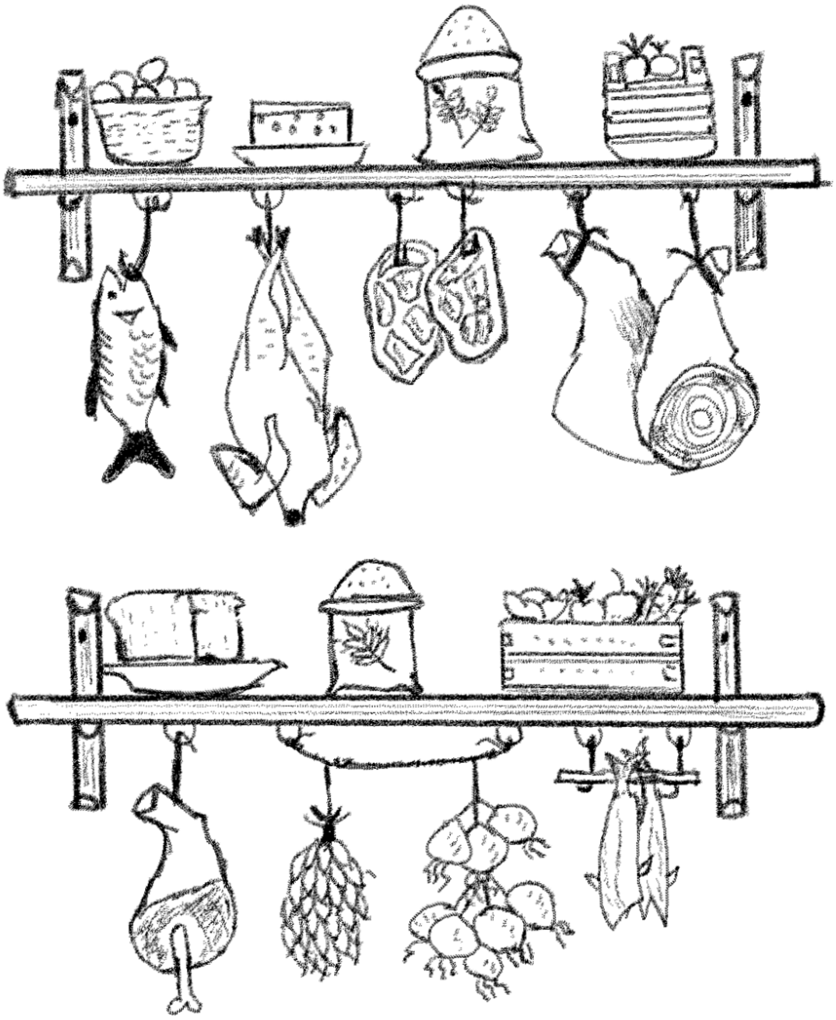
UNIVERSITY
OF OSLO

Unveiling Medieval Oslo: Social Status and Dietary Patterns through Burial Organisation and Stable Isotope Studies



PHUNG MY TRAN

ARK4090 – Master's thesis in Archaeology

Department of Archaeology, Conservation and History

Faculty of Humanities

Autumn 2023

Acknowledgements

Completing my master's thesis journey has made me feel incredibly lucky to have received so much support from wonderful people who have been involved along the way. I want to express my deep appreciation and gratitude to my supervisor, Professor David Keith Wright. He has been there every step of the way, guiding me through the project, reading and giving feedback, and enthusiastically answering my questions. I cannot thank you enough for all the invaluable support and knowledge you have shared.

I want to thank Professor Marianne Vedeler from KHM, Egil Lindhart Bauer at NIKU, Maria Amundsen from IAKH, Julia Kotthaus from DSS for their assistance at the start of my project. A big shout-out to Anastasia, an excellent ‘tutor’ for ArcGIS/R, and a kind-hearted classmate who went above and beyond to help me through demanding tasks; and to all my archaeology classmates who enhanced my project with constructive feedback in the seminars.

A warm and sincere thank you to my family for supporting me throughout this journey. They have always been there with patience and care, never doubting my choice of study. Special appreciation goes to my best friend Dinh, who has been my food fairy for this journey. Last but not least, a thousand thanks to my dearest friend Werner for always being there, believing in me, offering endless support, and patiently engaging in numerous discussions about the medieval diet even when he had no prior knowledge of the subject.

Oslo in November 2023

Phung My Tran

The front page is illustrated by Phung My Tran, inspired by the contents of "An Early Meal – a Viking Age Cookbook & Culinary Odyssey" (2013) written by Daniel Serra and Hanna Tunberg.

Abstract

Medieval societies exhibited significant stratification and food was a prominent social status marker. Individual's social standing was often discernible through their dietary habits, as revealed by isotopic analyses of medieval skeletal remains. My research hypothesises that individuals with higher wealth and possessions held more significant influence over resource distribution and control within the community, resulting in distinct socio-economic hierarchies and disparities in resource access among different societal strata in medieval Oslo. This stratification extends to the food chain, where higher social classes typically access more exclusive foods due to their broader resource pool, while lower classes have simpler dietary choices. My thesis utilises stable carbon and nitrogen results from 36 individuals within St. Nicholas's churchyard in Gamlebyen, Oslo (Norway), spanning the 13th to 15th centuries as a case study. This case study aims to explore dietary habits and answer whether the diets of individuals in the churchyard were uniform or diverse. Additionally, by examining location-based patterns within the churchyard, a broader understanding of rank-related behavioural tendencies alongside dietary practices in medieval Norwegian societies is developed. Ultimately, I examine the correlation between dietary patterns identified through stable isotope analyses and the differences in inferred social status based on the burial locations within St. Nicholas's churchyard. The stable isotope results indicate that most individuals' diets encompass various food sources, incorporating contributions from both land and sea. Notably, terrestrial input has a significant presence, indicating a high-protein diet. The isotopic findings across three burial areas do not reflect significant differences in diet, suggesting a uniform dietary pattern among individuals. This lack of distinction makes it challenging to confirm the presence of social stratification at the churchyard based on dietary differences.

Table of Contents

List of Figures

List of Tables

1. Introduction

Throughout history, human society has been characterised by social inequality, and the concept of social status has been of fundamental importance in archaeological studies (Price and Feinman 1995, 2010). In the archaeological study of inequality, the medieval period was a time of significant social segregation (Alexander et al. 2015; Van Steensel 2020). As a result, archaeologists wonder how inequality was expressed at that time because social stratification can be defined as a significant characteristic of human social complexity. From this perspective, dietary factors have been considered as one of many approaches that help explain the observed social stratification in medieval communities (Müldner et al. 2009). Furthermore, analyzing skeletons from archaeological sites offers a chance to investigate human diets. Numerous projects now concentrate on excavated remains from funerary contexts, mainly cemeteries and churchyards, to scrutinize the social structure of burials (Ambrose et al. 2003; Huray and Schutkowski 2005; Naumann et al. 2014; Schutkowski et al. 1999)

The hierarchical framework of medieval burial customs and individual distinctions continues to shape our ongoing approach to infer social organisation from the past. The distinct treatment of bodies in burial is a characteristic feature from the ancient period that lasted until the medieval period. According to Jonsson (2009), various burial customs and regulations governing social segregation were evident in numerous graveyards across medieval Scandinavia. In particular, there are two forms of segregation observed in burial practice. One involves social stratification based on status, where individuals of higher status, such as priests and barons, were buried in proximity to the church, while individuals of lower status, e.g. thralls, were buried adjacent to the periphery of the churchyard (Jonsson 2009:37). Another form of segregation, known as sex segregation, wherein women were typically buried to the north, and men were buried to the south of the churchyard (Jonsson 2009:34). As a result, early medieval societies adhered to clear ideas of spatial separation, as manifested in burial practices.

The medieval period in Norway began at the end of the Viking Age (AD 1050), and there are three phases in medieval period in Norway: Early Medieval (AD 1030-1130), High Medieval (AD 1130-1349), with the bubonic plague in AD 1349 as the watershed, and Late Medieval (AD 1349-1537), marks the end of the medieval period with the Reformation in AD 1537 (Emblem et al. 1993:48,50). Much of our knowledge of this period comes from historical sources; however, even well-researched histories can only reveal what the people who lived at that time deemed essential to include (Moseng et al. 2007:25). Documents rarely cover the more mundane details of life, such as dietary habits, mobility and social organisation. Hence, the advent of archaeological studies has illuminated various intricate facets of the human past.

Expanding archaeometric research forms and utilising scientific techniques have provided more reliable answers to past human society in recent years. Renfrew and Bahn state that *"archaeology, in short, is a science as well as a humanity"*, which is proved by the development of technical methods of archaeological science, from radiocarbon dating to studies of food residues in ceramic pots (Renfrew and Bahn 2012:13). The advancement of scientific exploration in archaeology extends beyond the analysis of residues absorbed into the artefacts, progressing to the examination of human and animal bones through stable isotope analysis. Using isotopic ratios of the light elements (carbon and nitrogen) and heavy elements (strontium and lead) found in human and animal bones (specifically collagen and apatite) offers new insights into various aspects, such as individual-level diet and mobility patterns, weaning practices, and even social equality in the past (Leatherdale 2013; Lee-Thorp 2008).

Studying stable carbon and nitrogen isotopes in collagen of human and animal bones has become a popular method for reconstructing dietary patterns in archaeological research. Furthermore, the analysis of stable isotope ratios from skeletal remains is now an essential approach for comprehending the dietary practices of both humans and animals in archaeological settings (DeNiro and Epstein 1978, 1981; Katzenberg and Waters-Rist 2019; Schoeninger and Moore 1992; Van der Merwe and Vogel 1978; Vogel and Van der Merwe 1977). This method is striking as it empowers archaeologists to investigate human consumption patterns within the realm of diet - a domain tightly interwoven with considerations of social status and social stratification within a society. Stable isotope data has significantly expanded the body of research dedicated to exploring dietary habits during medieval Europe. It has also revealed how diet choices were socially expressed, with a notable emphasis on studies conducted in regions such as Scandinavia (Halley and Rosvold 2014; Johansen et al. 1986; Kjellström et al. 2009; Yoder 2010).

1.1 Research aims and objectives

Medieval societies exhibited significant stratification, with food serving as a crucial indicator of social status. This association is underscored by dietary practices markedly influenced by social class, as revealed through isotopic analyses of medieval skeletal remains (Müldner et al. 2009). My research premise suggests that an individual's status is intricately linked to wealth and possessions. This implies the existence of different distributions of resources used and controlled within a community, ultimately influencing the hierarchical structure of the society (Schutkowski 2006:162). In the context of food webs, the stratification of social classes adheres to a common principle: the diets of the upper class frequently comprise more exclusive and diverse foods, reflecting their robust economic standing and increased access to various resources (Tierney and Ohnuki-Tierney 2012:126). Conversely, the lower class maintains a more modest diet with fewer options for food selection.

In contemporary archaeological research, stable carbon and nitrogen isotopes have become standard tools for conducting dietary studies. This method has rarely been applied to the medieval period, which is unfortunate because isotope analysis can complement existing approaches. When solely using zooarchaeological and botanical samples, bulk information about the site is available as a whole, limiting the ability to classify individuals' social rank and status. On the other hand, stable carbon and nitrogen isotope ratios found in bone offer valuable insights into the composition of dietary protein and carbohydrates of individual's diet (Müldner and Richards 2005:39). There are two key isotopic markers involved: carbon isotope composition ($\delta^{13}C$ values), represents the ratio $^{13}C/^{12}C$ reported relative to the standard, Vienna Pee Dee Belemnite, or 'VPDB' and nitrogen isotope composition ($\delta^{15}N$ values), represents the ratio $^{15}N/^{14}N$ reported relative to the standard, atmospheric N_2, or 'AIR'. The $\delta^{13}C$ values offer insight into the proportional contributions of aquatic and various terrestrial sources, whereas $\delta^{15}N$ values indicate whether the diet's protein originates from plants or animals (Müldner et al. 2009:1123).

Analyzing a protein-rich diet (identified by elevated levels of ^{15}N isotopes) can be employed as a method to differentiate food sources between different social strata, considering their limitations or varying access to protein sources. Therefore, my thesis aims to utilise the outcomes of stable carbon and nitrogen analyses conducted on the remains of 36 individuals from St. Nicholas's churchyard in Gamlebyen in Oslo (Norway) during the 13th to 15th centuries as a case study (Figure 1). This case study investigates dietary patterns alongside funerary practices within the archaeological milieu to uncover dietary behavioural trends associated with social hierarchy in medieval Norwegian societies. In the scope of this thesis, the examination of isotopic outcomes from 36 individuals will address the following research questions:

1. Was there uniformity or diversity in the diets of individuals at St. Nicholas's churchyard?
2. Do the dietary patterns identified through stable isotope analyses align with distinctions in social status inferred from the spatial distribution of graves within St. Nicholas's churchyard?

In alignment with the stated objective, my thesis also explores burial customs in medieval Oslo, specifically focussing on their correlation with gender and social structures. Subsequently, I aim to evaluate hypotheses concerning the spatial distribution of genders and social classes, drawing insights from Norwegian provincial laws. Specifically, it is conjectured that individuals buried in peripheral sections of the churchyard may exhibit lower concentrations of ^{15}N and ^{13}C, indicative of lower-quality nutrition or poor diets. In contrast, those buried near the church may demonstrate higher isotopic values in carbon and nitrogen, suggesting they had access to richer and various protein sources in their diets. While numerous studies have investigated medieval burial customs correlated with grave goods as a social status and power markers (e.g. Gejvall 1960; Jonsson 2009; Kieffer-Olsen 1993; Nilsson 1994; Sellevold 2001), integrating dietary considerations through stable isotope analyses is relatively scarce in the existing literature. Consequently, I anticipate this thesis will stimulate renewed interest in the combined examination of dietary patterns through stable isotope analyses and burial practices, offering a novel approach to understanding past societies.

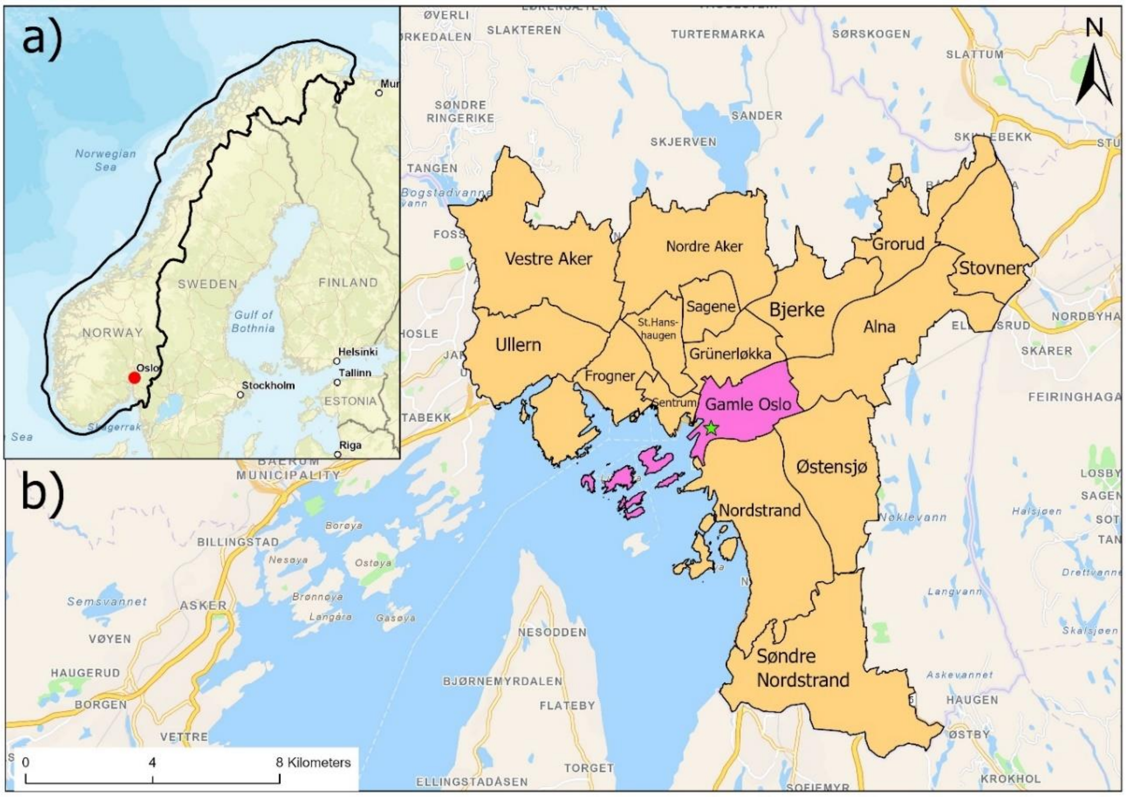


Figure 1. *(a) Map of Norway with the location of Oslo (red point) (b) Map of the site of St. Nicholas's church (green star) in the administrative district (bydel) of Gamlebyen (Gamle Oslo) in Oslo.*

1.2 Ethics considerations

The motivation behind this project is to establish the influence of an individual's social status on their dietary preferences, a conclusion drawn from the results of stable carbon and nitrogen analyses. Therefore, this thesis attempts to place context around the previous research and does not involve new, destructive analyses. However, it is crucial to acknowledge that these stable isotope analyses, by their nature, involve destroying the material being analyzed. Jensen (2018) released a report containing preliminary analysis results; however, the dissemination of this report was limited and not widely circulated.

Skeletal remains are a rich source of biological knowledge conditions encompassing aspects such as physical appearance, health, and living conditions; also, they can contribute to our understanding of past societies (Jensen 2018:16). They have been employed for scientific purposes in various studies for decades; however, the practice of destructive sampling for stable isotope analysis raises significant ethical questions. Whether in the form of whole cadavers or skeletons, human remains represent individuals who were once alive, with their lives intricately connected to social contexts such as kinship relationships, cultural history, religious beliefs, and value systems (Lambert 2011:17). When exploring the relationship between diet and human history through destructive methods; it raises a significant ethical question - should the burial and integrity of a body be sacrificed for the sake of scientific research? In this sense, ethical dilemmas often arise because there is a tension between the necessity to generate new knowledge and the priority of preserving the collections intact for future generations (Mays et al. 2013:4). Therefore, it is crucial to follow strictly professional codes of ethics and good practice guidelines when engaging in destructive sampling of human remains, including Statement Concerning the Treatment of Human Remains (The Society for American Archaeology 2021) and Guidelines for research ethics on human remains (The Norwegian National Research Ethics Committees 2016). It is imperative to note that the collection of human remains from St. Nicholas's church is thought to exclude individuals of Sami origin.

Before the analysis phase of the human remains from St. Nicholas’s churchyard, NIKU, which was in charge of the excavation project, sent an application to the National Committee for Research Ethics on Human Remains on 10 November 2014 accompanied with written permission from the Cultural History Museum (KHM) (Jensen 2018:16). After a long waiting time and disagreement on responsibility and authority of this case between NIKU, KHM and the National Committee for Research Ethics on Human Remains. On 4/1/2016, KHM granted permission for NIKU to conduct the analysis (Derrick 2018:21; Jensen 2018:16).

2. Background

In the following section, we will embark on a journey through time to unearth the deeper historical roots of Medieval Oslo, providing a comprehensive background to contextualise the case study conducted in this thesis.

2.1 Historical context

2.1.1 Medieval towns formation

In the Viking Age, several trading posts appeared in Norway, but none were big enough to be comparable to urban centres. In the Medieval period, especially the 11th century, it became more common for a king to establish a settlement and raise a city or a town there. There were only eight medieval towns within what is today Norway's borders, including Oslo, Sarpsborg (Borg), Hamar, Tønsberg, Skien, Stavanger, Bergen, and Trondheim (Nidaros) (Molaug 2002:8) (Figure 2). The foundation of the cities has been studied using a combination of the Norse sagas, historical sources and archaeological materials. Many historians disagreed about the story of different kings who founded the towns and would like to discuss more regarding town formation in the medieval period.

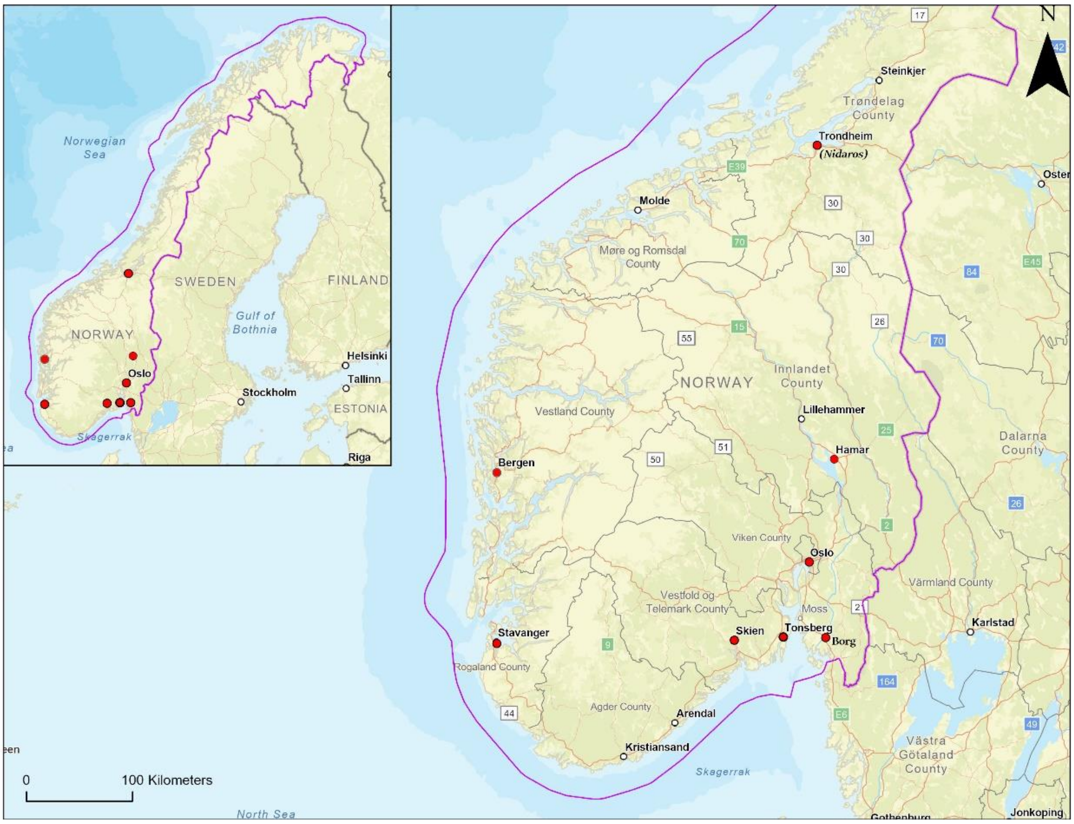


Figure 2*. Map of eight important Medieval towns (red points) in Norway.*

In 1849, Peter A. Munch came up with the "beach site theory" (*strandstedsteorien*), which assumed that most of the medieval Norwegian towns were self-growing marketplaces or settlements located in proximity to the shoreline and the King empowered the place by giving the status of a trading town in later time (Helle 2006:43). In 1899, Gustav Storm introduced the "king site theory" (*kongestadteorien*), asserting that most important towns in Norway, such as Nidaros, Bergen and Oslo had been founded by the King on bare ground and the areas were chosen to become the King's residence (Helle 2006:43). To put it differently, Storm's theory fundamentally opposed the "beach site theory" by contending that medieval towns did not evolve from marketplaces. Instead, he asserted that these towns were directly established by royal authority based on the similarity of the street plans in Oslo, Bergen, and Trondheim, leading him to conclude that a royal regulation must have dictated their layouts rather than a spontaneous growth from market activities (Nedkvitne and Norseng 2000:40).

Different from Storm's and Munch's theories, Edvard Bull (1922) centred his attention on the economic foundation and the role of the church in the establishment of Oslo as a town (*kirketeorien*). Bull emphasized that the founders of medieval towns were individuals possessing the power and capability to generate profits from their own lands, while simultaneously relying on agricultural products from others for their sustenance, e.g a king who collects taxes, a landowner who raises building taxes, a trader and a craftsman (Bull 1922:28). Otherwise, the town fillers of the medieval town, were individuals who resided within the town but lacked the capacity to generate surplus on their own and made a living by selling goods to the town's people, e.g servants and merchants (Bull 1922:28). In Norway, Bull believed that the formation of ecclesiastical centres was instrumental in acquiring substantial surpluses from the agricultural efforts of others, enabling them to sustain themselves (Bull 1922:29). That is to Bull's theory suggests that the emergence of towns was primarily determined by the presence of churches, and only these ecclesiastical institutions possessed the financial strength to provide a livelihood for the townspeople.

The various theories scholars such as Munch, Storm, and Bull proposed regarding the origins of the oldest Norwegian towns are not entirely incompatible. It appears that Storm's idea of royal foundations is only maintained for Bergen, as there might have been a royal harbour under the King's residence (Storm 1899). The "beach site theory" from Munch does not lend additional support to the initial development of marketplaces or locales near beaches. Instead, it asserts that royal intervention played a crucial role by aiding the early transformation of marketplaces into towns (Helle and Nedkvitne 1977:208). Bull emphasised the significance of the church in the formation of towns, yet he did not delve into the very earliest tendencies of town development (Helle and Nedkvitne 1977:208). This perspective aligns somewhat with Munch and Storm's main hypotheses. However, a more deliberate and systematic engagement with the various theories is necessary. In this context, archaeological materials hold the promise of offering novel perspectives on the history of medieval towns and provide an opportunity to delve deeper into the emergence of these medieval towns.

Within the broader context of historical exploration, the thesis now shifts its attention to a more specific and focused inquiry, delving into an in-depth exploration of the historical roots of Medieval Oslo. This exploration will unearth the detailed layers of the city's past, shedding light on a more coherent and contextually relevant examination.

2.1.2 A brief history of Medieval Oslo

Oslo initially appears in "The Legendary Saga" (*Den legendariske sagaen*) by Theodoricus Monachus. According to the saga, in AD 1021, King Olav Haraldsson stopped by Oslo during a Christian journey in the East of Norway and stayed for a few nights (Nilsen 1976:179). In this historical context, Oslo's origins can be traced back to the 10th century when King Olav Haraldsson visited. However, this account does not provide evidence of Oslo being designated as a town before this period. In another saga titled "The Chronicle of the Kings" (*Snorres kongesagaer*) by Snorre Sturlasson- an Icelandic historian, the history and formation of most medieval Norwegian towns are attributed to various kings (Holtsmark and Seip 1957). According to Snorre’s account, King Harald Hardråde (1046–1066) was the founder of Oslo, as he mentioned, "King Harald established a marketplace *(kaupang)* in the eastern region in Oslo" (Fischer 1950:3). However, both sagas are viewed as containing limited and uncertain information due to the considerable time gap between the events and their documentation. The reliability is further questioned because these sagas intertwine historical facts with elements of fiction. As a result, readers often wonder whether the depictions of people and events in the sagas are based on factual accounts or are more of a product of fictional narrative elements.

The findings from archaeological excavations in Gamlebyen have given rise to diverse interpretations of the medieval town. During the excavation at the church of St. Clement *(Klemenskirken)* in 1970-71, the oldest settlement at the site dates to AD 1000, and the graves beneath St. Clement's church also align with the same period between AD 980 and AD 1030 (Schia 1995:119). There is a plausible suggestion that the medieval town might have been founded in the first half of the 11th century, potentially between AD 1025 and AD 1050 (Schia 1995:119–120). Moreover, the orientation of the oldest graves at the site suggests that St. Clement's church was positioned on a pre-existing topographical high point (Schia 1995:95). Consequently, this indicates that the emergence of medieval Oslo could have unfolded in two possible scenarios. It might have evolved into a town, with a marketplace strategically positioned between the land and sea, aligning with P. A. Munch's "beach site theory" (Schia 1995:95). Alternatively, it could have been deliberately developed by royal force from the bare ground by King Harald Hardråde around AD 1050, following Snorre's historical account and Gustav Storm's "king site theory" (Schia 1995:95). Nonetheless, the establishment of medieval Oslo remains ambiguous and poses challenges in defining precise origins.

The medieval Oslo site is now in the administrative district (*bydel*) known as Gamlebyen (The Old Town) or Gamle Oslo. Over the years, extensive archaeological excavations within this medieval town have unveiled the topography as it existed in the 1300s. The current landscape of the present-day medieval town has undergone significant alterations due to the development of extensive railway facilities (Figure 3a). Nevertheless, Gamlebyen preserves its historical essence, evident in the King's residence, other medieval structures, and the remnants of churches and monasteries that can still be observed within the Medieval Park *(Middelalderparken)* today (Johannessen and Eriksson 2015:36; Krogstad and Schia 1993:3).

The medieval town of Oslo was situated in a well-chosen location, providing an ideal setting for the construction of an urban settlement with a good harbour conducive to trading goods (Johannessen and Eriksson 2015:37). It lies on a triangular land area bounded by the sea in the west, Hovinbekken in the north and the Alna River in the southeast (Figure 3b). From the 12th to the 13th century, the medieval town featured two primary centres: the first being the King's residence (*kongsgården*) and the second being the ecclesiastical centre, also known as the Bishop's residence (*bispegården*) (Christie 1966:47). King Harald Hardråde constructed his residence, which later became the focal point of the royal chancellery. This establishment served as a dwelling where the king resided during specific periods of the year and a meeting place for him and his men in Oslo (Emblem et al. 1993:58; Moseng et al. 2007:250). Religion swiftly took root in the town, giving rise to the construction of churches, with the ecclesiastical administrative centre situated to the northeast of the town (Christie 1966:47; Emblem et al. 1993:55). The spread of Christianity in Oslo coincided with the development of stone churches in the medieval town, encompassing five churches (Church of St Mary's, Church of St Clement's, Church of St Nicholas', St Halvard's Cathedral and the Holy Cross Church) and three monasteries (Franciscan friary, St Olav's priory and Nonneseter nunnery) (Krogstad and Schia 1993:4). Nevertheless, all the churches and monasteries ceased their functions during the Reformation in the 16th century, and the town underwent relocation in 1624 (Eide 1974:29).

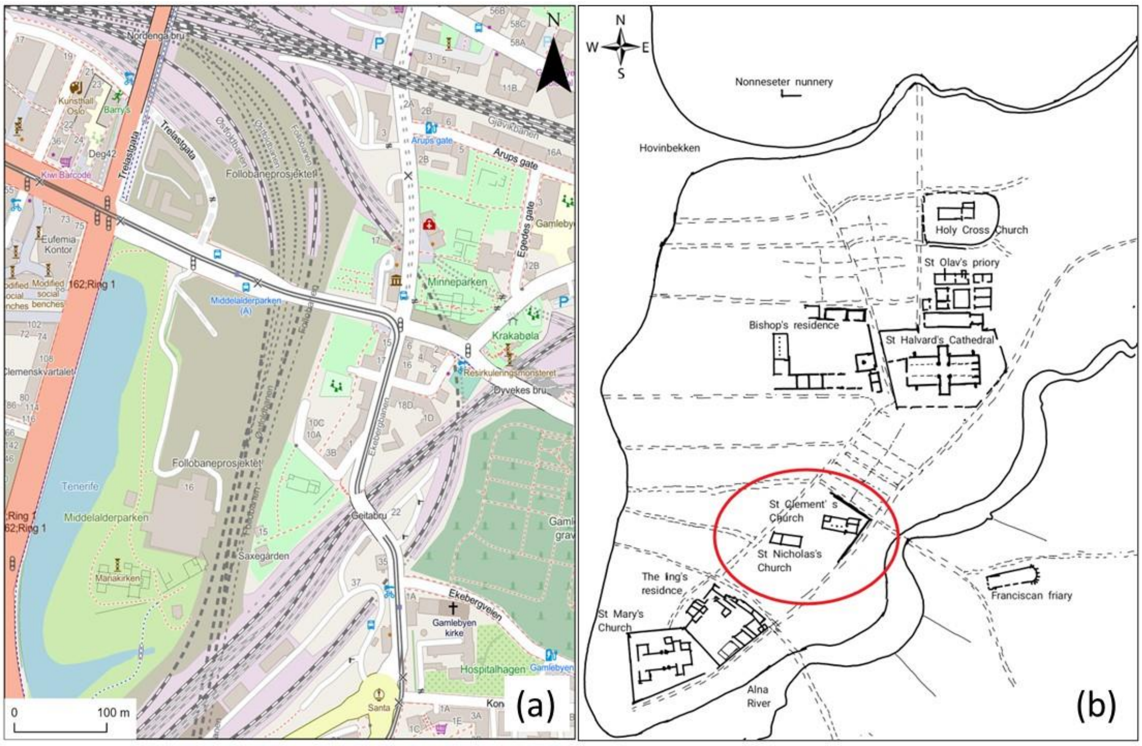


Figure 3. *(a) Medieval Oslo in a present-day map in Gamlebyen, Oslo. (b) Drawing map of medieval Oslo in AD 1300 with a red circle focus on St. Nicholas's church. Adapted from Erik Schia (1991).*

The medieval town covered approximately 2500 square metres with an estimated population of about 2700 – 3300 inhabitants in AD 1300 (Krogstad and Schia 1993:4; Nedkvitne and Norseng 1991:179). Residents often lived in tenement plots *(bygårder)*, each consisting of numerous wooden houses, a farm with animals, and a storage area for food (Bauer 2020:257; Brendalsmo 1996:14). These plots were delineated by boundaries such as fences or drainage ditches. Since a tenement plot comprises both the dwelling and the land area for different usage, the owners often rent their properties to other inhabitants (Bauer 2020:257; Schia 1995:174). Most tenement plots in the town were owned by the king, wealthy individuals, and the church (Bauer 2020:257). Consequently, many farmers had to rent the land from the upper classes. The town's population was highly diverse as the owners of tenement plots resided in their properties throughout the year, resulting in circumstances contributed to a growing demand for servants (Brendalsmo 1996:19). Furthermore, as product development expanded to meet daily needs, various artisans such as shoemakers, comb makers, carpenters, goldsmiths, and masons, quickly joined the administrative centres (Brendalsmo 1996:19; Schia 1995:143).

The growth in trade and urban development contributed to a glorious period of the medieval town. However, from 1346 to 1353, the bubonic plague caused by the bacterium Yersinia pestis swept over Europe, resulting in a devastating population loss, and Norway was no exception. The plague epidemic is believed to have initially occurred in Oslo during late autumn 1348, with a re-emergence in early spring 1349 that intensified into a widespread outbreak extending beyond the boundaries of Oslo (Benedictow 2021:412). The bubonic plague was transmitted by fleas and ravaged half of Norway's population within a year, leaving many tenement plots empty (Christie 1966:46; Nedkvitne and Norseng 2000:338). Moreover, the plague epidemic profoundly impacted political development, primarily due to a significant reduction in income from rents and taxes for the king and nobles (Benedictow 2021:12). This financial decline occurred as most tenants died, and the lands were left abandoned. By the end of 1349 to 1350, the plague epidemic had subsided in Oslo, and it was not until the 15th century that the population began to experience a gradual increase again (Benedictow 2021:413).

This tragedy altered the social fabric and resulted in significant political consequences, impacting the financial stability of the state (Emblem et al. 1993:77). In the years that followed, a series of transformations occurred, and Norway was drawn into political unions with Denmark, eventually becoming a Danish province in 1537 (Emblem et al. 1993:77). Ultimately, the city experienced a violent fire in 1624, destroying the entire town. This event prompted the relocation and renaming of the city to Christiania (Keller and Schia 1994:9). Even though Oslo ceased to function as a town, it was not entirely abandoned. A substantial part of it was repurposed into arable land known as Oslo Ladegård, serving as an area that supplied provisions for the Akershus fortress (Norseng 1986:24).

2.2 St. Nicholas’s church

St. Nicholas’s church is not mentioned so often in historical sources. However, its first mention was in Håkon Håkonsson's saga in connection with a battle in AD 1240 (Norseng 1986:16). However, the church of St. Nicholas and the church of St. Clement was located in the same area, which led to confusion in distinguishing between these two churches in the saga (Norseng 1986:17). Among the Medieval churches in Oslo during the same period, St. Nicholas's church was one of the smallest and was very poor in terms of property (Bull 1922:104; Derrick 2018:183). The church was dedicated to Saint Nicholas of Myra, the patron saint of sailors, merchants, and young clerks, and it was believed that this was a parish church for farmers in the southern area of the town (Schia 1995:37–38). Following a significant fire in 1352, the church was abandoned. Subsequently, between 1386 and 1396, Bishop Alasksson rebuilt the church (Nedkvitne and Norseng 2000:352). Its last recorded mention dates back to the 1460s, and the church did not persist as an institution beyond the Reformation (Norseng 1986:23).

In 1877-79, the church of St. Nicholas was discovered and documented by railway architects Peter Blix and Johan Meyer during construction work for the Smålensbanen railway track built through the medieval Oslo in Klypen (Blix 1879; Holck and Kvaal 2000:5). Based on the church's ground plan documented by Peter Blix (1879) and Gerhard Fischer (1950), the stone church had a rectangular shape without a small and narrow chancel, suggesting a date to around AD 1300. In the 1870s excavation, 50 burials were discovered and removed from the southern side of the church. Following these interventions, the church ruins and its churchyard were removed, leading to the assumption that this area was no longer accessible for further research (Blix 1879:39; Holck and Kvaal 2000:5). Thus, the dating of this church is still difficult to trace further back than the time mentioned in Håkon's saga because there are no visible remains of the church on the site today to support the dating.

Railway work has been active in Gamlebyen through the 21st century, and the development in analysis methods provided more opportunities to study the site than Blix had in the 1870s. The Norwegian Institute for Cultural Heritage Research *(Norsk institutt for kulturminneforskning, NIKU),* which is responsible for the archaeological excavations in the medieval town, carried out further archaeological research at the site of St. Nicholas's church in connection with the Follo Line project in 2014. Within this project, the churchyard was rediscovered with more than hundreds of graves, and traces of early settlements have been identified under the churchyard (Derrick and Bauer 2014). Figure 4 depicts the St. Nicholas's Church site in the Medieval park, which is currently surrounded by fences for construction purposes.

Figure 4. *The site of St.Nicholas's church was situated behind the construction fences in the Medieval Park in Gamlebyen, Oslo. Photo: Author, taken 17/11/2023.*

Figure 5. *Map of the churchyard (Area A-Område A) associated with St. Nicholas's church and graves' location from excation in 2014-2015 by NIKU. Taken from Jensen (2018:Figure 1) with permission from NIKU.*

The graves excavated by NIKU in 2014 are situated in the eastern section (Area A – *Område A*) that was removed during the 1870s construction, aligning closely with the graves documented by Blix (Jensen 2018:15) (Figure 5). A total of 430 individuals (106 *in-situ* and 324 *ex-situ*) from St. Nicholas's churchyard were discovered during excavations conducted in 2014-2015. The demographic makeup of the early population comprises a diverse group of men, women, and children. Notably, there is an overrepresentation of women and children in the *in-situ* graves (Jensen 2018:20). Through the analysis of radiocarbon data from individuals buried at the site, it became evident that the graveyard was in active use starting from the 12th century, reached its peak during the mid-13th century, and ceased to be used in the mid-

15th century (Derrick 2018). Finally, the archaeological dating of the graves corresponds with the dates documented in written sources regarding the establishment of St. Nicholas's church.

2.3 The dietary background in the medieval period

Entirely different influences shape the dietary choices of modern society compared to those of the medieval era. In today's world, our food preferences are a blend of personal choices and are often swayed by economic considerations, ethnic origin, health, and body ideals. Conversely, in the medieval period, food preferences were primarily based on seasonal availability, regional availability, religious beliefs, and social class distinctions. Hence, dietary practices and food consumption behaviours are crucial in determining inclusion or exclusion within specific social circles. Often, they serve as expressions of association and distinction among individuals and social groups within a society (Isaksson 2000:7). When investigating the dietary habits of medieval Scandinavians, scholars draw upon a diverse range of literary and written sources. In later periods, the integration of advanced analytical techniques and a growing interest in food studies led to the incorporation of excavated food remains from plants and animals. Additionally, examining tissues extracted from human remains has become a crucial component in advancing research on exploring ancient dietary practices. The synergy between historical records and archaeological materials significantly enriches our comprehension of the foods consumed, culinary customs, and prevailing dietary habits of that era.

2.3.1 Overview of food sources in medieval Oslo

A general overview of the possible food resource in medieval Oslo is provided to understand isotopic data better. In the early medieval period, the majority of the population in Oslo were self-sufficient farmers who relied on the resources they cultivated. It was not until the high medieval period that the city evolved into a bustling port for trade, leading to an influx of imported food (Skaar 2014a:15). The primary source of consumed meat in this era was domesticated animals, specifically cattle, pigs, goats, and sheep, constituting the central protein intake for the people of the time (Lie 1988:161). There was a higher consumption of pork and beef in the early medieval period, but this trend declined over time with the consumption of lamb, mutton, and goats increased towards the end of the medieval period (Lie 1988:193, 195, 1991:83). Additionally, the diet was supplemented to a lesser extent by various wild game meat such as elk, deer, beaver, otter, bear, wolf, fox, and squirrel (Lie 1988:161). In contrast to mammal meat, bird meat comprised a smaller portion of the diet, with domestic chicken being the dominant source in the bird menu (Hufthammer 2000:174–175; Lie 1988:180). Regarding fish, species like cod, herring, ling, and pollack were prevalent in the Oslo diet, and dried codfish (*torsk*) constituted a regular component, although its consumption was less frequent than meat (Lie 1988:184). Freshwater fish held minimal importance in medieval Oslo (Lie 1991:81).

Grain was paramount as a food staple, constituting one of the primary sources of protein and calories (Øye 2002:314). Various grain types were utilised, including barley, oats, wheat, and rye (Øye 2002:314). Oats were predominantly employed for making gruel, bread, flatbread, and beer and were commonly associated with lower social status (Øye 2002:316). In contrast, wheat was an imported grain and viewed as a more exclusive grain, underscored by the church's preference for using it in the production of altar bread during the Eucharist (Griffin 1988:94; Øye 2002:317). Additionally, onions emerged as one of the earliest cultivated vegetables in the country and cabbage, turnips, and wild celery (*kvann*) gained significant popularity in the town (Øye 2002:321). Cultivated legumes like peas and beans also found their place in the culinary landscape, particularly peas, which were an essential source of nutrition as they could be used fresh or dried (Øye 2002:320,324). Furthermore, there was a notable expansion in the variety of fruits during the 13th century, including apples, plums, pears, cherries (*kirsebær*), grapes, figs, various berries types and various nuts (Øye 2002:322; Sture and Bauer 2017:47). During the medieval era, beer, a highly favoured beverage, was not only imported from foreign lands but also brewed locally in Norway, utilizing a combination of various grains and cultivated spice plants such as sweet gale (*pors*) and hops (*humle*) (Øye 2002:321–322; Skaar 2014b:41).

Even though medieval inhabitants had diverse dietary sources, food in the medieval period was shaped not only by what was available for sustenance but also by broader social stratification. In other words, it is reasonable to assume that these distinctions were reflected in the choices of food and beverages consumed by individuals within different social strata (Skaar 2014a; Sture and Bauer 2017). Additionally, the introduction of Christianity significantly impacted the inhabitants' dietary habits (Maraschi 2019; Sanmark 2005a). Therefore, when examining the medieval diet, one should consider these two noteworthy observations, which will be further discussed in Chapter 7 of this thesis.

2.3.2 Written sources

In examining the historical foundations that underpin our understanding of the diet in Norway, particularly within the broader context of Scandinavia, a crucial starting point is the medieval Old Norse literature. Although these sagas have been scrutinised due to potential biases and the considerable time gap between their creation and the events they depict, they still stand as invaluable resources that describe the past's culinary traditions and food-related practices (Tang and Ashby 2021:223). In addition to the Old Norse sagas, other literary sources also deserve attention. These sources include law texts, poetry, and cookbooks, each providing unique insights into food preparation, food production, and the contents of upper-class larders (Pulsiano and Wolf 1993:134).

Law codes

Law codes often provide regulations and traditions that govern food production and restrictions, offering a legal perspective on dietary practices. For instance, within the medieval Icelandic *Grágás* law codes, specific guidelines were explicitly outlined regarding meat consumption. The law specifically outlines the types of meat that are permissible for consumption: *Þat er kiot er meɴ lata af navt eþa fær sauði. oc geitr. oc svín* – “Meat derived from cattle, sheep, goats, and pigs was permissible” (Dennis et al. 1980:e1170; Finsen 1852:33–34). The law also addresses prohibitions on consuming specific types of meat: *Ros eigv meɴ eigi at eta oc hvnda. oc melracca. oc kottv. oc en engi kló dýr. oc eigi hræ fogla* – “Horses, dogs, arctic foxes, and cats, as well as any animals with claws must not be eaten, and cautioned against consuming carrion birds” (Dennis et al. 1980:1182; Finsen 1852:34). Provisions regarding dietary restrictions are also evident in the early Norwegian Gulating ecclesiastical law, which expressly prohibits against the consumption of horse meat. The law stipulates that those who partake in horse meat face consequences: *En ef maðr etr roſſakiot. þa borte hann firi þat morcom .iij. biſcope. aller menn a vara tungu. oc gange til ſkripta oc borte við Criſt* – “Who eat horsemeat must pay a fine of three marks to the bishop, every individual who speaks our language, go to confession, and do penance for Christ” (Erik and Jørgensen 2021:29; Keyser and Munch 1846:11). These dietary regulations demonstrate the significant influence of the legal framework on shaping food consumption practices. As a result, early Scandinavians likely experienced subtle shifts in their eating patterns.

Norse Poem

In addition to legal texts, Nordic poetry offers valuable insights into the prevailing food and culinary customs spanning the transition from the pre-Christian to Christian era in

Scandinavia. The Old Norse Eddic poem *Rígsþula* vividly portrays the nuances of social stratification, particularly through the lens of food consumption and table arrangements (Aars 1864; Gjessing 1899; Johansson 1998). The poem narrates the journey of the Norse god Heimdall, disguised as a wandering god named Rig, who visits different farms and lodges with three childless couples of varying social statuses—the thrall, the peasant, and the nobleman (Grøn 1927:28; Johansson 1998:67). During his visit, he spent three days in each household, and as a result, children were conceived. These offspring were named Thræll (representing the slave class), Karl (symbolizing the peasant class), and Jarl (signifying the noble class), corresponding directly to their respective social statuses (Scher 1963:403–404). The poem meticulously describes distinct physical attributes, home decor, clothing, and the nature of meals, providing a rich tapestry of societal divisions (Johansson 1998:67; Notaker 2009:3).

Rig's journey began with a visit to the first household of Ái and Edda (Great-grandfather and Great-grandmother). Edda, who wore an old-fashioned head-dress, offered a modest meal consisting of hearty loaves of thick and dark bread with seeds and cups of meat broth for a drink (Gjessing 1899:93–94, stanza 1-4). After Rig's departure, nine months later, Edda welcomes a son named Þræll (Thræll); his swarthy complexion symbolises his belonging to the slave class (Gjessing 1899:94, stanza 7). This event in the poem's narrative underscores the allegorical representation of social stratification through the offspring of Rig's visits. Continuing his journey, Rig arrived at the dwelling of Afi and Amma (Grandfather and Grandmother). Rig conceived Amma and gave birth to a son, Karl, who represented the peasant farmer class (Gjessing 1899:96, stanza 21). Regrettably, the manuscripts detailing the meals of this house remain incomplete, but stanza 18 mentions a bowl of boiled veal, providing a glimpse into the culinary offerings of this household (Gjessing 1899:95,96). At the third house, Rig was treated to a more luxury hospitality by the couple Faðir and Móðir (Father and Mother) (Gjessing 1899:96–100, stanza 27). Nine months after Rig's visit, Móðir gave birth to a robust and warlike son named Jarl, who became the heir of Rig and represents the warrior and nobleman class (Gjessing 1899:98, stanza 33). In contrast with a simple meal from the first couple, Ái and Edda, the menu of Faðir and Móðir featured delicate white loaves of wheat bread, light and dark pork selection, and roasted birds; the table was adorned with white linen and full silver-plated dishes, and to complement the meal, wine was served in elegant plated drinking cups (Gjessing 1899:97, stanzas 30,31).

In short, the ancient Norse poem Rígsþula, recounting Rig's journey through these households, offers a unique glimpse into medieval Scandinavia's culinary practices and social distinctions. The poem vividly portrays the stark differences in the meals and the overall hospitality offered to Rig based on the social status of each of the couples he visits. The dishes mentioned in the poem were likely so commonplace that the author attached them to specific social classes (Notaker 1993:17). These poetic narratives not only uncover historical food culture but also highlight how food and feasting were intricately tied to the social structure of the era.

Cookbooks

The growing interest in gastronomy spurred a demand for cookbooks in the medieval period. These culinary guides were predominantly handwritten, often commissioned by wealthy individuals such as kings and noblemen who could employ professional cooks (Notaker 1993:19). By the 14th – 15th century, a limited but notable selection of cookbooks had emerged in Scandinavia, including two Danish works and one Icelandic (e.g. Austin 1888; Veirup 1993). This early culinary literature offers practical guidance on how food was prepared, the ingredients that were commonly used and the food that was presumably eaten, giving us a tangible glimpse into the culinary techniques of the period. In the cookbooks, chicken meat is the most frequently featured ingredient, and in some instances, it is even combined with pork (Vedeler 2017:62). The presence of recipes featuring pork in the cookbooks aligns with archaeological findings, providing a clearer understanding of the prevalent consumption of this meat in medieval Oslo (Vedeler 2017:65). The abundance of pork bones discovered in the medieval town emphasised the significance of these animals in the diet of early medieval Oslo inhabitants (Lie 1988:195). In contrast to the plentiful zooarchaeological finds of cattle, sheep, and goats, the utilisation of these meats is only indirectly mentioned in the cookbooks (Vedeler 2017:64).

Another prominent feature that stands out in the cookbook is the widespread use of exotic spices like cardamom, saffron, cinnamon, cloves, and nutmeg, which are employed in various ways, predominantly for creating flavourful sauces (Vedeler 2017). For example, a sauce recipe includes ingredients like pepper, nutmeg, cinnamon, and ginger, demonstrating a sense of savoury and cultural wealth that only a few could indulge in such luxurious goods (Notaker 1993:22). These "spicy" sauces were frequently paired with exclusive meats derived from wild game (Vedeler 2017:73). People in the medieval period were just as concerned about their health as individuals are today. As a result, food served a dual purpose, not only for sustenance but also as a form of medicine (Skaar 2014b:45). Additionally, due to the influence of Christianization, the consumption of meat was prohibited on fast days. This led to including specific recipes for fasting days in the cookbooks. Examples include dishes like "fast pie," made solely with vegetables, as well as various fish-based recipes such as "fish sausages" and "fish in jelly" (Skaarup and Jacobsen 1999, as cited in Skaar 2014b:45).

However, none of the cookbooks offer insights into the dietary habits of the lower social classes, who constituted most of the medieval population (Adamson 2004:xvi–xvii). These culinary manuscripts primarily reflect the tastes and preferences of the privileged segments of society; they say less about how ordinary farmers and townspeople ate. The recipes predominantly highlight specific types of ingredients, with limited to no mention of contributions from vegetables, fruits, porridge, or bread in the cookbooks (Vedeler 2017:74). Although cookbooks offer glimpses into aspects of medieval culinary practices, it is crucial to recognize that this culinary literature was still in its infancy. Therefore, they may not provide an entirely representative picture of the everyday diet, the specific composition of meals consumed by the general population, and cooking methods employed by people of all social classes during that time.

The written sources of medieval culinary practices provide a fascinating window into the diverse and intricate world of historical food culture. From illuminated Old Norse manuscripts to early cookbooks, these records offer valuable insights into the ingredients, techniques, and social dynamics that shaped past meals. Nevertheless, it is crucial to approach them with a discerning perspective, acknowledging their inherent limitations in representing the full spectrum of dietary habits across different social strata. Seamlessly integrating these written sources with archaeological findings, for example, midden deposits, tools, and faunal remains, allows us to gain a broader understanding of prevalent culinary practices and specific dietary sources consumed by different social strata in the medieval period. This implies that while written records may provide insight into specific end products and ingredients favoured by the wealthiest members of medieval society, archaeological excavations can expose more mundane and widely employed resources. This combined approach allows us to bridge the gap between historical records and tangible remnants, providing a holistic view of how food was central in shaping people's lives in medieval Scandinavia.

2.3.3 Archaeological evidence

In the broader scope of their research endeavours, archaeologists have maintained a sustained curiosity regarding food remnants within the framework of dietary practices and subsistence strategies. This work enriches the understanding of the historical evolution of food practices and its profound impact on societies. Our understanding of prehistoric human dietary patterns has predominantly relied on the reconstruction of diet from preserved faunal and botanical remains. However, these sources are several stages removed from actual consumption and have not supplied enough of the precise information needed to address the archaeological inquiries related to economic, social, and structural aspects (Hastorf 1985:19). Accordingly, the collaboration between geochemists and archaeologists has paved the way for innovative research avenues that offer clear and actionable insights into dietary and consumption patterns. Building upon the foundational geochemical work conducted by M. DeNiro and S. Epstein (1978, 1981), followed by M. DeNiro, M. Schoeniger, and Tauber (1983), stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) analyses have emerged as a powerful tool to investigate various aspects of dietary dynamics. This analytical approach demonstrates that the distribution of carbon and nitrogen isotopes in bones is influenced by diet (DeNiro and Epstein 1978, 1981). Moreover, the analysis of tissues from both human and animal bones reflects the isotopic composition of their respective diets, enabling us to understand better the dietary patterns of both the individuals and the animals, shedding light on their nutritional habits and interactions within their environments.

A significant amount of isotopic research has already been conducted to investigate people's dietary habits in Medieval Norway. In one of the pioneering studies conducted by Johansen and colleagues (1986), carbon isotopes were utilized in the analysis of human bone collagen and marine protein fractions. This investigation aimed to discern dietary patterns across various sites and regions in Norway. Notably, Træna, a cluster of islands off the Nordland coast, and Heidal, a remote valley in the interior of eastern Norway, were identified as sites with medieval significance. The $\delta^{13}C$ values from Træna exhibited a range between -15.7‰ and -19.0‰, indicating a diverse dietary pattern in contrast to the expectation of seafood being a predominant staple for island dwellers (Johansen et al. 1986:758). This variability can be attributed to socio-economic disparities, as individuals of higher social standing could afford imported foods such as cereals, while lower-status people relied more heavily on local marine sources (Johansen et al. 1986:758). On the other hand, the $\delta^{13}C$ values observed in Heidal fall within the range of -19.9‰ to -21.1‰ (Johansen et al. 1986:759). This implies a diet predominantly centred around terrestrial foods, aligning with expectations for an inland settlement with limited access to marine resources (Johansen et al. 1986:759).

The isotopic study conducted by Price and Naumann (2015) also encompassed multiple regions in Norway, employing a different approach compared to the material analysis undertaken by Johansen et al. (1986). Instead of bone collagen, Price and Naumann (2015) utilised tooth enamel from individuals found at several medieval cemeteries in Bryggen, Hamar, and Trondheim as their primary material for stable isotopic analysis, focussing on strontium, oxygen, and carbon. This choice of tissue yielded distinct insights into diet, as bone collagen offers records of adult dietary patterns and tooth enamel provides a glimpse into early childhood diet, and more positive enamel values indicate higher marine component in diet (Price and Naumann 2015:92). In Hamar, carbon isotope values range from -11.2‰ to -15.0‰, and notably, the δ^{13}C values of five individuals in Hamar exceed -13.0‰, and four surpass -14.0‰, indicating a diet with a more substantial marine influence (Price and Naumann 2015:95). This suggests that these individuals were likely not native to Hamar but migrated there during their lifetimes. Meanwhile, in Trondheim and Bryggen, carbon isotope values present a distribution typical of a coastal region, ranging from -14.5‰ to -16.1‰ and from -13.7‰ to -16.9‰, respectively (Price and Naumann 2015:94,96). These findings offer a valuable understanding of dietary shifts and migration patterns during this period, particularly regarding the role of seafood in childhood diet in Trondheim and Bryggen and the presence of migrated individuals in Hamar.

Van der Sluis and colleagues (2016) conducted another noteworthy study shedding light on human dietary patterns in Norway. This investigation examined stable isotopic values derived from human and animal remains from the cemetery at Stavanger's cathedral, Norway. The study's overarching aim was to reconstruct dietary patterns in the Stavanger region across the entire spectrum from the Viking Age to the Post-Reformation era. The study showed distinct mean δ^{13}C and δ^{15}N values for humans across different periods in Stavanger. Specifically, during the Viking Age, the mean δ^{13}C value was -20.7‰; in the Early Medieval period, it was -18.7‰, and in the post-Reformation period, it was -19.4‰ (Van der Sluis et al. 2016:126).

Similarly, the mean δ^{15}N values for these respective periods were 10.8‰, 13.7‰, and 12.9‰ (Van der Sluis et al. 2016:126). Based on these findings, the study suggests that individuals in Stavanger had a high protein diet, indicated by elevated δ^{13}C and δ^{15}N ratios. This could be attributed to either a diet rich in marine resources or a terrestrial-based diet supplemented by pigs fed on ^{15}N-enriched soils, particularly prominent in the Early Medieval period (Van der Sluis et al. 2016:129). The observed shift towards a more marine-based diet may be linked to Christian dietary practices encouraging reduced meat consumption during fasting periods (Van der Sluis et al. 2016:130). Additionally, the demographic imperative arising from a growing urban population's need for affordable and easily preserved protein sources likely contributed to the increased consumption of fish in this region (Barrett et al. 2011:1523, as cited in Van der Sluis et al. 2016).

Recently, a sustained and enthusiastic effort has been made to reconstruct medieval diets. Once again, Naumann and colleagues (2019) have significantly contributed to this field by conducting a study that investigates changes in individual diets during the urbanisation period, extending from the early 11th to the late 12th century in Oslo, Norway. This research entailed the examination of 20 individuals from St. Clement's cemetery in Oslo, and stable isotopic analyses of teeth and bone collagen were employed to discern the main component of dietary protein and evaluate the dietary diversity among the inhabitants of Oslo. The δ^{13}C values from the samples ranged from -17.67‰ to -21.82‰ and δ^{15}N values ranged from 10.33‰ to 15.57‰ (Naumann et al. 2019:1121). These findings suggest a diet that draws from marine and terrestrial sources, with most individuals maintaining a consistent dietary pattern throughout their lives (Naumann et al. 2019:1121). This lack of significant individual dietary change starkly contrasts the dynamic dietary shifts observed in individuals from the Viking Age (Naumann et al. 2014).

Indeed, it is essential to note that the high acidity of Norwegian soil poses a significant unfavourable preservation condition of skeletal remains, thereby restricting the scope of stable isotope studies in this region. Despite this challenge, archaeologists have demonstrated a sustained and passionate interest in exploring medieval diets. They have delved into this subject by employing various isotopic analyses and examining different sources, ranging from bone collagen to tooth enamel. These investigations unveil the dietary patterns and underscore how environmental conditions, socio-economic factors, and religious practices can influence what people consume in medieval Norway.

3. Stable isotopes in the reconstruction of diet

Dietary patterns and the isotopic composition of bones were of interest to archaeologists beginning in the 1970s. The field of stable isotope dietary tracing began with the study of the rise and spread of maise agriculture in North America (Van der Merwe and Vogel 1978; Vogel and Van der Merwe 1977) and followed with the study of the transition from marine to terrestrial diets during the Neolithic period in Denmark (Tauber 1981). The outcomes of stable isotope analysis offer valuable information across various applications. For example, information about shifts in diet and geographical habitat and discerning the dietary practices of ancient humans are needed (Makarewicz and Sealy 2015). When individuals are alive, they ingest food and beverages sourced from their local environment, and these elements become incorporated into their skeletons, persisting even after burial. Consequently, as archaeologists, we can extract samples from both human and faunal remains to reconstruct people's environment and dietary practices from the past.

The stable carbon and nitrogen isotope analysis of human bone collagen is a firmly established technique that has been extensively utilised to reconstruct past human diets across various geographical locations and historical periods (Ambrose 1993; DeNiro 1987; Fischer et al. 2007; Naumann et al. 2014; Schwarcz et al. 2011; Van der Merwe 1982; Van der Sluis et al. 2016). Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopic ratios in human bone collagen offer a dietary record of the individual approximately 10 to 20 years before their passing (Katzenberg and Waters-Rist 2019:483). Stable carbon analysis in bone collagen provides insight into the proportion of C_3 and C_4 plants in an organism's diet through isotopic fractionation. On the other hand, stable nitrogen analysis in bone collagen helps distinguish between marine and terrestrial food sources in an organism's diet and ascertain the consumer's trophic level. This method has played a crucial role in uncovering the nuanced aspects of ancient diets and human adaptations in their dietary practices.

3.1 What do stable isotopes reflect in bone?

In this section, I delve into the significance of utilising bone as a primary material for stable isotope analysis. Given the limited survival of soft tissues in archaeological deposits, stable isotope analyses predominantly rely on hard tissues like bones and teeth, as they tend to be exceptionally well-preserved archaeological materials (Lee-Thorp et al. 1989:586). The bone matrix is a complex mixture of organic and inorganic components and water (Krueger and Sullivan 1984:209). Within the organic portion, approximately 90% is composed of collagen, while the remaining 10% comprises non-collagenous proteins, lipids, carbohydrates, enzymes and hormones (Pate 1994:163). On the contrary, the inorganic matrix primarily comprises calcium hydroxyapatite, also known as bone carbonate, and trace amounts of other inorganic minerals and ions (Katzenberg and Waters-Rist 2019:473).

Bone collagen, a protein-rich in both carbon and nitrogen elements, possesses a remarkable resilience to post-mortem processes, known as diagenesis (Ambrose 1993:72; Schoeninger and Moore 1992:261). In environments characterized by cool and stable conditions, bone collagen can endure for millennia after being buried (Ambrose 1993:72). Additionally, human bones undergo elemental remodelling (turnover) throughout a person's lifetime and can be traced back to a period of 10 to 20 years before the individual's passing, bone isotopic ratios provide a window into long-term dietary patterns and the final years before death (Katzenberg and Waters-Rist 2019:483; Sealy et al. 1995:290–291). As a result, bone collagen is a reliable source of carbon and nitrogen isotopic values. On the other hand, bone carbonate retains only carbon but not nitrogen because it undergoes exchange with carbon from the surrounding environment, predominantly from atmospheric CO_2 and dissolved-CO_2 in groundwater (Malainey 2011:181). Additionally, bone carbonate poses challenges in dietary analysis due to its susceptibility to diagenetic processes because it has a propensity to undergo unpredictable alterations in its biogenic isotopic ratios (Lee-Thorp et al. 1989:586).

The isotopic composition of collagen and hydroxyapatite, as primary carbon sources for potential isotopic analysis, reflects the long-term dietary patterns of an individual due to their continuous resorption and replenishment processes (bone turnover) (Pate 1994:164; Tykot 2004:434). However, the carbon found in bone carbonate comes from distinct dietary sources compared to the carbon in bone collagen (Katzenberg and Waters-Rist 2019:473). This is because bone collagen primarily forms from a combination of essential and non-essential amino acids contained in dietary proteins, while bone carbonate forms from dissolved bicarbonate in the blood, which is derived from carbohydrates, proteins, and fats (Brown and Brown 2011:197; Katzenberg and Waters-Rist 2019:473) Consequently, collagen carbon primarily signifies the intake of dietary protein, whereas the carbon in apatite provides a broader representation of the entire diet (Krueger and Sullivan 1984:220). Additionally, examining nitrogen isotopes in bone collagen yields distinctive nitrogen isotopic values for marine resources in contrast to terrestrial plants (Schoeninger and DeNiro 1984; Schoeninger et al. 1983). Therefore, stable carbon and nitrogen analyses of bone collagen from diverse skeletal remains can reveal variations in isotopic composition. This information provides archaeologists with crucial data to reconstruct subsistence strategies and infer the diets of individuals in prehistoric times.

An essential consideration when selecting bone collagen as sample material for stable carbon and nitrogen isotope analysis is the potential for collagen degradation or bone diagenesis. Following an individual's death, human skeletons undergo various degradation processes influenced by the specific burial environment. These processes can be attributed to a range of factors falling into two categories: extrinsic factors, which encompass variables like temperature, weather, soil conditions, humidity, scavengers, and intrinsic factors, including the age at death, sex, and body weight of the remains (Falgayrac et al. 2022:2). In simpler terms, diagenesis encompasses all the processes, whether chemical or physical, that alter the chemical composition or the structure of skeletal remains (Ambrose 1993:64). For example, microbiological factors, such as fungi, bacteria, or microorganisms, can break down the organic components of bone, including collagen and increased bone porosity, leading to physical deterioration (Hedges 2002:321–322). Additionally, temperature and soil conditions play a crucially sensitive role in influencing the maximum preservation of collagen. For instance, high temperatures in hot climate sites can expedite microbial activity, while extreme soil conditions - whether highly acidic or strongly alkaline - can exacerbate the effects of hydrolysis (Kendall et al. 2018:9). This combination of factors can result in a more rapid loss of collagen from bone remains.

Over the years, numerous efforts have been made to develop quality indicators that can assess the preservation condition and distinguish isotopic data in bone tissue that has been altered by diagenetic processes (Ambrose 1990, 1993; DeNiro 1985; DeNiro and Weiner 1988; Van Klinken 1999). The most frequently encountered quality criterion for collagen in the literature is the ratio of carbon (C) to nitrogen (N), often referred to as the C/N ratio of collagen (DeNiro 1985). This criterion is rooted in a study conducted by DeNiro (1985), who proposed that the range of C/N ratios from 2.9 to 3.6 serves as an indicator of well-preserved collagen in archaeological bones and findings show collagen with C/N ratios in the 3.4-3.6 range suggest the presence of potential contamination, likely from humic acids (DeNiro 1985:808). Ambrose (1993) suggests an additional criterion for assessing the suitability of bone collagen, which involves considering the weight percentage of extractable collagen (collagen %) from the entire bone, along with the percentages of carbon (C%) and nitrogen (%N) in the extract (Ambrose 1993:75). For reliable isotope analysis, it is advised that both the weight percentages of carbon (C) and nitrogen (N) should surpass 3% and 1%, respectively. Bone collagen that yields less than 1% is considered unreliable, mainly because bone usually initially contains over 20% collagen (Ambrose 1993:72,75). Given the potential variability in collagen preservation within archaeological sites, assessing the bone collagen concentrations, carbon and nitrogen concentrations within the collagen, and the atomic C/N ratio for each sample is crucial. This evaluation is essential for understanding the preservation status of the samples and ensuring the reliability of the subsequent isotopic analyses.

Using bone as a fundamental material for stable isotope analysis offers a remarkable avenue for extracting significant information from the past. Bones hold chemical information that indicates the overall consumption patterns of different food groups. By utilising the chemicals in animal and human bones, we can determine the relative use of foods from various sources, such as different environments (like marine versus terrestrial), climates (such as arid versus humid regions), specific chemical environments (like local areas with different geological characteristics), trophic levels (including primary producers, herbivores, and carnivores), and photosynthetic categories (like C_3, C_4, and CAM plants) (Pate 1994:162). Understanding the characteristics and behaviours of these components is essential for making accurate interpretations of isotopic compositions, which, in turn, allow us to gain insights into the intricate interactions between humans, animals, and their environments in the field of palaeodietary research.

3.2 Principles of Stable Isotope Analysis

3.2.1 What are stable isotopes?

Atoms are made of subatomic particles, most importantly, electrons, protons and neutrons. An atom is composed of a nucleus with positively charged protons (known as the atomic number), neutral neutrons and electrons orbiting around the nucleus because they are negatively charged (Brown and Brown 2011:80). Isotopes of an element are atoms that have the same number of protons and electrons but differing numbers of neutrons. The different numbers of neutrons lead to the differences in mass numbers (the total number of protons and neutrons) (Brown and Brown 2011:80). For instance, the isotope of carbon-12 (^{12}C) often denoted with $^{12}_{6}C$ 12 is the mass number, and 6 is the number of neutrons, while carbon-13 (^{13}C) and carbon-14 (^{14}C) comprise six protons but seven and eight neutrons, respectively. Thus, they are written as $^{13}_{6}C$ and $^{14}_{6}C$.

The properties of an isotope can change by adding just one neutron, which divides isotopes into two fundamental kinds: stable and unstable (radioactive). In the case of carbon, ^{12}C makes up the majority of natural carbon on earth at 98.9%, and ^{13}C is much less abundant at 1.1%, while ^{14}C is unstable and undergoes radioactive decay to stable nitrogen (^{14}N) and makes up as much as $1x10^{-12}$ (one part per trillion) (Smith 1972:226). The same idea applies to nitrogen, it has two naturally occurring isotopes that have seven protons but with seven and eight neutrons. Thus, they are classified as nitrogen-14 (^{14}N) and nitrogen-15 (^{15}N), whose relative abundances in nature are approximately 99.64% and 0.35%, respectively (Ostrom and Ostrom 1999:431). A significant component of the dietary studies of the human past is the analysis of stable carbon isotopes ^{12}C and ^{13}C and those of nitrogen, ^{14}N and ^{15}N.

3.2.2 Stable isotope fractionation

The electronic of an element often determines its chemical behaviours, and due to the same number of electrons in all isotopes of an element, they tend to have similarities in chemical behaviours (Hoefs 2018:3). For this reason, ^{12}C and ^{13}C work the same way in biological process and chemical reactions. However, the differences in mass number can affect the rate of chemical reactions and differences in energy requirements. Therefore, they differ in physical properties in which ^{13}C is 8,3% heavier than ^{12}C (Brown and Brown 2011:81). In other words, the heavier isotopes with a higher mass number (^{13}C and ^{15}N) react and move slower (consume less energy) during chemical reactions than the lighter ones (^{12}C and ^{14}N) (Katzenberg and Waters-Rist 2019:472). These differences in chemical reactions, such as photosynthesis and metabolism in an organism, cause the change in isotopic ratios, known as ***isotope fractionation*** or discrimination against the heavier isotopes (Ambrose 1993:94).

In terms of isotope exchange reactions between different phases in a natural system, we can categorise them as two types of isotopic fractionation processes, namely, "equilibrium fractionation" and "kinetic fractionation" (Fry 2006). ***Equilibrium fractionation*** involves the exchange reactions between chemical substances in different phases based on the differences in bond strength of the different isotopes of an element (Hoefs 2018:5). Notably, the equilibrium fractionation process occurs in a two-way reaction when an element with a 'heavier' isotope concentrates where it is bound most strongly (Fry 2006:204). On the other hand, the ***kinetic fractionation*** process occurs when the molecule containing lighter isotopes reacts more rapidly than that containing the heavier ones in irreversible physical or chemical processes (one-way reaction) (Brown and Brown 2011:81). Isotopic variations in most biological systems are caused by kinetic effects such as photosynthesis and bacterial processes (Hoefs 2018:35). In addition, to get reliable isotopic compositions between certain materials and standardise the isotope ratio, it is necessary to compare it to a known standard so that we can use the same kind of notation and isotope values.

3.2.3 Notation and delta value

During the measurement of the isotopic ratios, the differences in their abundance can be varied and usually very small. Therefore, measurements of stable isotope abundance ratios are made by comparing the ratio value from a sample and a specific standard in a mass spectrometer. The ratio value of the isotope composition in a sample relative to its reference standard is expressed by the delta (δ) notation (Katzenberg and Waters-Rist 2019:479). The following formulas are used to calculate the isotope composition of ^{13}C and ^{15}N:

$$\delta^{13}\mathrm{C} = \left[\frac{^{13}\mathrm{C} / {}^{12}\mathrm{C}_{\mathrm{sample}}}{^{13}\mathrm{C} / {}^{12}\mathrm{C}_{\mathrm{PDB\ standard}}} - 1 \right] \times 1000$$

$$\delta^{15}\mathrm{N} = \left[\frac{^{15}\mathrm{N} / {}^{14}\mathrm{N}_{\mathrm{sample}}}{^{15}\mathrm{N} / {}^{14}\mathrm{N}_{\mathrm{AIR\ standard}}} - 1 \right] \times 1000$$

For C isotopes, the Vienna Pee Dee belemnite (VPDB) from a Cretaceous marine fossil sample is used as an international reference standard, and δ^{13}C represents the isotopic composition ratio of ^{13}C/^{12}C reported relative to the standard VPDB. For N isotopes, atmospheric air N_2, Ambient Inhalable Reservoir (AIR) is the standard reference material and δ^{15}N expresses the isotopic combination ratio of ^{15}N/^{14}N reported relative to the standard AIR (Malainey 2011:40). To make the variation more apparent, the δ values have to multiply by 1000, thereby expressing in unit parts per thousand (denoted as ‰ or per mille) (Malainey 2011:40).

When comparing the isotopic composition of two materials, terms such as heavy vs. light, less positive vs. more positive, and enriched vs. depleted are employed. A negative delta (δ) value is given to substances whose ratios are less than the standard, referring to these substances as ***less positive***; on the other hand, if a substance’s isotope ratio is greater than the standard, it is given a positive δ value and is said to be called ***more positive*** than the standard (Pate 1994:172). Other terms that make comparisons of delta values between two materials are ***depleted*** and ***enriched***. An atom always contains "heavy" and "light" isotopes, and basically, a “heavy” isotope has more neutrons and has higher mass (^{13}C and ^{15}N), and when it has fewer neutrons, it is a “light” isotope because it has less mass (^{12}C and ^{14}N) (Baseline-earth, n.d.). Thus, delta value is ***negative*** when the sample ***depleted in the heavy isotope*** (contains less heavy isotope) and enriched in the light isotope (contains more light isotope) than the international standard gas (Brown and Brown 2011:81). Otherwise, delta value is ***positive*** indicates an ***enrichment in heavy isotope*** and a depletion in light isotope, relative to the international standard (Brown and Brown 2011:81). For example, PDB carbonate is more enriched in ^{13}C than most terrestrials or freshwater contexts which result in a delta value of 0. While most natural and biological materials are more enriched is ^{12}C than the PDB carbonate, the materials are depleted in ^{13}C relative to the PDB standard and suggest negative $\delta^{13}C$ values (Price et al. 1985:430).

3.3 Stable carbon isotopes

In living organisms, the long turnover time of carbon in bone collagen makes the isotopic measurement an effective reflection of an individual's lifetime dietary intake (Chisholm et al. 1983:355). Therefore, prehistoric people's diet can be detected using the behaviour of carbon isotopes during photosynthesis. As a result, dietary analysis is widely used to assess the consumption of different food types, whether marine or terrestrial. In this method, researchers measure carbon stable isotope values $\delta^{13}C$ ($^{13}C/^{12}C$ ratios) in bone collagen to indicate food composition because most plants undergo photosynthesis through various pathways.

3.3.1 Photosynthetic pathways

Photosynthesis is a process by which plants metabolise atmospheric carbon dioxide (CO_2) and water into carbohydrates and absorb them into their tissues (Malainey 2011:36; Tykot 2006:132). To facilitate photosynthesis, plants prefer to ingest CO_2 that is composed of lighter isotopes $^{12}CO_2$ (enrichment in the ^{12}C isotope) and discriminate against heavier isotopes $^{13}CO_2$ (Ambrose 1993:86). As a result of this discrimination, terrestrial plants can be categorized into various photosynthetic pathways based on the method they use for carbon fixation (O’Leary 1988). Three distinct photosynthesis groups include C_3, C_4 and crassulacean acid metabolism (CAM) pathways. Different photosynthetic pathways produce different fractionation rates in plants, which are primarily responsible for variations in $\delta^{13}C$ values (Hoefs 2018:334). The vast majority of carbon isotope variation comes from direct or indirect (via animals) consumption of C_3 or C_4 plants because the CAM pathway often found in succulent plants in deserts, such as cacti, are unlikely to be a usual source of human dietary

(Van der Merwe 1982:597). Therefore, CAM pathway has little relevance to this study and is not discussed further here.

C_3 photosynthetic pathway is also known as the Calvin-Benson cycle since it was first discovered by Melvin Calvin and Andrew Benson in 1948 under an experiment with unicellular green algae (Calvin and Benson 1948). Plants that undergo C_3 photosynthesis and produce sugars with a three-carbon compound (3-phosphoglyceric acid/3-PGA) are termed C_3 plants and plants that follow C_3 pathway mostly from temperate regions, including some of the most important sources of calories: rice, wheat, barley, beans, tubers (cassava and potatoes), nuts and also most of the temperate shrubs and grasses (Calvin and Benson 1948; Pate 1994:172). The isotopic fractionation process in C_3 plants favours ^{12}C and discriminates against ^{13}C. Thus, C_3 plants have a less positive $\delta^{13}C$ value of around -26.5‰ with a range of -20‰ to -35‰ compared to the $\delta^{13}C$ value of atmospheric CO_2 is -7‰ (O'Leary 1988:330; Van der Merwe 1982:598).

Another photosynthetic pathway among terrestrial plants is the C_4 photosynthetic pathway, or the Hatch-Slack cycle, as described by Charles R. Slack and Marshall D. Hatch in 1966 under a study with sugar-cane leaves (Hatch and Slack 1966). Different from the C_3 photosynthetic pathway, C_4 plants undergo the C_4 photosynthetic pathway to metabolise CO_2 into sugar; with its first product yields a four-carbon compound (oxaloacetic acid/OAA) and besides sugar-cane, this pathway has been found in some plants that operate in tropical areas with hot and arid environments: maize, sorghum, and millet (Malainey 2011:40; Pate 1994:172). A different ^{13}C isotopic composition characterises the products of this pathway compared to C_3 plants, in which C_4 plants discriminate ^{13}C less than C_3 plants (O'Leary 1988). Hence, the $\delta^{13}C$ values of plants which use C_4 photosynthetic pathways are more positive at about -12.5‰, with a range of -9‰ to -16‰ (O'Leary 1988:330; Van der Merwe 1982:598).

Currently, my discussion has centred around terrestrial plants; however, it is crucial to acknowledge the significance of stable carbon isotopes in aquatic ecosystems as well. As opposed to terrestrial plants that only use atmospheric CO_2 ($\delta^{13}C$ = -7‰) in photosynthesis, marine plants can synthesise CO_2 by utilising inorganic carbon dissolved in seawater (Beer et al. 2014:95). Therefore, marine plants have an isotopic composition of a mixture between dissolved CO_2 and dissolved bicarbonate CO_2 ($\delta^{13}C$ = 0‰) (Craig 1953:74). Since marine organisms, such as algae and plankton, are more enriched in ^{13}C, the $\delta^{13}C$ values of marine organisms are less negative than those of terrestrial organisms. However, depending on the environmental condition (nutrient, light and temperature), $\delta^{13}C$ values for marine plants range from -10‰ to -31‰, which can lead to overlap with the $\delta^{13}C$ values of those terrestrial plants when we come to the studies of seafood in human diets (Maslin and Swann 2006:246).

3.3.2 Carbon isotope variation in bone collagen

In trophic ecology, stable carbon isotope analysis relies on the idea that the $\delta^{13}C$ values of consumers closely mirror those in their diet, allowing us to track changes in isotope compositions as consumers assimilate food (DeNiro and Epstein 1978). The usefulness of carbon isotope signatures in trophic studies hinges on the connection between a consumer's diet and the isotopic composition of its tissues. This is important because various foods can have notably different carbon isotope values. Based on empirical data from large mammals and experimental data from rats and mice, it has been observed that bone collagen $\delta^{13}C$ tends to be enriched by about ~5‰ compared to $\delta^{13}C$ of the diet (Ambrose and Norr 1993; Schoeninger et al. 1983; Van der Merwe 1989). In simpler terms, this enrichment tends to occur in the dietary intake of most animals and humans due to the natural fractionation process that results in the bone collagen being about 5‰ more enriched than their diet. If a primary consumer, such as a herbivore, mainly eats C_3 plants, its dietary $\delta^{13}C$ value is likely to be around -26.5‰, while the $\delta^{13}C$ value in its bone collagen is expected to be approximately -21.5‰ (Figure 6) (Brown and Brown 2011:84).

The crucial point to note is that this isotopic enrichment persists as one moves up the food chain. When a carnivore consumes a herbivore (assuming the herbivore had a diet primarily composed of C_3 plants with a $\delta^{13}C$ value of approximately -26.5‰), there is an additional 1‰ enrichment in the bone collagen of the carnivore (Figure 7) (Brown and Brown 2011:85). This results in the $\delta^{13}C$ value of the carnivore's bone collagen being around -20.5‰. As we ascend the food chain, humans, being omnivores, consume both plants and animals, although not always in equal measure. Consequently, the $\delta^{13}C$ value of bone collagen falls between the two extremes (Malainey 2011:179–180).

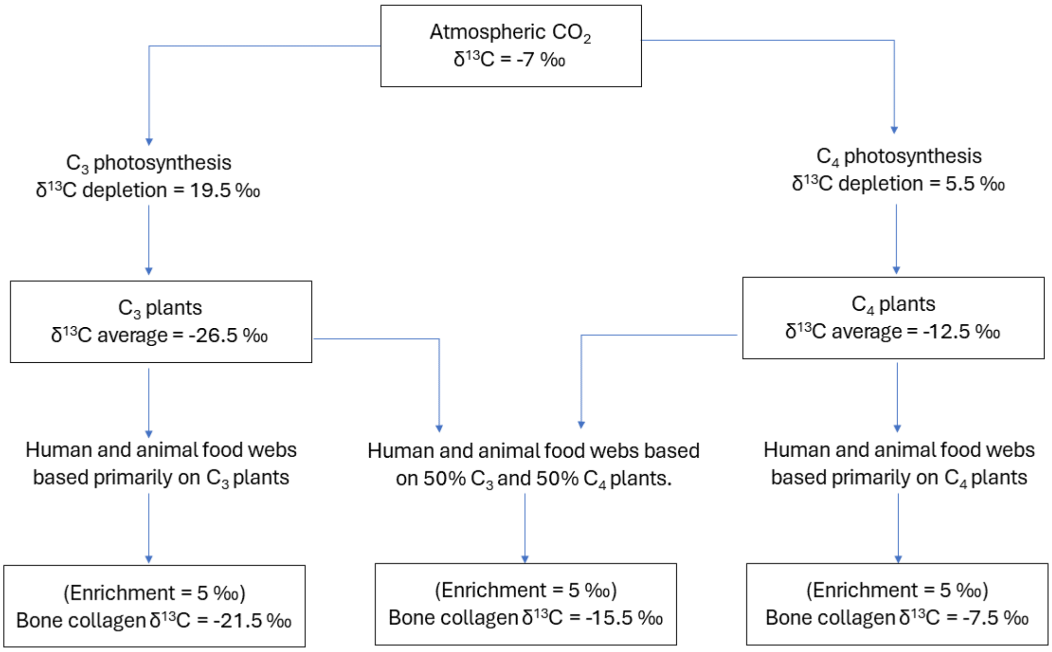


***Figure 6**. Flow chart of carbon isotope fractionation in terrestrial foodwebs. Adapted from Van der Merwe (1982:602).*

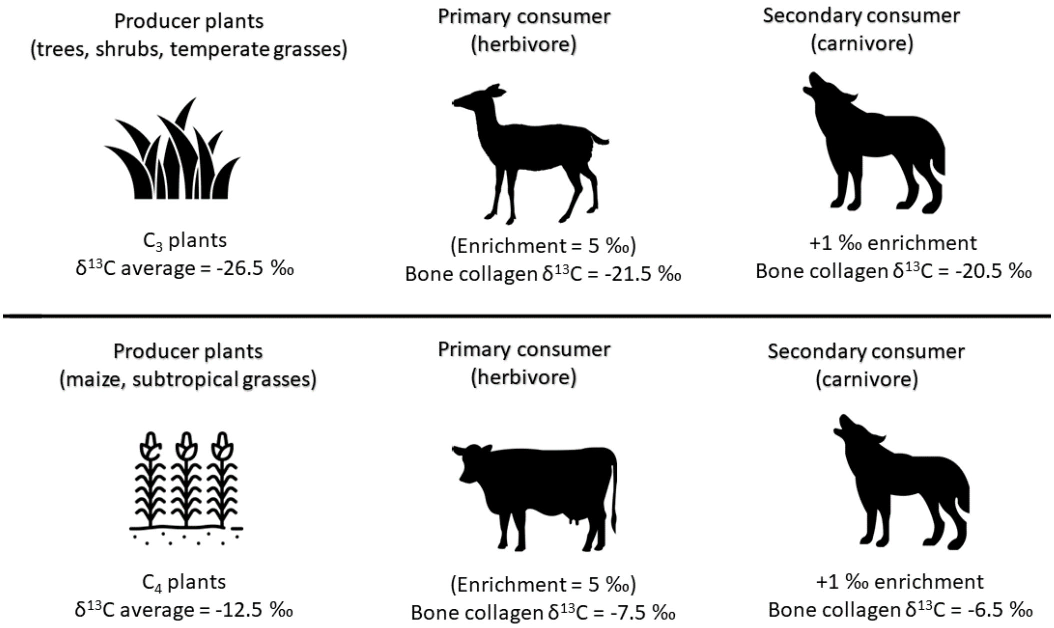


***Figure 7** Enrichment in bone collagen values in a food chain. Adapted from Malainey (2011:180).*

3.3.3 Factors influencing $\delta^{13}C$ values

The $\delta^{13}C$ values within a food chain serve as indicators of the photosynthetic pathways employed by primary producers, and as such, the rate of photosynthesis can be impacted by environmental factors that contribute to the wide variation of $\delta^{13}C$ values in plants. The carbon isotope ratios of C_3 plants are influenced by a range of factors, including water availability, light intensity, temperature, the partial pressure of CO_2, and nutrient availability (Table 1) (Ambrose 1993:89; Farquhar et al. 1989; Tieszen 1991). Unlike C_3 plants, C_4 plants are less affected by environmental factors like humidity, light intensity, and temperature in terms of isotope effects (Ambrose 1993:91). However, differences in the anatomies, climate preferences, and physiologies of various C_4 plant species may introduce some variation in their $\delta^{13}C$ values (Ambrose 1993:91).

Archaeologists find it particularly intriguing when environmental factors lead to variations in isotope ratios of plants and animals, and one such fascinating occurrence is the presence of extremely negative $\delta^{13}C$ values in the food webs of dense forests. This phenomenon happens because the “canopy effect” alters the isotopic composition of the CO_2 processed during photosynthesis (Van der Merwe 1982:599). The canopy effect occurs in areas with dense, tall vegetation that limits air movement in more humid and low-light conditions (Farquhar et al. 1989; Tieszen 1991; Van der Merwe and Medina 1991). In such environments, soil respiration produces CO_2 with a lower ^{13}C content, which is subsequently recycled during photosynthesis, resulting in the depletion of ^{13}C in forest leaves (Van der Merwe and Medina 1991:258). This process creates a gradient of leaf $\delta^{13}C$ values, with the most depleted values closer to the ground and gradually increasing towards the canopy (Van der Merwe and Medina 1991:251). As an example, a study conducted in the Bavarian forest by Van der Merwe and Medina (1991) demonstrated that the undergrowth at the forest floor exhibited the most negative $\delta^{13}C$ value of about -31.5‰, while the leaves from the upper canopy showed the least negative $\delta^{13}C$ value, approximately -28‰ (Van der Merwe and Medina 1991:251). The $\delta^{13}C$ values of C_3 plants will be at their lowest in closed and humid environments as the ^{13}C depletion of forest plants moves up the food chain and animals feeding on the forest floor are expected to exhibit the most negative $\delta^{13}C$ values among terrestrial ecosystems (Ambrose 1993:90). This leads to an enrichment of about 2‰ more negative $\delta^{13}C$ values in animal bone collagen compared to those that are fed on C_3 plants in open habitats (Van der Merwe and Medina 1991:257).

Table 1. *Factors that affect $\delta^{13}C$ values in C_3 plants based on Ambrose (1993) and Tieszen (1991)*

Categories	Factors contributing to more ***positive $\delta^{13}C$ values*** in plants	Factors contributing to more ***negative $\delta^{13}C$ values*** in plants
Physiology	Increase in water-stress High water use efficiency	Well-watered condition/unstressed plants
Environment	Arid environment (savanna) High nutrient content Increase in CO_2 concentration due to burning of fossil fuel	Humid and closed environment (forest) Low nutrient content
Climate	Low altitudes High temperature High light intensity Low rainfall	High altitudes Low temperature Low light intensity

When estimating diet composition based on carbon isotope ratios in bone collagen, it is crucial to consider and adjust for the influence of the canopy effect, along with other climate and habitat-related factors affecting plant $\delta^{13}C$ values. This adjustment is essential for accurate assessments and comparisons of diet composition between populations residing in different environments. By accounting for these influences, we can enhance the precision and reliability of dietary reconstructions in archaeological and ecological studies.

3.4 Stable nitrogen isotopes

Stable nitrogen isotope analysis is a powerful tool often used in environmental and ecological studies. This analysis investigates the dietary habits and trophic interactions between various organisms in an archaeological context. Initially, nitrogen isotopes were employed to discern the presence of legumes in terrestrial diets (DeNiro and Epstein 1981). This is because legumes exhibit lower $^{15}N/^{14}N$ ratios than other plants due to their ability to fix molecular nitrogen instead of depending solely on nitrates and nitrites in the soil (DeNiro and Epstein 1981). Following this discovery, subsequent studies proposed that $^{15}N/^{14}N$ ratios could also serve to distinguish between marine and terrestrial sources of protein as marine food webs are more intricate and have higher levels of ^{15}N, potentially functioning as a trophic indicator (Schoeninger and DeNiro 1984). Under this circumstance, nitrogen isotope analysis provides complementary information that enables researchers to obtain more precise results from their studies because marine organisms contain a higher concentration of ^{15}N due to denitrification occurring in the oceans (Price et al. 1985:431).

3.4.1 Variation in the trophic level

Nitrogen primarily enters foodwebs through a trophic process wherein soil nourishes plants, animals consume these plants, and humans consume these animals, contributing to the dispersion of $\delta^{15}N$ values as it experiences enrichment or depletion as they progress through the food chain. Therefore, in order to determine the trophic level of omnivorous consumers and assess the proportion of plant-based and animal-based foods in their diet, researchers usually compare the $\delta^{15}N$ values of the specific omnivorous species being studied, often humans, with the values of herbivores and carnivores coexisting within the same ecosystem (Makarewicz and Sealy 2015:148). Nitrogen isotopes play a crucial role in distinguishing between food sources derived from legume and non-legume plants and protein intake between marine vs terrestrial sources by determining the trophic level within the food chain.

The first application of nitrogen isotopic method involves analysing the nitrogen that plants incorporate through various sources, including direct nitrogen fixation, ammonium (NH_4^+), and nitrate (NO_3^-) from soil water or soil nitrogen (Lee-Thorp 2008). For example, legumes, which include plants like beans, peas, alfalfa and blue-green algae in aquatic environments, are categorized as nitrogen-fixing plants. They earn this designation because they possess a unique ability to directly convert atmospheric nitrogen (N_2) into soluble nitrates (NH_3) by symbiotic bacteria like *Rhizobium*, as well as free-living bacteria such as *Azotobacter* and *Clostridium*, which reside in their roots (Ambrose 1991:296; Malainey 2011:41). On the other hand, non-leguminous plants obtain nitrogen by breaking organic compounds in soil to form compounds like ammonia (NH_3), ammonium (NH_4+) or nitrate (NO_3^-) without the help from symbiotic bacteria, known as non-nitrogen-fixing plants (Ambrose 1991:296, 1993:94).

Due to characteristic distinctions between the two types of plants, nitrogen isotope ratios exhibit variability. Specifically, the $\delta^{15}N$ values observed in legume plants are typically closer to atmospheric nitrogen ($\delta^{15}N= 0$), averaging around 1‰ and ranging from -2‰ to 2‰. Whereas non-leguminous plants are more enriched in ^{15}N, resulting in a higher $\delta^{15}N$ value of approximately 3‰, with a range spanning from 0 to 6‰ (Pate 1994:180). Correspondingly, primary consumers that feed on legume plants tend to exhibit lower $\delta^{15}N$ values than those that feed on non-leguminous plants. However, environmental and climatic factors have the potential to influence the $\delta^{15}N$ values of plants (Richards 2020:135). For instance, in arid environments, plants tend to exhibit higher $\delta^{15}N$ values (range from -5‰ to 20‰) compared to those in temperate environments, and this distinction arises because the input of N_2 into the soil is reduced in hot weather, leading to altered isotopic values in the plant material (Ambrose 1991:296).

A second precious application of nitrogen isotopic method lies in discerning the proportions of terrestrial and aquatic protein sources in a consumer's diet. This distinction arises from the trophic level dynamics, where consumers higher up in the food web obtain higher nitrogen isotope values than the foods they eat, with an average enrichment of around 3-4‰ for each trophic level (Figure 8) (Minagawa and Wada 1984:1139; Schoeninger and DeNiro 1984:632). In the case of marine food webs, atmospheric N_2 dissolves in water and converts into nitrates and ammonia that are enriched with ^{15}N for aquatic plants, in contrast to the nitrates in soil used by terrestrial plants (Pate 1994:179). Certainly, marine plants typically exhibit $\delta^{15}N$ values within the range of 5–6‰, whereas terrestrial plants tend to have values ranging from 1–3‰ (Brown and Brown 2011:84). Consequently, the consumption of proteins derived from marine plants and animals yields higher $\delta^{15}N$ values in nitrogen isotopic analyses compared to individuals who primarily consume terrestrial plants and animals (Schoeninger and DeNiro 1984:633).

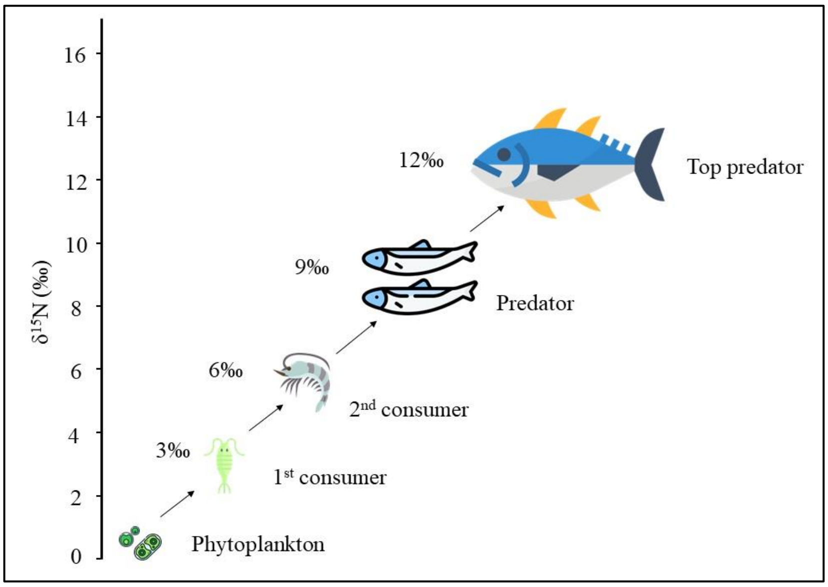


***Figure 8**. Illustration of increasing $\delta^{15}N$ values for each trophic level in the food chain. Adapted from Sackett (2017).*

In research by Schoeninger and DeNiro (1984), animals primarily consuming terrestrial food sources exhibit a $\delta^{15}N$ value less than 9‰ in their bone collagen, while those exclusively consuming marine food sources display higher $\delta^{15}N$ values, typically exceeding 15‰ in their bone collagen (Schoeninger and DeNiro 1984:636). Following trophic levels, a human whose diet is primarily based on marine sources will exhibit higher δ^{15}N values in their bone collagen, ranging from 17‰ to 20‰, with an average enrichment of approximately 3-4‰ (Schoeninger et al. 1983:1382). While those who consume terrestrial plants and animals will have lower δ^{15}N values, ranging from 6‰ to 12‰ (Schoeninger et al. 1983:1382). However, the stepwise trophic enrichment becomes apparent only when the initial δ^{15}N values of the baseline are comparable. Due to variations in δ^{15}N values of nitrogen sources in distinct habitats, animals feeding in distinct ecosystems may not exhibit the expected trophic separation (Pate 1994:180). Although bone collagen δ^{15}N values are helpful for estimating a human diet's marine and terrestrial components, it may be challenging to differentiate between freshwater and terrestrial food sources through nitrogen isotope analysis (Schoeninger et al. 1983:1382). Freshwater fish have δ^{15}N values ranging from 6.6‰ to 9.5‰ which lie within the δ^{15}N range measured for both marine and terrestrial organisms (Schoeninger et al. 1983:1382).

Another particular application of nitrogen isotope ratios is their ability to provide insights into infants' nursing and weaning practices. Ever since the groundbreaking revelation that the stable nitrogen isotope ratios can serve as an indicator of weaning age (Fogel et al. 1989), researchers have extensively applied this method to skeletal remains to reconstruct breastfeeding and weaning practices within archaeological populations as there were many infant and young children skeletons found in historic cemeteries (Katzenberg et al. 1993; Mays et al. 2002; Schurr 1997; Schurr and Powell 2005). In the study by Fogel and colleagues (1989), it was found that breastfeeding infants are positioned one trophic level above their mothers in the food chain, as they essentially consumed their mother's tissue through breast milk. Consequently, the δ^{15}N values obtained from the fingernails and bone collagen of nursing infants are enriched by 2.4‰ compared to their mothers (Fogel et al. 1989:114). However, during the weaning process, the introduction of supplementary foods leads to a decline in the δ^{15}N values of infants (Fogel et al. 1989:116). Extensive research has enabled archaeologists to use δ^{15}N values in bodily tissues of infants’ remains for gaining insights into the timing and duration of nursing and weaning within specific populations.

3.4.2 Factors influencing δ^{15}N values

From an environmental perspective, δ^{15}N values are subject to many influences. Substantial climatic and environmental factors, such as the presence of organic material in the soil, temperature, altitude, salinity, sediment composition, and chemical fractions within soil profiles, significantly impact the stable nitrogen composition of plants (Ambrose 1991). In an ecosystem, saline soil with higher nitrate and ammonium content in arid environments leads to elevated δ^{15}N values compared to non-saline soil sites in moist forest areas (Table 2) (Ambrose 1991:296–297). Additionally, human activities, such as the use of manures, can introduce modifications to ecosystems, potentially disrupting the delicate balance of nitrogen dynamics in ecosystems (Bogaard et al. 2007). Inorganic fertilizers typically have consistently low δ^{15}N values, falling from -4‰ to 4‰ (Kendall et al. 2007:390). On the contrary, organic fertilizers display relatively higher and more variable δ^{15}N ratios, ranging from 2‰ to 30‰, depending on their composition (Kendall et al. 2007:391). Indeed, the above factors substantially influence the expected δ^{15}N values within the entire food web because the difference in δ^{15}N value at the base level of the food chain is then passed on to herbivores and other animals that feed within these habitats.

Table 2. *Factors that affect δ^{15}N values in plants and soils. Adapted from Malainey (2011:184).*

Categories	Factors contributing to ***higher δ^{15}N values*** in plants and soils	Factors contributing to ***lower δ^{15}N values*** in plants and soils
Climate	Low rainfall Lower altitudes Higher temperatures	High rainfall amounts Higher altitudes (closed habitats) Low temperatures
Environment	Desert biomes (dry soils) Saline soil Clay Organic fertilizers (guano deposits)	Forest biomes (moist soils) Non-saline soil Sand and silt No fertilizers

Similarly, along with environmental factors, animals’ physiology, such as urea excretion, water availability and dietary habits, all play integral roles in generating varied δ^{15}N values in animal tissue (Table 3) (Malainey 2011:184). The observed ^{15}N enrichment in arid-land herbivores is primarily due to their physiological adaptations to cope with water stress and low-protein diets (Pate 1994:181). In a dry climate with restricted water availability, changes in the rate at which urea is excreted due to water and heat stress influence the nitrogen isotope ratios (Ambrose 1991:305). This phenomenon arises because urea contains less than ^{15}N compared to the animals' diet. In situations of water stress, there is an increased excretion of urea relative to urine volume, and animals tend to consume less food when experiencing heat and water stress, resulting in a reduced availability of ^{15}N for tissue synthesis in the body (Ambrose 1991:307). Consequently, δ^{15}N values in animal tissue will increase during extended periods of water stress, unlike unstressed animals that excrete ^{15}N-enriched urea and consume more food (Ambrose 1991:307). The variety and intricacy of water and heat stress adaptations can clarify the differences in nitrogen isotope levels among different trophic levels.

Due to the predominant influence of hot and high-temperature environments, organisms typically exhibit elevated $\delta^{15}N$ values compared to those inhabiting cooler regions. Consequently, the $\delta^{15}N$ values of animals in arid regions might resemble those of aquatic environments (Pate 1994:182). This situation can make it challenging to differentiate between marine and terrestrial dietary components when analysing $\delta^{15}N$ values in bone collagen. In short, it is imperative to consider the influence of climatic factors when interpreting paleodiet from $\delta^{15}N$ values in bone collagen, as these factors can significantly impact the isotopic signatures.

Table 3. *Factors that affect $\delta^{15}N$ values in animal tissue. Adapted from Malainey (2011:184).*

Categories	Factors contributing to ***higher $\delta^{15}N$ values*** in animal tissue	Factors contributing to ***lower $\delta^{15}N$ values*** in animal tissue
Physiology	Increased excretion of urea Water stress Higher trophic level Carnivore Grazing Water independence/conservation Marine diet	Decreased excretion of urea Water abundance Lower trophic level Herbivore Browsing and mixed feeding Obligate drinking of water Terrestrial diet (especially legumes)
Environment	Long distance to water	Short distance to water
Climate	High temperatures	Low temperatures

4. Spatial organisation of churchyard

The burial of the dead is a powerful arena for establishing relationships of status, power, and inequality in contemporary society (Tarlow and Stutz 2013:8). During the Medieval period, the treatment of death emerged as a reflection of social hierarchy. In the 1970s, processual archaeologists such as Lewis Binford (1971), Arthur Saxe (1971), and James Brown (1971) began to examine social structure through the use of burial customs to form a relationship between social status and power. Reconstruction of social position from grave goods, the form of the tombs, and the location of burials are often seen as a common approach in archaeology to correlate with social status (Dark 1995:90). Artefacts discovered in graves from the early medieval period (AD 500 to AD 700) encompass a diverse range of objects and these objects are distributed across different regions or are organised based on gender-specific assortments (Härke 2014:43). Nonetheless, the establishment of Christianity and urbanisation in Scandinavia around the year AD 1000, led to significant changes in political, economic, cultural, religious adherence and social organisation including the matters related to the death and burials.

As one of Christian ideologies, the act of burial using only a shroud or wooden coffin, with no accompanying grave goods, can represent the belief that all Christians were considered equal at death, regardless of their gender or social class, as there was no difference between the poor and the rich in death (Bagge 1998:215; O'Sullivan 2013:264). Based on archaeological research, burial practices in the medieval period involved fewer or even no grave goods, and the majority of graves followed the standard west-east alignment with the head of the deceased at the west end of the grave (Gilchrist 2013:204; Pearson 1999:6). In the absence of grave goods, burial traits such as the presence or absence of coffins and burial location can serve as indicators of social markers (Zoëga 2018:110). From this point of view, Christian burial customs have evolved into a system marked by social differentiation based on factors such as gender, age, and occupation, and such societies are referred to by the anthropological term 'segmentary lineages' (Dark 1995:89). In European churchyards, it is expected to observe hierarchical patterns reflected throughout variations in burial placements (Pearson 1999:13–14).

The churchyard usually surrounds the parish church and stands as a visible symbol of religious practices. Burials inside the churchyard not only manifest the idea of Christian burials but also serve as a reflection of evidence about kinship, gender and other indicators of social status and social structures (Pearson 1999:12). Archaeological excavations and scholarly studies of churchyards have provided further evidence supporting the notion that the location of burials indicated a certain degree of sex segregation or status segregation in medieval burial customs (Gejvall 1960; Jonsson 2009; Kieffer-Olsen 1993; Nilsson 1994; Zoëga 2018). This segregation was reflected in the association of specific genders and social classes with burial orientation, such as being buried on the southern or northern sides of the churchyard, proximity to the church or distant, and placement inside or outside of the church. In Norway, medieval ecclesiastical laws, particularly the Norwegian Borgating and Eidsivating provincial laws, provide details regarding specified burial plots within churchyards according to social status.

4.1 Medieval churchyard laws

Before the enactment of formal legislation, conventional practices were frequently observed and transmitted orally within local communities. In the medieval period, Norway's governance was structured with two distinct legislative chambers, one representing royal power and the other ecclesiastical power. As a result of state formation, the country was further divided into larger regions and landscapes and different legislations also created (Selberg 2013:12). In the 11th and 12th centuries, Norway was governed by four primary landscape laws *(landskapslovene)*: Gulating provincial law in western Norway, Frostating provincial law in the central and northern regions, Eidsivating provincial law in the interior eastern part of the country, and Borgarting provincial law along the coastal areas in the east (Imsen 2013:19; Sunde 2012:35). Given that my thesis focuses on the correlation between medieval legislation and burial customs in Medieval Oslo, the Borgarting and Eidsivating provincial laws holds particular relevance as it contains provisions related to the segregation of burials within the ecclesiastical law sections (Hamre 2011:15).

Ecclesiastical laws of Borgarting

According to the ecclesiastical laws of Borgarting, specific guidelines were provided for allocating of burial locations within the churchyard based on social status (Figure 3). The law stipulated that churchyards were divided into quarters for burials, each designated for specific social groups (Collinson et al. 2021:31–32; Gejvall 1960:121). Notably, barons *(lendmenn)* - the men who held land from the king and were in his service should be buried east of the church and to the land in the south beneath the church's eavesdrip (Collinson et al. 2021:31). In cases where they did not own a part of the churchyard, their burials should be located alongside the farmers. Subsequently, a hierarchical progression was established, with the free-born farmers *(hauldmenn)* and their children, followed by the freed thralls (*løysinger)* and their children, then the newly-freed thralls *(frigitte træller)* and their children (Collinson et al. 2021:32). The outermost zone or nearest to the church enclosure was designated for the burial of thralls *(træller)* – and men who have been washed ashore with their haircut in the manner of a Norseman (Collinson et al. 2021:32). It is worth noting that in a subsequent version of the Borgarting ecclesiastical laws, the category of newly-freed thralls *(frigitte træller)* was excluded (Hamre 2011:20). As a result, only the freed thralls *(løysinger)* were explicitly recognized as a distinct social group to apply legislation (Hamre 2011:20).

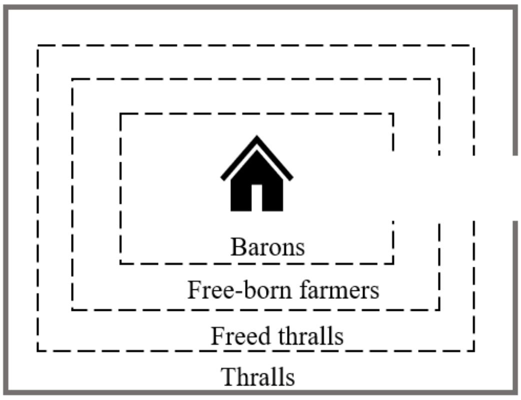


Figure 9*. Burial zones in churchyard based on Borgarting ecclesiastical laws. Adapted from E. Bull (1985:51).*

In addition to these provisions, there were penalties if people violated the laws. These included buried in the wrong area based on social class, a corpse was unearthed that still retained hair and articulation during the burial of another, and situations where bones were dug up; it was mandated that the bones be positioned beside the coffin (Collinson et al. 2021:32). Failing to comply with this and intended to leave the bones exposed to the sun, resulting in a fine (Collinson et al. 2021:32; Hamre 2011:20).

Ecclesiastical laws of Eidsivating

The Eidsivating ecclesiastical law has a very similar description with the Borgarting ecclesiastical laws regarding specific instructions for the burial zones in the churchyard but with one main different rule related to sex segregation that men shall be buried to the south of the church and women to the north (Collinson et al. 2021:112; Gejvall 1960:122). N. Nicolaysen (1871) noted such segregation of burials in Norwegian churches: *kvinnelige personer.. altid begraves i eller ved nordre vegg, medens mænd fordetmeste lægges i eller ved søndre vegg* – "women buried to the north and men to the south of the choir" being used for burials (Nicolaysen 1871:17). The ecclesiastical laws stipulate that the highest social rank, including the barons *(lendmenn)*, their children, and wives, should be buried nearest the church building (Collinson et al. 2021:111). Moving farther from the church, the free-born farmers *(hauldmenn)* and their families occupy the next tier of burial location (Collinson et al. 2021:111). Following this, freed thralls (*løysinger*), their wives and their children were to be buried (Collinson et al. 2021:112). Lastly, in the most peripheral section, the lowest social group with male and female thralls *(trœller*) will be buried closest to the churchyard fence (Collinson et al. 2021:112).

Furthermore, excluded from the privilege of burial within the churchyard were individuals engaged in acts of violence such as robbery, murder, arson, theft, assassination, open plunder, and those who violated the law of lords, peace disturbers, or those formally banned from the Holy Church (Collinson et al. 2021:112). This also applies to those who take their own lives, promote false beliefs, practice usury openly, and adults or children who pass away without having been baptized before death (Collinson et al. 2021:112). The Eidsivating laws also specified penalties for violating related burial regulations. These particular regulations encompass several provisions, including those tasked with grave digging must avoid disturbing other bodies, and graves must be dug to a depth that ensures a full ell of earth remains above the coffin (*ell - an old unit of measurement roughly equivalent to a cubit)* (Collinson et al. 2021:112). Additionally, digging in another one's burial site is strictly forbidden, and removing or discarding another person's bone from the churchyard results in a fine payable to the bishop (Collinson et al. 2021:112).

The burial laws outlined in the historical context reflect the time's intricate social and religious customs. It becomes evident that these laws were crafted with a preference for wealthier and morally esteemed individuals. The churchyard is divided into sections, with those of the highest social class buried closest to the church and the lowest social class buried in the periphery of the churchyard. The deliberate separation of burial spaces for men and women further illuminates the norms of sex-based segregation, reinforcing traditional gender roles and divisions. This delineating of specific burial practices based on social status and gender offers a tangible glimpse into the stratified nature of these communities. Indeed, distinguishing factors related to social and sex-based segregation in burial zones have been observed in specific instances. Most investigations into stratification during the medieval period primarily relied on analysing skeletal remains unearthed from churchyard excavations, complemented by examining burial placements. As such, it becomes imperative to provide a concise overview of prior research endeavours centred on burial customs, specifically those that trace social structures within medieval Scandinavia.

4.2 Social segregation

Several studies have demonstrated the existence of social segregation within medieval churchyards and osteological analysis is often used to provide valuable data for evaluating the social aspects by examining age, sex, stature, and pathology (Cinthio and Boldsen 1984; Gejvall 1960; Jonsson 2009; Sellevold 2001). In 1960, the osteologist Nils-Gustaf Gejvall published his study of human remains from the cemetery of Westerhus in Jämtland, Sweden, with an attempt to investigate the social structures of the medieval population by osteology and the spatial organization of the churchyard (Gejvall 1960). Gejvall (1960) observed a correlation wherein taller individuals were generally buried close to the church, whereas shorter individuals were buried farther away (Gejvall 1960:51–52). This stature-based analysis hypothesised that higher social classes would have had superior dietary and nutritional conditions compared to lower classes, resulting in greater physical stature (Brødholt et al. 2022).

Another study based on stature was done at the Löddeköpinge medieval cemetery in Scania, Sweden, by Hampus Cinthio and Jesper Boldsen (1984). Their research substantiated that an individual's social standing played a significant role in determining their burial location. They particularly highlighted the relationship between social status and sex segregation within three distinct social strata: higher, middle, and lower classes. Notably, their findings indicated an absence of sex segregation within the higher and lower social classes, while it was maintained within the middle class (Cinthio and Boldsen 1984:121). Consequently, their analysis revealed a significant correlation, where both males and females buried to the south of the church exhibited taller stature and were associated with higher social status, while those buried to the north of the church exhibited shorter stature, indicating a lower social class (Cinthio and Boldsen 1984:123). Cinthio and Boldsen’s (1984) research centred on social stratification based on the placement of burials on the southern and northern sides of the church, whereas Gejvall (1960) emphasised burial distance from the church in his study.

Following a similar research trajectory as Cinthio and Boldsen (1984) and Gejvall (1960), the osteologist Sellevold undertook a stature-based study on skeletal remains from Hamar Cathedral in Norway (Sellevold 2001). However, her research was inspired by the burial regulations found in the ecclesiastical section of the Eidsivating provincial law, which addressed the organisation of burials based on three key provisions: high-status individuals should be buried close to the church; there should be segregation by sex with women buried in north and men to the south of the church; and family should be laid to rest together (Sellevold 2001:193). In Sellevold's (2001) analysis, she compared the height of individuals buried near the church to those buried farther away, and she did not discern any conclusive evidence linking tall stature to proximity to the church because tall males are distributed around the church with a cluster to the south (Sellevold 2001:193). Regarding sex segregation, Sellevold (2001) suggested that the determination of sex-based zoning was better achieved by considering individuals' marital status, as marriage was more prevalent in high social classes and relatively rare in lower classes, such as among thralls (Sellevold 2001:193). Furthermore, due to the intermingling of men's and women's graves in Hamar, Sellevold (2001) observed no clear indication of sex segregation. Lastly, the idea that family should be buried together was reinforced through the observation of clusters of children's graves alongside those of adults, and the presence of hereditary metopic sutures in the cranial materials of children can interpret family members were buried in the same churchyard, even if their graves were not adjacent to one another (Sellevold 2001:203).

In his study of different types of graves and spatial patterns in the cemeteries in Lund, Sweden, Anders Andrén (2000) demonstrated a correlation between the classification of graves based on zoning and their associated social dimension. Three burial zones were discovered based on the consistency of the graves' design at the cemeteries in Lund during the 11th and 12th centuries (Andrén 2000:10). The first and second zones, while partially overlapping, exhibited specific characteristics. The zone nearest to the churches was dedicated to individuals of the highest esteem from the church's perspective, comprising priests and builders. The second zone encompassed donors and building craftsmen's burials at the cemeteries' far end. The third zone, situated at the periphery, was reserved for individuals considered in the lower class. Andrén's (2000) findings indicated a lack of clear sex-based divisions in the burials, instead highlighting a spatial hierarchy within the cemeteries in Lund, which corresponded with the normative provisions outlined in the Borgarting and Eidsivating provincial laws, particularly in terms of burials' proximity to the church (Andrén 2000:14).

Building upon the methodologies employed by Gejvall (1960), Cinthio and Boldsen (1984), and Sellevold (2001), which relied on skeletal stature and spatial analysis to discern social stratification in churchyards, Kjellström (2005) introduces a distinct approach to investigating social hierarchy in medieval Swedish parish churches. Kjellström's (2005) methodology encompassed anthropological analyses, including sex and age assessment, with stable isotope analyses and evaluating pathological conditions derived from skeletal remains from several cemeteries in Sigtuna, Sweden. This multifaceted approach unveiled social distinctions both between sexes within the same cemetery and among individuals of the same sex across different cemeteries (Kjellström 2005:47). The results of stable isotope analyses demonstrated that dietary practices varied between buried groups, indicating that social status played a more significant role in the social structure than sex (Kjellström 2005:88).

The burial practices in medieval Scandinavia reflect a complex system of social stratification. Studies by researchers like Gejvall (1960), Cinthio and Boldsen (1984), Sellevold (2001), Andrén (2000), and Kjellström (2005) have shed light on various aspects of this phenomenon. From Gejvall's (1960) analysis of stature-based zoning to Sellevold's (2001) scrutiny of familial interments, and further to Kjellström's (2005) multi-dimensional approach integrating anthropological and dietary assessments, a clear pattern of social differentiation in burial practices emerge. This differentiation, evident through the spatial organization of graves, dietary disparities, and body stature analysis, emphasises the profound influence of social status on the treatment of the deceased. Together, these studies elucidate the multifaceted nature of social segregation in burial practices, offering valuable insights into the societal structures of medieval Scandinavia.

4.3 Sex segregation

Anthropologist Jon Steffensen (1943) presented the earliest indication of sex-based division within a churchyard through his excavation of the site of Skeljastaðir in Þjórsárdalur – a Christian cemetery in Iceland. Notably, based on the analysis of human remains found at the site, Steffensen (1943) observed that most of the men were buried to the east of the choir of the church, while women and children were buried to the north, with some exceptions (Steffensen 1943:231). This distinct separation emphasised a marked instance of sex-based segregation in medieval burial customs, but it was not customary in Iceland. Thus, segregation by sex was believed to be practised at the beginning of Christian time, and it was eventually discontinued later (Steffensen 1943:229–234). Subsequently, an expanding number of studies have turned to osteological analysis to determine the biological age and sex of interred individuals. By reconstructing the demography of churchyards through assessments of biological sex, researchers have uncovered signs of social stratification. The noted practice of sex segregation in certain early medieval churchyards has garnered attention among scholars, who have explored its implications within the context of a north-south dichotomy which saw women buried to the north and men to the south (Gejvall 1960; Nilsson 1994; Staecker 1997; Zoëga 2014).

Returning to Gejvall's (1960) study at the Westerhus cemetery in Jämtland, Sweden, both osteological analysis of the skeletons and spatial organisation assessments substantiated the practice of sex-based segregation within the cemetery during the 12th to 14th centuries. The cemetery included 364 buried individuals, with 74 determined as men and 80 as women, demonstrating a distinct pattern: nearly all women were buried in the northern section, while men were buried in the southern half (Gejvall 1960:43–44). Gejvall’s (1960) study succeeded in drawing up a clear adherence to sex segregation and such practices belong to the early structure phase at the cemetery. Together with the evidence from Steffensen’s (1943) study in Iceland, he concluded that the principle of sex segregation is strictly observed and can demonstrate morphological similarities, indicating of kinship (Gejvall 1960:126).

In a separate study conducted by Jörn Staecker (1997) at various churchyards on the island of Gotland, Sweden, three key aspects - namely, the churchyard's layout, spatial organization, and sexual segregation, along with the arrangement of grave furnishings - were examined to shed light on the emergence of these medieval burial practices as signs of Eastern missionary efforts. As a result, the presence of sex-segregated cemeteries from the early medieval period indicates Christian practices, placing a significant emphasis on the context of burial (Staecker 1997:75). Another site that shows a complete separation of the sex in burial practice was in Tygelsjö in Scania (former Danish province, today’s Malmo, Sweden) by Kieffer-Olsen (1993). The churchyard remained active from the 12th century to the latter half of the 13th century (Kieffer-Olsen 1993:80). Examination focussed exclusively on the south or south-western section of the churchyard, as burials ceased in the western part of the field (Kieffer-Olsen 1993:110). The findings of his study unveiled a sex separation with the entire southern area preserved for the men, evidenced by the fact that among the 75 excavated individuals, only 5% were women (Kieffer-Olsen 1993:110). His summary supports the tradition of women being buried in northern and men to the south of the church; however, this division practice was abandoned during the 13th century in Jutland but maintained in the eastern parts of Denmark – and possibly lasted until the 14th century in the north Scandinavia (Kieffer-Olsen 1993:121).

Six decades after Steffesen's (1943) work in Iceland, Zoëga Guðný conducted various studies on medieval Icelandic cemeteries to explore the characteristics of the earliest Christian cemeteries and churches in North Iceland (Zoëga 2008, 2014, 2018). The cemeteries at Keldudalur and Keflavík in the Skagafjörður region from the 11th century present compelling evidence of gender division, aligning with the north-south dichotomy outlined in Norwegian ecclesiastical laws (Zoëga 2008:22). Most of the graves exhibit a Christian burial style, with the deceased positioned in an east-west orientation and the head placed towards the west within the coffin (Zoëga 2008:22). However, there are also numerous instances where children were interred directly in the ground without using coffins (Zoëga 2008:7,23). Although both cemeteries clearly demonstrate sex segregation in burial practices, this norm is not explicitly mentioned in the Medieval Icelandic laws (Zoëga 2018:110). It is worth highlighting that Zoëga's (2018) study also addressed the clustering of children's graves within the cemeteries. She proposed that children may have been assigned similar burial arrangements based on sex, mirroring the practices observed with adults (Zoëga 2018:110).

Indeed, the investigation of sex-based segregation in medieval burial practices has been significantly advanced through archaeological excavations and osteological analyses conducted on cemeteries across Iceland and Scandinavia. These studies have brought to light clear and consistent patterns of interment, notably with men predominantly laid to rest in southern sections and women in northern areas, though exceptions do exist. For instance, the research by Steffensen (1943) highlighted a deviation from the norm, as men were buried to the east due to the north side not being used at the churchyard. This nuanced understanding suggests that the practice may have arisen as a localized custom rather than being mandated by broader legislative regulations.

As we explore burial practices during the medieval period, it becomes apparent that while the spatial arrangement of graves offers significant insights into social hierarchy, it may not provide a complete picture. Recognizing this, Kjellström (2005) has taken the initiative to incorporate stable isotope analysis as an additional tool for comprehending social status. This method examines the chemical signatures found in skeletal remains, shedding light on dietary habits and potential indicators of social stratification among individuals from that historical era. By integrating the findings from studies on burial segregation with stable isotope analysis, we can craft a more detailed and all-encompassing portrayal of medieval society, uncovering the complexities of class and social structure in the medieval period.

5. Material and Methods

5.1 Analysis samples from St. Nicholas's churchyard

5.1.1 Human remains

At the time of excavation in 2014-2015 by NIKU, the churchyard of St. Nicholas's church contained 101 *in situ* graves with 106 individuals, which comprised 13 males, 39 females, 38 children and 16 indeterminate sexes (Jensen 2018). The majority of double graves documented at St. Nicholas's churchyard consist of women with children, precisely five out of every six, while only one in six double graves include a man and a child (Jensen 2018:34). This paper is based on data compiled from the result of stable carbon and nitrogen analyses of unburned bones and data of *in situ* burial locations from a well excavated and published the Follo Line project in Klypen East and Saxegaardsgata 15 in Gamlebyen, Oslo, Norway. The data collected for stable isotope analyses exhibit well-preserved quality and are distributed randomly in terms of both age and gender. The samples comprised 37 *in situ* individuals from the churchyard, dated between the 13th and 15th centuries. Simultaneously with the radiocarbon (^{14}C) analysis, the submitted bone samples were subjected to examination for stable carbon (^{13}C) and nitrogen (^{15}N) analyses in 2014-2015 (Derrick 2018). However, one individual from the sample list likely originated from a bone pit, and their gender and age could not be conclusively determined. Consequently, I decided to exclude the results from this individual in the dataset, opting to utilise data from the remaining 36 *in situ* individuals instead (Table 4).

Table 4. *36 individuals from St. Nicholas's churchyard in the study.*

	Sample No	Grave No	Gender	Age	Graves' location
1	P289431	SA15971	Child/Unknown	9 -11	Area 1
2	P289464	SA16239	Child/Unknown	4,5-6,5	Area 1
3	P289474	SA19833	Woman	60-80	Area 1
4	P289452	SA20281	Possible woman	40-50	Area 1
5	P289494	SA20681	Woman	32-42	Area 1
6	P289505	SA23806	Child/Unknown	30-50	Area 1
7	P289430	SA24281	Possible man	28-40	Area 1
8	P289483	SA50351	Child/Unknown	11-15	Area 1
9	P289429	SA13067	Child/Unknown	13-15	Area 2
10	P289441	SA13226	Woman	18-21	Area 2
11	P289436	SA13611	Woman	21-28	Area 2
12	P289444	SA14500	Child/Unknown	7,5 - 9	Area 2

13	P289475	SA14557	Woman	50-65	Area 2
14	P289479	SA14590	Man	30-40	Area 2
15	P289449	SA15485	Child/Unknown	9 -11	Area 2
16	P289461	SA16885	Possible man	18-25	Area 2
17	P289470	SA17786	Possible man	28-40	Area 2
18	P289466	SA17961	Possible woman	35-55	Area 2
19	P289445	SA18111	Possible woman	23-50	Area 2
20	P289468	SA18377	Man	35-45	Area 2
21	P289454	SA18878	Child/Unknown	0-1	Area 2
22	P289480	SA19169	Man	55-70	Area 2
23	P289488	SA20368	Child/Unknown	7md(f) - 6m	Area 2
24	P289450	SA21073	Child/Unknown	4-6	Area 2
25	P289443	SA22711	Possible woman	28-40	Area 2
26	P289437	SA23141	Possible woman	21-28	Area 2
27	P289439	SA23858	Woman	30-45	Area 2
28	P289462	SA24133	Child/Unknown	35-45	Area 2
29	P289503	SA25321	Child/Unknown	6-8	Area 2
30	P289463	SA25395	Child/Unknown	7-9	Area 2
31	P289477	SA50519	Woman	22-28	Area 2
32	P289481	SA50521	Woman	28-35	Area 2
33	P289459	SA50530	Child/Unknown	8-10	Area 2
34	P289455	SA28626	Man	40-50	Area 3
35	P289457	SA30668	Possible woman	22-30	Area 3
36	P289501	SA30855	Child/Unknown	3-5	Area 3

5.1.2 Graves' location

Figure 10 depicts a map of the churchyard linked to St. Nicholas's church and the investigated area known as Area A. The map also includes the locations of 36 *in situ* graves, as documented by NIKU during the years 2014-2015 and the graves exhibited an uneven distribution, primarily concentrated on the southern side of the church and ceased toward the southern part of Area A (Derrick 2018:194). Additionally, it was observed that there was no evidence of wooden coffins, and no grave goods were found within the graves. The absence of grave goods in these graves aligns with the theory of burial customs without accompanying objects during the Christian period in the Medieval era. The burials display diversity in their allocated burial zones, suggesting the inclusion of individuals from various social strata.

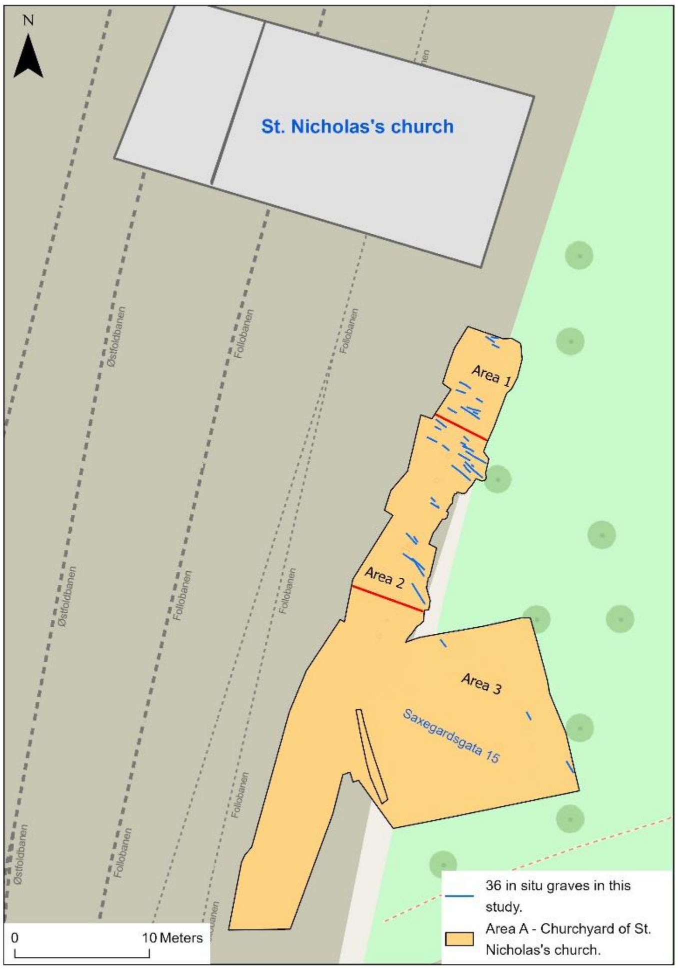


Figure 10. *Map of the church yard associated with St.Nicholas's church and graves' location divided into three areas.*

Remarkably, there were no graves present on the northern side of the church, as determined through Blix's excavation in 1879 (Derrick 2018:194). The majority of graves were situated on the southern side, with a notable prevalence of women and children. This observation suggests the possibility that this area may have been designated for the burial of females and children. This aligns with the type of segregation prescribed by the Christian legal code, a topic discussed in the previous chapter. Furthermore, a cluster of graves positioned in the northernmost part of Area A, near the chancel of the church, supports the notion consistent with Christian traditions. It aligns with the belief that only individuals of higher social status or wealth were afforded the privilege of being buried in close proximity to the church if they could not be interred inside the church. Nevertheless, it is worth noting that graves situated southeast of Area A may have been associated with the churchyard of St. Clement's church

(Derrick 2018:206). This suggests the possibility of a shared or interconnected burial ground in the vicinity.

In this study, the locations of the graves for the 36 individuals have been classified into three distinct areas based on their proximity to the church (Figure 10), as outlined below:

Area 1	The graves located closest to the church were found in the northern part of Area A (< 15 metres from the church)
Area 2	The graves located farther from the church were found in the southern part of Area A (< 30 metres from the church)
Area 3	The graves located furthest from the church were found in the southeastern part of Area A (> 40 metres from the church)

5.2 Analysis methods

5.2.1 Laboratory method

The samples were sent to the Ångström laboratory at the University of Uppsala, Sweden, and the analyses were conducted there. However, due to the departure of the researcher in charge of stable isotope analyses at NIKU and the laboratory technician formerly affiliated with the University of Uppsala, I possess limited knowledge regarding the specific details of the human bones and analysis work conducted by the laboratory. This section primarily relies on concise protocols derived from the report 40/2015 (Derrick 2018) and making inferences based on analytical techniques gathered from other relevant literature sources (Brown et al. 1988; Longin 1971; Sealy 1986). Before commencing the laboratory work, it was essential to photograph and thoroughly document all bones for future reference, following the procedure undertaken by NIKU, and include these records as an appendix in the report 160/2016 (Jensen 2018), which are not reproduced in this thesis.

In the University of Uppsala laboratory, the surface of bone samples undergoes mechanical cleaning, which may involve scraping or, in some instances, sandblasting. Subsequently, the sample is subjected to ultrasonic cleaning in boiled distilled water with a regulated pH of 3. The sample is ground in a mortar to get the bone powder. In conducting isotopic analysis on bone samples, the initial step entails the isolation of collagen for examination. This process entails demineralising the bone with acid (with variations in the choice of acid, concentrations, and temperatures across different laboratories). In this context, hydrochloric acid (HCl) was employed. The ground bone was demineralised in 0.8M HCl, and the mixture was stirred at 10°C for 30 minutes, removing apatite or any organic pollutants. In this step, the acid disrupts certain hydrogen bonds within the collagen structure, rendering it soluble in hot water (Longin 1971:141). The soluble fraction is denoted as "fraction A." The extraction of collagen involves heating the “fraction A” with distilled water (pH = 3), and the mixture is stirred for a period ranging from 6 to 8 hours at a temperature of 90°C. This process is called gelatinisation because the residue remaining from this procedure is collagen in the form of gelatine, referred to as "fraction D".

In customary practice, gelatinised collagen undergoes a process of ultrafiltration to isolate large collagen fragments that exceed 30k Dalton in size, as well as contaminants (Brown et al. 1988:172). Subsequently, it is transferred into microcentrifuge tubes and subjected to freeze-drying. The dried collagen samples are then analysed through isotope ratio mass spectrometry (IRMS). In this analytical procedure, the sample undergoes combustion, transforming into a gaseous state, after which the CO_2 (carbon dioxide) and N_2 (nitrogen) gases are separated by gas chromatography, and C/N ratios serve as a metric for validating the integrity of collagen samples. All the samples presented in this context exhibited a C/N ratio falling within the specified range of 2.9-3.6, which is essential to maintain the authenticity of their isotopic composition (DeNiro 1985). The isotope ratios of these gasses are subsequently quantified using a mass spectrometer. The carbon isotopic values are the ratios $^{13}C/^{12}C$ expressed relative to the standard Vienna-PDB, and nitrogen isotopic values are the ratios $^{15}N/^{14}N$ expressed relative to the standard AIR. The values are reported in the delta (δ) notion in parts per thousand (‰).

5.2.2 Data-interpretation methods

Sampled data of both nitrogen (^{15}N) and carbon (^{13}C) were visualised and analysed using the ***ggplot*** package with scatter plots and box and whisker plots (known as boxplots) in R statistical software environment (version 4.2.3) (Mcgill et al. 1978; Wickham 2009). The isotope data were typically represented using a scatter plot featuring the most distinguishing characteristics, specifically those with the greatest disparity in isotope ratios among potential source origins (Le Bot et al. 2011:306). In other words, a scatter plot is a graphical representation that displays the values of two variables as individual points on a coordinate plane. Each point on the plot represents a single observation or a data point, and its placement is determined by the specific values of the variables assigned to the x-axis and y-axis (Data

Visualization 2023). Additionally, scatter plots can reveal potential associations or relationships (correlations) between two numerical variables of interest, pinpoint outliers, detect clusters of data points, uncover trends over time or across conditions, and highlight any gaps or irregularities in the data (Wickham 2009). A box and whisker plot is a visual representation of data distribution. It illustrates key summary statistics, including the minimum, maximum, and median and the lower and upper quartiles (Mcgill et al. 1978). This plot allows for observing essential metrics such as the dataset's range, interquartile range, and skewness (Anon 2023). Box plots are a valuable tool for visually comparing two or more data sets.

This study generated scatter plots to provide a concise summary based on the carbon and nitrogen isotopic composition of δ^{13}C and δ^{15}N values, distinguishing between burial locations and genders within a sample set of 36 individuals. This approach allowed for a clear visual representation of the relationships and potential distinctions in stable isotope data across different categorical variables, ultimately aiding in interpreting dietary patterns within the studied population. Box and whisker plots visually represent the variations in δ^{13}C and δ^{15}N values within different groups, categorised explicitly by gender and burial areas. I also utilise a one-way ANOVA (Analysis of Variance) to compare the δ^{13}C and δ^{15}N values across gender categories (five groups) and graves' locations (three areas). These analyses aim to highlight the differences among the values within each gender group and burial areas. The F-value and p-value are crucial to understanding the data within a one-way ANOVA test. The higher the F-value in the ANOVA test, the higher the variation between samples means relative to the variation within the samples (Zach 2017). The higher the F-value, the lower the corresponding p-value. When the p-value is less than 0.05, we can reject the null hypothesis and conclude there is a significant difference between group means (Zach 2017).

Conversely, when the p-value is more than 0.05, we have to accept the null hypothesis of the ANOVA and conclude that there is no statistically significant difference between group means. If a significant difference is indicated by the F and p values among some of the test groups, a post-hoc test (specifically, Tukey's Honest Significant Difference) will be conducted. This additional test aims to assess the significance of differences between means within pairs of groups.

6. Results

6.1 Carbon and nitrogen isotope analyses

Table 5 shows δ^{13}C and δ^{15}N values for 36 individuals, including 14 women/possible women, 7 men/possible men, and 15 children/unknown sex. These results are based on bone collagen samples and categorised based on the graves' location at the churchyard. Despite the absence of collagen percentage data in the samples, it is noteworthy that all samples exhibited a C/N ratio falling within the prescribed range of 2.9-3.6, and this observation underscores the proteinaceous nature of the organic material present in the extracts (DeNiro 1985).

***Table 5**. Stable isotope values of carbon and nitrogen of bone collagen of 36 individuals at St. Nicholas's churchyard.*

Lab No	Graves' location	Grave No	δ^{13}C ‰	δ^{15}N ‰	C/N
Ua-52801	Area 1	SA15971	-21.6	12.4	3.2
Ua-52802	Area 1	SA16239	-22.6	11.9	3.2
Ua-52810	Area 1	SA19833	-21.2	12.9	3.2
Ua-52811	Area 1	SA20281	-20.9	13.5	3.2
Ua-52815	Area 1	SA20681	-21.7	13.1	3.3
Ua-52818	Area 1	SA23806	-23.0	13.1	3.3
Ua-52820	Area 1	SA24281	-21.6	13.3	3.2
Ua-52824	Area 1	SA50351	-23.8	13.0	3.3
Ua-52794	Area 2	SA13067	-22.9	10.6	3.3
Ua-52795	Area 2	SA13226	-23.0	11.9	3.3
Ua-52796	Area 2	SA13611	-22.7	12.2	3.3
Ua-52797	Area 2	SA14500	-23.0	11.6	3.3
Ua-52798	Area 2	SA14557	-21.8	12.5	3.3
Ua-52799	Area 2	SA14590	-21.6	12.5	3.2
Ua-52800	Area 2	SA15485	-21.7	13.7	3.2
Ua-52803	Area 2	SA16885	-21.6	11.8	3.2
Ua-52804	Area 2	SA17786	-21.0	13.2	3.2
Ua-52805	Area 2	SA17961	-22.2	12.6	3.2
Ua-52806	Area 2	SA18111	-21.2	12.8	3.2
Ua-52807	Area 2	SA18377	-22.5	11.5	3.2
Ua-52808	Area 2	SA18878	-19.9	14.8	3.2
Ua-52809	Area 2	SA19169	-22.0	12.8	3.2
Ua-52812	Area 2	SA20368	-24.7	7.0	3.3
Ua-52814	Area 2	SA21073	-23.4	10.9	3.3
Ua-52816	Area 2	SA22711	-23.4	12.5	3.2
Ua-52817	Area 2	SA23141	-21.0	13.8	3.2
Ua-52819	Area 2	SA23858	-22.0	13.7	3.2
Ua-52821	Area 2	SA24133	-22.7	12.0	3.2

Ua-52822	Area 2	SA25321	-24.5	13.1	3.2
Ua-52823	Area 2	SA25395	-24.3	12.5	3.2
Ua-52825	Area 2	SA50519	-23.9	13.0	3.2
Ua-52826	Area 2	SA50521	-23.3	13.7	3.3
Ua-52827	Area 2	SA50530	-24.2	12.6	3.3
Ua-52828	Area 3	SA28626	-24.0	13.1	3.3
Ua-52829	Area 3	SA30668	-23.9	12.5	3.3
Ua-52830	Area 3	SA30855	-25.2	12.1	3.2

6.2 Statistic results of the whole sample

For the entire sample, the overall $\delta^{13}C$ values ranged from -19.9‰ to –25.2‰, with an average and standard deviation of -22.61 ± 1.26‰. The overall $\delta^{15}N$ values ranged from 7‰ to 14.8‰, with an average and standard deviation of 12.51 ± 1.26‰. Both $\delta^{13}C$ and $\delta^{15}N$ values have a standard deviation of 1.26‰, suggesting a large variation in isotopic composition within 36 samples. The $\delta^{13}C$ results also suggest the absence of C_4 plants in the diet, and it is reasonable to assume that most of these individuals had a varied diet that included terrestrial and marine food sources. The results are included in Table 6.

***Table 6**. Summary statistics of $\delta^{15}N$ and $\delta^{13}C$ values (‰), including Averages, Minimum and Maximum, and Standard Deviation (σ) of 36 individuals.*

Overall	**$\delta^{13}C$**	**$\delta^{15}N$**
Mean	-22.61	12.51
S.D (σ)	1.26	1.26
Min	-25.2	7
Max	-19.9	14.8

Figure 12 depicts the variations in both $\delta^{13}C$ and $\delta^{15}N$ values, providing insight into the dietary data distribution of 36 individuals across different burial areas and genders. The ellipses highlight the significant variation in Area 2 compared to Area 1 and Area 3, leaning towards enrichment in $\delta^{13}C$ values. Based on the data points in the plot and the correlation value ($r = 0.45$), it can be inferred that there is a weak positive correlation between $\delta^{13}C$ and $\delta^{15}N$ values. Most individuals exhibit an enrichment in $\delta^{15}N$ values exceeding 10‰. However, it is worth noting that there are two outliers: one individual has a $\delta^{15}N$ value below 8‰, while another individual exceeds 14‰.

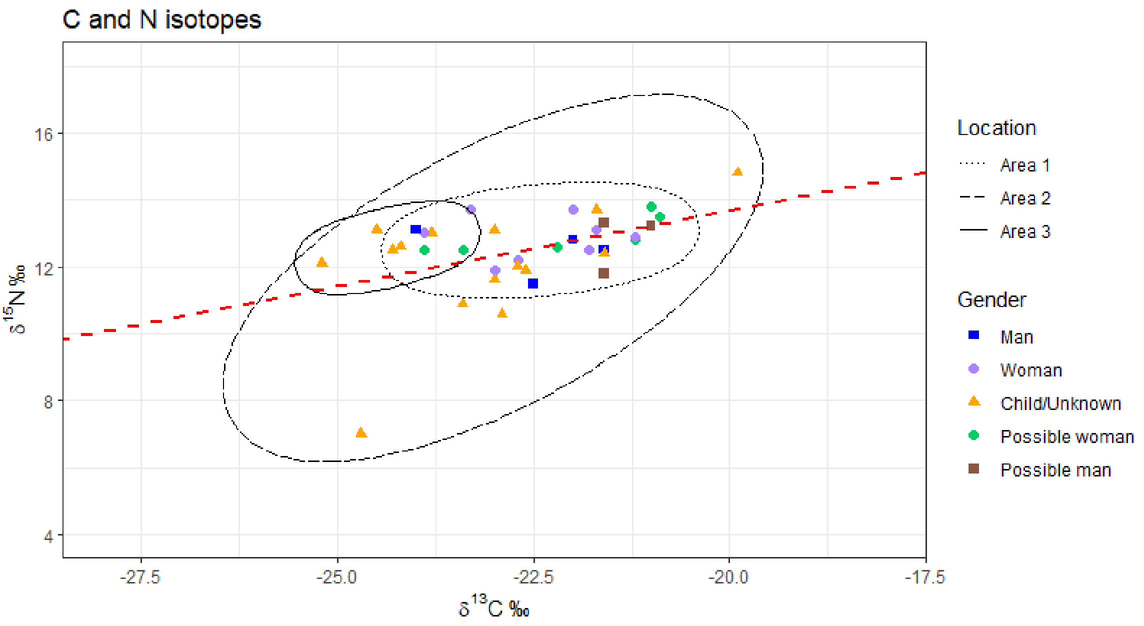


Figure 11. *Scatter plot of δ^{13}C and δ^{15}N values of 36 individuals. Each dot represents an individual and each ellipse represents each churchyard area.*

6.3 Statistic results by graves' location

Samples retrieved from St. Nicholas's churchyard have been categorised into distinct areas based on the locations of the graves, enabling an examination of the correlation between the dietary variation (δ^{15}N and δ^{13}C values) and their spatial distribution (Figure 12). Table 7 and Table 8 display the average, standard deviation (S.D), minimum, and maximum values of δ^{15}N and δ^{13}C from three specific areas: Area 1, Area 2, and Area 3.

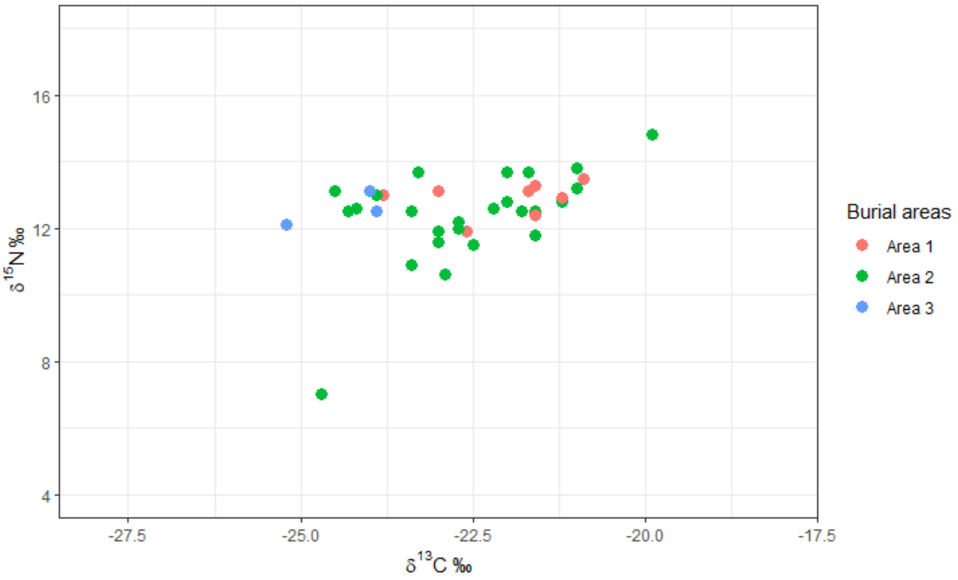


Figure 12. *Scatter plot of δ^{13}C and δ^{15}N values of 36 individuals, categorized into three distinct burial areas within the churchyard*

Table 7. *Summary statistics of* $\delta^{13}C$ *values, including averages, minimum and maximum, and standard deviation (σ) from three areas.*

Location	N	Mean $\delta^{13}C$	S.D (σ) $\delta^{13}C$	Min $\delta^{13}C$	Max $\delta^{13}C$
Area 1	8	-22.05	0.98	-23.8	-20.9
Area 2	25	-22.58	1.22	-24.7	-19.9
Area 3	3	-24.36	0.72	-25.2	-23.9

Table 8. *Summary statistics of* $\delta^{15}N$ *values, including averages, minimum and maximum, and standard deviation (σ) from three areas.*

Location	N	Mean $\delta^{15}N$	S.D (σ) $\delta^{15}N$	Min $\delta^{15}N$	Max $\delta^{15}N$
Area 1	8	12.90	0.51	11.9	13.5
Area 2	25	12.37	1.4	7.0	14.8
Area 3	3	12.56	0.50	12.1	13.1

Area 1 (< 15 meters): The $\delta^{13}C$ values for area 1 (n=8) ranged from -23.8‰ to -20.9‰ with an average and standard deviation of -22.05 ± 0.98‰. The $\delta^{15}N$ values range from 11.9‰ to 13.5‰ with an average and standard deviation of 12.90 ± 0.51‰.

Area 2 (< 30 meters): The $\delta^{13}C$ values for area 2 (n=25) ranged from -24.7‰ to -19.9‰ with an average and standard deviation of -22.58 ± 1.22‰. The $\delta^{15}N$ values range from 7.0‰ to 14.8‰ with an average and standard deviation of 12.37 ± 1.4‰.

Area 3 (> 40 meters): The $\delta^{13}C$ values for area 3 (n=3) ranged from -25.2‰ to -23.9‰ with an average and standard deviation of -24.36 ± 0.72‰. The $\delta^{15}N$ values range from 12.1‰ to 13.1‰ with an average and standard deviation of 12.56 ± 0.50‰.

6.4 Statistic results by gender-based and graves' location

The one-way ANOVA revealed no statistically significant difference between the gender groups, both in terms of $\delta^{13}C$ values ($F_{4,31}$=1.87, p=0.141) and $\delta^{15}N$ values ($F_{4,31}$=0.784, p=0.544). Nevertheless, the results of one-way ANOVA indicated significant differences in $\delta^{13}C$ values among individuals from three different areas ($F_{2,33}$=4.426, p=0.0198). In other words, the variation of $\delta^{13}C$ values among different areas is much greater than the variation of $\delta^{13}C$ values within each area. A post-hoc test found that the mean $\delta^{13}C$ values were significantly different between Area 3 and Area 1 (p=0.0150), as well as Area 3 and Area 2 (p=0.0417). However, there was no significant difference in $\delta^{13}C$ values between Area 2 and

Area 1. The one-way ANOVA results suggest no significant differences in δ^{15}N values among individuals from three different areas ($F_{2,33}$=0.52, p=0.599).

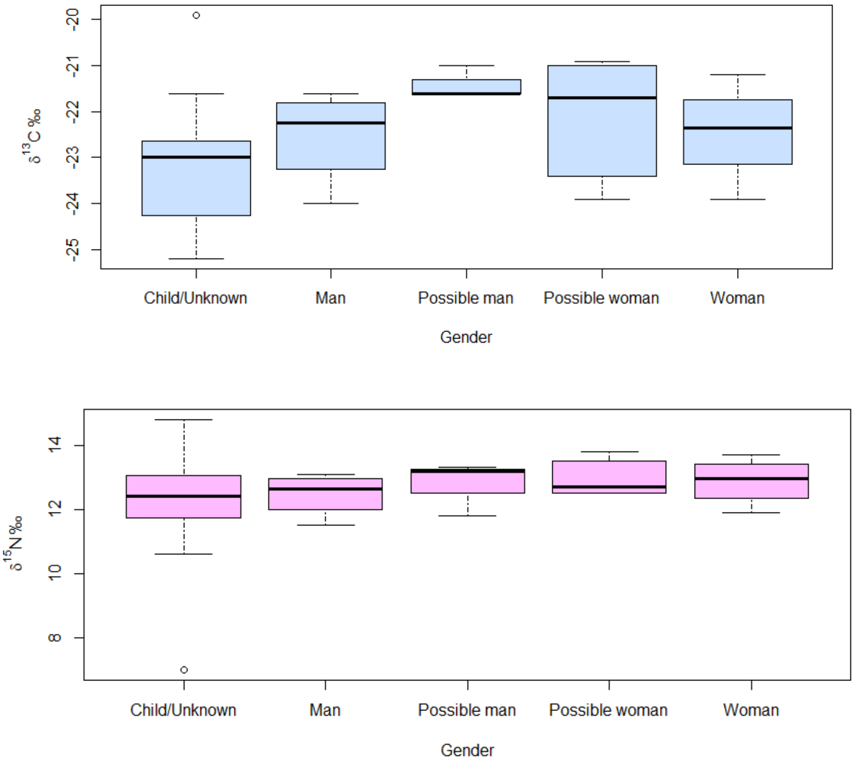


Figure 13. *Boxplots of the δ^{13}C values (above) and δ^{15}N values (below) for five gender groups*

Figure 13 displays two boxplots comparing gender groups regarding δ^{13}C and δ^{15}N values. The median is represented by the black line inside the box, which is a common measure of the centre of the data with the upper and lower whiskers (dash-dotted lines connections with the boxes) displaying the data range (maximum–minimum). The characteristics of the data are apparent, with all gender groups showing a high degree of similarity to each other. However, it is worth noting that the "possible man" group is underrepresented in the data, which may limit the statistical interpretation. Furthermore, in the “child/unknown” group, an outlier exists for both δ^{13}C and δ^{15}N values. Outliers are data points that deviate significantly from the rest of the data and are identified by small circles outside of the whiskers on the box plot.

The boxplot of δ^{13}C values for gender groups reveals a higher variability in δ^{13}C input. The "possible woman" group exhibits a broader range, suggesting a more dispersed distribution, potentially leaning towards the left or negatively skewed. The data distribution for the "woman" group appears symmetrical, indicated by the median line aligning with the centre of the box and similar lengths of the upper and lower whiskers. The "possible woman" group also has the highest median value, suggesting notable differences between this group and the others (not including “possible man” group). On the other hand, the boxplot for $\delta^{15}N$ values indicates a high degree of similarity in $\delta^{15}N$ input across the gender groups. This is evident from the small size of the boxes, which suggests less dispersion of data. The “child/unknown” group has the largest range, and the median is in the centre. Thus the distribution is more even.

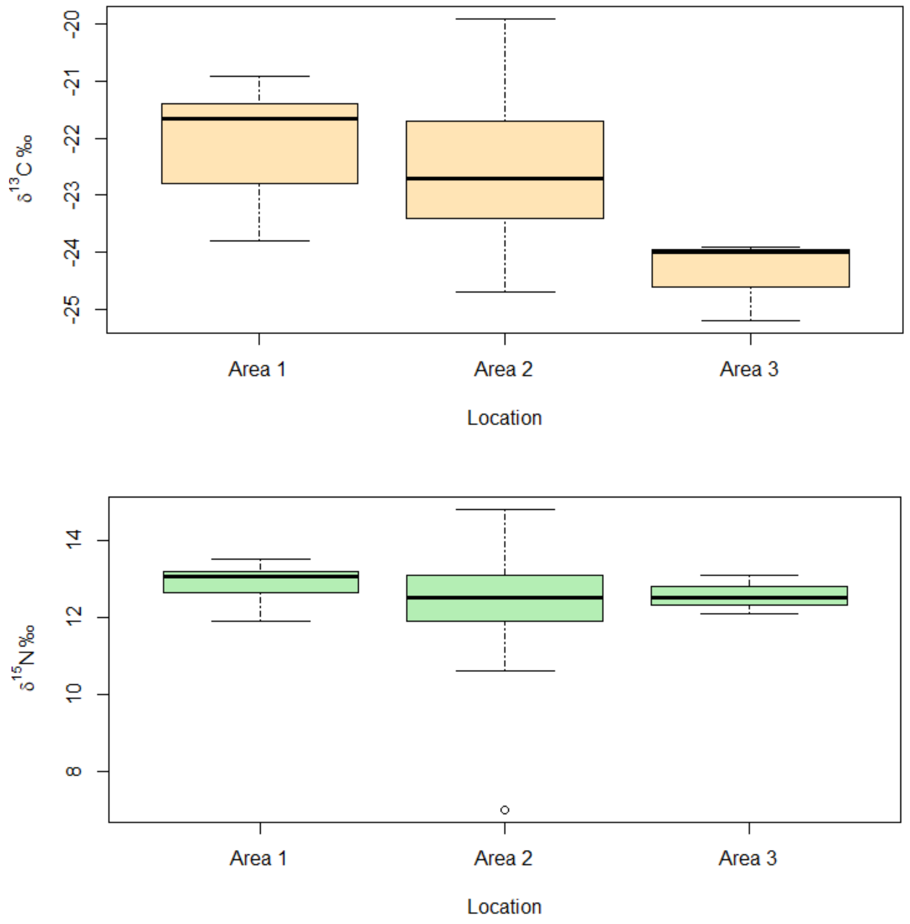


Figure 14. *Boxplots of the $\delta^{13}C$ values (above) and $\delta^{15}N$ values (below) for three areas based on the location of graves at the churchyard.*

Figure 14 displays the two boxplots comparing three areas in terms of $\delta^{13}C$ and $\delta^{15}N$ values. The boxplot for $\delta^{13}C$ values shows greater variability in $\delta^{13}C$ input across three areas, as evidenced by the longer boxes, which indicate a wider dispersion of $\delta^{13}C$ values. Area 2 displays the broadest range of data and potentially leans towards the right or is positively skewed. Because of the limited sample size in Area 3 (n=3), obtaining a precise interpretation may prove challenging. Area 1 has the highest median, which indicates differences from other areas. The boxplot for $\delta^{15}N$ values indicates high similarity in $\delta^{15}N$ input across the three areas. This is evident from the small size of the boxes, which suggests less dispersion of data. Area 2 has one outlier of $\delta^{15}N$ value; however, this area has the largest range with data distribution that appears symmetrical (more even) as the median line is in the centre of the box.

7. Discussion

The broad range observed in both $\delta^{13}C$ and $\delta^{15}N$ values suggests that all individuals within the St. Nicholas's churchyard population followed a uniformly similar diet. Nevertheless, it is important to note that the population had diverse dietary practices, encompassing a variety of food types, emphasized by the relatively high standard deviation in both $\delta^{13}C$ and $\delta^{15}N$ values (S.D = 1.26). It appears that the diets of all individuals revealed significant variations in proteins derived from terrestrial sources. These findings are consistent with other studies on medieval material in Norway, highlighting diets characterised by terrestrial-origin proteins (Hufthammer 2000; Naumann et al. 2019). This prompts us to contemplate the potential for differences in food sources within the population, particularly regarding social status, as inferred from the distinct burial locations within the churchyard.

7.1 Dietary reconstruction from $\delta^{13}C$ and $\delta^{15}N$ analyses

In the Norwegian context, the baseline values for humans are anticipated to fall within the range of approximately -24‰ (terrestrial) to -12‰ (marine) for $\delta^{13}C$ (Naumann et al. 2019:1114). These expectations are drawn from insights gathered from prior studies on both human and faunal samples (Barrett et al. 2011; Johansen et al. 1986; Naumann et al. 2019, 2014; Rosvold et al. 2010; Van der Sluis et al. 2016). The data from this study reveals that 35 out of 36 individuals exhibit $\delta^{13}C$ values surpassing -20‰ and have $\delta^{15}N$ values exceeding 10‰, indicating a substantial consumption of a mixed diet, consistent with the intake of both terrestrial and marine food sources. There are two infant individuals stand out in the dataset due to its extremely low $\delta^{15}N$ value of 7‰ (SA20368) and highest $\delta^{15}N$ value of 14.8‰ (SA18878). This low value appears to be an outlier, and as of now, there is no readily apparent explanation for this exceptionally low $\delta^{15}N$ values based on the factors typically associated with such values in the dataset. The individual with the highest $\delta^{15}N$ value, who was approximately one year old at the time of death, may suggest that the diet consists entirely of breastmilk. The indication of breastfeeding practice is reinforced by the typical enrichment in both $\delta^{15}N$ and $\delta^{13}C$ (Chinique de Armas et al. 2022). Moreover, considering the age of approximately one year, the expectation remains that the individual still receives breastfeeding from the mother.

During the medieval times in Oslo, meat was a favoured protein source and was believed to have been consumed in large quantities, and the discovery of cattle or pig bones in the town further supports this notion (Lie 1988:161; Øye 2002:353). Apart from these, grains and grain products were the primary food sources, regardless of social status. They constituted about 60% to 80% of the overall food intake, with cereals and bread being the most critical contributors (Øye 2002:323, 406). Additionally, dishes like porridge, gruel, soup, and stews made from grains and vegetables were likely common fare on the sustenance menu (Sture and Bauer 2017:47). Furthermore, the dominant diet for the general population of Norway during this period has been described as monotonous, consisting of staples like bread, flatbread, butter, milk, beer, meat, and fish (Grøn 1927:26).

The $\delta^{13}C$ results from bone collagen point toward a C_3 plant-based diet such as wheat and vegetables. Deducting the impacts of trophic level enrichment from the measured $\delta^{13}C$ values (with an average of -22.61‰) suggests that the average $\delta^{13}C$ values for regional animal resources are around -21.66‰, while those for plant resources are approximately -26.66‰. These values align with expectations for a C_3 environment (Brown and Brown 2011:84). Hence, it is probable that the C_3-derived protein component of the Oslo diet did not originate directly from plants but rather from animals that consumed these plants. The average $\delta^{15}N$ values of about 12.51‰, along with statistical analysis results, indicate a consistent pattern in protein intake. This also suggests that marine predators were not a predominant component of the diet. The average $\delta^{15}N$ values of approximately 12.51‰, along with the statistical analysis results, indicate a consistent pattern in protein intake. In addition, the $\delta^{15}N$ values of this study can be explained by two potential factors: the consumption of terrestrial protein or freshwater resources. However, archaeological evidence from the medieval town did not strongly support the notion of a freshwater fish-based diet, as only minimal remnants of freshwater fish have been found in this context (Lie 1988:184, 1991:81). Regrettably, based on the available data, we do not have a complete baseline for marine species in the region. However, the range of $\delta^{13}C$ values and the fact that all $\delta^{15}N$ values are under 15‰ provide sufficient evidence to conclude that none of the individuals consumed exclusively marine foods.

When evaluating the diets of individuals from St. Nicholas's churchyard compared to other medieval Norwegians with accessible stable carbon and nitrogen isotope ratios, it becomes evident that individuals from different regions reflect different dietary components (Table 9). The mean $\delta^{13}C$ values observed in St. Clement's cemetery (Naumann et al. 2019) and St. Nicholas's churchyard in Oslo, Stavanger's cathedral (Van der Sluis et al. 2016) and St. Mary's churchyard in Bergen (Dolphin et al. 2023), reveal distinct patterns. Notably, the mean $\delta^{15}N$ values for individuals from Stavanger and Bergen are higher than those of Oslo, indicating a more pronounced marine consumption in the coastal regions than in a semi-inland region like Oslo. Upon analyzing the standard deviation of δ^{13}C at the four sites, it becomes evident that the protein components in the diets of individuals from St. Mary's and St. Nicholas's display considerable variability. Regarding standard deviation for δ^{15}N, St. Mary's individuals exhibit the highest variability, while St. Nicholas's and St. Clement's individuals show almost similar levels of variation. Since St. Clement's church is situated northeast of St. Nicholas's church (Figure 3), sharing the same geographic area. The findings for individuals from both churchyards in Olso exhibit similar dietary patterns, suggesting that most individuals likely consumed different foodstuffs with a substantial amount of terrestrial food.

Table 9. *δ^{13}C and δ^{15}N isotope values for human remains from Norwegian medieval sites*

Medieval sites	**δ^{13}C (‰) Range**	**δ^{13}C Mean ± S.D**	**δ^{15}N (‰) Range**	**δ^{15}N Mean ± S.D**
St. Nicholas's churchyard in Olso	-19.9 to -25.3	-22.61 ± 1.26‰	10.6 to 14.8	12.51 ± 1.26‰
St. Clement's cemetery in Oslo	-17.67 to -21.82	-19.9 ± 0.96‰	10.33 to 15.57	12.82 ± 1.35‰
Stavanger's cathedral	-17.9 to -20.7	-19.2 ± 0.7‰	10.7 to 14.7	13.1 ± 1.1‰
St. Mary's churchyard in Bergen	-16.2 to -21.4	-18.4 ± 1.3‰	10.1 to 16.6	13.5 ± 1.9‰

However, when delving into the discussion of medieval diets in Oslo from a broader perspective, it is crucial to take into account two key factors. Firstly, the surge in fish consumption during the medieval period can be viewed as a result of religious practices influencing dietary choices. Secondly, fluctuations in meat consumption, whether increasing or decreasing, can be linked to diet variations associated with social status.

7.1.1 Fasting regulations influencing food choices

With the introduction of Christianity in Scandinavia, the medieval population began incorporating significant quantities of fish into their diets, likely in response to the dietary requirements associated with religious fasts (Müldner and Richards 2005). The earliest Christians considered the practice of fasting to be a significant virtue. As outlined in Norwegian provincial laws, fasting days include various occasions like Lent, the Rogation Days, Vigil fasts, the Quatember fasts, and the Friday fasts (Sanmark 2005b:2). Lent was the longest among all the fasting periods, taking place before Easter and spanning across a period of 40 days and there was at least one fasting day, Friday, every week. Consequently, if people adhered to these fasting regulations, they would have fasted for almost one-third of the year (Sanmark 2005b:2).

In Norway, there existed three levels of abstention from certain foods (Sanmark 2005b). The first and most permissive level was the 'non-meat fast', which allowed the consumption of fish, milk, eggs, and other foods. The second level was the 'dry fast,' which excluded meat, eggs, and dairy products. Finally, the strictest level of abstention was the 'water fast,' in which only bread and salt were allowed. Dispensations from fasting during Lent were common for children, elderly individuals, pregnant women, and lactating women (Yoder 2010:1184). Nevertheless, the majority of individuals without special dispensations were bound by the fasting rule. Depending on the church calendar, fasting was mandated, involving abstaining from meat, but fish or shellfish were permitted during these fasting periods. Individuals faced punishment and fines if they violated the regulations and consumed meat on fasting days. As a result of these significant dietary restrictions, there may be a discernible isotopic signature in human bones.

During the medieval period, fish appeared on the dietary menu for two primary reasons. Firstly, it provided a vital source of protein, and secondly, it acted as a substitute for meat during fasting periods (Müldner 2009:334). It is difficult to establish the exact effect of fasting on the diet of medieval Oslo residents, as there is uncertainty surrounding how strictly they followed the fasting rule. The results of this study revealed that fish consumption did not significantly impact the bone isotope ratio of individuals buried at St. Nicholas's churchyard. Even though people incorporated marine resources into their diets, their influence was not as great as anticipated, especially if they strictly adhered to the medieval fasting regulations. Consequently, the prohibition of eating meat had a relatively minor influence on the dietary patterns of medieval people in Oslo. This implies a degree of flexibility or deviation from strict adherence to the fasting regulations, wherein individuals might have opted for alternatives such as bread, vegetables, fruits, or milk as substitutes for meat. The ability to incorporate varied food options indicates a pragmatic approach to dietary practices during the fasting periods, allowing for a more diverse and adaptable eating pattern among the medieval population.

7.1.2 Variations in diet based on social status

Social status significantly influenced the types and quantity of food resources accessible to individuals in society, leading to socially based differences in the medieval diet (Yoder

2012). This correlation extends to factors such as age, sex, and health status, as inferred from osteological assessments of the skeleton (Müldner 2009:334). The bioarchaeological evidence for status-based differences in diet in medieval Norway and Scandinavia was previously discussed by bone mineral density and stature (Brødholt et al. 2022). Brødholt and colleagues (2022) identified social stratification indications, revealing that lower-class individuals exhibit lower bone mineral density and shorter stature. This observation implies a potential correlation with living conditions, dietary practices, and various nutritional and lifestyle factors.

The application of stable isotope analysis enables the direct correlation of dietary information with individual-specific archaeological data. Drawing insights from isotope studies and faunal analyses suggest that individuals of higher social status tended to consume larger quantities of animal protein from domestic cattle and game meat (Kjellström et al. 2009; Yoder 2012). Conversely, those of lower social status appear to have consumed a higher proportion of vegetables and cereals (Iregren et al. 2000). Another research on medieval skeletal material from Northern Italy also demonstrated a notable difference between the diets of high and low status in bone δ values (Reitsema and Vercellotti 2012). The authors note that there is a broader range of variation in bone δ values among low-status individuals, whereas high-status individuals exhibit more consistent values. This is attributed to elites consistently having access to animal protein, while the variability among low-status individuals is attributed to individual circumstances, both fortunate and unfortunate, and the ongoing uncertainty in their access to resources (Reitsema and Vercellotti 2012:597). This novel perspective on distinct dietary habits among various social classes holds merit in specific contexts. In the case of this study in Oslo, it may be worthwhile to explore this perspective further.

It is evident that the upper and lower classes have consistently maintained distinct standards of living, even when sharing the same social class or profession. The gap in living standards between these classes has remained pronounced. As previously discussed in the context of the *Rígsþula* poem, a stark contrast is depicted in the quality of food and beverages, with the upper class enjoying tastier and more refined options. In Oslo, medieval trading played a crucial role in gradually transforming dietary patterns by introducing a supply of finer grain products, rice, fruits, and various spices from abroad (Sture and Bauer 2017:47). The upper classes, due to their greater financial means and susceptibility to foreign influence, were quick to embrace and enjoy these imported goods, taking the lead in this culinary shift (Grøn

1927:11). Considered a delicacy among shellfish, oysters were exclusively sold to the upper class on fishing boats, and the lower class unlikely to have experienced its consumption (Grøn 1927:129–130). Additionally, dairy products, such as cream, played a minor role and were scarcely consumed in both households of upper and lower classes (Grøn 1927:73). However, butter and sour milk (*skyr*) became widespread and common foodstuffs in Norway (Grøn 1927:93).

In essence, the medieval lower class predominantly comprised natural raw products and constituted the fundamental sustenance for the majority. Primary sources of nutrition included meat from cattle and pork, fish (both fresh and dried, such as cod and herring), dairy products (milk, butter, cheese), porridge, and bread (Grøn 1927:235). Alongside these basic diet elements, the upper class enjoyed a more diverse culinary experience, incorporating European cuisines enriched with imported sources, especially wheat (fine bread) and spices, larger amounts of meat, various game meats, fish, and the inclusion of wine in their diet (Grøn 1927:235; Hufthammer 2000:184).

However, the depopulation caused by the plague in 1349 presented a new opportunity for surviving farmers. They were able to move in and take over the farms that were left vacant, often at lower rents (Emblem et al. 1993:79). With an abundance of open land and pasture available after the plague, it became easier for farmers to manage cattle farms, leading to improved livestock conditions. Consequently, farmers enjoyed a more diversified diet, gaining greater access to milk, butter, egg and meat (Emblem et al. 1993:79). The significant population decline resulting from the devastating plague has prompted shifts in dietary habits among social classes, with a notable increase in meat consumption for everyone because the decreased cost and lower demands within the population (Dyer 1989). The shift towards a more meat-centric diet could lead to discernible alterations in isotopic signatures. Therefore, as the population transitioned to a diet with increased meat intake after the plague, we might anticipate shifts in stable carbon and nitrogen isotope ratios in human bones.

Applying the dietary model to the medieval population in Oslo allows us to discern variations in δ^{13}C and δ^{15}N values between social classes. The upper classes are expected to exhibit higher δ^{15}N values, pointing to a diet rich in high-protein sources, such as meat and fish. In contrast, the lower classes are anticipated to show lower δ^{15}N values, indicative of a diet with comparatively lower protein intake. Additionally, the less negative δ^{13}C values in the lower classes suggest a diet with a greater reliance on C_3 plants (grain products and vegetables), potentially reflecting a higher proportion of plant-based foods in their overall dietary composition. From this perspective, I would further explore the correlation between spatial distribution in the churchyard and social stratification in diet among medieval Oslo inhabitants.

7.2 Burial organisation and dietary patterns

Although the notion of Christian burial traditionally signifies equality in the eyes of God in death (with no graves good in burials), there exists evidence that stratification in burial practices did reflect social differences. As previously discussed in Chapter 4, the Christian section of the Borgating and Eidsivating provincial laws outlines regulations for organising burial in churchyards based on social status. This led to a pattern where the upper classes were often interred in the church or as close to it as possible, while the lower classes found their resting place farther from the church or near the perimeter wall of the churchyard. The guidelines also dictated that men should be buried to the south of the church and women to the north. Consequently, the location of graves emerged as an accepted means of expressing social status during the medieval period. Investigating disparities among individuals buried in distinct areas combined with the result of stable isotopic analyses can provide insights into inequalities between social classes at St. Nicholas's churchyard.

7.2.1 Sex segregation

In accordance with historical records from the Christian section of the Eidsivating provincial law, a medieval churchyard was occasionally segregated by sex, as outlined in section 4.3. The primary directive specified that men were to be buried to the south of the church, while women were to be buried to the north. The Eidsivating law initially pertained to the inner part of eastern Norway but eventually expanded to encompass most of Viken (the Oslofjord area), including the area around Oslo (Knudsen 1958:526). It is noteworthy that the Norwegian Eidsivating law stands out as the sole Scandinavian legislation explicitly mandating sex-segregated areas in churchyards. However, the practical implications of this law are more evident in Sweden and Iceland, while clear evidence of its implementation in Norway is not readily found.

The existence of several studies related on sex-segregated Norwegian medieval churchyards, including those at St. Clement’s in Oslo (Holck and Kvaal 2000), Hamar’s cathedral (Sellevold 2001), Mære’s cemetery in Trøndelag (Lidén 1969), and St. Olav’s churchyard (Anderson and Göthberg 1986), is notable. However, these studies collectively suggest limited evidence of sex segregation in these specific churchyards. The lack of conclusive evidence raises questions about the practical application of regulations regarding sex segregation in medieval burial contexts in Norway. Indeed, the studies of burials at St. Nicholas's churchyard do not present a strong exception to the general trend of sex segregation observed in other Norwegian medieval churchyards.

In terms of dietary interpretation, the results of isotopic analysis revealed variations in $\delta^{13}C$ sources across gender groups. Interestingly, despite these variations in carbon sources, a consistent and similar pattern was observed in $\delta^{15}N$ intake among all individuals. This suggests that while dietary choices regarding terrestrial sources differed between genders, there was a shared pattern in protein intake among the studied population. Additionally, the statistical analysis aligns with the observation that there is no significant difference in diet between gender groups at St. Nicholas's churchyard. It can be concluded that individuals, regardless of sex, share a uniform diet.

Nevertheless, the prescribed sex segregation is not strongly evident in St. Nicholas' churchyard due to an uneven distribution of samples across genders, with a higher representation of females and children. This uneven distribution makes it less than ideal to draw dietary interpretations solely based on gender groups. Moreover, the observation that the churchyard is only used on the southern side, with no activity on the northern side of the church, does not align with the expected pattern of sex-based separation in burials. This finding adds further weight to the argument that the prescribed sex segregation is not strongly reflected in dietary patterns.

7.2.2 Status segregation

The absence of significant differences in diet between genders underscores the importance of broader social and cultural factors that may have influenced dietary practices in this particular historical context. As Nordeide and Gulliksen (2007) suggested, the cemetery appears to have encompassed various social groups, each possibly associated with different kin or ethnic affiliations. Indeed, examining the burial locations of different individuals alongside their isotopic data can offer a more detailed understanding of isotopic variations within the churchyard. This approach recognizes the potential correlation between burial position and social distinctions during the medieval period in Oslo.

The existence of social hierarchy and status divisions within churchyards has been documented through various indicators, including the absence of coffins, shorter stature, and the presence of diseases and handicaps among individuals interred closer to or further from the churchyard wall (Andrén 2000; Hamre 2011; Jonsson 2009; Sellevold 2001). No other social markers are readily apparent in cases where physical and mortuary assemblages are absent. In such instances, employing isotopic studies of individuals in conjunction with their burial locations can serve as valuable tools to discern social stratification within churchyards.

My study has categorized St. Nicholas's churchyard into three conceptual burial areas, each serving as a hypothetical representation of a distinct social group. The differentiation is based on the varying distances of these burial areas from the church (Figure 10). This approach allows for exploring potential social stratification within the community, as the spatial arrangement of burials often indicates social status or other community-related factors. Area 1 was allocated for the barons (upper class), Area 2 for the farmers (middle class), and Area 3 for the thralls (lower class). The variation in the diet of individuals buried in Area 3 is relatively small compared to that of individuals in the other two areas, suggesting a more homogenous dietary pattern within this specific group.

In contrast, Area 1 and 2 exhibit greater variability, particularly in carbon values, indicating a more diverse range of dietary practices among individuals in these areas. The analysis of standard deviation and boxplots for $\delta^{15}N$ values in the three designated areas suggests that there is no significant difference in marine intake among all individuals. This observation may indicate that regardless of their designated social areas, each group exhibits a moderate contribution of marine protein in their diet. The consistent patterns in $\delta^{15}N$ values across the three areas suggest a relatively uniform marine protein intake among individuals, highlighting a shared dietary aspect among the studied population.

However, the observed discrepancy, wherein individuals from Area 3 display lower $\delta^{13}C$ values than their counterparts in Area 1 and 2, presents a conflict in the data hypothesis. The combination of a diet containing a substantial proportion of animal protein and a burial location farther from the church appears to be at odds with the theory of status segregation. This unexpected difference challenges the initial expectation that the lower class would have less varied dietary sources regarding animal protein intake. However, this situation can be explained by the study of Reitsema and Vercellotti (2012), as mentioned earlier, where individuals of lower status might have had a variety of food sources based on their life circumstances.

On the other hand, individuals in Areas 1 and 2 exhibit a diet heavily composed of terrestrial animal protein, correlated with their burial locations near the church, suggesting a potential association with an upper-class diet. This combination aligns more closely with the expected pattern of status segregation, where individuals of higher social status might have had access to a more diverse and protein-rich diet. In short, significant isotopic differences in diet between individuals at different burial locations in this period are a notable observation. However, these observed differences are insufficient to confirm a direct connection between isotopic patterns and the spatial distribution based on social class at St. Nicholas's churchyard.

7.3 Limitations and recommendations

Similar to other methods of dietary reconstruction, stable isotope analysis has inherent limitations, and it is crucial to be aware of these limitations to interpret the information provided by isotopic data accurately. As explained earlier, stable isotopes primarily offer insights into diet in broad terms, focusing predominantly on sources of dietary protein. Historical documents provide valuable insights into the differentiation in diet among social classes. These records can illuminate distinctions such as variations in the consumption of grain products between the upper and lower classes, disparities in the quantity and types of meat sources consumed, and potential consumption of dairy products and eggs in upper classes’ diets compared to lower classes (Yoder 2012:1191). Regrettably, these distinctions in diet based on social status may not always be visible in isotopic data.

Furthermore, it is important to note that foods with relatively low protein content, such as fruits, vegetables, fats, and oils, are not clearly reflected in the isotopic signal, while high-protein sources like meat and fish tend to be overemphasized in isotopic analyses (Ambrose 1993, as cited in Müldner 2009:330). The differences in diets among various social classes might be subtle, and relying solely on stable carbon and nitrogen analyses in human bone collagen may not provide a robust method for capturing these nuances. Hence, it becomes crucial to integrate various sources of evidence, incorporating isotopic analyses of soils, plants, and animals specific to the region to establish baseline values, enabling a more comprehensive understanding of past dietary patterns and the associated social dynamics (Ambrose 1993:113).

Also, considering a broader range of environmental influences in archaeological contexts is necessary to enhance the accuracy and depth of interpretations regarding the intricacies of ancient diet data. For example, the unexpected combination of lower δ^{13}C value (a diet rich in animal protein) and a burial location farther from the church (Area 3) can be explained by two factors. First, we suggest that the base plants in the lower class diet originated from an environment with low light intensity or experienced “canopy effect”, resulting in δ^{13}C values of plants that may be as low as or lower than -30‰ (Leatherdale 2013:44). As enrichment occurs in the food chain, human bone collagen δ^{13}C values become more negative when individuals consume animals that have been fed with these plants. The second explanation involves post-mortem alteration, or diagenesis, in bone collagen due to soil bacteria. This process can result in a shift towards more negative δ^{13}C values and more positive δ^{15}N values (Leatherdale 2013:45). The interpretation of isotopic data in archaeological studies is complex, and this unexpected result may prompt a reevaluation of assumptions or the consideration of additional factors that could contribute to the observed isotopic variations within the studied population.

In brief, stable isotope analysis can be complemented and integrated with various other techniques such as amino acid or lipid residue analysis, gas chromatography (GC), gas chromatography-mass spectrometry (GC/MS) to increase the accessibility and precision in characterizing archaeological residues and remains. Although archaeobotanical and zooarchaeological methods alone may not comprehensively capture all aspects of a diet, their integration with other scientific analysis techniques can yield valuable insights. Combining these methods makes it possible to discern specific plants and animals consumed and ascertain their geographical origins. This multidisciplinary approach enhances the depth and accuracy of dietary reconstructions in archaeological studies, contributes to a richer interpretation of archaeological findings and resolves conflicting patterns in the isotopic data.

8. Conclusion

Stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) have been studied on 36 *in situ* individuals at St. Nicholas's churchyard in the medieval town of Oslo in Norway, revealing insights into dietary variations among these individuals. The analysis of $\delta^{13}C$ indicated that the protein intake in Oslo predominantly originated from terrestrial sources, while the $\delta^{15}N$ values exhibited a consistent input of marine fish in the diet, with none of the individuals relied solely on a diet consisting of marine-based food sources. Despite Oslo's semi-coastal setting, the consistency in marine consumption is somewhat surprising. Given the proximity to the ocean, fish could be perceived as a high protein resource, yet the isotopic results suggest a more uniform pattern in marine intake. Additionally, it can be concluded that Christian dietary regulations are unlikely to have significantly altered the daily eating habits of the studied population as the isotopic nitrogen results derived from this dataset do not reveal any trend of increased marine consumption, implying that people maintained a consistent level of fish consumption over time. When it comes to agricultural production in Norway, a significant amount of livestock is considered in light of the country's landscape and climate (Bagge 1998:56). Therefore, it appears that many farmers could have relied on subsistence from farms. The abundance of arable land and grazing areas for livestock in Oslo suggests that fish held relatively lesser importance in the overall diet (Naumann et al. 2019:1125).

The conclusion can be drawn that a significant number of individuals sustained themselves on what appears to be a relatively uniform diet but diversity in dietary food sources. The comparison of stable carbon and nitrogen isotope ratios among individuals from different burial locations in the medieval churchyard of St. Nicholas highlights a mixed diet of terrestrial and marine food sources. While the availability of various food items was undoubtedly influenced by economic means, it is worth noting that specific foods were intricately tied to social status (Aven and Mathiesen 2014:17). Initially, it was anticipated that individuals buried in close proximity to the church would exhibit the high enrichment in both ^{13}C and ^{15}N, and the findings corroborated this expectation. However, the anticipated lower concentrations of ^{13}C and ^{15}N in the diet of those buried in the peripheral section of the churchyard were not confirmed due to conflicting data results. Surprisingly, individuals buried farther from the church also exhibited enrichment in both ^{13}C and ^{15}N.

Moreover, this study also tested the differences in dietary composition between the gender groups, but no such difference was observed. Hence, specific isotopic results align smoothly with information from historical sources; others are more unexpected. These findings imply that the intricacies of social differences in medieval diet and the numerous economic and cultural factors influencing them are much more complex than our current understanding allows. Although the findings may not be applicable across different contexts, this study exemplifies how individualized isotope profiles can effectively complement historical and archaeological data. Doing so offers insights into various aspects, including dietary distinctions based on sex and social factors, religious practices, the distribution of burial locations, and additional dietary behaviours.

Due to the current limitations in identifying the social hierarchy in the dietary habits of individuals at St. Nicholas's churchyard in my study, I believe that future research, especially through the use of stable isotope analyses ($\delta^{13}C$ and $\delta^{15}N$) of teeth and strontium ($\delta^{34}S$), could provide more detailed information on both the diet during childhood and the geographic origins of each individual. This integration would strengthen and complement the missing pieces to the broader picture of societal dynamics influencing dietary choices across different social strata, resulting in a more comprehensive and detailed interpretation of the archaeological context at St. Nicholas's churchyard.

Bibliography

Aars, J.
1864 *Udvalgte norske Oldkvad, som Bidrag til Kundskap om vore Forfædres Religion og Liv i Hedenold.* Cappelens Forslag, Kristiania.

Adamson, Melitta W.
2004 *Food in Medieval Times*. Greenwood Press, London.

Alexander, Michelle M., Christopher M. Gerrard, Alejandra Gutiérrez, and Andrew R. Millard
2015 Diet, society, and economy in late medieval Spain: Stable isotope evidence from Muslims and Christians from Gandía, Valencia. *American Journal of Physical Anthropology* 156(2):263–273. DOI:https://doi.org/10.1002/ajpa.22647.

Ambrose, Stanley H.
1990 Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archaeological Science* 17(4):431–451. DOI:https://doi.org/10.1016/0305-4403(90)90007-R.
1991 Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial foodwebs. *Journal of Archaeological Science* 18(3):293–317. DOI:https://doi.org/10.1016/0305-4403(91)90067-Y.
1993 Isotopic analysis of paleodiets: Methodological and interpretive considerations. In *In Investigations of Ancient Human Tissue: Chemical Analyses in Anthropology*, edited by Marry K. Sandford, pp. 59–130. Gordon and Breach Science, New York.

Ambrose, Stanley H., Jane Buikstra, and Harold W. Krueger
2003 Status and gender differences in diet at Mound 72, Cahokia, revealed by isotopic analysis of bone. *Journal of Anthropological Archaeology* 22(3):217–226. DOI:https://doi.org/10.1016/S0278-4165(03)00036-9.

Ambrose, Stanley H., and L. Norr
1993 Experimental Evidence for the Relationship of the Carbon Isotope Ratios of Whole Diet and Dietary Protein to Those of Bone Collagen and Carbonate. In *Prehistoric human bone: archaeology at the molecular level*, edited by J. B. Lambert and G. Gruppe, pp. 1–37. Springer, Berlin.

Anderson, T., and H. Göthberg
1986 Olavskirkens kirkegård : humanosteologisk analyse og faseinndeling. Vol. 2. Meddelelser (Prosjektet Fortiden i Trondheim bygrunn: folkebibliotekstomten). Riksantikvaren, Utgravningskontoret for Trondheim, Trondheim.

Andrén, Anders
2000 Ad sanctos – de dödas plats under medeltiden. *Hikuin* 27:7–26.

Anon
2023 How to Understand and Compare Box Plots. Maths at home. https://mathsathome.com/understand-and-compare-box-plots/, accessed August 11, 2023.

Austin, T.
1888 *Two fifteenth-century cookery-books: Harleian MS. 279 (ab 1430), & Harl. MS. 4016 (ab. 1450), with extracts from Ashmole MS. 1439, Laud MS. 553, & Douce MS. 55. N*. Oxford University Press, London.

Aven, Håvard B., and Henrik O. Mathiesen
2014 Intervju med Henry Notaker. *Fortid* 11(2):15–21.

Bagge, Sverre
1998 *Mennesket i middelalderens Norge: tanker, tro og holdninger 1000-1300*. Aschehoug, Oslo.

Barrett, James H., David Orton, Cluny Johnstone, Jennifer Harland, Wim Van Neer, Anton Ervynck, Callum Roberts, Alison Locker, Colin Amundsen, Inge Bødker Enghoff, Sheila Hamilton-Dyer, Dirk Heinrich, Anne Karin Hufthammer, Andrew K. G. Jones, Leif Jonsson, Daniel Makowiecki, Peter Pope, Tamsin C. O'Connell, Tessa de Roo, and Michael Richards
2011 Interpreting the expansion of sea fishing in medieval Europe using stable isotope analysis of archaeological cod bones. *Journal of Archaeological Science* 38(7):1516–1524. DOI:https://doi.org/10.1016/j.jas.2011.02.017.

Baseline-earth
How do we use and refer to the delta values? BASE-LiNE Earth. https://www.baseline-earth.eu/teaching-unit.

Bauer, Egil Lindhart
2020 Self-expression through Eponymous Tenement Plots in Medieval Oslo. In *Approaches to the Medieval Self: Representations and Conceptualisations of the Self in the Textual and Material Culture of Western Scandinavia, c. 800-1500,* edited by Stefka G. Eriksen, Karen Langsholt Holmqvist, and Bjørn Bandlien, pp. 255–278.

Beer, Sven, Mats Bjork, and John Beardall
2014 *Photosynthesis in the Marine Environment*. John Wiley & Sons, Ltd.

Benedictow, Ole
2021 *The Complete History of the Black Death*. Boydell and Brewer.

Binford, Lewis
1971 Mortuary Practices: Their Study and Potential. *Memoirs of the Society for American Archaeology* 25:6–29.

Blix, Peter
1879 Fortidslevninger i Aaslo. *Den norske Ingeniör og Arkitektforenings Organ.* Ingeniør & Arkitektforeningsens Forlag, Kristiania.

Bogaard, A., T. H. Heaton, P. Poulton, and I. Merbach
2007 The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices. *Journal of Archaeological Science* 34(3):335–343. DOI:https://doi.org/10.1016/j.jas.2006.04.009.

Brendalsmo, Jan
1996 *Livet i middelalderen*. Mykle illustrasjoner I samarbeid med PR-produksjon A/S, Tønsberg.

Brødholt, Elin T., Kaare M. Gautvik, Clara-Cecilie Günther, Torstein Sjøvold, and Per Holck
2022 Social stratification reflected in bone mineral density and stature: Spectral imaging and osteoarchaeological findings from medieval Norway. *PLOS ONE* 17(10):1–18. DOI:10.1371/journal.pone.0275448.

Brown, James
1971 The Dimension of Status in the Burials at Spiro. *Memoirs of the Society for American Archaeology* (25):92–112. DOI:https://www.jstor.org/stable/25146714.

Brown, T. A., D. E. Nelson, J. Vogel, and J. R. Southon
1988 Improved collagen extraction by modified Longin method. *Radiocarbon* 30(2):171–177. DOI:https://doi.org/10.1017/S0033822200044118.

Brown, T., and K. Brown
2011 *Biomolecular Archaeology: An Introduction*. Wiley-Blackwell, UK.

Bull, Edv.
1922 *Kristianias historie: Oslos Historie. Bind 1*. Cappelen, Christiania.

Bull, Edvard
1985 *Nordmenn før oss: norgeshistorie for den videregående skolen. Bind 1 - til 1870.* Tano.

Calvin, M., and A. A. Benson
1948 The path of Carbon in Photosynthesis. *Science* 107(2784):476–480. DOI:10.1126/science.107.2784.476.

Chinique de Armas, Yadira, Anna-Maria Mavridou, Jorge Garcell Domínguez, Kaitlyn Hanson, and Jason Laffoon
2022 Tracking breastfeeding and weaning practices in ancient populations by combining carbon, nitrogen and oxygen stable isotopes from multiple non-adult tissues. *PLOS ONE* 17(2):1–28. DOI:ttps://doi.org/10.1371/journal.pone.0262435.

Chisholm, B. S., D. E. Nelson, K. A. Hobson, H. P. Schwarcz, and M. Knyf
1983 Carbon isotope measurement techniques for bone collagen: Notes for the archaeologist. *Journal of Archaeological Science* 10(4):355–360. DOI:https://doi.org/10.1016/0305-4403(83)90073-0.

Christie, Haakon
1966 Old Oslo. *Medieval Archaeology* 10(1):45–58. DOI:10.1080/00766097.1966.11735281.

Cinthio, H., and J. Boldsen
1984 Patterns of distribution in the early medieval cemetery at Löddeköpinge. In *Meddelanden från Lunds universitets historiska museum 1983-1984*, pp. 116–127. Lund University Historical Museum, Lund.

Collinson, Lisa, Torgeir Landro, and Bertil Nilsson (editors)
2021 *The Borgarthing Law and the Eidsivathing Law: The Laws of Eastern Norway*. Routledge, New York.

Dark, K. R.
1995 *Theoretical Archaeology*. Cornell University Press, New York.

Data Visualization
2023 How do you use scatter plots to explore correlations and outliers in your data? Linkedin. https://www.linkedin.com/advice/0/how-do-you-use-scatter-plots-explore-correlations, accessed August 11, 2023.

DeNiro, Michael J.
1985 Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature* 317(6040):806–809. DOI:10.1038/317806a0.
1987 Stable isotopy and archaeology. *American Scientist* 75(2):182–191. DOI:https://www.jstor.org/stable/27854539.

DeNiro, Michael J., and Samuel Epstein
1978 Influence of diet on the distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta* 42(5):495–506. DOI:https://doi.org/10.1016/0016-7037(78)90199-0.
1981 Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et Cosmochimica Acta* 45:341–351. DOI:https://doi.org/10.1016/0016-7037(81)90244-1.

DeNiro, Michael J., and Stephen Weiner
1988 Chemical, enzymatic and spectroscopic characterization of "collagen" and other organic fractions from prehistoric bones. *Geochimica et Cosmochimica Acta* 52(9):2197–2206. DOI:https://doi.org/10.1016/0016-7037(88)90122-6.

Dennis, A., P. Foote, and R. Perkins
1980 *Laws of Early Iceland, Grágás I: The Codex Regius of Grágás With Materials From Other Manuscripts*. University of Manitoba Press, Winnipeg, Canada.

Derrick, Michael
2018 Follobaneprosjektet F04 Klypen Øst og Saxegaardsgata 15. Arkeologisk utgravning mellom Bispegata og Loenga. Middelalderparken og Saxegaardsgata 15 & 17, Oslo. Norsk institutt for kulturminneforskning, Oslo.

Derrick, Michael, and Egil Lindhart Bauer
2014 Kirkegården ved middelalderens Nikolaikirke – en adventsoppdatering. *NIKUs arkeologiblogg*. https://arkeologibloggen.niku.no/kirkegarden-ved-middelalderens-nikolaikirke-en-adventsoppdatering/, accessed March 28, 2023.

Dolphin, Alexis, Mathew Teeter, and Paul Szpak
2023 The Role of Status, Diets, and Mobility in Understanding the Impacts of Urbanization in Early Medieval Bergen, Norway (St. Mary's Church): Insights from Stable Isotope Analyses. *International Journal of Osteoarchaeology* 33. DOI:10.1002/oa.3216.

Dyer, C
1989 *Standards of living in the later middle ages: social change in England c.1200-1520*. Cambridge University Press, Cambridge.

Eide, O. E.
1974 De toskipede kirker i Oslo: et forsøk på redatering og opphavsbestemmelse med utgangspunkt i de siste utgravninger i Clemenskirken. Unpublished Thesis, University of Bergen, Bergen.

Emblem, Terje, Ivar Libæk, and Øivind Stenersen
1993 *Norgeshistorie før 1850*. Utg. 3. Cappelen Forslag A.S, Oslo.

Erik, Simensen, and Torstein Jørgensen
2021 *The Older Gulathing Law*. Routledge.

Falgayrac, Guillaume, Raffaele Vitale, Yann Delannoy, Hélène Behal, Guillaume Penel, Cécile Olejnik, Ludovic Duponchel, and Thomas Colard
2022 Bone Molecular Modifications Induced by Diagenesis Followed-Up for 12 Months. *Biology* 11(10):1–12. DOI:10.3390/biology11101542.

Farquhar, G. D., J. R. Ehleringer, and K. T. Hubick
1989 Carbon isotope discrimination and photosynthesis. *Annual review of plant physiology and plant molecular biology* 40(1):503–537. DOI:https://doi.org/10.1146/annurev.pp.40.060189.002443.

Finsen, Vilhjálmur
1852 *Grágás: Islæandernes lovbog i fristatens tid, udgivet efter det kongelige Bibliotheks Haandskrift. Vol. II*. Brødrene Berlings Bogtrykkeri, Copenhagen.

Fischer, Anders, Jesper Olsen, Mike Richards, Jan Heinemeier, Árny E. Sveinbjörnsdóttir, and Pia Bennike
2007 Coast–inland mobility and diet in the Danish Mesolithic and Neolithic: evidence from stable isotope values of humans and dogs. *Journal of Archaeological Science* 34(12):2125–2150. DOI:https://doi.org/10.1016/j.jas.2007.02.028.

Fischer, Gerhard
1950 Oslo under Eikaberg. Aschehoug, Oslo.

Fogel, Marilyn L., N. Tuross, and Douglas W. Owsley
1989 Nitrogen Isotope Tracers of Human Lactation in Modern and Archaeological Populations. *Annual Report of the Director of the Geophysical Laboratory* 88:111–117.

Fry, Brian
2006 Isotope Notation and Measurement. In *Stable Isotope Ecology*, pp. 21–39. Springer, New York.

Gejvall, Nils-Gustaf
1960 *Westerhus. Medieval population and chutch in the light of skeletal remains*. Håkan Ohlssons Boktryckeri, Lund.

Gilchrist, Roberta
2013 *Medieval Life - Archaeology and the Life Course*. Cambridge University Press.

Gjessing, Gustav A.
1899 *Den Ældre Edda. Norrøne oldkvad fra vikingetiden 9- 11 aarh. e. Chr. H.* Aschehoug &Co.s Foslag, Kristiania.

Griffin, Kerstin
1988 Plant Remains. In *De Arkeologiske utgravninger i Gamlebyen, Oslo : 5 : "Mindets Tomt"- "Søndre felt" : animal bones, moss-, plant-, insect- and parasite remains*, edited by Erik Schia and Kerstin Griffin, pp. 15–108. Alvheim & Eide akademisk forlag.

Grøn, F.
1927 *Om kostholdet i Norge indtil aar 1500*. Jacob Dybwad, Oslo.

Halley, D.J., and Jørgen Rosvold
2014 Stable isotope analysis and variation in medieval domestic pig husbandry practices in northwest Europe: absence of evidence for a purely herbivorous diet. *Journal of Archaeological Science* 49:1–5. DOI:10.1016/j.jas.2014.04.006.

Hamre, Stian S.
2011 Burial Practices in Early Christian Norway. An Osteoarchaeological Study Into Differences and Similarities Between Four Burial Assemblages. Unpublished Dissertation for the degree philosophiae doctor (PhD), University of Bergan, Norway.

Härke, Heinrich
2014 Grave goods in early medieval burials: messages and meanings. *Mortality* 19(1):1–21. DOI:10.1080/13576275.2013.870544.

Hastorf, Christine A.
1985 Dietary Reconstruction in the Andes: A New Archaeological Technique. *Anthropological Today* 1(6):19–21.

Hatch, M. D., and C. R. Slack
1966 Photosynthesis by sugar-cane leaves. A new carboxylation reaction and the pathway of sugar formation. *Biochemical Journal* 101(1):103–111. DOI:10.1042/bj1010103.

Hedges, R. E. M.
2002 Bone Diagenesis: An Overview of Processes. *Archaeometry* 44(3):319–328.

Helle, Knut
2006 *Norsk byhistorie : urbanisering gjennom 1300 år*. Pax, Oslo.

Helle, Knut, and Arnved Nedkvitne
1977 Sentrumsdannelser og byutvikling i norsk middelalder. In *Urbaniseringsprosessen i Norden. Del 1 Middelaldersteder*, edited by Grethe A. Blom, pp. 189–286. Universitetsforslaget, Trondheim.

Hoefs, Jochen
2018 *Stable Isotope Geochemistry*. Eight edition. Springer.

Holck, Per, and Sigrid I. Kvaal
2000 *Skjelettene fra Clemenskirken i Oslo*. Anatomisk institutt, Universitetet i Oslo.

Holtsmark, Anne, and Didrik A. Seip (editors)
1957 *Snorres Kongesagaer.* Gyldendal Norsk Forslag, Olso.

Hufthammer, Anne Karin
2000 Kosthold hos overklassen og hos vanlige husholdninger i middelalderen. Ensammenligning mellom animalosteologisk materiale fra Trondheim og Oslo. In *Osteologisk materiale som historisk kilde*, edited by Audun Dybdahl, pp. 163–187. Tapir Akademisk Forslag, Trondheim.

Huray, Jonathan D. Le, and Holger Schutkowski
2005 Diet and social status during the La Tène period in Bohemia: Carbon and nitrogen stable isotope analysis of bone collagen from Kutná Hora-Karlov and Radovesice. *Journal of Anthropological Archaeology* 24(2):135–147. DOI:https://doi.org/10.1016/j.jaa.2004.09.002.

Imsen, Steinar
2013 *Legislation and State Formation. Norway and its neighbours in the Middle Ages*. Akademika Publishing, Trondheim.

Iregren, Elisabeth, Hogne Jungner, Jyrki Räisänen, and Verner Alexandersen
2000 Dieten hos barn och vuxna I Westerhus: Data från spårämnen, kolisotoper och odontologi. *Hikuin* 27(27):179–202.

Isaksson, Sven
2000 Food and Rank in Early Medieval Time. Unpublished Doctoral dissertation. The Archaeological Research Laboratory. Department of Archaeology, Stockholm University, Stockholm.

Jensen, Anne Østergaard
2018 Osteologisk analyse av skjelettmaterialet fra Nikolaikirkens kirkegård. Follobaneprosjektet F04 Klypen Øst/Saxegaardsgata 15. Norsk institutt for kulturminneforskning (NIKU), Oslo.

Johannessen, L., and Jan-Erik G. Eriksson (editors)
2015 *Faglig program for middelalderarkeologi. Byer, sakrale steder, befestninger og borger*. Riksantikvaren, Oslo.

Johansen, O. V, S. Gulliksen, and R. Nydal
1986 δ13C and diet: analysis of Norwegian human skeletons. *Radiocarbon* 28:754–761.

Johansson, Karl G.
1998 Rígsþula och Codex Wormianus: Textens funktion ur ett kompilationsperspektiv. *Alvíssmál* 8:67–84.

Jonsson, Kristina

2009 Practices for the Living and the Death. Medieval and Post-reformation Burials in Scandinavia. Unpublished PhD dissertation, Department of Archaeology and Classical Studies,Stockholm University, Stockholm.

Katzenberg, M. Anne, Shelley R. Saunders, and William R. Fitzgerald
1993 Age differences in stable carbon and nitrogen isotope ratios in a population of prehistoric maize horticulturists. *American Journal of Physical Anthropology* 90(3):267–281. DOI:https://doi.org/10.1002/ajpa.1330900302.

Katzenberg, M. Anne, and A. L. Waters-Rist
2019 Stable Isotope Analysis: A tool for studying past diet, demography, and life history. In *Biological Anthropology of the Human Skeleton*, edited by M. Anne Katzenberg and A. L. Grauer, pp. 469–504. John Wiley & Sons, Inc.

Keller, Karl-Fredrik, and Erik Schia
1994 *Middelalderbyen i Oslo: en rekonstruksjon*. William Dall, Prosjekthuset produksjon AS.

Kendall, Carol, Emily M. Elliott, and Scott D. Wankel
2007 Tracing anthropogenic inputs of nitrogen to ecosystems. In *Stable isotopes in ecology and environmental science*, edited by Robert Michener and Kate Lajtha, pp. 375–449. Wiley.

Kendall, Christopher, Anne Marie Høier Eriksen, Ioannis Kontopoulos, Matthew J. Collins, and Gordon Turner-Walker
2018 Diagenesis of archaeological bone and tooth. Palaeogeography, Palaeoclimatology, *Palaeoecology* 491:21–37. DOI:https://doi.org/10.1016/j.palaeo.2017.11.041.

Keyser, R., and P. A. Munch (editors)
1846 *Norges gamle Love indtil 1387 : Første Bind. Vol. I.* Christiania.

Kieffer-Olsen, Jakob
1993 Grav og gravskik i det middelalderlige Danmark. Unpublished PhD dissertation, Aarhus University, Højbjerg.

Kjellström, A.
2005 The urban farmer: Osteoarchaeological analysis of skeletons from medieval Sigtuna interpreted in a socioeconomic perspective. Unpublished Doctoral dissertation, Department of Archaeology and Classical Studies, Stockholm University, Sweden.

Kjellström, A., J. Storå, G. Possnert, and A. Linderholm
2009 Dietary patterns and social structures in medieval Sigtuna, Sweden, as reflected in stable isotope values in human skeletal remains. *Journal of Archaeological Science* 36(12):2689–2699. DOI:https://doi.org/10.1016/J.JAS.2009.08.007.

Knudsen, T
1958 Eidsivatingsloven. In *Kulturhistorisk leksikon for nordisk middelalder fra vikingetid til reformationstid. Bind III: Datering- Epiphania*, edited by F. Hødnebø, pp. 526–528. Gyldendal Norsk Forslag, Oslo.

Krogstad, Morten, and Erik Schia
1993 *Guide to Gamlebyen and medieval Oslo*. Directorate for Cultural Heritage, Norway.

Krueger, Harold W., and Charles H. Sullivan
1984 Models for Carbon Isotope Fractionation Between Diet and Bone. In *Stable Isotopes in Nutrition*, edited by J. F. Turnland and P. E. Johnson, pp. 205–222. American Chemical Society.

Lambert, P. M.
2011 Ethics and Issues in the Use of Human Skeletal Remains in Paleopathology. In *A Companion to Paleopathology*, edited by A. L. Grauer, pp. 17–33. Blackwell Publishing.

Le Bot, B., Y. Oulhote, S. Deguen, and P. Glorennec
2011 Using and interpreting isotope data for source identification. *Trends in analytical chemistry* 30(2):302–312.

Leatherdale, Alexander J.
2013 Interpreting stable carbon and nitrogen isotope ratios in archaeological remains: An overview of the processes influencing the $\delta^{13}C$ and $\delta^{15}N$ values of type I collagen. *Totem: The University of Western Ontario* 21(1):40–50. DOI:10.5206/uwoja.v21i1.8936.

Lee-Thorp, Julia
2008 On isotopes and old bones. *Archaeometry* 60(6):925–950. DOI:10.1111/j.1475-4754.2008.00441.x.

Lee-Thorp, Julia A., Judith C. Sealy, and Nikolaas J. Van der Merwe
1989 Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet. *Journal of Archaeological Science* 16(6):585–599. DOI:https://doi.org/10.1016/0305-4403(89)90024-1.

Lidén, Hans-Emil
1969 Utgravningen av Mære kirke. Steinkjer.

Lie, R. W.
1988 Animal Bones. In *De Arkeologiske utgravninger i Gamlebyen, Oslo . Bind 5 : “Mindets Tomt”-"Søndre felt" : animal bones, moss-, plant-, insect- and parasite remains*, edited by Erik Schia and Kerstin Griffin, pp. 153–200. Alvheim & Eide akademisk forlag.
1991 Dyrebein fra Oslogt. 4 og Kanslergt. 10. In *De Arkeologiske utgravninger i Gamlebyen, Oslo . Bind 10 : Grøftegravinger*, edited by Erik Schia and Tina Wiberg, pp. 75–84. Alvheim & Eide akademisk forlag.

Longin, R.
1971 New Method of Collagen Extraction for Radiocarbon Dating. *Nature* 230:241–242. DOI:https://doi.org/10.1038/230241a0.

Makarewicz, Cheryl A., and Judith Sealy
2015 Dietary reconstruction, mobility, and the analysis of ancient skeletal tissues: Expanding the

prospects of stable isotope research in archaeology. *Journal of Archaeological Science* 56:146–158. DOI:https://doi.org/10.1016/j.jas.2015.02.035.

Malainey, M. E.
2011 *A Consumer's Guide to Archaeological Science*. Springer, New York.

Maraschi, Andrea
2019 The Impact of Christianization on Identity-Marking Foods in the Medieval North: Between Pagan Survivals, New Dietary Restrictions, and Magic Practice. *Food and History* 17(2):153–181. DOI:10.1484/J.FOOD.5.121083.

Maslin, Mark and George Swann
2006 Isotopes in Marine Sediments. In *Isotopes in Palaeoenvironmental Research*, edited by Melanie J. Leng, pp. 227–290. Springer Netherlands.

Mays, S.A., M.P. Richards, and B.T. Fuller
2002 Bone stable isotope evidence for infant feeding in Medieval England. *Antiquity* 76(293):654–656.

Mays, Simon, Joseph Edlers, Louise Humphrey, William White, and Peter Marshall
2013 *Science and the Dead A guideline for the destructive sampling of archaeological human remains for scientific analysis*. Advisory Panel on the Archaeology of Burials in England.

Mcgill, Robert, John W. Tukey, and Wayne A. Larsen
1978 Variations of Box Plots. *The American Statistician* 32(1):12–16.

Minagawa, Masao, and Eitaro Wada
1984 Stepwise enrichment of 15N along food chains: Further evidence and the relation between δ15N and animal age. *Geochimica et Cosmochimica Acta* 48(5):1135–1140. DOI:https://doi.org/10.1016/0016-7037(84)90204-7.

Molaug, Petter B. (editor)
2002 *Strategisk instituttprogram 1996-2001: norske middelalderbyer*. NIKU publikasjoner / 117. Oslo.

Moseng, Ole Georg, Erik Opsahl, Gunnar Pettersen, and Erling Sandmo
2007 *Norsk historie: 750-1537*. Universitetsforslaget.

Müldner, Gundula
2009 Investigating Medieval Diet and Society by Stable Isotope Analysis of Human Bone. In *Reflections: 50 Years of Medieval Archaeology, 1957–2007*, pp. 327–346.

Müldner, Gundula, Janet Montgomery, Gordon Cook, Rob Ellam, Andrew Gledhill, and Chris Lowe
2009 Isotopes and individuals: diet and mobility among the medieval Bishops of Whithorn. *Antiquity* 83(322):1119–1133. DOI:10.1017/S0003598X00099403.

Müldner, Gundula, and Michael P. Richards

2005 Fast or feast: reconstructing diet in later medieval England by stable isotope analysis. *Journal of Archaeological Science* 32(1):39–48. DOI:https://doi.org/10.1016/j.jas.2004.05.007.

Naumann, E., A. Z. T. Glørstad, M. P. Breiby, R. D. Mills, and P. D. Fullagar
2019 Who were the first urban settlers of Oslo? A discussion of early medieval urbanization based on isotopic analyses of human remains. *Archaeometry* 61(5):1111–1128. DOI:https://doi.org/10.1111/arcm.12469.

Naumann, Elise, T. Douglas Price, and Michael P. Richards
2014 Changes in dietary practices and social organization during the pivotal late iron age period in Norway (AD 550–1030): Isotope analyses of merovingian and viking age human remains. *American Journal of Physical Anthropology* 155(3):322–331. DOI:10.1002/ajpa.22551.

Nedkvitne, Arnved, and Per G. Norseng
1991 *Oslo Bys Historie Bind 1. Byen under Eikaberg. Fra byens oppkomst til 1536*. Cappelen Forslag A.S, Oslo.
2000 *Middelalderbyen ved Bjørvika. Oslo 1000-1536.* Cappelen Forslag A.S, Oslo.

Nicolaysen, N.
1871 Om de kongelige begravelser i Norge efter hedendommen. *Historisk Tidsskrift* 1:1–22.

Nilsen, Helge
1976 *Norrøne historieskriveres syn på de eldste norske byenes oppkomst og tidlige utvikling.* Universitetet i Bergen, Bergen.

Nilsson, B.
1994 *Kvinnor, män och barn på medeltida begravningsplatser. Vol. 3*. Lunne böcker, Uppsala.

Norseng, Per G.
1986 Nikolaikirken i Oslo - en sognekirke for Søndre Aker i middelalderen? In *Byminner*, pp. 13–28. Oslo Bymuseum, Oslo.

Notaker, Henry
1993 *Ganens makt : norsk kokkekunst og matkultur gjennom tusen år*. Aschehoug, Oslo.
2009 *Food Culture in Scandinavia*. Greenwood Press, London.

O'Leary, Marion H.
1988 Carbon Isotopes in Photosynthesis. *BioScience* 38(5):328–336.

Ostrom, Nathaniel E., and Peggy H. Ostrom
1999 Nitrogen isoptopes. In *Encyclopedia of Geochemistry*, edited by Clare P. Marshall and Rhodes W. Fairbridge, pp. 431–434. Encyclopedia of Earth Sciences Series. Springer Netherlands, Dordrecht.

O'Sullivan, Deirdre
2013 Burial of the Christian Dead in the Later Middle Ages. In *The Oxford Handbook of the Archaeology of Death and Burial*, edited by Liv Nilsson Stutz and Sarah Tarlow, pp. 259–280. Oxford University Press, UK.

Øye, I.
2002 Landbruk under press 800-1350. In *Norges Landbruks Historie I 4000 f.Kr.-1350 e.Kr. Jorda blir levevei*, pp. 215–414. Det Norske Samlaget, Oslo.

Pate, F. Donald
1994 Bone Chemistry and Paleodiet. *Journal of Archaeological Method and Theory* 1(2):161–209.

Pearson, Mike P.
1999 *The Archaeology of Death and Burial*. Texas A&M University Press, United States.

Price, T. Douglas, and Gary M. Feinman
2010 Social Inequality and the Evolution of Human Social Organization. In *Pathways to Power: New Perspectives on the Emergence of Social Inequality*, edited by T. Douglas Price and Gary M. Feinman, pp. 1–14. Springer New York, New York, NY.

Price, T. Douglas, and Elise Naumann
2015 The Peopling of the North Atlantic: Isotopic Results from Norway. *Journal of the North Atlantic* 7:88–102.

Price, T. Douglas, Margaret J. Schoeninger, and George J. Armelagos
1985 Bone Chemistry And Past Behavior: An Overview. *Journal of Human Evolution* 14(5):419–447. DOI:https://doi.org/10.1016/S0047-2484(85)80022-1.

Price, Timothy D., and Gary M. Feinman
1995 *Foundations Of Social Inequality*. Plenum Press, New York.

Pulsiano, Phillip, and Kristen Wolf (editors)
1993 *Medieval Scandinavia. An Encyclopedia*. Vol. 934. Garland, New York.

Reitsema, Laurie J., and Giuseppe Vercellotti
2012 Stable isotope evidence for sex- and status-based variations in diet and life history at medieval Trino Vercellese, Italy. *American Journal of Physical Anthropology* 148(4):589–600. DOI:https://doi.org/10.1002/ajpa.22085.

Renfrew, Colin, and Paul G. Bahn
2012 *Archaeology: theories, methods and practice*. 6th ed. Thames & Hudson, London.

Richards, Michael P.
2020 Isotope Analysis for Diet Studies. In *Archaeological Science: An Introduction*, edited by Michael P. Richards and KateEditors Britton, pp. 125–144. Cambridge University Press.

Rosvold, Jørgen, Duncan J. Halley, Anne Karin Hufthammer, Masao Minagawa, and Reidar Andersen
2010 The rise and fall of wild boar in a northern environment: Evidence from stable isotopes and subfossil finds. *Holocene (Sevenoaks)* 20(7):1113–1121.

Sackett, Dana
2017 Determining Trophic Position: Everyone Gets A Trophy, but Only the Top Doesn't Get

Eaten. The Fisheries Blog. https://thefisheriesblog.com/2017/06/04/determining-trophic-position-everyone-gets-a-trophy-but-only-the-top-doesnt-get-eaten/, accessed November 19, 2023.

Sanmark, Alexandra
2005a Dietary Regulations in Early Christian Norway. *Viking and Medieval Scandinavia* 1:203–224.
2005b Fast and Feast - Christianization through the Regulation of Everyday Life. *Viking Heritage*, 2005.

Saxe, Arthur A.
1971 Social Dimensions of Mortuary Practices in a Mesolithic Population from Wadi Haifa, Sudan. *Memoirs of the Society for American Archaeology* 25:39–57.

Scher, Steven P.
1963 Rígsþula as Poetry. *MLN* 78(4):397–404. DOI:https://doi.org/10.2307/3042821.
Schia, Erik
1995 *Oslo innerst i viken. Liv og virke i middelalderbyen*. Aschehoug, Oslo.

Schoeninger, Margaret J., and Michael J. DeNiro
1984 Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta* 48(4):625–639. DOI:https://doi.org/10.1016/0016-7037(84)90091-7.

Schoeninger, Margaret J., and Katherine Moore
1992 Bone stable isotope studies in archaeology. *Journal of World Prehistory* 6(2):247–296. DOI:10.1007/BF00975551.

Schoeninger, MJ, MJ DeNiro, and H Tauber
1983 Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science* 220(4604):1381–1383. DOI:10.1126/science.6344217.

Schurr, Mark R.
1997 Stable Nitrogen Isotopes as Evidence for the Age of Weaning at the Angel Site: A Comparison of Isotopic and Demographic Measures of Weaning Age. *Journal of archaeological science* 24(10):919–927.

Schurr, Mark R., and Mary Lucas Powell
2005 The role of changing childhood diets in the prehistoric evolution of food production: An isotopic assessment. American journal of physical anthropology 126(3):278–294.

Schutkowski, Holger
2006 *Human Ecology: Biocultural Adaptations in Human Communities. Human Ecology*. Vol. 182. Ecological Studies. Springer Berlin Heidelberg, Berlin, Heidelberg.

Schutkowski, Holger, Bernd Herrmann, Felicitas Wiedemann, Hervé Bocherens, and Gisela Grupe
1999 Diet, Status and Decomposition at Weingarten: Trace Element and Isotope Analyses on Early Mediaeval Skeletal Material. *Journal of Archaeological Science* 26(6):675–685. DOI:https://doi.org/10.1006/jasc.1998.0384.

Schwarcz, H. P., M. J. Schoeninger, and Baskaran, M.
2011 Stable Isotopes of Carbon and Nitrogen as Tracers for Paleo-Diet Reconstruction. In *Handbook of Environmental Isotope Geochemistry*, pp. 725–742.

Sealy, Judith C.
1986 *Stable carbon isotopes and prehistoric diets in the southwestern Cape Province, South Africa*. BAR International Series 293, Oxford.

Sealy, Judith C., Richard Armstrong, and Carmel Schrire
1995 Beyond lifetime averages: tracing life histories through isotopic analysis of different calcified tissues from archaeological human skeletons. *Antiquity* 69:290–300.

Selberg, Kjersti
2013 *Eldre norske rettskilder : en oversikt. 3. Utg*. Vol. 2. Juridisk biblioteks skriftserie. Juridisk bibliotek, Oslo.

Sellevold, B. J.
2001 *From death to life in medieval Hamar : skeletons and graves as historical source material*. Vol. 109. Faculty of Arts, University of Oslo, Oslo.

Skaar, Rebekka A.
2014a Matkultur i norsk middelalder: Drep meg konge, men ikke med graut! Unpublished Master Thesis, University of Oslo, Oslo.
2014b Middelalderens Kokebøker. *Fortid* 11(2):44–45.

Skaarup, B., and H. Jacobsen
1999 *Middelaldermad: kulturhistorie, kilder og 99 oppskrifter*. Gyldendal, Copenhagen.

Smith, Bruce N.
1972 Natural Abundance of the Stable Isotopes of Carbon in Biological Systems. *BioScience* 22(4):226–231. DOI:10.2307/1296391.

Staecker, Jörn
1997 *Searching for the Unknown. Gotland's churchyards from a Gender and Missionary perspective*. Lund Archaeological Review 1996 2:63–86.

Steffensen, Jón
1943 Knoglerne fra Skeljastaðir i Þjórsárdalur. In *Forntida gårdar i Island : meddelanden från den nordiska arkeologiska undersökningen i Island sommaren 1939*, edited by Mårten Stenberger, pp. 227–260. Ejnar Munksgaard, Copenhagen.

Storm, Gustav
1899 De kongelige byanlæg i Norge i middelalderen. *Historisk Tidsskrift* 3:433–436.

Sture, M., and Egil Bauer
2017 Heilag graut, franse hagar og barn døypt i øl: Skrift, arkeologi og botanikk som kjelder til matkultur i mellomalderen. *Primitive Tider* 19:43–60.

Sunde, Jørn Ø.
2012 Law, language and culture A survey of an intricate interconnection. *A Journal of Professional Communicatio*:31–40.

Tang, Harriet J. Evans, and Steven P. Ashby
2021 Of Pots and Porridge: Food, Cooking, and Serving in Old Norse Sources. *Viking and Medieval Scandinavia* 17:221–251. DOI:10.1484/J.VMS.5.126488.

Tarlow, Sarah, and Liv Nilsson Stutz
2013 *The Oxford handbook of the archaeology of death and burial. Oxford handbooks in archaeology*. Oxford University Press, Oxford.

Tauber, H
1981 ^{13}C evidence for dietary habits of prehistoric man in Denmark. *Nature* 292:332–333.

Tierney, R. Kenji, and Emiko Ohnuki-Tierney
2012 Anthropology of Food. In *The Oxford Handbook of Food History*, edited by Jeffrey M. Pilcher, pp. 117–134. online. Oxford University Press.

Tieszen, Larry L.
1991 Natural variations in the carbon isotope values of plants: Implications for archaeology, ecology, and paleoecology. *Journal of archaeological science* 18(3):227–248.

Tykot, Robert H.
2004 Stable isotopes and diet: You are what you eat. In *Physics Methods in Archaeometry*, edited by M. Martini, M. Milazzo, and M. Piacentini, pp. 433–444. IOS Press, Amsterdam.
2006 Chapter 10: Isotope Analyses and the Histories of Maize. In *Histories of Maize: Multidisciplinary Approaches to the Prehistory, Linguistics, Biogeography, Domestication, and Evolution of Maize*, edited by J. E. Staller, Robert H. Tykot, and B. F. Benz, pp. 131–142. Academic Press, New York.

Van der Merwe, N.
1989 Natural variation in 13C concentration and its effect on environment construction using ^{13}C/^{12}C ratios in animal bones. In *The Chemistry of Prehistoric Human Bone*, edited by T. Douglas Price, pp. 105–125. Cambridge University Press, UK.

Van der Merwe, N., and J. Vogel
1978 13C Content of human collagen as a measure of prehistoric diet in woodland North America. *Nature* 276:815–816. DOI:https://doi.org/10.1038/276815a0.

Van der Merwe, Nikolaas J.
1982 Carbon Isotopes, Photosynthesis, and Archaeology: Different pathways of photosynthesis cause characteristic changes in carbon isotope ratios that make possible the study of prehistoric human diets. *American scientist* 70(6):596–606.

Van der Merwe, Nikolaas J., and Ernesto Medina
1991 The canopy effect, carbon isotope ratios and foodwebs in amazonia. *Journal of archaeological science* 18(3):249–259.

Van der Sluis, Laura G., H. I. Hollung, P. U. Sandvik, S. D. Denham, and H. Kars
2016 A palaeodietary investigation of a multi-period churchyard in Stavanger, Norway, using stable isotope analysis (C, N, H, S) on bone collagen. *Journal of Archaeological Science*: Reports 9:120–133.

Van Klinken, Gert J
1999 Bone collagen quality indicators for palaeodietary and radiocarbon measurements. Journal of *Archaeological Science* 26(6):687–695.

Van Steensel, Arie
2020 Chapter Measuring urban inequalities. Spatial patterns of service access in sixteenth-century Leiden*. Firenze University Press*:369–388. DOI:10.36253/978-88-5518-053-5.23.

Vedeler, Marianne
2017 Fra kokebøker til matrester i middelalderbyen. *Primitive Tider* 19:61–77.

Veirup, H.
1993 *Til taffel hos Kong Valdemar: Europas ældste kogebog efter to middelalderhåndskrifter fra 1300tallet*. Systime.

Vogel, J., and N. Van der Merwe
1977 Isotopic evidence for early maize cultivation in New York State. *American Antiquity* 42(2):238–242. DOI:10.2307/278984.

Wickham, Hadley
2009 *Ggplot2: Elegant Graphics for Data Analysis. Use R.* Springer-Verlag, New York.

Yoder, Cassady
2010 Diet in medieval Denmark: a regional and temporal comparison. *Journal of Archaeological Science* 37(9):2224–2236. DOI:https://doi.org/10.1016/j.jas.2010.03.020.
2012 Let them eat cake? Status-based differences in diet in medieval Denmark. *Journal of Archaeological Science* 39(4):1183–1193. DOI:https://doi.org/10.1016/j.jas.2011.12.029.

Zach
2017 What Does a High F Value Mean in ANOVA? Statology. https://www.statology.org/what-does-a-high-f-value-mean/, accessed November 18, 2023.

Zoëga, Guðný
2008 Keldudalur í Hegranesi. *Skagfirðingabók* 31:1–38.
2014 Early church organization in Skagafjörður, North Iceland. The results of the Skagafjörður Church Project. *Collegium Medievale*:23–62.
2018 The Old and the Young in Early Medieval Iceland: The Evidence for Three-generational Families in the Household Cemeteries of Skagafjörður, Northern Iceland. In *Across the Generations: The old and the young in past societies*, edited by G. Lillehammer and E. Murphy, pp. 105–118. Museum of Archaeology, University of Stavanger.

Appendix – Stable isotope data

Lab No	Sample No	Grave No	DSSnumber	Gender	Age (years)	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Burial areas
Ua-52794	P289429	SA13067	8293	Child/Unknown	13-15	-22.9	10.6	3.3	Area 2
Ua-52795	P289441	SA13226	8318	Woman	18-21	-23.0	11.9	3.3	Area 2
Ua-52796	P289436	SA13611	8294	Woman	21-28	-22.7	12.2	3.3	Area 2
Ua-52797	P289444	SA14500	8306	Child/Unknown	7,5 - 9	-23.0	11.6	3.3	Area 2
Ua-52798	P289475	SA14557	8295	Woman	50-65	-21.8	12.5	3.3	Area 2
Ua-52799	P289479	SA14590	8296	Man	30-40	-21.6	12.5	3.2	Area 2
Ua-52800	P289449	SA15485	8304	Child/Unknown	9 -11	-21.7	13.7	3.2	Area 2
Ua-52801	P289431	SA15971	8287	Child/Unknown	9 -11	-21.6	12.4	3.2	Area 1
Ua-52802	P289464	SA16239	8288	Child/Unknown	4,5-6,5	-22.6	11.9	3.2	Area 1
Ua-52803	P289461	SA16885	8290	Possible man	18-25	-21.6	11.8	3.2	Area 2
Ua-52804	P289470	SA17786	8291	Possible man	28-40	-21.0	13.2	3.2	Area 2
Ua-52805	P289466	SA17961	8254	Possible woman	35-55	-22.2	12.6	3.2	Area 2
Ua-52806	P289445	SA18111	8255	Possible woman	23-50	-21.2	12.8	3.2	Area 2
Ua-52807	P289468	SA18377	8257-A	Man	35-45	-22.5	11.5	3.2	Area 2
Ua-52808	P289454	SA18878	8258	Child/Unknown	0-1	-19.9	14.8	3.2	Area 2
Ua-52809	P289480	SA19169	8259	Man	55-70	-22.0	12.8	3.2	Area 2
Ua-52810	P289474	SA19833	8262	Woman	60-80	-21.2	12.9	3.2	Area 1
Ua-52811	P289452	SA20281	8265	Possible woman	40-50	-20.9	13.5	3.2	Area 1
Ua-52812	P289488	SA20368	8267	Child/Unknown	7md(f) - 6m	-24.7	7.0	3.3	Area 2
Ua-52814	P289450	SA21073	8274	Child/Unknown	4-6	-23.4	10.9	3.3	Area 2
Ua-52815	P289494	SA20681	8270	Woman	32-42	-21.7	13.1	3.3	Area 1
Ua-52816	P289443	SA22711	8279	Possible woman	28-40	-23.4	12.5	3.2	Area 2
Ua-52817	P289437	SA23141	8244	Possible woman	21-28	-21.0	13.8	3.2	Area 2

Ua-52818	P289505	SA23806	8246	Child/Unknown	30-50	-23.0	13.1	3.3	Area 1
Ua-52819	P289439	SA23858	8247	Woman	30-45	-22.0	13.7	3.2	Area 2
Ua-52820	P289430	SA24281	8280	Possible man	28-40	-21.6	13.3	3.2	Area 1
Ua-52821	P289462	SA24133	8248	Child/Unknown	35-45	-22.7	12.0	3.2	Area 2
Ua-52822	P289503	SA25321	8308	Child/Unknown	6-8	-24.5	13.1	3.2	Area 2
Ua-52823	P289463	SA25395	8309	Child/Unknown	7-9	-24.3	12.5	3.2	Area 2
Ua-52824	P289483	SA50351	8252	Child/Unknown	11-15	-23.8	13.0	3.3	Area 1
Ua-52825	P289477	SA50519	8230-A	Woman	22-28	-23.9	13.0	3.2	Area 2
Ua-52826	P289481	SA50521	8231-A	Woman	28-35	-23.3	13.7	3.3	Area 2
Ua-52827	P289459	SA50530	8232	Child/Unknown	8-10	-24.2	12.6	3.3	Area 2
Ua-52828	P289455	SA28626	8234	Man	40-50	-24.0	13.1	3.3	Area 3
Ua-52829	P289457	SA30668	8240	Possible woman	22-30	-23.9	12.5	3.3	Area 3
Ua-52830	P289501	SA30855	8241-B	Child/Unknown	3-5	-25.2	12.1	3.2	Area 3