside of isotopic standards are noted in bold. Departures from the isotopic standards are minimal*

Burial	Sex	Age	Lab code	N, %	C, %	Atomic ratio	C:N ratio	Collagen yield (%)	^{14}C date BP	Cal AD	Study
K2	Male	20–25 (young adult)	FTMC-BD63-1	9.86	27.82	3.29	2.82	2.83	1644±29	265–538	Kurila (2024)
K22	Male	30–40 (middle adult)	FTMC-TB28-1	16.58	45.77	3.22	2.76	16.04	1562±27	429–569	This study
K26	Female	20+ (young adult)	FTMC-TB28-2	12.03	33.19	3.22	2.76	3.72	1633±28	380–540	This study
K40	Unknown	0–9 (nonadult)	FTMC-TB28-3	16.55	45.92	3.24	2.77	7.36	1677±27	258–429	This study
K50	Male	40+ (middle adult)	FTMC-OR27-31	11.67	32.32	3.23	2.77	3.02	1634±35	268–543	Kurila et al. (2023)
K54	Male	20–40 (young adult)	FTMC-RK25-2	13.77	37.52	3.18	2.72	6.63	1625±28	404–541	Kurila (2024)
K59.1	Male	55+ (old adult)	FTMC-WN33-1	12.32	33.33	3.16	2.71	3.79	1628±27	401–541	This study
K59.2	Male	55+ (old adult)	FTMC-BD63-3	7.73	21.89	3.30	2.83	2.02	1534±29	435–600	Kurila (2024)
K59.3	Male	55+ (old adult)	FTMC-EN84-1	12.59	31.93	2.96	2.54	4.41	1531±27	435–602	Kurila (2024)
K61	Male	25–34 (young adult)	FTMC-OR27-5	**4.74**	13.25	3.26	2.80	**1.78**	1613±49	265–568	Kurila et al. (2023)
K64	Male	45–50 (middle adult)	FTMC-RK25-1	13.89	37.32	3.13	2.69	6.25	1589±28	420–546	Kurila (2024)
K76	Male	30–39 (young adult)	FTMC-OR27-14	**3.93**	11.23	3.33	2.86	**1.71**	1714±48	235–430	Kurila et al. (2023)
K80	Male	20–40 (young adult)	FTMC-BD63-2	7.88	22.10	3.27	2.80	3.19	1581±29	420–555	Kurila (2024)
K82	Female	50–55 (old adult)	FTMC-TB28-4	14.06	38.67	3.21	2.75	7.46	1596±27	419–543	This study
K91	Female	50+ (old adult)	FTMC-OR27-15	6.97	18.65	3.12	2.68	2.08	1615±50	265–567	Kurila et al. (2023)
K92	Male	40+ (middle adult)	FTMC-WN33-2	5.17	14.23	3.21	2.75	2.49	1585±28	420–550	This study
K106	Male	40–49 (middle adult)	FTMC-OR27-13	6.67	17.79	3.11	2.67	2.06	1639±49	259–550	Kurila et al. (2023)
K111	Unknown	0–9 (nonadult)	FTMC-TB28-5	15.57	44.05	3.30	2.83	8.45	1680±27	258–425	This study
K115	Female	20–29 (young adult)	FTMC-KK14-1	16.72	45.52	3.18	2.72	9.78	1531±28	435–602	Kurila et al. (2023)
K125	Male	20-40 (young adult)	FTMC-OU48-6	12.49	33.57	3.14	2.69	4.49	1581±29	420–555	This study
K144	Male	50+ (old adult)	FTMC-OR27-6	7.52	20.38	3.16	2.71	2.20	1563±50	415–600	Kurila et al. (2023)
K162A	Unknown	6–12 (nonadult)	FTMC-OR27-45	16.17	44.46	3.21	2.75	9.88	1696±28	255–419	Kurila et al. (2021)
K162B.1	Male	35–45 (middle adult)	FTMC-OR27-9(1)	6.45	17.68	3.20	2.74	**1.55**	1660±49	255–541	Kurila et al. (2021)
K162B.2	Male	35–45 (middle adult)	FTMC-OR27-9(2)	8.39	23.17	3.22	2.76	2.95	1667±30	258–531	Kurila et al. (2021)
K162C.1	Female	> 20 (young adult)	FTMC-OR27-10(1)	9.35	25.80	3.22	2.76	2.89	1666±37	256–535	Kurila et al. (2021)
K162C.2	Female	> 20 (young adult)	FTMC-OR27-10(2)	8.87	24.57	3.23	2.77	2.89	1697±28	255–419	Kurila et al. (2021)
K162C.3	Female	> 20 (young adult)	FTMC-OR27-10(3)	9.29	25.67	3.22	2.76	2.89	1706±28	254–415	Kurila et al. (2021)
K162D.1	Unknown	3–5 (nonadult)	FTMC-OR27-46(1)	14.34	42.92	3.49	2.99	14.25	1662±36	258–535	Kurila et al. (2021)
K162D.2	Unknown	3–5 (nonadult)	FTMC-OR27-46(2)	12.89	35.64	3.23	2.76	3.97	1692±28	256–420	Kurila et al. (2021)
K177	Female	25–30 (young adult)	FTMC-WN33-3	**3.82**	10.47	3.20	2.74	**1.67**	1621±28	407–540	This study
K190	Female	50+ (old adult)	FTMC-OR27-33	12.94	35.66	3.22	2.76	2.98	1551±35	429–589	Kurila et al. (2023)
K197A	Male	25–30 (young adult)	FTMC-TB28-6	7.72	21.30	3.22	2.76	2.03	1721±28	250–410	This study
K197B	Male	18–20 (young adult)	FTMC-TB28-7	**4.94**	14.02	3.31	2.84	**1.63**	1616±28	411–540	This study
K201	Male	20–40 (young adult)	FTMC-WN33-4	10.86	29.47	3.17	2.71	2.85	1568±27	427–564	This study
K205	Female	20–40 (young adult)	FTMC-TB28-8	15.11	41.04	3.17	2.72	11.98	1626±27	404–540	This study
K210	Female	20–40 (young adult)	FTMC-TB28-9	14.38	39.39	3.20	2.74	6.94	1698±27	256–418	This study
K212	Male	40+ (middle adult)	FTMC-WN33-5	8.14	21.17	3.03	2.60	3.40	1656±27	261–535	This study
K223	Male	40+ (middle adult)	FTMC-WN33-6	13.79	37.15	3.14	2.69	5.06	1593±27	420–544	This study
K224	Female	20–29 (young adult)	FTMC-OR27-12	8.86	23.76	3.13	2.68	2.07	1680±44	249–535	Kurila et al. (2023)
K227	Female	45–50 (middle adult)	FTMC-TB28-10	9.08	24.67	3.17	2.72	3.40	1577±27	424–555	This study

Table 1. *(Continued)*

Burial	Sex	Age	Lab code	N, %	C, %	Atomic ratio	C:N ratio	Collagen yield (%)	^{14}C date BP	Cal AD	Study
K246	Male	25–35 (young adult)	FTMC-TB28-11	14.22	38.80	3.18	2.73	6.76	1691±27	257–419	This study
K254.1	Male	30–35 (young adult)	FTMC-TB28-12	15.44	42.21	3.19	2.73	7.00	1748±26	241–383	This study
K254.2	Male	30–35 (young adult)	FTMC-WN33-7	14.20	38.38	3.15	2.70	5.89	1759±27	236–377	This study
K258	Unknown	18–20 (nonadult)	FTMC-TB28-13	13.29	36.25	3.18	2.73	4.55	1693±26	258–418	This study
K262	Male	20–25 (young adult)	FTMC-TB28-14	15.13	41.20	3.18	2.72	5.79	1779±27	215–350	This study
K280	Male	40+ (middle adult)	FTMC-OR27-32	14.22	38.82	3.18	2.73	8.79	1745±35	241–403	Kurila et al. (2023)
K281	Unknown	0–9 (nonadult)	FTMC-TB28-15	15.41	42.19	3.19	2.74	10.67	1587±27	421–547	This study
K287	Female	45–50 (middle adult)	FTMC-TB28-16	15.06	40.95	3.17	2.72	9.45	1772±26	227–361	This study
K291	Male	40+ (middle adult)	FTMC-WN33-8	14.77	39.85	3.15	2.70	5.04	1774±27	220–353	This study
K300	Male	35–40 (young adult)	FTMC-TB28-17	7.89	21.39	3.16	2.71	**1.75**	1659±28	260–535	This study
K319	Female	40–45 (middle adult)	FTMC-TB28-18	14.98	40.95	3.19	2.73	8.26	1744±27	243–401	This study
K324	Male	30–35 (young adult)	FTMC-OU48-7	13.68	36.69	3.13	2.68	5.96	1598±29	417–544	This study
K332	Male	40–49 (middle adult)	FTMC-OR27-7	6.23	16.99	3.18	2.73	**1.58**	1592±50	383–591	Kurila et al. (2023)
K336A.1	Male	40+ (middle adult)	FTMC-OR27-8(1)	7.83	21.13	3.15	2.70	**1.63**	1744±50	220–415	Kurila et al. (2021)
K336A.2	Male	40+ (middle adult)	FTMC-OR27-8(2)	6.07	16.89	3.25	2.78	**1.83**	1764±32	229–383	Kurila et al. (2021)
K336A.3	Male	40+ (middle adult)	FTMC-OR27-8(3)	5.35	**14.94**	3.26	2.79	**1.83**	1750±28	240–383	Kurila et al. (2021)
K336A.4	Male	40+ (middle adult)	FTMC-OR27-8(4)	8.96	24.58	3.20	2.74	**1.83**	1758±28	236–380	Kurila et al. (2021)
K336B	Unknown	8–14 (nonadult)	FTMC-OR27-47	15.53	42.68	3.21	2.75	7.71	1772±29	221–363	Kurila et al. (2021)
K337A	Female	25+ (young adult)	FTMC-OR27-48	15.95	43.57	3.19	2.73	10.77	1726±28	250–407	Kurila et al. (2021)
K337B.1	Unknown	3–7 (nonadult)	FTMC-OR27-49(1)	16.59	45.65	3.21	2.75	6.06	1645±27	265–537	Kurila et al. (2021)
K337B.2	Unknown	3–7 (nonadult)	FTMC-OR27-49(2)	16.52	45.12	3.19	2.73	6.06	1648±30	263–537	Kurila et al. (2021)
K337B.3	Unknown	3–7 (nonadult)	FTMC-OR27-49(3)	16.62	45.33	3.18	2.73	6.06	1663±30	258–534	Kurila et al. (2021)
K337B.4	Unknown	3–7 (nonadult)	FTMC-OR27-49(4)	16.61	45.32	3.18	2.73	6.06	1646±30	264–537	Kurila et al. (2021)
K338	Male	20–40 (young adult)	FTMC-TB28-19	14.86	40.07	3.15	2.70	11.13	1680±26	258–425	This study
K342	Male	40+ (middle adult)	FTMC-WN33-9	14.52	39.35	3.16	2.71	6.55	1707±27	254–415	This study
K348	Male	45–50 (middle adult)	FTMC-OU48-8	7.08	18.62	3.07	2.63	3.22	1648±30	263–537	This study
K356	Male	20–40 (young adult)	FTMC-TB28-20	15.10	40.59	3.14	2.69	9.69	1589±27	420–546	This study

suggests that freshwater fish consumption may have been possible, but significant marine contributions are not evident within the sample.

The samples were taken from adult and nonadult skeletons housed in the repository of Vilnius University's Faculty of Medicine, Department of Anatomy, Histology and Anthropology using a cut off Dremel® wheel. Ascriptions of sex and age at death were performed by Prof. Gintautas Česnys, pathological conditions and trauma by Prof. Rimantas Jankauskas with later revisions by Vilnius University Faculty of Medicine (Kazakevičius 1993). Age categories were assigned by applying the following scale to ascriptions made by the original archaeologist, Prof. Vytautas Kazakevičius: young adults (20–40), middle adults (Older than 40 and younger than 50), old adults (Over 50 and 55+). The sample, inclusive of previously published radiocarbon dates, included 14 females, 32 males, and 8 individuals of unknown biological sex. The age distribution included 24 young adults, 5 old adults, 8 nonadults, and 17 middle adults.

To verify the results, a destroyed burial with prior dating information (Kurila 2024) was redated (K59), one newly dated burial (K254) was dated twice, and both individuals from a previously undated double burial (K197) were dated. Some of the previously dated individuals also had multiple ^{14}C measurements (Kurila et al. 2021). All dates utilized in this study were calibrated based on the most recent IntCal20 curve (Reimer et al. 2020) using the OxCal 4.4.4 software (Bronk Ramsey 2001, 2009) with all ^{14}C dates reported in the 95.4% (2σ) range. Preparation of samples and AMS dating were completed at the Center for Physical Sciences and Technology, Vilnius, Lithuania. Bone collagen extraction procedures were performed as described in Molnár et al (2013). All samples were assessed for preservation based on atomic ratio, percent carbon, percent nitrogen, and collagen yield (Ambrose 1990; DeNiro 1985; Schoeninger and DeNiro 1982; Tuross et al. 1988; White and Schwarcz 1989; White et al. 1993). Based on the identified preservation criteria it was determined that the sample was well preserved. Some individuals had slightly higher/lower percent carbon and nitrogen values (see bolded values in Table 1). There were also some individuals with percent collagen yield values slightly below 2%, but collagen yield as an indicator of preservation has been contested in archaeological samples (Schoeninger and DeNiro 1982; Tuross et al. 1988; White and Schwarcz 1989; White et al. 1993;). The other measures of preservation and preliminary analysis of the stable carbon and nitrogen values as part of an ongoing study (unpublished) further suggests that the bone collagen from individuals at Plinkaigalis is well preserved.

The dates from individuals for burials 59 and 254 were combined in OxCal using the R_Combine command (used for combination before calibration) for the samples from the same individual in each burial. The same procedure was applied to several individuals from group burials 162 (four individuals), 336 (two individuals), and 337 (two individuals), which had several ^{14}C measurements each (Kurila et al. 2021). The Combine command (used for combination after calibration) was used to combine dates for individuals from double or group burials (197, 162, 336, and 337). Combinations returning poor agreement were removed from further analysis. The Sum command in conjunction with the Interval command was used to approximate the general range of the cemetery's use based on currently available dates. However, this method generally returns a larger estimation of use than is ideal (Bronk Ramsey 2001, 2009).

Two Bayesian models of calibrated dates were created to further refine the cemetery's use over time. Bayesian analysis allows for the probabilistic modeling of calibrated radiocarbon dates while allowing for non-normal probability distributions (Bronk Ramsey 2001, 2009). The model's effectiveness can be evaluated based on the A_{model}, $A_{overall}$, A_{comb}, and, A index values, which should be greater than 60% to be considered statistically robust (Bronk Ramsey 2001, 2009). These values indicate how well the data fit the chronological model (A_{model}), how well phases and sequences fit within the model ($A_{overall}$), the agreement for combined dates (A_{comb}), and the agreement for individual dates (A index values). The Convergence value, C, should be greater than 95% (Bronk Ramsey 2001, 2009). Model 1 assumes the periods of use overlap following the initial Roman period–Migration period typological chronology applied to Western and Central Lithuanian archaeological material by Audronė Bliujienė (2013)

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Table 2. Chronology of the Early Roman and Migration periods derived from Bliujienė (2013)

Archaeological phase	Archaeological chronology (AD)	Period
B_{1b}	40/50–70	Early Roman Period
B_2	70–150	
B_2/C_1	150–200	Transition
C_{1a}	150–220	Late Roman Period
C_{1b}	220–250/260	
C_2	250/260–300	
C_3	300–350/370	
D_1	350/370–400/410	Early Migration Period
D_2–D_3	400/410–450	
E_1	450/470–520	Late Migration Period
E_{2a}	520–570	
E_{2b}	570–600	
E_3	600–650/680	
Beginning of F (E_3/F–F)	2nd half of the 7th c.–8th c.	Latest Migration Period
Ending of F	Late 8th c.–early 9th c.	

(Table 2). Model 2 assumes the periods of use are abutting, rather than overlapping. A model wherein time periods are considered distinct was not considered as the archaeological evidence and currently accepted chronology does not support the idea of distinct periods of use at Plinkaigalis. Distinguishing these models will allow for better understanding of the cemetery's use and aid in identifying potential cultural subgroupings in future analysis. As the accepted chronology has transitional periods (Table 2), both an abutting and overlapping model were considered. To generate the models, burials were assigned to the Late Roman period (150–350/370 AD, Phases C_1–C_3), Early Migration period (350/370–410/450 AD, Phases D_1–D_3), or Late Migration period (450/470–650/680 AD, Phases E_1–E_3) (Bliujienė 2013) based on original dating ascriptions derived from grave goods, extant chronological research, and burial location (Kazakevičius 1993; Kurila 2024; Kurila et al. 2021, 2023). Burials without known temporal context were placed into a chronological phase based on proximity to regions of the cemetery with associated chronology and available archaeological information, such as grave goods. Phases are utilized to group dates in both models as the relative chronology of individual burials over time is not precisely known. Sequences and boundaries were placed to model the chronological structure of the Late Roman–Late Migration periods. Burials that did not return a statistically significant agreement (60% or greater) within a phase were evaluated to determine if the burial should be considered as part of an earlier/later phase or removed from the model as an outlier (Bronk Ramsey 2001, 2009). This process was repeated until two models with high agreement were reached.

IDW (Inverse Distance Weighted) interpolation models were generated using ArcMap 10.8.2 for comparison to the Bayesian models. IDW uses the values of known points to interpolate unknown points based on a weighted distance average (Philip and Watson 1985). This creates a continuous surface representative of the variable of study, in this case radiocarbon dates, where unknown values are interpolated from nearby known values. The distance between known points determines the weight given to the nearby values used to generate an unknown point. The first model is based on median date from initial excavation assessments, the second on median carbon date (initially available), and the third model includes all currently available radiocarbon dates for Plinkaigalis. The initially available dates are presented separately here to better reflect the research process wherein an IDW model was generated as a part of an early pilot study before all dates included in this research had been completed. The median

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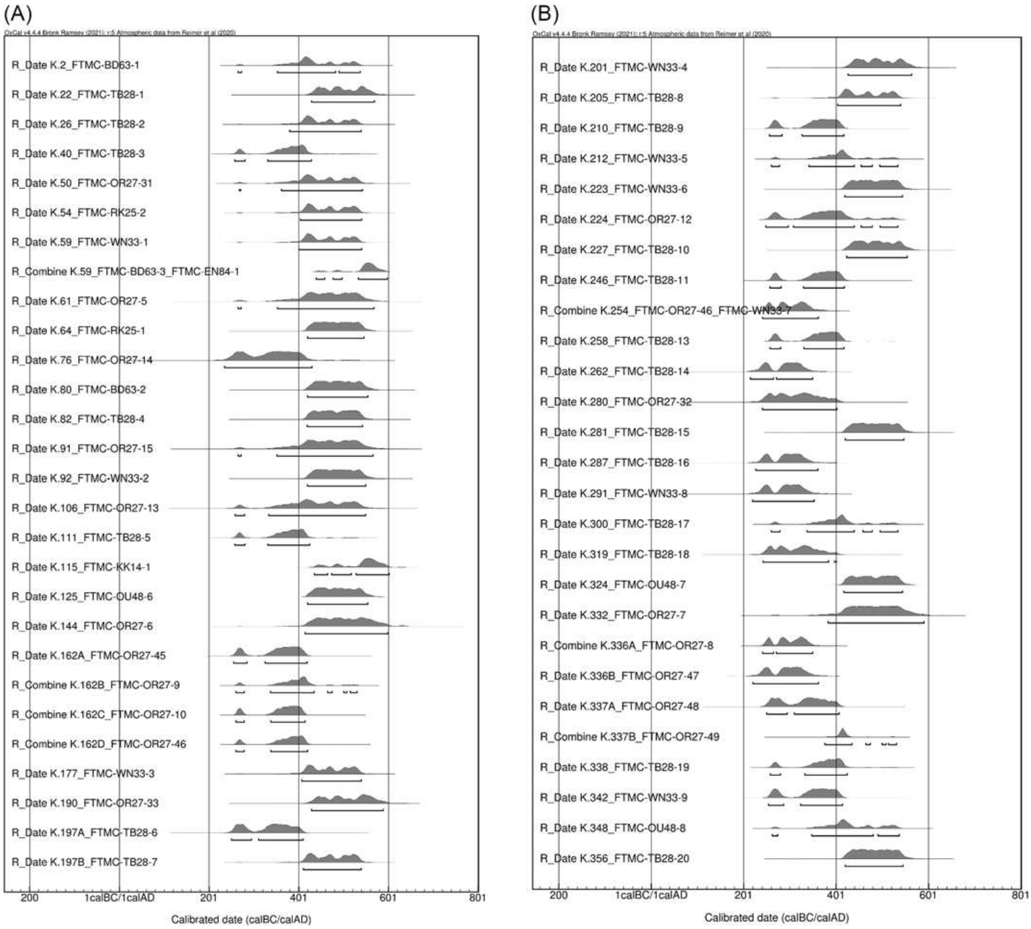

Figure 2A. *Calibrated radiocarbon dates (Table 1).*

date derived from the calibrated radiocarbon dates were the basis for the IDW interpolation. Medians were chosen as this measure is generally robust to outliers (Hahs-Vaughn and Lomax 2013). Incorporating distance into this model allows for burial location to be considered in tandem with temporal data in a distinct manner from the Bayesian models. While Bayesian modeling via OxCal allows for stratigraphic information to be considered in the model, the IDW model considers the more human component of burial location wherein individuals with similar lived experiences are more likely to be buried in close proximity than individuals representing lived experiences in other time periods of use. This is distinct from Bayesian consideration of stratigraphy in that it relies on a general assumption of human behavior rather than archaeological stratigraphy. In generating and comparing these models a clearer understanding of temporal groups and the use of the Plinkaigalis cemetery is provided.

Results

To generate the models all burials with multiple radiocarbon dates were first combined and assessed for agreement. Any burials with multiple dates returning poor agreement were removed from further analysis. All burials with associated dates were calibrated using the IntCal20 curve (Figure 2A/2B).

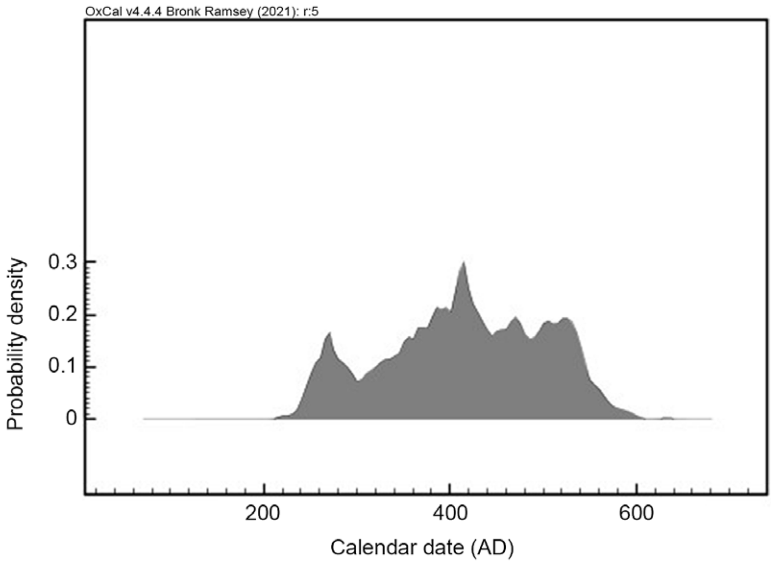

Figure 3. *Sum command output reflecting a broad period of use from 200–600 AD.*

Burial 254 was a young adult (30–35) male with two associated radiocarbon dates: 1748 ± 26 BP (241–383 cal AD) and 1759 ± 27 BP (236–377 cal AD). The combination of dates from burial 254 returned a statistically significant agreement with a calibrated date of 242–362 cal AD which narrows the interval for this burial and suggests the date is accurate.

The combination of dates from burial 59 returned poor agreement. Burial 59 has three associated radiocarbon dates: 1531 ± 27 BP and 1534 ± 29 BP (Kurila 2024), and 1628 ± 27 BP (this study). The samples from the Kurila (2024) study were taken from the occipital bone, while the sample from this study was femoral. Burial 59 was an older (55+) male buried with a battle axe, battle and working knives, a gouge, two iron spurs, a belt with metal fittings and buckle, and a drinking horn. The male was buried in a supine position with the legs extended and the head to the north. The burial was partially disturbed in the upper portion by double burial 60 and the original excavation report indicates that the remains from burial 60 were found in the same region as the cranial and chest area of burial 59. Due to poor agreement and potential for commingling of these burials this individual was removed from further analysis.

The combination of dates from burial 197 also returned poor agreement (A_{comb}= 26.4, An= 50.0%). This burial included two young adult males (197A, age 25–30 and 197B, age 18–20). One individual was in a prone position with the head oriented south-west, the left arm behind the back with the palm on the pelvis and knees bent. The second individual was buried oriented to the north-east laying on his left. The skeleton is reported to have been abnormally curved and covered with 3 stones on the chest, pelvis, and thighs. The positioning of the arms was unable to be determined *in situ* and the legs were outstretched near the first individual. There were no associated grave goods, and it has been suggested that this was a case of contemporaneous violent deaths (Kazakevičius 1993). Due to poor agreement these individuals were removed from further analysis.

The Sum command indicates a period of use spanning 200–600 cal AD based on all currently available radiocarbon dates for Plinkaigalis (Figure 3). The first model considers three sequences (Late Roman, Early Migration, and Late Migration periods) with a corresponding phase for each sequence. In this model the periods of use are modeled assuming overlapping periods of use based on the high degree

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of overlap across phases in currently accepted chronology (Bliujienė 2013). Burials assigned to the Late Roman period included burials 258, 254, 246, 319, 262, 287, 291, 280, 336, and 337 (total burials = 10). The Early Migration period included burials 2, 22, 50, 64, 338, 26, 40, 54, 61, 76, 190, 162, 227, 281, 332, and 342 (total burials = 16). The Late Migration period included burials 82, 91, 92, 106, 111, 115, 125, 144, 177, 201, 205, 210, 212, 223, 224, and 356 (total burials = 16).

Bayesian models

The first iteration of this model returned poor agreement (A_{model}=16, $A_{overall}$=15.1). Review of the multiplot distributions resulted in shifting burials 111, 210, 212, and 224 to the Early Migration period. In addition, burials 115 and 337B returned poor agreement with the model. This is similar to the findings of Kurila et al. (2021) who reported poor agreement with this individual (337B) and with potentially associated individuals in burial 336/337. Due to the uncertainty surrounding this individual's association with other individuals in this burial and related burials individual 337B was removed from the model. Burial 115 was also removed after attempting to run the model with this burial associated with the Early Migration period and the Late Migration period with poor agreement (Bronk Ramsey 2009). The calibrated date at the 95.4% confidence level is 435–602 cal AD for burial 115. This burial could represent the latest date in the assemblage but at this time it is considered an outlier as its inclusion in any time period with the presently available data severely impacts the agreement of the model. However, given the wider range observed in the results of the Sum command, this date should be reconsidered in future studies inclusive of additional samples, e.g. the somewhat later horse burials (Piličiauskienė et al. 2022a) or the cremations, which still lack radiocarbon dating, likely to represent the latest period of cemetery's use to verify if the date is truly an outlier. The model was revised six times in this manner—reviewing distributions and adjusting phase associations as needed for each burial. Burials were shifted when poor agreement was noted regardless of grave goods as there is some degree of overlap in cultural items across time periods at Plinkaigalis.

The final model returned significant agreement (A_{model}=188.2, $A_{overall}$=181.7) (Figure 4). The Late Roman period is suggested to have begun between 230 and 330 cal AD and ended between 252 and 372 cal AD spanning (Span command) approximately 0–85 years. The Interval command widens the Late Roman period slightly from 0–113 years. The final model included burials 254, 319, 262, 287, 291, 280, 337, and 336 in this phase. The Early migration period likely began from 365–414 cal AD and ended between 401–433 cal AD with a span of 0–53 years (Interval: 0–59 years). This phase included burials 258, 348, 246, 2, 50, 338, 26, 40, 54, 61, 76, 342, 162, 111, 210 212, and 224. The Late Migration Period is suggested to begin around 414–514 cal AD and ended between 444–560 cal AD with a span of 0–105 years (Interval: 0–119). Burials included in this phase were 80, 332, 281, 64, 227, 22, 190, 356, 82, 91, 92, 106, 125, 144, 177, 201, 205, and 223.

The second model was created based on the findings of the Model 1 resulting in fewer necessary revisions. Model 2 differs from Model 1 in that time periods are abutting rather than overlapping. Burials assigned to the Late Roman period initially included burials 254, 319, 262, 287, 291, 280, 336, and 337. The Early Migration period initially included burial 258, 348, 246, 2, 50, 338, 26, 40, 54, 61, 76, 162, 111, 210, 212, 80, 224, and 342. The Late Migration period initially included burials 332, 281, 64, 227, 22, 190, 356, 82, 91, 92, 106, 125, 144, 177, 201, 205, and 223. After adjusting burial 80, which had poor agreement in the Early Migration period, to the Late Migration period, Model 2 had high agreement indices (A_{model}=197.1, $A_{overall}$=194.7) (Figure 5). This model places the start of the Late Roman period burials between 220–331 cal AD, the Late/Early Migration Period boundary at 331–406 cal AD, the Early/Late Migration period boundary between 409–445 cal AD, and the end of the Late Migration period between 435–550 cal AD.

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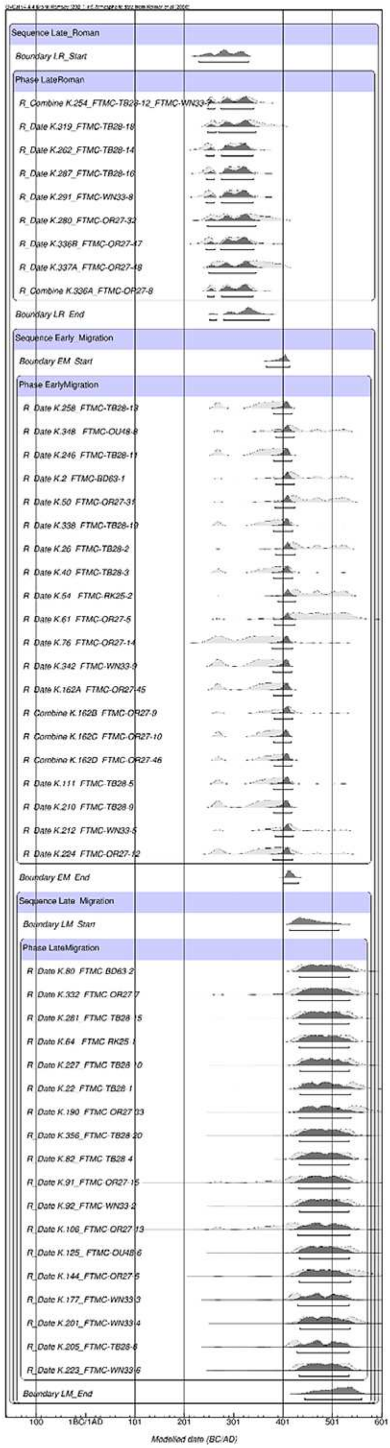

Figure 4. *Model 1 structure with all dates in statistical agreement across phases.*

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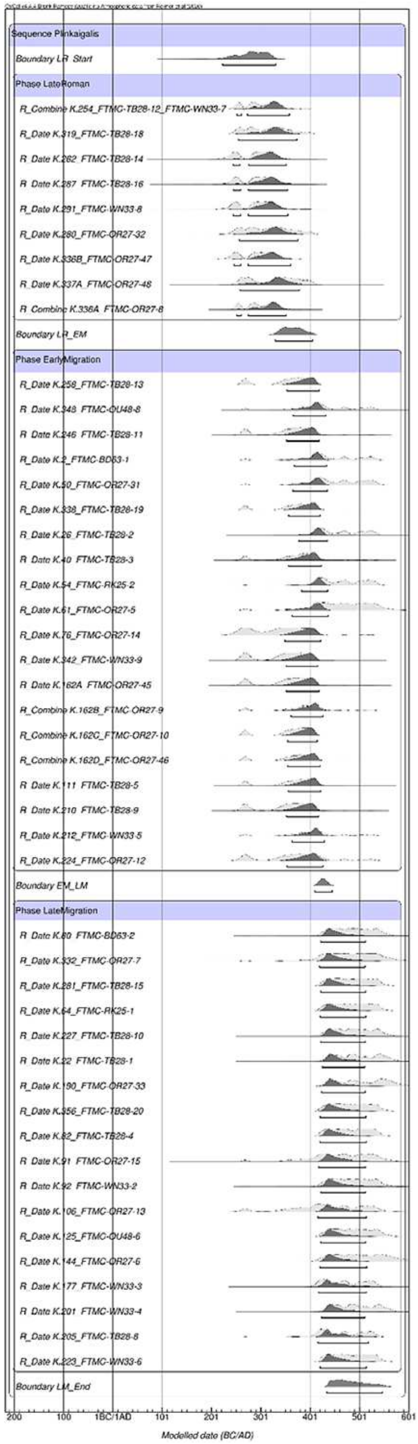

Figure 5. *Model 2 structure with all dates in statistical agreement across phases.*

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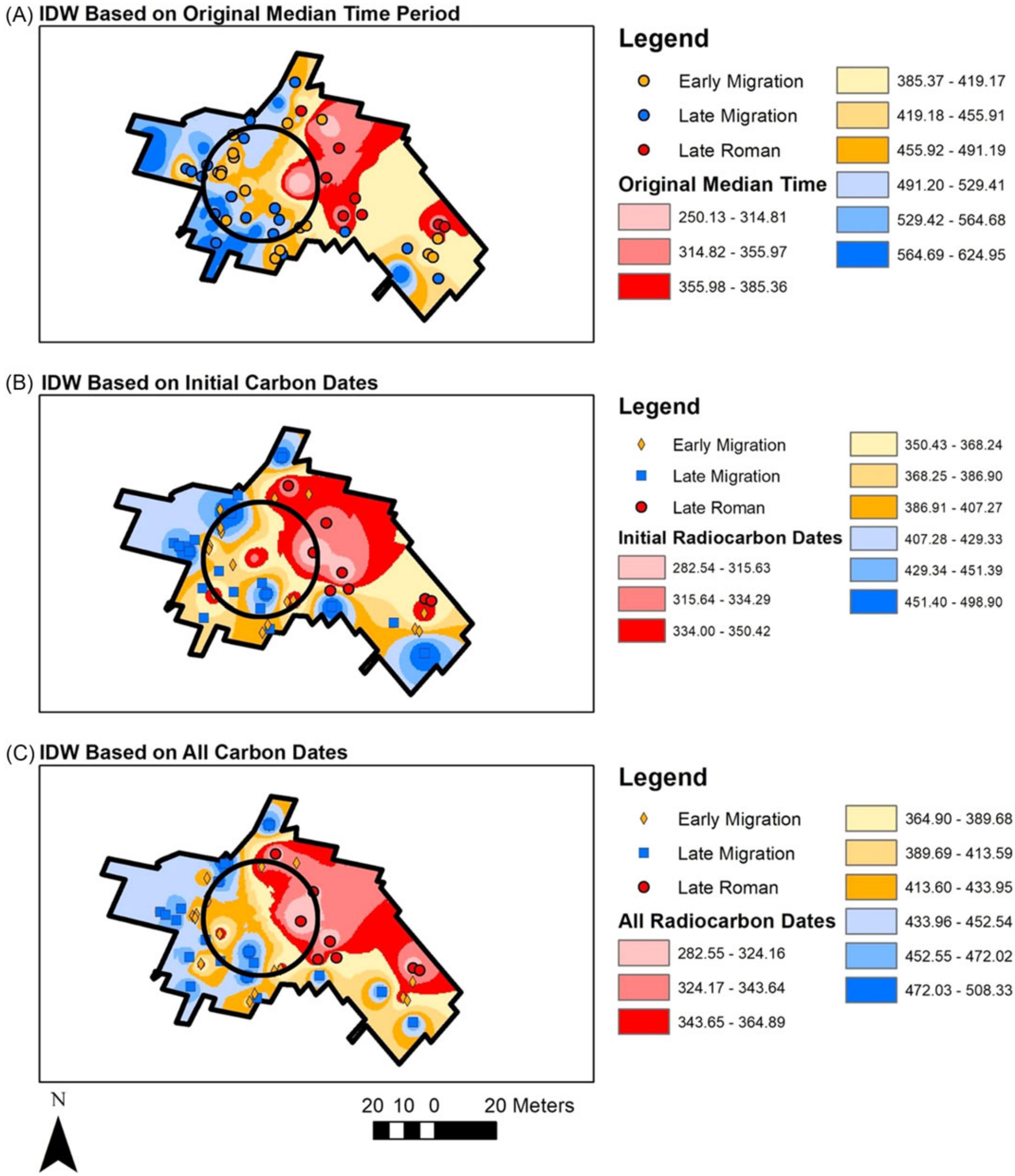

Figure 6. *IDW modeling completed in ArcMap 10.8.2 including IDW analysis of median typological date (A), initially available radiocarbon dates based on median (B), and all median radiocarbon dates from this study, Kurila et al. 2021, 2023 and Kurila 2024 (C). The black circle indicates areas of interest across the models where there are burials potentially associated with earlier use.*

IDW modeling

The IDW interpolation models based on originally available dating information (A) and first available radiocarbon dates (B) was compared to the model generated inclusive of all radiocarbon dates (C) as a part of this study (Figure 6). The initially available dates are compared separately to better reflect the research process wherein an IDW model was generated as a part of an early pilot study before all dates included in this research had been completed. When the interpolation models are reviewed for temporal and refined social subgroupings across burials there are no apparent trends at this time. Across all

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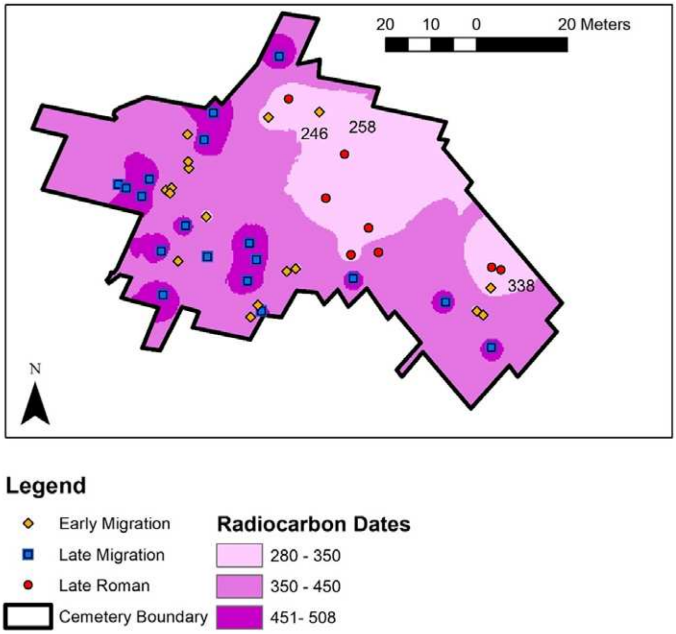

Figure 7. *Comparison of IDW classifications completed in ArcMap 10.8.2 (represented as a color gradient) to the Bayesian models assignment of burials (indicated by marker shape/color for each burial).*

models, earlier burials are located in the north-east and later burials located to the southwest, which was already known (Kazakevičius 1993). The consistency in this trend and expected use over time as derived from archaeological information suggests that the model is accurate.

A shift in the distribution of burials ascribed to the earliest periods of use from the north central portion of the cemetery to the northeast was noted when comparing the model based on original ascriptions of time (A) to the model inclusive of the first available radiocarbon dates (B). When the model was updated with additional radiocarbon dates (C) this eastward shift was still noted, but the north central portion was included in the earliest period of use when all available radiocarbon dates (C) are considered as compared to the distribution derived from initially available radiocarbon dates alone (B).

The IDW model based on all median radiocarbon dates with good agreement in the Bayesian models (A) reduced the range of use to approximately 280–508 cal AD and saw the area identified as the oldest portion of use shift more northward. This agrees well with the interpolation based on initial radiocarbon dates (B) but is reduced as compared to initial assessments during excavation (A). The model based on original excavation (A) identified many areas with potentially earlier burials in the south central portion of the cemetery (indicated by a black circle on Figure 6). The models generated based on median radiocarbon (B and C) dates reduce these areas with greater reduction noted in the model inclusive of the most radiocarbon dated burials (C). Interestingly, the final IDW model (C) does not completely remove the possibility of these areas being attributed to earlier periods of use. In addition, there are 3 burials (246, 258, and 338) attributed to a different time period based on the final IDW model (C) as compared to the subgroups identified by the Bayesian models (Figure 7). These burials were attributed to the Early Migration period by the Bayesian models and the Late Roman period by the IDW model. These burials do not have sufficient associated grave goods or contextual information to make further interpretations about their most appropriate temporal ascription at this time. It is also possible that the IDW model is skewing the data towards the Late Roman period due to more Late Roman burials being located in close proximity to burials 246, 258, and 338 as the model is based on proximity to others.

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Discussion

The results of this analysis demonstrate continuous use of the Plinkaigalis cemetery over time. The Sum command placed the use of the cemetery between 200–600 cal AD, while the Bayesian models suggested use from 230–560 cal AD (Model 1) or 220–550 cal AD (Model 2). The range suggested by the Sum command encompasses the Late Roman Period C_{1a} through the E_3 Phase of the Late Migration Period and was expected given the known context of the cemetery (Bliujienė 2013; Kazakevičius 1993). The boundary modeling completed as a part of the Bayesian analysis aligns well with relative chronology and suggests that the first burials at Plinkaigalis did not occur until the Late Roman period around 220/230 AD. Although, habitation near the cemetery could have been earlier than the first internment at Plinkaigalis. The last date of internment is estimated around 550/560 AD. It is worth noting that there are cremations and horse burials dated into the 7th century, and potentially the 8th century AD, that could impact the range of the Sum command results as well as the other models generated in this study. Model 1 and 2 both place the Early and Late Migration period boundary near the early 400s AD. When compared to chronology by Bliujienė (2013) this follows the accepted structure for West and Central Lithuania phases D_1–D_3.

The poor combination of dates for burials 59 and 197 can be explained by potential human or lab error. It is possible that skeletal elements were misattributed to individuals during initial excavation. The individuals in burial 197 could represent two distinct burial events wherein the disturbance of the first burial was not initially noted. The dates in burial 59 could be explained by the disturbance of this burial. However, it is not presently possible to understand why the dates for these burials returned poor agreement. Kurila et al. (2021) have also noted poor agreement in group burial 336/337 at Plinkaigalis for individual 337B. However, in this case the burial (337A) was considered an internment of one female during the excavations, and the remains of the infant (377B) were identified only during the osteological analysis. This does not allow one to rule out the possibility that the latter was actually a later burial. These misalignments in some group burials (59 and 197, this study and Kurila 2024; 337B, Kurila et al. 2021), but not others (162A–D and 336A, B/337A) suggest that additional dating and investigation is necessary to fully understand group burial contexts at Plinkaigalis. Barring these exceptions, both Bayesian models returned good agreement, and one model cannot be differentiated as more accurate.

The original IDW interpolation based on median available date (derived from initial excavations) placed use of the cemetery between 250–625 AD based on typological assessments. This falls within the range of expected values but places the interval later in time than the Bayesian models and Sum command. Given the lower statistical power of the Sum command, the Bayesian and IDW ranges are suggested to be more accurate. The IDW interpolation based on median carbon dates with good agreement in both Bayesian models further reduced the range of use to 283–508 cal AD. The range of earliest use in the north central portion of the cemetery shifted eastward suggesting that the south central portion of the cemetery is more likely associated with later use and the eastern central region with earlier use. The comparison of the original IDW model to the newly generated IDW models based on radiocarbon dates suggests that temporal groupings based on grave goods and burial location identified in initial excavation may require revision as many of the areas correlated to a temporal range in initial excavation do not correspond with the IDW or Bayesian models of radiocarbon dates. Given the high degree of spatial overlap in Late Roman/Early Migration and Early/Late Migration period burials, it is reasonable to expect greater difficulty in typological dating. The interspersed distribution of burials further suggests that the cemetery was likely in continuous use which would necessitate a certain degree of cultural continuity over time that could confuse typological dating methods. It is not possible to identify more targeted temporal or social subgroupings for future analysis beyond Early (northern/eastern) and Later (southern/western) periods of use.

When the IDW interpolation model is considered within the context of the Bayesian models, burials 246, 258, and 338 were correlated with the Late Roman period by the IDW model and the Early Migration Period by the Bayesian models. The IDW analysis considers burial location more heavily assuming that individuals buried around the same time are likely buried near to one another. This would favor the IDW classification of the burials. However, the IDW classification is derived from the median

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of calibrated dates AD while the Bayesian models consider the distribution more robustly and within a geochemical context. At this time, it is suggested that the Bayesian classifications are more accurate as the model is statistically more robust and considers a wider range of the data distribution. Additional sampling and refinement of the modeling method (IDW) within the context of radiocarbon dates is likely needed to generate more targeted interpolations within the cemetery. The general agreement across modeling methods, exclusive of these three burials, supports the classification of burials to phases in the Bayesian models. This study demonstrates the utility of pairing chronological and spatial modeling methods in understanding site chronology by providing comparative models with consideration for burial location.

Conclusion

The models suggest that Plinkaigalis cemetery has been in continuous use from the Late Roman to Late Migration periods, but likely not the latest phases of the Migration period (from around 220/230 AD to around 550/560 AD). While two Bayesian models were generated, one cannot be identified as more accurate at this time and IDW modeling suggests that the later portion of use in the cemetery is likely greater than initial assessments suggested. The intermixing of burial locations from the Roman/Early Migration and Early/Late migration periods suggests that future analysis should investigate the transition between periods. Despite the agreement of many burials included in the models, the poor agreement noted in group burials and burials with multiple dates necessitates further analysis of these individuals, spatial distribution of burials, and the potential for human error. The comparison of IDW and Bayesian models indicates some disagreement in Late Roman/Early Migration period burials. Comparison of the IDW and Bayesian modeling methods demonstrates the utility of integrating spatial assessments with traditional chronological modeling.

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Competing interests. The authors declare no competing interests.

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