DIET AT MEDIEVAL ALYTUS, LITHUANIA: STABLE CARBON AND NITROGEN ISOTOPE ANALYSIS OF BONE AND DENTIN COLLAGEN

by

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ABSTRACT

The Baltic region was a vibrant center of power and economic prosperity in medieval Europe; Lithuania in particular. Until now, little stable isotopic analysis has been utilized to assess diet in this region during this time period. The aim of this study was to undertake a preliminary assessment of the composition of diet at late medieval Alytus (late 14^{th} to early 18^{th} centuries) from bone (N=35) and dentin (N=38) collagen samples. The stable carbon isotopic data suggest a diet primarily comprised of C_3 plants such as barley, rye, wheat, and flax, and animals consuming C_3 plants. The stable nitrogen isotopic data indicate the use of aquatic resources, and reflects the protein portion of the diet as including mainly terrestrial non-legumes. There are no significant differences in the pattern of resource consumption between juvenile males and females. There is a significant difference between adult males and adult females; the more depleted bone collagen $\delta^{15}N$ values indicates that adult females were consuming less protein resources, or protein resources of a lower trophic level, compared to their male counterparts. This difference could also be affected by physiological factors such as pregnancy or disease. A difference between juvenile and adult stable nitrogen isotope values might indicate latter weaning of juvenile males, the incorporation of more terrestrial or aquatic protein into juvenile male diet, the incorporation of less terrestrial or aquatic protein into adult female diet, or a combination of the three.

To my parents Bill and Diane, for their love and support.

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CHAPTER 1: INTRODUCTION

A myriad of literature is available regarding daily life and diet in medieval Europe and although medieval texts provide a limited amount of information on the diets of juveniles, females, and lower social classes stable isotope research has been used to investigate a number of issues, including weaning ages (Bourbou and Richards, 2007; Fuller et al., 2010; Mays et al., 2002; Richards et al., 2002), diachronic change in diet (Bourbou et al., 2011; Lightfoot et al., 2012; Müldner and Richards, 2007b; Reitsema, 2012; Richards et al., 2006; Yoder, 2010), differences in diet between males and females (Reitsema and Vercellotti, 2012; Richards et al., 2006), and differences in diet between social classes or status (Czermak et al., 2006; Kjellstrom et al., 2009; Le Huray and Schutkowski, 2005; Müldner et al., 2009; Reitsema et al., 2014; Schutkowski et al., 1999; Yoder, 2012). However, in Lithuania there is very little published dietary research utilizing stable isotopic analyses (e.g. Antanaitis-Jacobs et al., 2009), and none that investigate diet during the medieval period.

The medieval period (5th to the 17th centuries) was a dynamic era of change; and the agrarian revolution impacted access to food resources, populations were decimated due to the Black Plague and famine, and Catholicism spread across the entirety of Europe. All of these factors impacted the types of food medieval individuals were consuming, including Lithuanians. Conversion to Christianity occurred in varying chronology, manners, and degrees. In some areas the conversion process was unchallenged, in other areas people resisted, and in yet others Christianity was adapted syncretistically (Wesler, 2012). For an individual living in the medieval period, a basic

mark or definition of a Christian was participation in the weekly and Lenten fast days (Bynum, 1987). One way to assess how Christianity was adopted at Alytus is to examine the manner in which individuals accepted Christian practices, such as fasting and food taboos. Stable isotope analysis can be used to elucidate individual and group involvement in these types of food practices. Stable isotope analysis can illuminate dietary differences between groups, such as between males and females and between juveniles and adults. Additionally, stable isotope analysis can provide information regarding physiological processes taking place in the body.

Research Aims

The primary aim of this research is to explore the dietary patterns in individuals from the late medieval site of Alytus (late 14th to early 18th centuries), Lithuania and to investigate how social and cultural factors might have impacted access and consumption of resources. Four questions will be asked through the analysis of bone and dentin collagen stable carbon and nitrogen isotopic data:

1. What was the diet of individuals from medieval Alytus?
2. Are there dietary differences between adult males and females, or between juvenile males and females at medieval Alytus?
3. Are there dietary differences between juveniles and adults at medieval Alytus?
4. What are possible social or cultural factors influencing the types of resources that were consumed at medieval Alytus?

Stable carbon and nitrogen isotope data will be compared to other European medieval archaeological sites to explore how the dietary composition at Alytus differed from other medieval European sites. Additionally the Alytus data will be compared to faunal data from Lithuanian archaeological sites as well as a medieval Polish site to further understand the composition of Alytus human diet.

The thesis is organized as follows: Chapter 2 provides a review and summary of stable carbon and nitrogen isotope analysis and introduces the social and cultural background context for medieval Europe and medieval Lithuania specifically. Chapter 3 presents the materials and methodologies used in this study. Chapter 4 provides the results of the stable carbon and nitrogen isotope analysis for bone and dentin collagen. Chapter 5 discusses the results in relation to other archaeological sites and in the context of the social and cultural changes experienced during the medieval period. Chapter 6 provides a brief conclusion and suggestions for further research.

CHAPTER 2: LITERATURE REVIEW

Stable Isotope Analysis

The use of stable isotope analysis to understand diet in the past is based on the idea that the substances consumed through eating and drinking, are converted metabolically during life into chemical markers that can be isolated and analyzed by modern researchers (Lambert, 1997). Bioarchaeologists often use the analysis of stable carbon and nitrogen isotopes of bone and teeth because carbon and nitrogen are important elements in food (Lambert, 1997). The ratio of stable carbon and nitrogen in the consumed diet will be reflected in the ratio of stable carbon and nitrogen in skeletal remains (Price et al., 1985).

Protons, neutrons, and electrons are the three particles in an atom. The positively charged nucleus is composed of protons and neutrons, and equally negatively charged electrons are found orbiting the nucleus (Pollard et al., 2007). Neutrons are electrically neutral while protons are positively charged. Therefore, an electrically neutral atom will have the same number of electrons as protons. Protons and neutrons have approximately the same mass (Pollard et al., 2007). The number of protons in the nucleus is equal to the atomic number of an atom; this same number governs the chemical characteristics of an element and thereby differentiating between elements. Specifically, the chemical identity of an atom is dictated by the number of positively charged protons in an atom (Pollard et al., 2007). An element's isotope will have the

same number of protons as the element itself but will differ in the number of neutrons, which affects the mass of the atom (Pollard et al., 2007).

The analysis of isotopic data generally refers to the ratio of two stable isotopes. The following equations represent the calculations for the δ values for nitrogen (Equation 1):

$$\delta^{15}N_{AIR} = \left[\left(\frac{^{15}N/^{14}N\ _{Sample}}{^{15}N/^{14}N\ _{AIR}}\right) - 1\right] X\ 1000‰ \quad (1)$$

and carbon (Equation 2):

$$\delta^{13}C_{PDB} = \left[\left(\frac{^{13}C/^{12}C\ _{Sample}}{^{13}C/^{12}C\ _{PDB}}\right) - 1\ X\right] \times 1000‰ \quad (2)$$

More simply, if the sample is isotopically lighter than the standard, the δ value (for example, $\delta^{15}N$) will be negative, and if the sample is identical to the standard sample the δ value will equal zero. If the sample is isotopically heavier than the standard the δ value will be positive (Pollard et al., 2007). Therefore as the δ value of the sample becomes more positive, the sample is more isotopically heavy. Conversely as the δ value of the sample becomes more negative it is more isotopically light. The ratios of the stable isotopes are expressed as 'per mil' or parts per thousand, and use the symbol ‰. In summation, $\delta^{15}N$ refers to the difference in the $^{15}N/^{14}N$ ratio between a sample and the agreed upon standard (atmospheric air) in ‰ units (Lambert, 1997; Pollard et al., 2007; Price et al., 1985). PDB carbonate is more enriched in ^{13}C than

most biogenic materials (causing the δ value to be more positive), therefore the $\delta^{13}C$ values of bone collage are negative (Price et al., 1985). Thus a sample with a $\delta^{13}C$ value of -15.0‰ means that the sample contains 15 parts per thousand (1.5%) less ^{13}C than the PDB. Due to the fact that atmospheric air is less enriched in ^{15}N than most biogenic materials (causing the δ value to be more negative), the $\delta^{15}N$ values of bone collagen are positive (Price et al., 1985). Therefore a sample with a $\delta^{15}N$ value of 15.0‰ means that the sample contains 15 parts per thousand (1.5%) more ^{15}N than atmospheric air (Price et al., 1985).

Carbon Isotopes

Carbon has two stable isotopes: ^{12}C and ^{13}C. ^{12}C has six protons and six neutrons and can be differentiated from ^{13}C which has six protons and seven neutrons (Lambert, 1997; Pollard et al., 2007). The agreed upon standard for carbon is the CO_2 from Pee Dee Formation (PDB) in South Carolina, which is composed of Cretaceous belemnite rock (Pollard et al., 2007). ^{12}C naturally occurs at about 99%, while ^{13}C is less abundant, occurring at approximately one percent.

Plants obtain carbon from the carbon dioxide in the stratosphere during photosynthesis. Plants form carbon-carbon bonds, utilizing this carbon source and create larger molecules. The formed molecules are more enriched in ^{12}C than the atmosphere because the lighter ^{12}C isotopes form these bonds faster. This process is referred to as isotopic fractionation (Lambert, 1997). The fractionation of carbon begins with photosynthesis; cellulose is produced through the combination of CO_2 from the

atmosphere and H_2O obtained by the root system. The carbon isotopic composition of plant material ($\delta^{13}C_p$, Equation 3) is expressed as:

(3)

$$\delta^{13}C_p = \delta^{13}C_{atm} - a - (b - a)\frac{c_i}{c_a}$$

where

> "*a* is the discrimination against $^{13}CO_2$ compared to $^{12}CO_2$ during diffusion of CO_2 through air, and *b* is the discrimination in a particular plant species against ^{13}C during the carboxylation reaction. $\delta^{13}C_{atm}$ is the isotopic value of atmospheric CO_2, and c_i and c_a are the partial pressures of CO_2 within the intercellular spaces of the leaf and the atmosphere, respectively" (Pollard et al., 2007:172).

However, the isotopic fractionation process is not identical for every plant, the extent of the isotopic fractionation varies, which has an effect on the ratio of ^{12}C and ^{13}C (Lambert, 1997). There are three major pathways; the first group of plants includes trees, most grasses, and woody shrubs from temperate environments. These plants are referred to as C_3 plants because they convert CO_2 to molecules that contain three carbon atoms (Lambert, 1997). C_3 plants include wheat, barley, flax, rice, beans, tubers, nuts, and most fruits and vegetables, and have $\delta^{13}C$ signatures ranging from -33.0‰ to -22.0‰ (DeNiro, 1987). The second group of plants includes grasses from areas with high temperatures and sunny conditions in the subtropics. These plants are referred to as C_4 plants because they convert CO_2 to molecules that contain four carbon atoms (Lambert, 1997). C_4 plants include maize, sorghum, some millets, sugarcane, and

tropical grasses, and have $\delta^{13}C$ signatures ranging from -16.0‰ to -9.0‰ (DeNiro, 1987; Lee-Thorp et al., 1989; Schwarcz et al., 1985). The third group of plants includes cacti and succulents, and is referred to as CAM plants. However because they rarely contribute to diet, they are often not incorporated in investigations of past diet (Lambert, 1997).

Researchers are able to investigate the different consumption of C_3 and C_4 plants due to the significant difference in the ratio of ^{13}C to ^{12}C between the two pathways. Table 1 presents the approximate $\delta^{13}C$ values for C_3 and C_4 for plants and animals.

Table 1. Approximate $\delta^{13}C$ values for C_3 and C_4 for plants and animals*

Diet	Approximate $\delta^{13}C$ in Plants (‰)	Approximate $\delta^{13}C$ in Animals (‰)
C_3	-26.0	-21.0
Mixed Feeders	-	intermediate
C_4	-12.0	-7.0

**Adapted from Lambert (1997)*

Animals that consume C_4 plants rather than C_3 plants will have less negative $\delta^{13}C$ values. Intermediate $\delta^{13}C$ values can be found in mixed feeder herbivores. Therefore, carnivores that consume these types of herbivores may have slightly less negative $\delta^{13}C$ values (Lambert, 1997). The shift from hunter-gathering to agriculture has allowed researchers to carefully investigate the difference in the consumption of C_3 and C_4 plants. In some regions of the world the shift to agriculture is often synonymous with the increased consumption of maize, a C_4 plant, and the decreased reliance on other C_3

plant resources. Isotopically, this would be evident in collagen by the less negative $\delta^{13}C$ values, trending towards the -7.0‰ value reflected in organisms that consumed only C_4 plants (Lambert, 1997).

Compared to the carbon cycle in terrestrial plants, the carbon cycle for plants in marine contexts is much more complex. The food chain in ocean contexts begins with plankton, mollusks, and zooplankton, up to seals and predatory ocean fish (excluding humans). Mollusk meat has $\delta^{13}C$ values of approximately -18.0‰, whereas seals and predatory ocean fish have $\delta^{13}C$ values of approximately -12.0‰ (Lambert, 1997). Coastal human populations would be expected to consume more marine resources resulting in less negative $\delta^{13}C$ values than human populations consuming more terrestrial based resources. Chisholm et al. (1982) found on average an approximately 7.0‰ difference between marine and terrestrial fauna, a difference that would also be reflected in the $\delta^{13}C$ values of human consumers. This difference reflects the differences between atmospheric and oceanic carbon. Further, Chisholm et al. (1982) found that individuals consuming primarily marine diets had a mean $\delta^{13}C$ value of -13.0‰ and individuals consuming primarily terrestrial diets had a mean $\delta^{13}C$ value of -20.0‰. Caution should be used in determining freshwater resource consumption from $\delta^{13}C$ values alone as freshwater fish exhibit a great amount of variation in $\delta^{13}C$ values. This is due to the myriad of carbon sources for freshwater plants in comparison to terrestrial plants (Katzenberg, 2008). In Lake Baikal, Siberia, freshwater fish had $\delta^{13}C$ values ranging from -14.2‰ to -24.6‰ (Katzenberg and Weber, 1999). However, due to

varied differences in the $\delta^{13}C$ values the use of nitrogen isotopes allows researchers to further investigate marine resource consumption (Lambert, 1997).

Nitrogen Isotopes

Nitrogen has two stable isotopes: ^{14}N and ^{15}N. ^{14}N has seven protons and seven neutrons and can be differentiated from ^{15}N which has seven protons and eight neutrons (Lambert, 1997; Pollard et al., 2007). The agreed upon standard for nitrogen is atmospheric nitrogen (AIR), at 0.0‰ (Lambert, 1997; Pollard et al., 2007; Price et al., 1985). ^{14}N naturally occurs at 99.7%, while ^{15}N is less abundant, occurring at 0.3% (Lambert, 1997).

The use of nitrogen isotopes in diet reconstructions is used to explore the differences between marine and terrestrial diets (DeNiro, 1985). Ambrose states, “a variety of biochemical and physical processes tend to cause enrichment or depletion in foodweb $\delta^{15}N$ values, which result in variations in values within and between ecosystems” (1991:295). Much like carbon, the specific resources influences how nitrogen fractionates metabolically. Legumes have a $\delta^{15}N$ value close to 0.0‰ because they fix nitrogen directly and do not reflect isotopic fractionation. Non-legume plants have $\delta^{15}N$ values around 3.0‰ to10.0‰, animals that consume non-legume plants have $\delta^{15}N$ values around 9.0‰ to13.0‰, and carnivores that consume these animals have $\delta^{15}N$ values around 13.0‰ to16.0‰ (Ambrose, 1991; Lambert, 1997). Table 2 presents a summary of $\delta^{15}N$ values for plants and animals.

Table 2. Approximate $\delta^{15}N$ values by diet for plants and animals*

Diet	Approximate $\delta^{15}N$ in Plants (‰)	Approximate $\delta^{15}N$ in Animals (‰)
Terrestrial legumes	0.0 to 3.0	4.0 to 7.0
Terrestrial non-legumes	3.0 to 10.0	9.0 to 16.0
Marine algae	0.0	unknown
Marine plants	3.0 to 10.0	10.0 to 20.0

**Adapted from Lambert (1997)*

The trophic level effect, or food-chain effect, creates differences in $\delta^{15}N$ values. Marine resources produce an even more pronounced trophic level effect because marine resources are part of a longer food chain. This results in $\delta^{15}N$ values that range from 0.0‰ to 20.0‰ (Lambert, 1997). The impact of the trophic level effect on $\delta^{15}N$ values has been widely investigated. The majority of researchers agree that the enrichment in mammals in ^{15}N is about 3.0‰ to 5.0‰ (Ambrose, 1991; 2000; Hedges and Reynard, 2007; Tykot, 2006). The trophic level effect is produced by a consumer becoming enriched in ^{15}N over the food resource because the consumer excretes waste nitrogen, as urea, depleted in ^{15}N relative to the whole organism (Dupras and Schwarcz, 2001). Other resources, such as milk and dairy products, will also be affected by trophic level, resulting in more positive $\delta^{15}N$ values (van Klinken et al., 2000). Additional studies have found that freshwater resources such as fish will differ from marine resources in their $\delta^{15}N$ values (van Klinken et al., 2000). In Canada, river fish were found to have $\delta^{15}N$ values around 7.0‰ to 9.0‰ (Katzenberg, 1989). In the Lake Baikal region of

Siberia humans consuming both freshwater and terrestrial resources had $\delta^{15}N$ values ranging from 10.1‰ to 14.4‰ and freshwater fauna had $\delta^{15}N$ values ranging from 7.0‰ (carp) to 14.0‰ (freshwater seals) (Katzenberg and Weber, 1999).

$\delta^{15}N$ values are not only affected by resources consumed. Environmental and physiological factors can affect $\delta^{15}N$ values. In environments with minimal rainfall, such as dry, arid regions, animals reflect $\delta^{15}N$ values that are higher than those found in animals from regions with greater rainfall (Dupras and Schwarcz, 2001; Hedges and Reynard, 2007; Lambert, 1997; Pollard et al., 2007). This fact makes it extremely difficult, if not impossible to differentiate between terrestrial and marine food resources in dry coastal regions (Lambert, 1997). The difference in $\delta^{15}N$ values has been attributed to the effect of water stress. Under water stress, the $\delta^{15}N$ values will vary in animals of the same species from arid versus wetter regions (Ambrose, 1991; Dupras and Schwarcz, 2001; Hedges and Reynard, 2007; Katzenberg, 2008). Ambrose (1991) explored $\delta^{15}N$ in mammals living in arid regions and the physiological basis for variation in $\delta^{15}N$ values, proposing a model on the variable nitrogen loss in urea, which is expelled in urine. Diet is enriched in ^{15}N relative to urea, and more urea is excreted relative to the total volume of urine under conditions of water stress, and therefore, a greater amount of the lighter isotope ^{14}N is lost. This leads to a greater retention of ^{15}N in the body, where ^{15}N is available and used for tissue synthesis. The final outcome is an increase in the $\delta^{15}N$ values of tissues under prolonged water stress conditions (Ambrose, 1991; Katzenberg, 2008). The enrichment of ^{15}N in arid-region plants is also related to the increase in $\delta^{15}N$ values in desert regions (Schwarcz et al., 1999).

Protein stress is another source of elevated $\delta^{15}N$ values relative to expected diet $\delta^{15}N$ values. Protein stress is related to the water stress model above. Insufficient protein intake results in the breakdown and reutilization of existing tissues enriched in ^{15}N in the body because of preferential excretion of ^{14}N (Katzenberg, 2008). During pregnancy, the body becomes anabolic and enters positive nitrogen balance, increasing protein synthesis and decreasing the nitrogen excretion (Fuller et al., 2004). Duggleby and Jackson (2002) suggest that this can lead to 0.5‰ to 1.0‰ depleted $\delta^{15}N$ values in pregnant females and increased nitrogen retention. There are two manners in which this can take place: (1) at sites of tissue synthesis, the body can preferentially reroute more dietary amino acids from excretion and oxidation toward deposition, and (2) the decrease in $\delta^{15}N$ values in pregnant female could be affected by increased urea salvage by microflora in the colon. Clinical studies indicate that anorexia nervosa also enriches $\delta^{15}N$ values (Mekota et al., 2006). Additionally, Katzenberg and Lovell (1999) found that $\delta^{15}N$ values were affected by disease and trauma. $\delta^{15}N$ values were depleted by 0.8‰ in well-healed fractures, $\delta^{15}N$ values enriched by 2.0‰ in bone with osteomyelitis (from an individual with AIDS), $\delta^{15}N$ values were enriched in individuals with atrophy due to nutritional stress, and there was little change in $\delta^{15}N$ values in individuals with atrophy due to nerve damage. Table 3 presents a summary of some of the factors influencing $\delta^{15}N$ values.

Table 3. Summary of some environmental, physiological and metabolic factors influencing $\delta^{15}N$ values in human bone collagen*

Factor	Increase/ Decrease in $\delta^{15}N$	Known $\delta^{15}N$ Change (‰)
Trophic Level	Enrich	3.0
Arid Climates	Enrich	-
Protein Stress	Enrich	-
Starvation/ anorexia	Enrich	-
Pregnancy	Deplete	0.5 to 1.0
Healed Fracture	Deplete	0.8
Osteomyelitis	Enrich	2.0
Atrophy from Nutritional Stress	Enrich	-
Atrophy from Nerve Damage	Little Change	-

**Compiled from Ambrose, 1991, 2000; Duggleby and Jackson, 2002; Dupras and Schwarcz, 1999, 2001; Fuller et al., 2004; Hedges and Reynard, 2007; Katzenberg 2008; Katzenberg and Lovell, 1999; Tykot, 2006*

Sample Material: Bone and Dentin

Bone is made of three components: water, an inorganic fraction, and an organic matrix. Ninety percent of the organic portion of dry, fat-free bone is collagen. As stated by Price et al., “the function of collagen is to provide nucleation centers for initiating the calcification of bone” (1985:419). There is variation in the rate of turnover in skeletal

elements throughout the body due to differing densities of each skeletal element (Tykot, 2006). Bone collagen in adults represents at least the last five to seven years of life, and frequently is thought of as representing approximately the last decade of an individual's life because adult bone has a slow turnover rate.

Dentin has both mineral, 72% by dry weight, and organic components, 18% collagen by dry weight. The majority of the inorganic portion of the mineral portion is apatite (Hillson, 2003; 2005). According to Hillson, "one of the dominant features of dentine structure is the collagen, which is secreted in mats of fine fibres. Within this organic matrix the crystallites are seeded and their orientation is a further main determinant of dentine structure" (2005:184). In contrast to enamel, dentin is a living tissue. However, dentin does not turnover or continually remodel and replace tissue like bone does. Rather it is a static tissue; after the initial formation the chemical composition does not change (Dupras and Tocheri, 2007; Hillson, 2003; 2005). Dentin takes several years to completely form and is found in both the crown and root portion of the dentition. Depending on the tooth, approximately one third to three quarters of a root is formed when the tooth erupts and the remainder of the root completes formation after eruption (Scheuer and Black, 2004). The first permanent molars have begun mineralization at birth, and during the first year of life the permanent first molar begins formation. The crown is formed prior to the root, and in the first permanent mandibular molar, the crown completes formation in males at 2.5 years and in females at 2.4 years (Scheuer and Black, 2004). The root completes formation in the first permanent mandibular molar in males at 7.0 years and in females at 6.5 years (Scheuer and Black,

2004). See Table 4 for a summary of the formation timing of permanent first molars for males and females. Thus, dentin collagen will reflect the bulk diet during the early juvenile period from the first year of life to approximately seven years of age.

Table 4. Formation timing of first mandibular and maxillary molars for males and females

	M^1 and M_1	M_1	
	Mineralization	Crown Complete (Years)	Root Complete (Years)
Males	Birth	2.5	7.0
Females	Birth	2.4	6.5

Europe During the Medieval Period

Medieval Europe underwent a number of social and cultural changes including those related to agriculture, disease, and religion. Immediately prior to the Black Death there had been a decrease in the productivity of agricultural lands and livestock husbandry as a result of an increase in population density throughout Europe, which decreased the variety of available foods (Woolgar et al., 2006). In the wake of the Black Death individuals in medieval Europe saw an increase in the standards of living (Stone, 2006). The plague significantly decreased population size leading to less dense living conditions (Jankauskas and Urbanavičius, 1998). With the decrease in population there were relatively more resources available to those that survived, meaning that regardless of social status individuals had access to better and higher quality foods (Stone, 2006). This increase in food variety is most strikingly viewed in the availability of meat and dairy products (Woolgar et al., 2006).

This phenomenon can also be observed in the consumption of ale throughout Europe. Not only did the consumption of ale increase during the 1300s, the overall quality of the ale also increased (Stone, 2006). Beer was almost exclusively produced from barley, however, through the medieval period some ale was produced using wheat or hops (Stone, 2006). The changing composition of ale is also reflected in the changing landscape of agriculture; there was a shift from production of rye and maslin (a mixed crop of winter wheat and rye grown together) to wheat and other brewing grains (Moffett, 2006; Stone, 2006). Throughout most of the medieval period 75% of the calories consumed by individuals came in the form of cereals that include ales, bread, porridges, and gruels (Jankauskas and Urbanavičius, 1998).

During the medieval period those of lower status and wealth struggled to feed their families. Additionally, after the Black Death took the lives of a large portion of individuals in Europe (some estimates approximate around one third of the population died), towns were faced with a number of beggars (Adamson, 2004). The importance of bread as a cost-effective resource rose in response. It is estimated that during the medieval period the average mason's wage would buy three to four times more calories if spent on bread rather than meat (Adamson, 2004). A good (or bad) grain harvest would clearly have been very important to individuals in the medieval period, especially those in the lower classes (Jankauskas and Urbanavičius, 1998). This situation was not helped by the fluctuating prices of grain, which varied more than other food resources (Adamson, 2004). Prices were high during bad harvests when they had little grain to sell and prices were low when crops were good (Adamson, 2004). In Lithuania 54 famine

years were recorded between the 14th and the 17th centuries, averaging one famine year every seven years (Jankauskas and Urbanavičius, 1998). When crops were good and prices were low, individuals living in towns benefited because, in addition to high caloric bread, individuals could supplement their diet with higher quality (and higher priced) food resources such as meat or fish, which cost around four times as much as bread (Adamson, 2004). However, when crops were bad and grain prices doubled or tripled, skilled workers and craftsman suffered. On average skilled workers spent more than half of their income on food (Adamson, 2004).

Another manner in which the plague affected diet of individuals in the medieval period was the consumption of meat. Prior to the Black Death, meat was considered a luxury item, reserved for the wealthy, powerful, or for special occasions (Adamson, 2004; Woolgar, 2006). However, after the Black Death an increase in meat consumption can be seen across Europe. Due to the decrease in population up to 70% of fields were unplanted. These fields were in turn used for grazing livestock (Adamson, 2004). This meant that more individuals, regardless of wealth, had access to relatively more meat and dairy products such as milk, cheese, and butter. It is even estimated that meat consumption in the decades following the Black Death rose to levels that exceed modern meat consumption (Adamson, 2004). The addition of protein in the form of meat and dairy products was a significant addition to a diet that had largely been based on cereals (Woolgar, 2006).

Religion in Medieval Lithuania

Prior to the Conversion of Lithuania in 1387 Lithuanians had contact with western Christianity. As a result of conflicts and the expansion of Lithuania into Poland, a number of Christian captives were brought into the country (Fletcher, 1997). It is estimated that the number of Christians brought in under expansions would have, by the mid-14th century, outnumber native, pagan Lithuanians seven to one (Fletcher, 1997). In 1323 the Grand Duke Gediminas, one of the most influential rulers of Lithuania, sent out an open letter to a number of western cities hoping to attract skilled immigrants to Lithuania, encouraging them to bring their faith with them (Fletcher, 1997). Within Gediminas' own family a number of religions were represented. Gediminas was a pagan throughout life, but at least five of his daughters were married to Christian husbands, one of whom, Daumantas, converted to the Orthodox faith when he became ruler of the Russian statelet of Pskov (Fletcher, 1997). The rulers of Lithuania showed a high degree of religious tolerance for the time period. Papal envoys quoted Gediminas as stating that each faith or group worshipped god in their own rite (Fletcher, 1997). However, Lithuania remained a pagan country up until its conversion; Christian priests could be executed if found publically trying to convert pagan Lithuanians (Fletcher, 1997).

Ultimately the decision to convert to Catholicism was political. For a century, the grand dukes of Lithuania considered both Catholicism and Orthodoxy, using the possibility of conversion as a political tool to gain alliances (Fletcher, 1997). However, the rise in conflicts with the Teutonic Knights increased pressure on the Lithuanian

grand dukes to convert. Finally, in 1385, the Grand Duke Jogaila was baptized a Catholic, married the twelve-year-old Polish princess Jadwiga, united Poland and Lithuania under one rule, and converted the country to Catholicism (Fletcher, 1997).

Impact of the Conversion to Catholicism

Cremation was an important aspect of the burial tradition in the pagan religion in Lithuania. While there was a degree of regional variety in the practice of cremation of the dead (e.g., in the north, burials were primarily inhumations), cremation remained the primary burial pattern in the west long after the conversion to Catholicism (Rowell, 1994). In fact, some of the dead were buried outside of Christian cemeteries and burials may have included a bull or horse into the seventeenth century (Fletcher, 1997). Due to the cemetery pattern in Alytus, where individuals were buried in a general west to east pattern, it stands to reason that the individuals here practiced the Catholic faith at least to some extent (Kozakaite, 2011). It is also possible that those still practicing the pagan faith were cremated, and the cremains were deposited somewhere else entirely.

Throughout history, food has acquired symbolic meaning in different cultures. Which food is deemed suitable for consumption and how that food is prepared can be used to differentiate between groups of people (Adamson, 2004). Food practices became a focal point for Christianity; examples of this are the Eucharist and fasting practices (Adamson, 2004). Restrictions on diet would have been imposed on individuals during the medieval period more often than just during Lent, as fast days were throughout the year (Adamson, 2004). Fish was an important resource in the

medieval period, especially for those living near marine resources. Scholars do not agree on the degree of availability of fish to the lower classes. Some argue it was cheap or even free to consume (Serjeantson and Woolgar, 2006). Others argue that fish was an exclusive commodity, costing about 16 times more than bread and having less than half the calories (Adamson, 2004). Aside from its convenience to those living near water sources, religious restriction turned fish into a primary protein component in many cases, such as on fast days and during Lent. It is not clear whether fish resources would have been an available option to the poor during Lent. According to Adamson (2004), dietary restrictions associated with Lent would have represented a hardship even for elite members of society given the time of year Lent occurs. In February and March there would have been limited access to green vegetables and root vegetables. Additionally, fruit and dairy products, such as eggs and cheese, were banned during Lent by the Church (Adamson, 2004). Some scholars have asserted that it is difficult to establish from historical sources how important a resource fish was and when fish first became an important food source (Serjeantson and Woolgar, 2006).

Fasting is not specifically a Catholic ideal, rather it has been found in a variety of religions worldwide. Prior to industrialization, hunger and famine were issues dealt with by many. It is thought that some believed that by intentionally controlling their hunger they could coerce god (or the gods) to be of assistance in some manner (Adamson, 2004). Additionally, much like communal eating, communal fasting is a way to bond a group of individuals together (Adamson, 2004). Jankauskas and Urbanavičius (1998)

suggest that the outbreaks of the Black Death may have encouraged organized prayer, processions, and fasts, and could have united different social groups.

Extreme forms of fasting can be found with certain monastic groups. Some monks, or other members of the Church, practiced abstinence from foods. More specifically, this can be thought of as dry-eating, meaning that individuals consumed bread, salt, and water, occasionally supplementing their diet with fruits and vegetables (Adamson, 2004). According to Adamson (2004) the stricter dietary restrictions could be found more in East Europe rather than West Europe. Most lay people would have practiced group fasting, in which all members of a church fasted at the same time. During the medieval period Christians observed three days per week of fast, the most important and widely followed of which was Friday, in memory of Jesus' crucifixion. The other two days were, Wednesday; in memory of the day Judas accepted money to betray Jesus; and Saturday, a day of consecration to Mary and her virginity. However, the common weekly fast days varied between regions (Bynum, 1987). In eastern European countries Wednesday was a more common fast day than Saturday (Adamson, 2004). Four times a year these days of fast were held with special seriousness, termed Ember Days (Henisch, 1976). Ember Days may have originally served to replace pagan holidays; however, through the medieval period the idea spread that fasts should come before feasts (Bynum, 1987). There are two long periods of fast throughout the year, Advent and Lent. Advent, the approximately four- week period prior to Christmas, marks the beginning of the ecclesiastical year and was viewed during the medieval period as a time of renewal for both individuals and the

Church (Henisch, 1976). Lent is the approximately six-week period prior to Easter that mimics Jesus' forty days in the desert and was viewed during the medieval period as a time of penitence and forgiveness of sin (Henisch, 1976). If all of the fast days of the week, Lent, and Advent were observed, an individual during the medieval period may have fasted almost a quarter to half of the year (Adamson, 2004). Children, the very elderly, pilgrims, and beggars were exempt from fasting days. Not exempt from fasting laws were the non-homeless poor (Adamson, 2004).

Fasting refers to the abstinence of food, something that would be difficult to accomplish for the longest fast (forty days) of Lent. In the medieval period fasting referred to the abstinence of certain foods and eating only one meal a day; however, emphasis was placed not on the quantity of food consumed but rather the type of food consumed (Adamson, 2004). For the general layman, the use of the term fast to include all of these days may be misleading. The amount of food that was eaten may have remained the same but what was changed was the main ingredient, from meat to fish (Henisch, 1976). However, during fasts such as Lent the number of meals consumed each day was restricted (Henisch, 1976). Early on in Church practices fasting referred to the exclusion of meat, fish, eggs, milk, other dairy products, and wine (Adamson, 2004). By the Middle Ages fish was permitted and excluded foods referred to the meat of warm-blooded animals, milk, eggs, and other dairy products (Adamson, 2004). In 1491 these restrictions were even further relaxed allowing for the consumption of eggs, milk, and dairy products (Adamson, 2004). For the poorer classes in areas with easy access to the ocean this meant that cheap fish was the predominant protein consumed

during fasts, while individuals that lived further inland subsisted on plant foods, bread, vegetables, and legumes (Adamson, 2004). Additionally, fasting days led to the increase of meat imitation products, most notably ground almonds and almond milk. However, these would have been mainly reserved for the wealthy (Adamson, 2004).

Alytus, Lithuania

Alytus is located in the southern portion of modern Lithuania (Figure 1). The cemetery at Alytus is the largest excavated cemetery in Lithuania, containing 1,152 undisturbed graves and approximately 300 disturbed graves (Figure 2). The cemetery dates to the late 14th to early 18th centuries and is approximately 500 meters from the Alytus hill-fort, on the western bank of the Nemunas River, which was established around 1365 in order to protect the capital city of Vilnius from ongoing conflicts with the Teutonic Knights (Kozakaite, 2011).

Despite the militaristic purpose of the hill-fort, Alytus was a rural town where the majority of its citizens were employed in agrarian occupations such as agriculture, hunting, fishing, and animal husbandry (Kozakaite, 2011). In fact, it is estimated that approximately 50% of the Alytus population worked in agriculture (Faerman et al., 1997). Agrarian staples of the Lithuanian economy included grain, hides, honey, flax, and cheese (Fletcher, 1997). Gardens and fields during this time would have included cabbages, turnips, onions, beets, parsnips, wheat, barley, rye, flax, and buckwheat (French, 1970; Stančikaitė et al., 2008).

Figure 1. Map of modern Lithuania, showing the location of the site of Alytus

However, there were a number of skilled craftsmen living at Alytus; historic records indicate that there were at least 50 types, ranging from woodworkers and smiths to millers and bakers (Kozakaite, 2011).

The social stratification of individuals at Alytus is currently not fully understood, however it is likely that the medieval feudal organizations found throughout Europe at this time would also be present in the Alytus community (Kozakaite, 2011). Jankauskas and Urbanavičius (1998) argued that in Medieval/Early Modern Europe individuals would judge socioeconomic status through access to quantity and quality food resources. Individuals with a higher socioeconomic status would have had greater access to certain protein resources such as meat (Jankauskas and Urbanavičius, 1998).

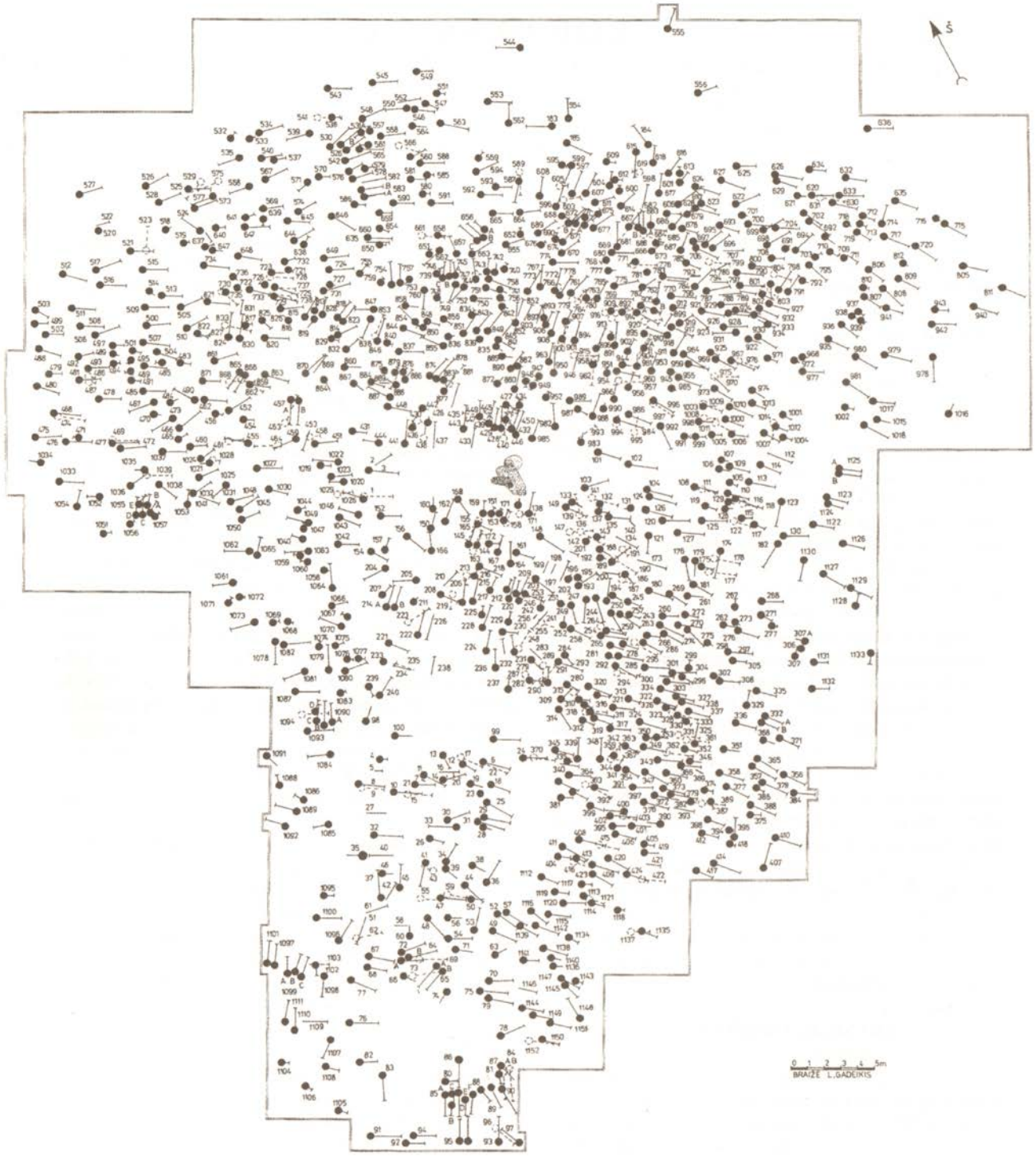

Figure 2. Alytus cemetery plan. Used with permission of R. Jankauskas from Svetikas (2003)

The cemetery at Alytus dates to an important period of religious change in Lithuania's history. The Conversion of Lithuania took place in 1387, around the earliest dates for the Alytus cemetery, indicating that the individuals buried at Alytus might be Catholic. However, the conversion to Christianity in Lithuania was complex. Lithuania was the last pagan country in Europe, and the adoption of Catholicism is considered to be the one of the most complicated processes of Christianization in history (Rowell, 1994). The conversion to Catholicism proceeded slowly in rural areas; it took 130 years after the Conversion of Lithuania for a legal religious institution to be established at Alytus (Kozakaite, 2011). Areas such as Alytus, which were established along the Nemunas River to defend Vilnius from Teutonic Knights, were often associated with pagan beliefs and, prior to the conversion, were the targets of attack (Rowell, 1994). The inconsistency between the institutionalized religion and the actual practice of this faith can be observed in the burial patterns in the Alytus cemetery (Kozakaite, 2011). Graves in Catholic cemeteries would be expected to be oriented in a west-to-east manner, and while the Alytus graves are generally oriented in this manner, there are many graves in the cemetery that deviate from this pattern. Some of the graves in Alytus included burial goods, which is contrary to Catholic burial practices, and may also indicate that pagan beliefs and practices continued (Kozakaite, 2011). However, pagan and Christian practices were sometimes combined in burial practices. For example, Hopkinson et al. (2008) found that approximately nine percent of individuals buried at the medieval and post-medieval Spanish Cathedral of Santa Maria were laid to rest with a coin placed in their mouths. The continued practice of this pagan ritual, intended to

allow the deceased to pay passage to cross the river of woe, illustrates how Catholic and pagan practices were combined in mortuary practices.

Some of the more important conflicts in Lithuania's medieval history and those that ultimately affected the decision of Lithuanian leaders to convert the country to Catholicism, were the numerous conflicts with the Teutonic Knights (Rowell, 1994). The conflict between the Lithuanians and the Teutonic Knights was reported to be especially vicious due to the pagan nature of the country prior to its conversion to Catholicism. In the 1290s, the war between the Teutonic Order and Lithuania intensified, and especially hard hit were the districts of Medininkai and Caikiai, and father to the east Ariogala and Raseiniai (Rowell, 1994). These regions were known to have been very closely associated with pagan worship and were targeted by the zealot Teutonic Knights (Rowell, 1994). A network of castles and forts were established alongside the Nemunas and Jura rivers to protect the capital city of Vilnius, and among these was the Alytus hill-fort (Kozakaite, 2011; Rowell, 1994).

Additionally, Alytus dates to a time of great disease prevalence in Europe's history. Bubonic plague affected the entirety of medieval Europe and Alytus was no exception (Adamson, 2004; Kozakaite, 2011; Jankauskas and Urbanavičius, 1998; Stone, 2006; Woolgar et al., 2006). The Black Death first broke out in parts of Europe in 1348 to 1350, with outbreaks continuing through the 17th century (Jankauskas and Urbanavičius, 1998). The plague is documented to have spread to Alytus in 1602, 1631, 1668, and 1709 to1711 taking the lives of many of the citizens of the town. However, citizens were likely affected by the plague prior to these dates (Kozakaite, 2011).

Aside from the plague there were a number of other diseases or conditions experienced by individuals of this time period. One of the most prevalent was tuberculosis. Tuberculosis became epidemic during the medieval period, and by the 1600s it is estimated that one in four deaths were a result of tuberculosis (Faerman et al., 1997). At Alytus, approximately 800 vertebral columns were preserved; of this number, 10 exhibited classical Pott's disease. Based on the fact that 5% to 7% of tuberculosis cases involve bones and joints, Faerman et al. (1997) estimated that 150 to 200 individuals suffered from tuberculosis, representing about 18% to 25% of the population of Alytus. Both males and females from Alytus were victim to tuberculosis. However, there appears to be a relative higher number of juveniles (under the age of 15 years) and elderly individuals (50 or more years of age) dying of tuberculosis (Jankauskas, 1998). This is not surprising as Jankauskas and Urbanavičius (1998) suggest that the impact of infectious disease is the greatest on those with poor nutritional status, such as malnourished children.

CHAPTER THREE: MATERIALS AND METHODS

Materials

The samples in this study originate from the Alytus cemetery (Figure 2) in Lithuania from the late 14th century to the early 18th century and were excavated between 1984 and 1986 (Kozakaite, 2011). The bone portion of the study is comprised of thirty-five samples represented by femoral shaft fragments from adult human skeletal remains. Thirty-eight dentin samples were obtained from adult first molars, both maxillary and mandibular. Thirty-four individuals are represented by both bone and dentin samples. A total of 39 different individuals were investigated in the study (Table 5). The sample of 39 individuals is comprised of 16 females (dentin, n=15; bone, n=13) and 23 males (dentin, n = 23; bone, n = 22) (Figure 3 and Table 5).

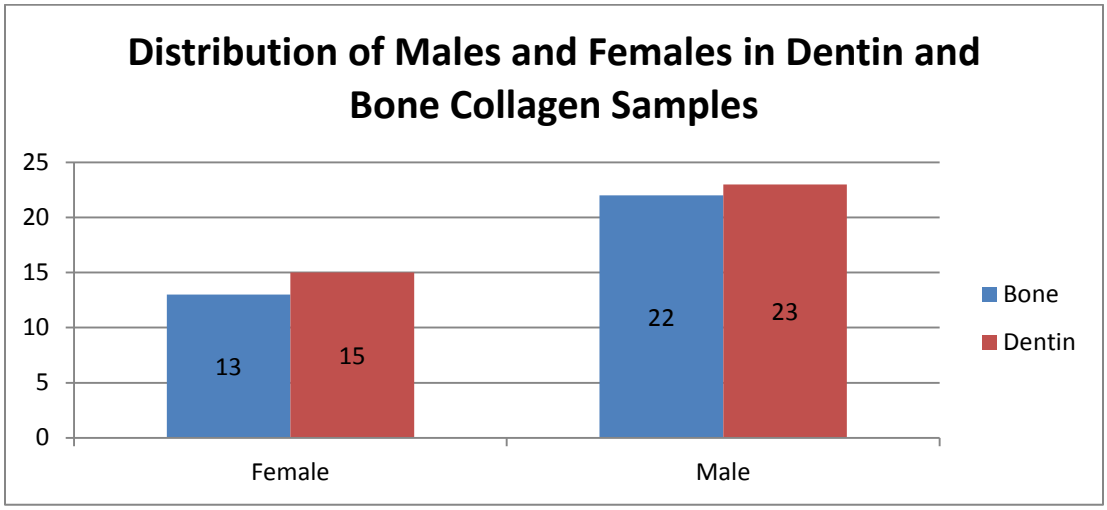

Figure 3. Distribution of males and females represented by dentin and bone collagen samples

Table 5. Summary information of individuals in the study, including sample ID, sex, age, and samples analyzed.

Sample ID	Sex	Age	Dentin	Bone
K10	female	30-35	X	X
K58	female	18-20	X	-
K155	female	20-25	X	X
K156	female	40-45	X	X
K214A	female	25-30	X	X
K269	female	50+	X	X
K426	female	35-40	X	-
K428	male	25-30	X	X
K484	female	25-30	X	-
K523	male	45-50	X	X
K543	male	20-25	X	X
K563	male	30-35	X	X
K617	female	45-50	X	X
K622	male	35-40	X	X
K706	male	50+	X	X
K727	male	20-25	X	-
K770	male	25-30	X	X
K785	male	35-40	X	X
K833	female	20-25	X	X
K849	male	35-40	X	X
K862	male	40-45	X	X
K863	male	50-55	X	X
K867	male	20-25	X	X
K888	male	25-30	X	X
K933	male	30-35	X	X
K934	female	25-30	X	X
K940	male	35-40	X	X
K1009	male	30-35	X	X
K1010	male	45-50	X	X
K1030	female	20-25	X	X
K1049	male	25-30	X	X
K1080	male	40-45	X	X
K1087	female	25-30	X	X
K1090B	male	45-50	X	X
K1115	female	35-40	X	X
K1127	male	30-35	X	X
K1149	female	35-40	-	X
K1150	female	30-35	X	X
K1152	male	20-25	X	X

The individuals in the study span a variety of adult age at death estimations with a total of one in the 18-20 age at death category (dentin, n=1), seven in the 20-25 age at death category (dentin, n= 7; bone, n= 6), eight in the 25-30 age at death category (dentin, n= 8; bone, n= 7), six in the 30-35 age at death category (dentin, n= 6; bone, n=6), seven in the 35-40 age at death category (dentin, n= 6; bone, n=6), three in the 40-45 age at death category (dentin, n= 3; bone, n=3), four in the 45-50 age at death category (dentin, n= 4; bone, n= 4, one individual in the 50-55 age at death category (dentin, n= 1; bone, n= 1), and two in the 50+ age at death category (dentin, n= 2; bone, n= 2) (Table 5 and Figure 4).

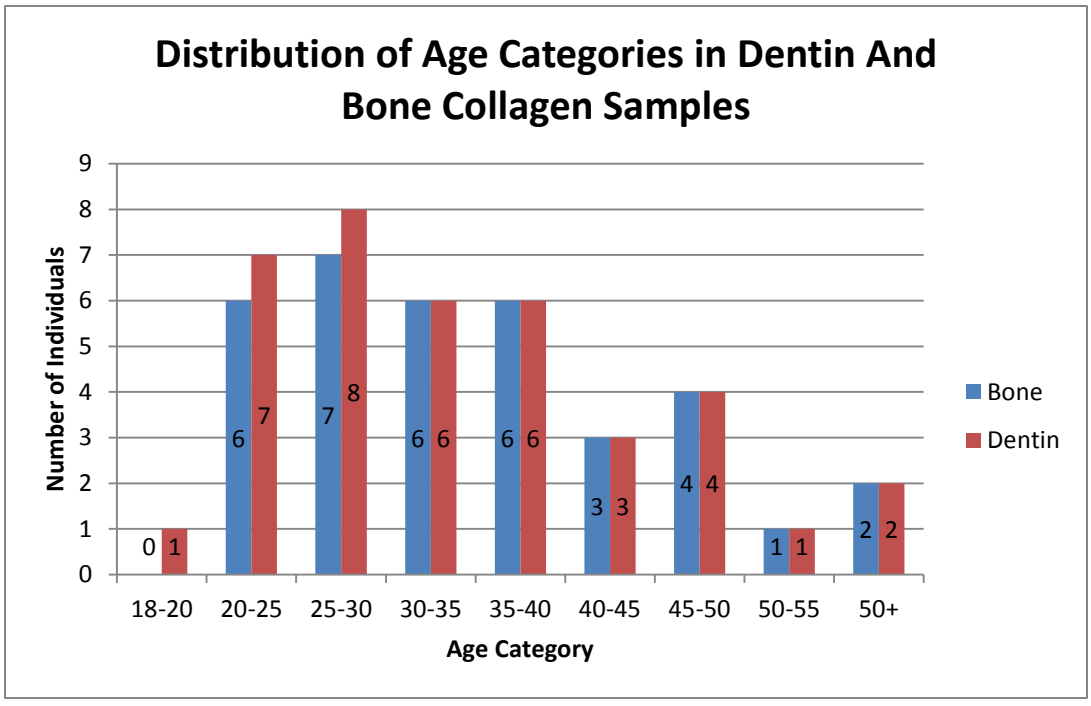

Figure 4. Distribution of individuals in age at death categories represented by dentin and bone collagen samples

The Alytus individuals were combined into three general age cohorts to assess differences in diet over the lifespan: young adult (dentin, n=16; bone, n=13), middle adult (dentin, n= 15; bone, n= 15), and old adult (dentin, n= 7; bone, n= 7) Figure 5).

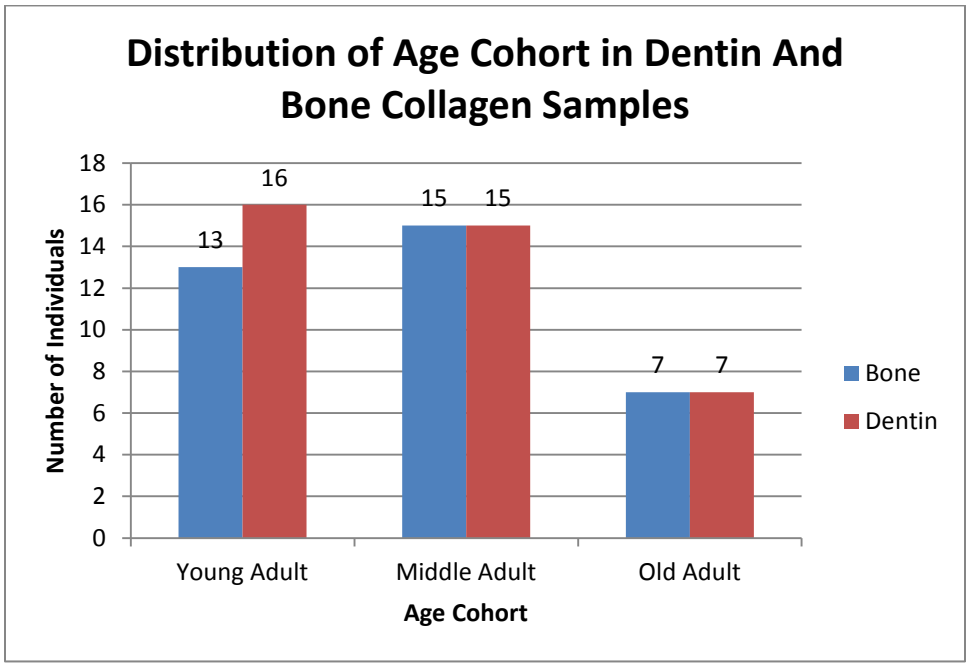

Figure 5. Distribution of individuals in age at death categories represented by dentin and bone collagen samples

A total of 20 individuals had no pathological conditions evident on the sampled skeletal element, while 15 did exhibit indications of a pathological condition on the sampled skeletal element. See Appendix A for additional descriptive information about the bone collagen samples.

Methods

Extraction of Collagen From Bone

The methodologies utilized for the extraction of collagen from the bone are a modified version of the Longin (1971) method. The bone samples were processed as follows. All samples were cleaned using ultrasonification, until all dirt and debris were removed and left to dry overnight in a 60°C oven. Bone samples were then ground into two to five millimeter fragments using a mortar and pestle, and the dry crushed weight was recorded (Appendix B for sample processing information). Each sample weighed between three and five grams. To remove lipids from the samples, each sample was treated with 2:1 chloroform: methanol mixture. The samples were left to dry overnight in the fume hood. To demineralize the samples, each sample was placed in 0.5M hydrocholoric acid (HCl). The acid in each sample was changed daily until the sample was completely deminerialized. After the samples deminerialized each sample was rinsed with distilled water until the pH of the samples was between 2.5 and 3.0. The samples were treated with 0.1M sodium hydroxide (NaOH) until all humic acids were removed. The samples were rinsed with distilled water until the pH of each sample was 7.0 ± 1.0. Then, 0.25 M HCl was added to the samples and removed, with ~5 ml of distilled water added to the samples until each sample had a pH between 2.5 and 3.0. The samples were then placed in a 90°C oven for 16 hours, in order to gelatinize. The gelatinized samples were pipetted into 2 dram glass vials and placed in 90°C oven until the remaining collagen was completely dry and exhibited a glassy or crystal-like texture.

The percent collagen yields for the samples were calculated in the following manner (Equation 4):

$$Collagen\ \%\ yield = \frac{(vial\ with\ collagen - vial\ without\ collagen)}{sample\ original\ weight} X\ 100\% \quad (4)$$

Finally, the dried gelatinized collagen was ground into a powder. Using a microgram scale, between 0.54 and 0.60 mg of the powdered, dried, gelatinized collagen was placed into 3.5 mm x 5 mm tin capsules and sent to the Colorado Plateau Stable Isotope Laboratory (CPSIL) for analysis using a Thermo- Electron DELTA V Advantage isotope ratio mass spectrometer configured through a CONFLO III using a Carlo Erba NC2100 Elemental Analyzer.

Extraction of Collagen from Dentin

The process for the extraction of collagen from bone and dentin are relatively similar. The process used to extract collagen from dentin is partially derived from the Wright and Schwarcz (1999) method. The dentin samples were processed as follows. All samples were cleaned using ultrasonification, until all dirt and debris were removed and left to dry overnight in a 60°C oven. Then, dentin samples were processed by separating the enamel from the dentin using a mortar, pestle, dental pick, and tweezers. The dry weight of the dentin was recorded. Each sample weighed between 0.48 and 1.98 grams. To demineralize the samples, each sample was placed in 0.5M and/or 0.75M hydrocholoric acid (HCl) (see the section on issues encountered during dentin collagen processing for more details). The acid in each sample was changed daily until

the sample was completely demineralized. After the samples demineralized, each sample was rinsed with distilled water until the pH of the samples was between 2.5 and 3.0. The samples were treated with 0.1M sodium hydroxide (NaOH) until all humic acids were removed. The samples were rinsed with distilled water until the pH of each sample was 7.0 ± 1.0. Then, 0.25 M HCl was added to the samples and removed, with ~5 ml of distilled water added to the samples until each sample had a pH between 2.5 and 3.0. The samples were then placed in a 90°C oven for 16 hours, in order to gelatinize. The gelatinized samples were pipetted into 2 dram glass vials and placed in 90°C oven until the remaining collagen was completely dry and exhibited a glassy or crystal-like texture. The percent collagen yields for the samples were calculated using Equation 4.

Finally, the dried gelatinized collagen was ground into a powder. Using a microgram scale, between 0.54 and 0.60 mg of the powdered, dried, gelatinized collagen was placed into 3.5 mm x 5 mm tin capsules and sent to CPSIL for analysis using a Thermo- Electron DELTA V Advantage isotope ratio mass spectrometer configured through a CONFLO III using a Carlo Erba NC2100 Elemental Analyzer.

Issues Encountered During Dentin Collage Processing

Each sample of dentin was initially placed in a single vial; however it immediately became apparent that the entire sample was not receiving sufficient contact with the HCl. To rectify this issue, samples were split into two subsamples (see Appendix A for descriptive information of dentin samples and Appendix C for sample processing information). Several samples (K10, K155, K156, K214A, K426, K428, K484, K523,

K617, K622, K727, K770, K833, K849, K862, K933, K934, K1049, K1080, K1087) had not demineralized in 0.5 M HCl after several months. In order to accelerate the demineralization process, samples were then placed in 0.75M HCl, which was changed daily. All samples placed in 0.75M HCl had demineralized after two weeks. After demineralization, these samples were processed for collagen extraction following the steps outlined in the above methodology section. Each of the dentin samples were demineralized separately as two subsamples, however each of the subsamples demineralized at the same rate and as such were processed through the humic acid removal and gelatinizing steps at the same time. Subsequently the subsamples were recombined for the final drying step and a single collagen yield was calculated.

CHAPTER 4: RESULTS

Stable carbon and nitrogen isotopes were measured in the samples by CPSIL using a Thermo- Electron DELTA V Advantage isotope ratio mass spectrometer configured through a CONFLO III using a Carlo Erba NC2100 Elemental Analyzer. The precision of the instrument was reported by CPSIL as ± 0.06 for carbon and ± 0.06 for nitrogen. Accuracy could not be calculated as multiple samples from the same individual were not analyzed.

Preservation and Collagen Yields

Preservation of collagen in dentin and bone is an important component to stable isotope analysis. Poorly preserved samples that do not meet the adequate weight percent collagen yields (wt% collagen), carbon to nitrogen ratio (C:N), weight percent carbon (wt% C), and weight percent nitrogen (wt% N) may be influenced by diagenetic contamination and should be excluded from interpretations. The equation for calculating wt% collagen yield was presented in the methods section above.

Bone Collagen

Approximately 90% of the organic component of bone is collagen (Price et al., 1985). In general, samples provide at least 5.0% collagen yield to be sufficiently preserved for study (Schoeninger et al., 1989; White and Schwarcz, 1989), however other studies maintain that collagen yield percentages between 1.0% and 3.5% are acceptable (Ambrose, 1990; 1993; Tykot, 2006). Collagen yields above 20% may

contain organic contaminants (Schoeninger et al., 1989). The wt% collagen of the bone samples from Alytus range from 3.10% to 23.92% and have a mean of 14.46% ± 7.25% (SE=1.22%) (Tables 6 and 7). Fifteen samples do not fall within the provided range; of those fifteen, all samples have a wt% collagen above 20.00%. Prior to exclusion on the basis of wt% collagen values, other measures of preservation and diagenetic contamination, such as atomic carbon to nitrogen ratio, weight percentage carbon, and weight percentage nitrogen, were considered (Schoeninger et al., 1989; Wright and Schwarcz, 1999).

The atomic carbon to nitrogen ratio (C:N ratio) provides the ratio of carbon to nitrogen (moles) in the sample. The atomic C:N ratio in fresh bone collagen that is unaltered by diagenetic contamination ranges between 2.9 and 3.6 (DeNiro, 1985). Archaeological bone with atomic C:N ratios within this range are considered sufficiently unaltered by diagenetic contamination. Collagen samples with atomic C:N ratios above 3.6 may indicate that lipid or humic acid contaminates are present in the sample. Collagen samples with C:N ratios below 2.9 may indicate that the sample is not adequately preserved for analysis and interpretation (Ambrose, 1993). The atomic C:N ratio for the bone collagen samples at Alytus range from 3.18 to 3.28 and have a mean of 3.23 ± 0.03 (SE= 0.00) (Tables 6 and 7). The atomic C:N ratios for all bone samples fall in the accepted range, indicating that the collagen for bone samples is well enough preserved for analysis and free from diagenetic contamination.

Table 6. Wt% collagen, wt% C, wt% N, and atomic C:N for bone collagen samples

Sample ID	wt% Collagen	wt %C	wt %N	Atomic C:N
K10	20.62	44.57	16.09	3.23
K155	22.12	40.81	14.70	3.24
K156	21.23	42.90	15.45	3.24
K214A	21.47	42.79	15.44	3.23
K269	7.04	42.82	15.34	3.26
K428	7.38	41.93	15.11	3.24
K523	20.51	42.40	15.26	3.24
K543	3.10	39.58	14.09	3.28
K563	6.96	41.01	14.76	3.24
K617	23.18	40.38	14.51	3.25
K622	22.11	41.63	14.99	3.24
K706	8.72	45.53	16.41	3.24
K770	7.70	43.31	15.61	3.24
K785	6.43	38.90	13.89	3.27
K833	18.99	43.88	15.83	3.23
K849	19.53	42.84	15.47	3.23
K862	7.85	41.98	15.03	3.26
K863	9.32	41.69	14.92	3.26
K867	8.91	43.87	15.96	3.21
K888	8.24	39.60	14.41	3.21
K933	21.58	43.11	15.75	3.19
K934	21.81	43.24	15.85	3.18
K940	4.48	40.05	14.41	3.24
K1009	7.67	40.07	14.59	3.20
K1010	6.26	38.64	14.02	3.21
K1030	10.97	41.25	15.00	3.21
K1049	23.92	43.64	16.01	3.18
K1080	22.50	44.01	16.00	3.21
K1087	21.79	42.91	15.65	3.20
K1090B	8.75	42.99	15.38	3.26
K1115	8.23	39.04	14.22	3.20
K1127	10.32	41.77	15.22	3.20
K1149	21.44	44.37	16.23	3.19
K1150	22.35	43.86	15.97	3.20
K1152	22.58	44.45	15.97	3.25

Table 7. Summary of weight percent collagen, atomic carbon to nitrogen, weight percentage carbon, weight percentage nitrogen, mean, standard deviation, and standard error for Alytus bone collagen samples.

	wt% Collagen	Atomic C:N Ratio	wt% C	wt% N
Minimum	3.10	3.18	38.65	13.89
Maximum	23.92	3.28	45.53	16.41
Mean	14.46	3.23	42.17	15.24
Standard Deviation	7.25	0.03	1.81	0.69
Standard Error	1.22	0.00	0.31	0.12

Satisfactory preservation is also evidenced by the weight percentage carbon (wt% C) and the weight percentage nitrogen (wt% N) which describe the weight of the carbon and nitrogen, respectively, in each collagen sample. In fresh bone collagen, the wt% C ranges from 15.3% to 47.0% (Ambrose, 1990). In the Alytus bone collagen samples the wt% C range between 38.65% to 45.53%, with a mean of 42.17% ± 1.81% (SE= 0.31%) (Table 6). The wt% C for all bone samples from Alytus falls within the accepted range. In fresh bone collagen, the wt% N ranges from 5.5% to 17.3% (Ambrose, 1990). In the Alytus bone collagen samples the wt% N range between 13.89% to 16.41% with a mean of 15.24% ± 0.69% (SE= 0.12%) (Table 6). The wt% N for all bone samples from Alytus falls within the accepted range. Based on the combination of evidence from the percentage collagen values, atomic C:N ratio, wt% C and wt% N, with an emphasis on the latter three, all bone samples were deemed adequately preserved and free from diagenetic contamination and were included in the samples for analysis.

Dentin Collagen

Similar to bone collagen, the preservation of dentin collagen is assessed through wt% collagen values, atomic C:N ratio, wt% C, and wt% N. The accepted values for each of these are the same as those presented above for bone collagen (Wright and Schwarcz, 1999). Table 8 presents the wt% collagen, atomic C:N ratio, wt% C, and wt% N values for each of the Alytus dentin collagen samples. The wt% collagen yields for the Alytus dentin samples ranged from 4.17% to 18.24% with a mean of 12.59% ± 2.61% (SE= 0.42%) (Tables 8 and 9). All of the Alytus dentin samples fall within the accepted range for wt% collagen yields. The atomic C:N ratio for the Alytus dentin samples range between 3.16 and 3.34 with a mean of 3.22 ±0.03 (SE= 0.00) (Tables 8 and 9). All of the Alytus dentin samples fall within the accepted range for atomic C:N ratio. The wt% C for the Alytus dentin samples ranges from 28.48% to 46.50% with a mean of 43.84% ± 2.88% (SE= 0.47%) (Tables 8 and 9). All of the Alytus dentin samples fall within the accepted range for wt% C. The wt% N for the Alytus dentin samples ranges from 9.96% to 16.79% with a mean of 15.87% ± 1.08% (SE= 0.18%) (Tables 8 and 9). All of the Alytus dentin samples fall within the accepted range for wt% N. Based on the combination of evidence from the wt% collagen, atomic C:N ratio, wt% C and wt% N values, all dentin samples were deemed adequately preserved and free from diagenetic contamination and were included in the samples for analysis.

Table 8. Wt% collagen, wt% C, wt% N, and atomic C:N for dentin collagen samples

Sample ID	wt% Collagen	%C	%N	Atomic C:N
K10	13.21	43.53	15.72	3.23
K58	11.69	42.83	15.44	3.24
K155	14.64	45.35	16.36	3.23
K156	15.03	45.41	16.34	3.24
K214A	18.24	44.40	16.04	3.23
K269	13.71	45.77	16.39	3.26
K426	15.00	44.98	16.22	3.23
K428	11.92	44.30	15.96	3.24
K484	12.70	46.16	16.69	3.23
K523	12.13	45.64	16.46	3.23
K543	4.17	43.09	15.73	3.20
K563	12.39	46.50	16.79	3.23
K617	15.10	44.66	16.18	3.22
K622	14.08	45.26	16.42	3.22
K706	12.09	44.91	16.23	3.23
K727	12.28	45.39	16.47	3.22
K770	12.65	44.43	16.13	3.21
K785	8.72	43.63	15.97	3.19
K833	12.14	44.48	16.10	3.22
K849	12.40	44.75	16.24	3.21
K862	12.83	45.08	16.36	3.21
K863	12.61	45.16	16.10	3.27
K867	10.25	41.93	15.49	3.16
K888	8.94	43.18	15.77	3.20
K933	11.21	44.40	16.12	3.21
K934	13.91	44.06	16.03	3.21
K940	8.63	40.57	14.68	3.22
K1009	11.83	43.04	15.67	3.20
K1010	11.36	45.02	16.31	3.22
K1030	10.19	41.66	15.26	3.18
K1049	15.97	42.67	15.38	3.24
K1080	13.57	44.58	16.20	3.21
K1087	13.47	44.65	16.23	3.21
K1090B	12.37	28.48	9.96	3.34
K1115	9.14	41.72	15.01	3.24
K1127	16.54	44.33	15.96	3.24
K1150	15.92	45.32	16.33	3.24
K1152	15.45	44.77	16.40	3.19

Table 9. Summary of weight percent collagen, atomic carbon to nitrogen, weight percentage carbon, weight percentage nitrogen, mean, standard deviation, and standard error for Alytus dentin collagen samples.

	wt% Collagen	Atomic C:N Ratio	wt% C	wt% N
Minimum	4.17	3.16	28.48	9.96
Maximum	18.24	3.34	46.50	16.79
Mean	12.59	3.22	43.84	15.87
Standard Deviation	2.61	0.03	2.88	1.08
Standard Error	0.42	0.00	0.47	0.18

Bone Collagen

$\delta^{13}C$ Values

Thirty-five bone collagen samples were analyzed and the $\delta^{13}C$ values for each of these individuals can be found in Table 10. The mean $\delta^{13}C$ value for these individuals is -20.08‰ ± 0.26‰ (SE= 0.04‰) and range from -20.59‰ to -19.54‰ (Table 11). Overall, the mean of -20.08‰ for the $\delta^{13}C$ values in the Alytus bone collagen samples indicate that individuals were consuming primarily C_3 plants during the last decade of their adult life, and likely consuming small amounts of aquatic protein resources. The mean $\delta^{13}C$ value for the 13 females represented by bone collagen samples is -20.16‰ ± 0.19‰ (SE= 0.05‰) and range from -20.59‰ to -19.96‰ (Table 10). The mean $\delta^{13}C$ value for the 22 males represented by bone collagen samples is -20.03‰ ± 0.28‰ (SE= 0.06‰) and range from -20.58‰ to -19.54‰ (Table 11).

Table 10. $\delta^{13}C$ values for bone collagen samples

Sample ID	$\delta^{13}C$ (‰)
K10	-20.02
K155	-19.96
K156	-20.59
K214A	-20.00
K269	-20.41
K428	-20.28
K523	-20.32
K543	-20.13
K563	-20.11
K617	-20.07
K622	-19.91
K706	-20.34
K770	-19.96
K785	-19.99
K833	-20.23
K849	-19.87
K862	-19.54
K863	-20.50
K867	-19.90
K888	-19.59
K933	-20.31
K934	-20.18
K940	-19.76
K1009	-19.79
K1010	-19.99
K1030	-19.98
K1049	-19.96
K1090B	-20.09
K1080	-20.04
K1087	-20.32
K1115	-20.03
K1127	-19.66
K1149	-20.02
K1150	-20.28
K1152	-20.58

Table 11. Mean, minimum, maximum, standard deviation, standard error, variance, and confidence interval (95%) for $\delta^{13}C$ for the overall Alytus population, sex, age at death category, and presence of pathological indication on selected element

				$d^{13}C$(‰)						
		Tissue	N	Mean	Minimum	Maximum	Standard Deviation	Standard Error	Variance	Confidence Interval (95%)
Overall		Bone	35	-20.08	-20.59	-19.54	0.26	0.04	0.07	0.09
		Dentin	38	-20.11	-20.80	-19.45	0.30	0.05	0.09	0.10
Sex	**Female**	Bone	13	-20.16	-20.59	-19.96	0.19	0.05	0.04	0.11
		Dentin	15	-20.10	-20.80	-19.58	0.32	0.08	0.11	0.16
	Male	Bone	22	-20.03	-20.58	-19.54	0.28	0.06	0.08	0.12
		Dentin	23	-20.11	-20.66	-19.45	0.29	0.06	0.08	0.12
Age Category	**YA**	Bone	13	-20.08	-20.58	-19.59	0.24	0.07	0.06	0.13
		Dentin	16	-20.11	-20.62	-19.68	0.26	0.07	0.07	0.13
	MA	Bone	15	-19.99	-20.59	-19.54	0.27	0.07	0.07	0.13
		Dentin	15	-20.07	-20.80	-19.45	0.37	0.10	0.14	0.19
	OA	Bone	7	-20.24	-20.50	-19.99	0.20	0.07	0.04	0.14
		Dentin	7	-20.17	-20.44	-19.85	0.23	0.09	0.05	0.17
Pathological Indication	**Yes**	Bone	15	-20.05	-20.59	-19.59	0.27	0.07	0.07	0.14
	No	Bone	20	-20.10	-20.58	-19.54	0.25	0.06	0.06	0.11

There are no significant differences in $\delta^{13}C$ values between males and females (p= 0.071), between males and the overall bone sample (p= 0.249), or between females and the overall bone sample (p= 0.147) for bone collagen (Table 12).

Table 12. T-test results for $\delta^{13}C$ of bone and dentin collagen for sex subsamples at Alytus

	Overall Bone	Overall Dentin	Male Bone	Male Dentin	Female Bone	Female Dentin
Overall Bone	-	0.310	0.249	0.313	0.147	0.371
Overall Dentin	-	-	0.150	0.486	0.286	0.147
Male Bone	-	-	-	0.162	0.071	0.222
Male Dentin	-	-	-	-	0.299	0.472
Female Bone	-	-	-	-	-	0.299
Female Dentin	-	-	-	-	-	-

Significance level was set to ≤0.05

Age at death cohorts were constructed based on the demographic age estimations provided for each individual. Three age at death cohorts were used, young adult (YA), middle adult (MA), and old adult (OA). Individuals with demographic age at death estimations of 18-20, 20-25, and 25-30 years were included in the YA age at death cohort. Individuals with demographic age at death estimations of 30-35, 35-40, and 40-45 years were included in the MA age at death cohort. Individuals in the 45-50, 50-55, and 50+ years were included in the OA age at death cohort. Age at death cohorts were arbitrarily constructed by dividing the age at death estimations roughly equally, in order to investigate general isotopic differences as related to age. However, any noted differences or similarities reflect generalized trends and may not reflect biological or social differences related to age. Mean $\delta^{13}C$ values and $\delta^{13}C$ ranges for

bone collagen in each age at death cohort can be found in Table 11. The mean $\delta^{13}C$ value for bone collagen in the 13 individuals in the YA age at death cohort is -20.08‰ ± 0.24‰ (SE= 0.07‰) and range from -20.58‰ to -19.59‰. The mean $\delta^{13}C$ value for bone collagen in the 15 individuals in the MA age at death cohort is -19.99‰ ± 0.27‰ (SE= 0.07‰) and range from -20.59‰ to -19.54‰. The mean $\delta^{13}C$ value for bone collagen in the seven individuals in the OA age at death cohort is -20.24‰ ± 0.20‰ (SE= 0.07‰) and range from -20.50‰ to -19.99‰. There is no significant difference in the $\delta^{13}C$ values between the YA and MA age at death cohorts (p= 0.186) and between the YA and OA age at death cohorts (p= 0.073) for bone collagen samples (Table 13). There is a significant difference in the $\delta^{13}C$ values between the MA and OA age at death cohorts (p= 0.019) for bone collagen samples (Table 13).

Table 13. T-test results for $\delta^{13}C$ of bone collagen for age at death cohort subsamples

	YA	MA	OA
YA	-	0.186	0.073
MA	-	-	**0.019**
OA	-	-	-

Significance level was set to ≤0.05
Significant differences are bolded

$\delta^{15}N$ Values

Thirty-five bone collagen samples were analyzed and the $\delta^{15}N$ values for each of these individuals can be found in Table 14. The mean $\delta^{15}N$ value for bone collagen is 10.29‰ ± 0.91‰ (SE= 0.15‰) and range from 8.69‰ to 12.15‰ (Table 15). Overall, the mean of 10.29‰ for the $\delta^{15}N$ values for the Alytus bone collagen samples indicate

individuals were primarily consuming terrestrial fauna during the last decade of their adult life. The mean and range of $\delta^{15}N$ values for the Alytus adults may also indicate the consumption of freshwater resources. The mean $\delta^{15}N$ value for bone collagen in the 13 females is 9.95‰ ± 0.92‰ (SE= 0.25‰) and range from 8.78‰ to 11.56‰ (Table 15). The mean $\delta^{15}N$ value for bone collagen in the 22 males is 10.49‰ ± 0.87‰ (SE= 0.19‰) and range from 8.69‰ to 12.15‰ (Table 15). There are no significant differences in $\delta^{15}N$ values between adult males and the overall bone sample (p= 0.208) or between adult females and the overall bone sample (p= 0.130) for bone collagen samples. There is a significant difference between adult males and adult females (p= 0.046) (Table 16).

Mean $\delta^{15}N$ values and $\delta^{15}N$ ranges for bone collagen in each age at death cohort can be found in Table 11. The mean $\delta^{15}N$ value for bone collagen in the 13 individuals in the YA age at death cohort is 10.32‰ ± 0.84‰ (SE= 0.23‰) and range from 8.78‰ to 12.15‰. The mean $\delta^{15}N$ value for bone collagen in the 15 individuals in the MA age at death cohort is 10.42‰ ± 1.06‰ (SE= 0.27‰) and range from 8.69‰ to 11.95‰. The mean $\delta^{15}N$ value for bone collagen in the seven individuals in the OA age at death cohort is 9.95‰ ± 0.71‰ (SE= 0.27‰) and range from 8.92‰ to 10.89‰. There is no significant difference in the $\delta^{15}N$ values between the YA and MA age at death cohorts (p= 0.388), between the YA and OA age at death cohorts (p=0.170), or between the MA and OA age at death cohorts (p= 0.148) for bone collagen samples (Table 17).

Table 14. $\delta^{15}N$ values for bone collagen samples

Sample ID	$\delta^{15}N$ (‰)
K10	8.81
K155	10.65
K156	8.85
K214A	10.64
K269	9.31
K428	9.94
K523	9.72
K543	10.54
K563	11.35
K617	10.89
K622	10.16
K706	9.84
K770	10.50
K785	10.59
K833	8.78
K849	11.95
K862	11.71
K863	8.92
K867	10.74
K888	12.15
K933	8.69
K934	10.43
K940	10.02
K1009	9.88
K1010	10.48
K1030	9.57
K1049	10.85
K1090B	10.47
K1080	10.80
K1087	9.17
K1115	10.41
K1127	11.25
K1149	11.56
K1150	10.28
K1152	10.14

Table 15. Mean, minimum, maximum, standard deviation, standard error, variance, and confidence interval (95%) for $\delta^{15}N$ for the overall Alytus population, sex, age at death category, and presence of pathological indication on selected element

				$d^{15}N$(‰)						
		Tissue	N	Mean	Minimum	Maximum	Standard Deviation	Standard Error	Variance	Confidence Interval (95%)
Overall		Bone	35	10.29	8.69	12.15	0.91	0.15	0.83	0.30
		Dentin	38	10.66	9.08	12.43	0.91	0.15	0.82	0.29
Sex	**Female**	Bone	13	9.95	8.78	11.56	0.92	0.25	0.84	0.50
		Dentin	15	10.53	9.09	12.42	0.95	0.25	0.90	0.48
	Male	Bone	22	10.49	8.69	12.15	0.87	0.19	0.75	0.36
		Dentin	23	10.74	9.08	12.43	0.89	0.19	0.79	0.36
Age Category	**YA**	Bone	13	10.32	8.78	12.15	0.84	0.23	0.71	0.46
		Dentin	16	10.60	9.09	12.43	0.89	0.22	0.79	0.44
	MA	Bone	15	10.42	8.69	11.95	1.06	0.27	1.12	0.53
		Dentin	15	10.93	9.08	12.42	0.96	0.25	0.93	0.49
	OA	Bone	7	9.95	8.92	10.89	0.71	0.27	0.50	0.52
		Dentin	7	10.20	9.44	11.01	0.70	0.26	0.48	0.52
Pathological Indication	**Yes**	Bone	15	10.31	8.85	12.15	0.78	0.20	0.61	0.39
	No	Bone	20	10.27	8.69	11.95	1.02	0.23	1.04	0.45

Table 16. T-test results for $\delta^{15}N$ of bone and dentin collagen for subsamples at Alytus

	Overall Bone	Overall Dentin	Male Bone	Male Dentin	Female Bone	Female Dentin
Overall Bone	-	**0.043**	0.208	**0.032**	0.130	0.203
Overall Dentin	-	-	0.239	0.360	**0.010**	0.320
Male Bone	-	-	-	0.167	**0.046**	0.449
Male Dentin	-	-	-	-	**0.008**	0.239
Female Bone	-	-	-	-	-	0.058
Female Dentin	-	-	-	-	-	-

Significance level was set to ≤0.05
Significant differences are bolded

Table 17. T-test results for $\delta^{15}N$ of bone collagen for age at death cohort subsamples

	YA	MA	OA
YA	-	0.388	0.170
MA	-	-	0.148
OA	-	-	-

Significance level was set to ≤0.05
Significant differences are bolded

$\delta^{13}C$ and $\delta^{15}N$ Values

Overall, the Alytus bone collagen sample has a greater range in $\delta^{15}N$ values than in the $\delta^{13}C$ values (Figure 6). Bone collagen samples cluster and generally follow a linear trend (r^2= 0.443), individuals with more positive $\delta^{15}N$ values also tend to have more positive $\delta^{13}C$ values and individuals with more negative $\delta^{15}N$ values tend to have more negative $\delta^{13}C$ values.

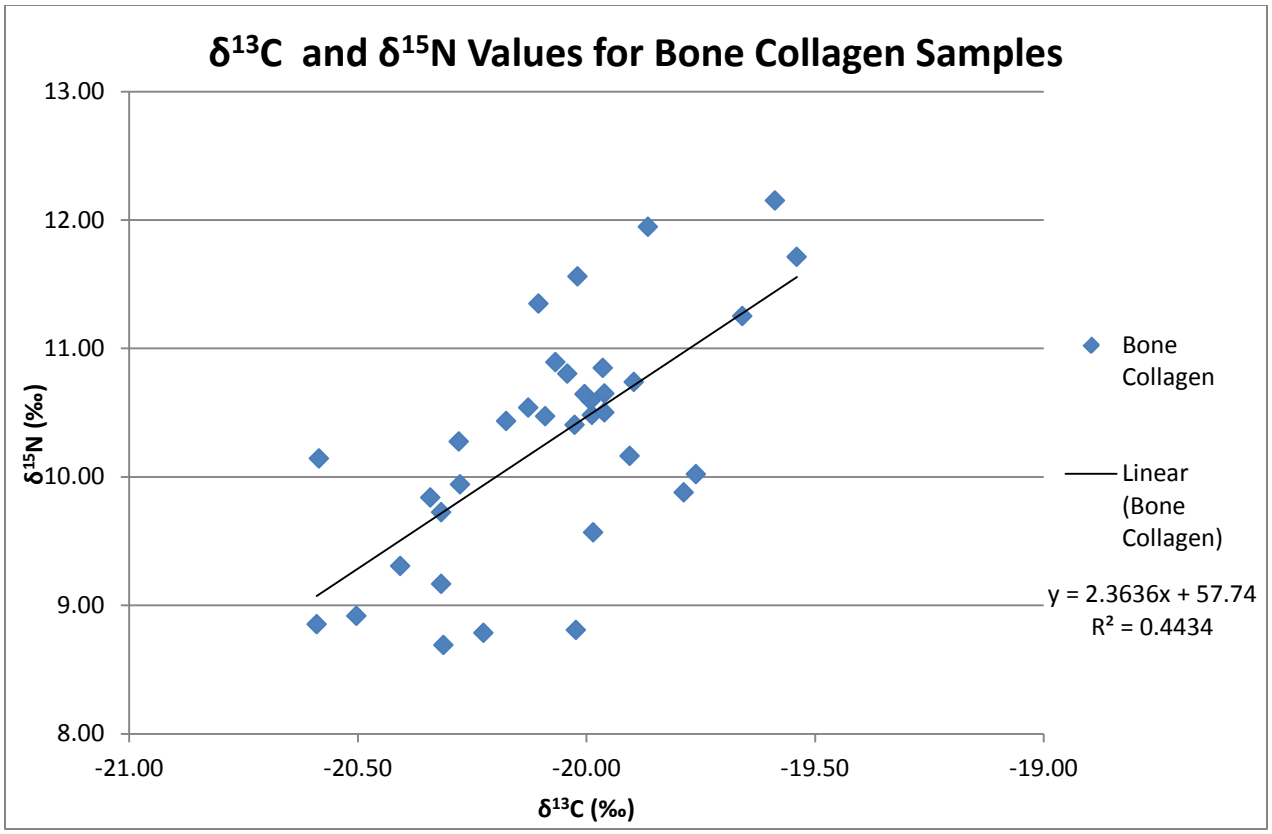

Figure 6. $\delta^{13}C$ and $\delta^{15}N$ values for all individuals in the Alytus bone collagen sample

This pattern might reflect the consumption of aquatic resources by individuals at Alytus. No individual appears to be a clear outlier in the overall adult sample.

Males in the bone collagen sample are represented throughout the entire range of $\delta^{13}C$ and $\delta^{15}N$ values for bone collagen in the overall Alytus sample (Figure 7). Males do not cluster and appear to be fairly evenly distributed throughout the entire sample. However, the eight most positive $\delta^{13}C$ values for bone collagen are all male and five of the six most positive $\delta^{15}N$ values are male. Females in the bone collagen sample are not represented throughout the entire range of $\delta^{13}C$ and $\delta^{15}N$ values in the overall

Alytus sample (Figure 7). Females are present in almost the entire Alytus $\delta^{15}N$ value range for bone collagen, excluding the 0.59‰ most positive portion of the $\delta^{15}N$ range. The $\delta^{13}C$ values for bone collagen in the entire Alytus sample only span just over 1.00‰, and of that, females are not represented in the 0.42‰ most positive portion of the $\delta^{13}C$ value range (Figure 7).

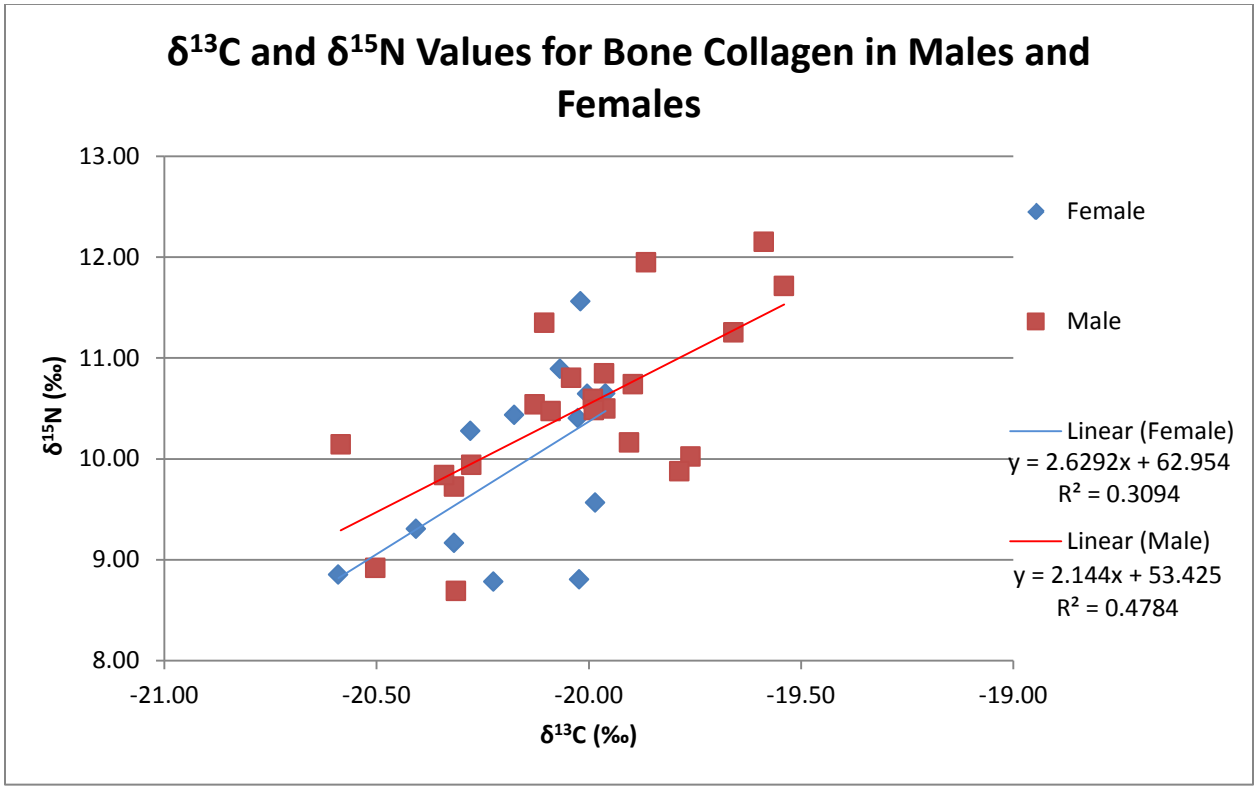

Figure 7. $\delta^{13}C$ and $\delta^{15}N$ values for males and females in the bone collagen sample

The MA age at death cohort is found throughout the entirety of the ranges of $\delta^{13}C$ and $\delta^{15}N$ values for bone collagen (Figure 8). The majority of the individuals in the YA age at death cohort have $\delta^{13}C$ values and $\delta^{15}N$ values in the more depleted portion of the $\delta^{13}C$ and $\delta^{15}N$ ranges for bone collagen. One individual (individual K888, male,

25-30 years at death) is the exception in the YA age at death cohort, and has enriched $\delta^{13}C$ (-19.59‰) and $\delta^{15}N$ values (12.15‰) for bone collagen. Interestingly, a similar pattern was observed in the bone collagen $\delta^{13}C$ and $\delta^{15}N$ values of adult female individuals at Alytus. However, only approximately half of the individuals in the YA age at death cohort are female. All of the individuals in the OA age at death cohort are only found in the more depleted portion of the $\delta^{13}C$ and $\delta^{15}N$ ranges for bone collagen. Again, this pattern was observed in the bone collagen $\delta^{13}C$ and $\delta^{15}N$ values for adult female individuals at Alytus. However, less than 30% of the individuals in the OA age at death cohort are female.

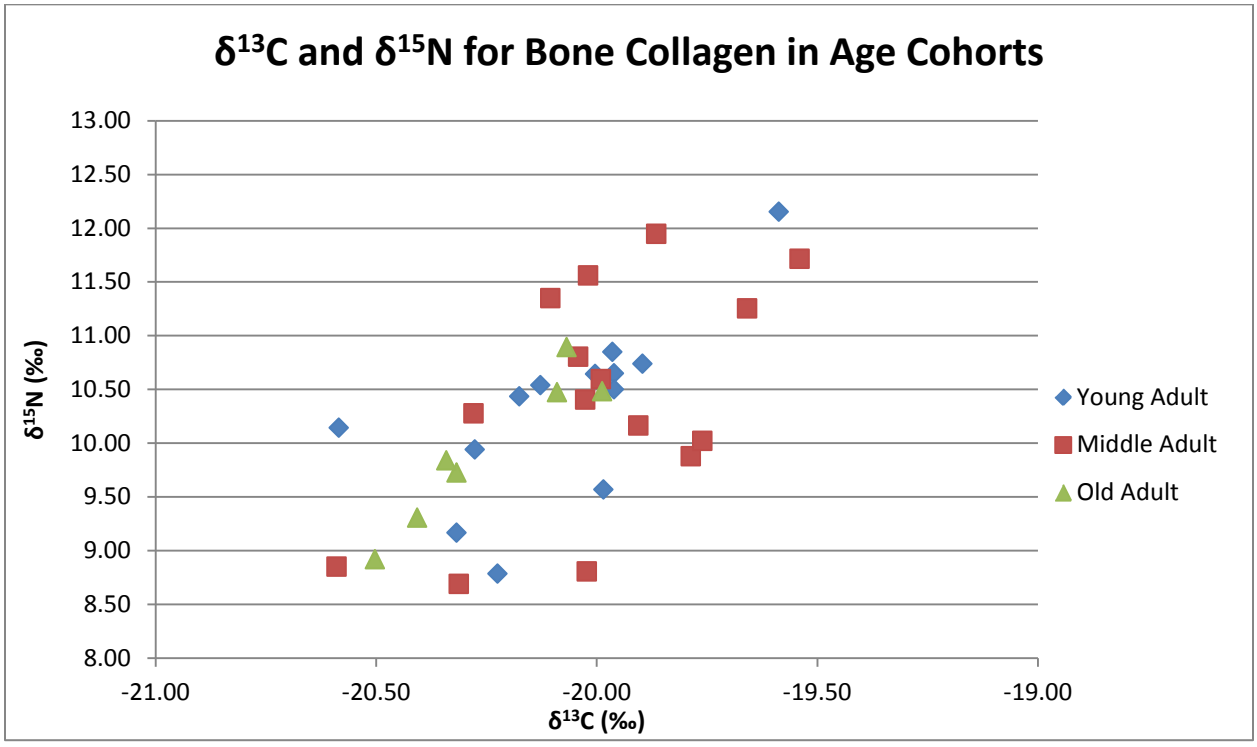

Figure 8. $\delta^{13}C$ and $\delta^{15}N$ values for age at death cohorts in the Alytus bone collagen sample

This data reflects whether there was a relationship between age at death and $\delta^{13}C$ and $\delta^{15}N$ values during approximately the last decade of life. A difference was observed in the bone collagen $\delta^{13}C$ and $\delta^{15}N$ values for OA compared to the other age at death cohorts. The mean for each of the age at death cohorts shows that the individuals in the OA age at death cohort are outside of the mean for the YA and MA age at death cohorts, however there is overlap in the standard error for all cohorts (Figure 9).

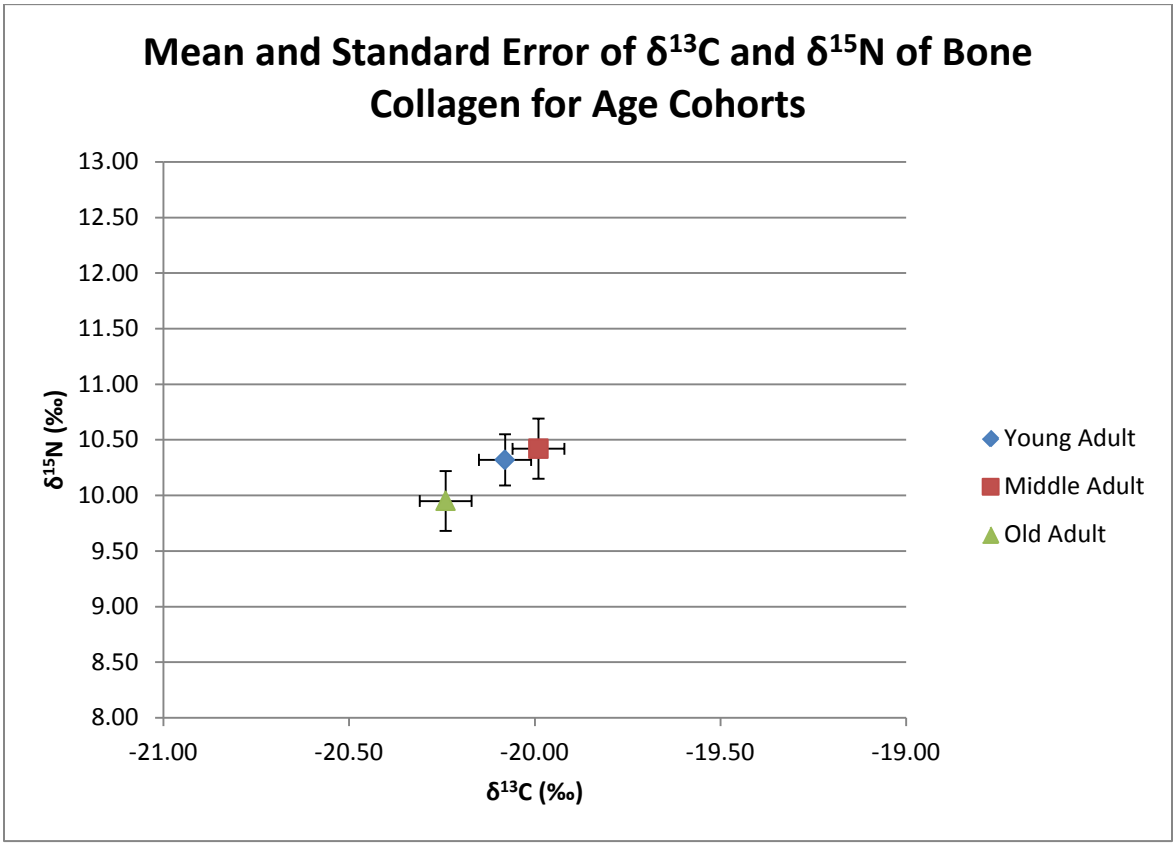

Figure 9. Mean and standard error of $\delta^{13}C$ and $\delta^{15}N$ values for age at death cohorts in bone collagen samples

The Alytus sample was divided into two subsamples in order to explore the effect of skeletal pathology on stable carbon and nitrogen isotope analysis. In this analysis, individuals with a noted pathological indication on the sampled element (right or left femur) were considered to have a pathological condition and individuals with no noted indication on the sampled element (right or left femur) were considered to have no pathological condition. While the most positive $\delta^{15}N$ value for bone collagen is present in an individual with a pathological condition, five of the six most positive $\delta^{15}N$ values for bone collagen are represented by individuals with no pathological indication on the selected element (Figure 10). Overall, individuals with pathological indications on the selected element do not cluster in their $\delta^{15}N$ values for bone collagen. Additionally, the $\delta^{13}C$ and $\delta^{15}N$ values for individuals with pathological indications on the sampled element and individuals with no pathological indications on the sampled element did not significantly differ for either the $\delta^{13}C$ values ($p= 0.274$) or for the $\delta^{15}N$ values ($p= 0.446$) for bone collagen.

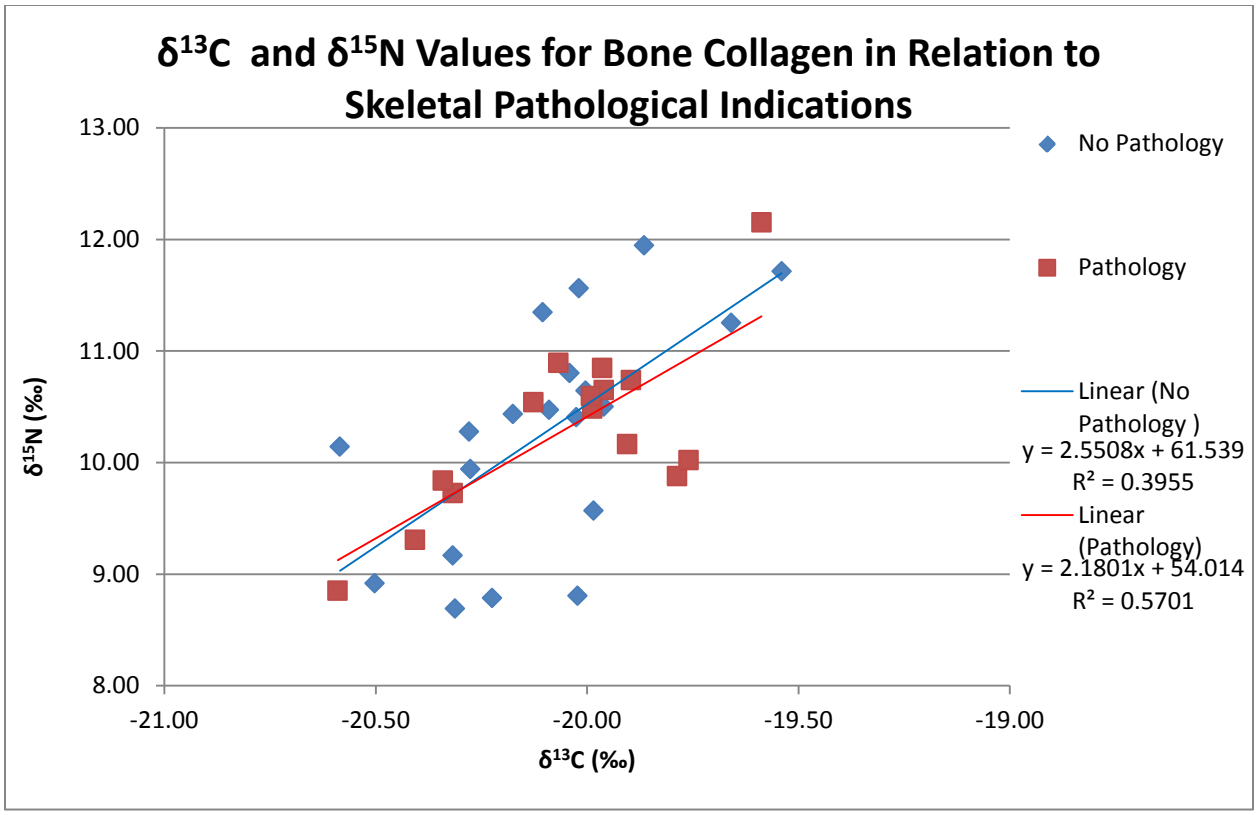

Figure 10. $\delta^{13}C$ and $\delta^{15}N$ values for individuals with and without pathological indications on the selected element (right or left femur) in the bone collagen sample

Dentin Collagen

$\delta^{13}C$ Values

Thirty-eight dentin collagen samples were analyzed, and the $\delta^{13}C$ values for each of these individuals can be found in Table 18. The mean $\delta^{13}C$ value for dentin collagen for these individuals is -20.11‰ ± 0.30‰ (SE= 0.05‰) and range from -20.80‰ to -19.45‰ (Table 11). Overall the $\delta^{13}C$ values for the Alytus dentin collagen samples with a mean of -20.11‰ indicate that individuals were primarily consuming C_3 plants during the juvenile period, and likely consuming small amounts of aquatic protein

resources. The mean $\delta^{13}C$ value for dentin collagen in the 15 females is -20.10‰ ± 0.32‰ (SE= 0.08‰) and range from -20.80‰ to -19.58‰ (Table 11). The mean $\delta^{13}C$ value for dentin collagen in the 23 males is -20.11‰ ± 0.29‰ (SE= 0.06‰) and range from -20.66‰ to -19.45‰ (Table 11). There are no significant differences in $\delta^{13}C$ values between juvenile males and juvenile females (p= 0.472), between juvenile males and the overall dentin sample (p= 0.486), or between juvenile females and the overall dentin sample (p= 0.147) for dentin collagen samples (Table 12). There are no significant differences in $\delta^{13}C$ values between mandibular and maxillary dentin (p= 0.434) for dentin collagen samples.

The mean $\delta^{13}C$ values and $\delta^{13}C$ ranges for dentin collagen in each of the age at death cohorts is presented in Table 11. The mean $\delta^{13}C$ value for dentin collagen in the 16 individuals in the YA age at death cohort is -20.11‰ ± 0.26‰ (SE= 0.07‰) and range from -20.62‰ to -19.68‰ (Table 11). The mean $\delta^{13}C$ value for dentin collagen in the 15 individuals in the MA age at death cohort is -20.07‰ ± 0.37‰ (SE= 0.10‰) and range from -20.80‰ to -19.45‰ (Table 11). The mean $\delta^{13}C$ value for dentin collagen in the seven individuals in the OA age at death cohort is -20.17‰ ± 0.23‰ (SE= 0.09‰) and range from -20.44‰ to -19.85‰ (Table 11). There are no significant differences in $\delta^{13}C$ values between any of the age at death cohorts for dentin collagen samples (Table 19).

Table 18. Dentin collagen samples and corresponding $\delta^{13}C$ values

Sample ID	$\delta^{13}C$(‰)
K10	-19.93
K58	-19.74
K155	-20.14
K156	-20.80
K214A	-19.91
K269	-20.00
K426	-20.12
K428	-20.32
K484	-20.50
K523	-20.44
K543	-20.62
K563	-20.66
K617	-20.43
K622	-20.09
K706	-20.34
K727	-20.15
K770	-20.09
K785	-20.28
K833	-20.18
K849	-20.10
K862	-19.61
K863	-20.15
K867	-20.11
K888	-19.68
K933	-20.19
K934	-19.72
K940	-19.99
K1009	-19.45
K1010	-19.85
K1030	-19.97
K1049	-20.22
K1080	-19.92
K1087	-20.21
K1090B	-20.01
K1115	-19.58
K1127	-20.05
K1150	-20.36
K1152	-20.27

Table 19. T-test results for $\delta^{13}C$ of dentin collagen for age at death cohort subsamples

	YA	MA	OA
YA	-	0.368	0.307
MA	-	-	0.263
OA	-	-	-

Significance level was set to ≤0.05
Significant differences are bolded

$\delta^{15}N$ Values

Thirty-eight dentin collagen samples were analyzed and, the $\delta^{15}N$ values for each of these individuals can be found in Table 20. The mean $\delta^{15}N$ value for dentin collagen in these individuals is 10.66‰ ± 0.91‰ (SE= 0.15‰) and range from 9.08‰ to 12.43‰ (Table 15). Overall the $\delta^{15}N$ values for the Alytus dentin collagen samples with a mean of 10.66‰ indicate that individuals primarily consuming terrestrial fauna during the juvenile period, with some aquatic protein resources. The mean $\delta^{15}N$ value for dentin collagen in the 15 females is 10.53‰ ± 0.95‰ (SE= 0.25‰) and range from 9.09‰ to 12.42‰ (Table 15). The mean $\delta^{15}N$ value for dentin collagen in the 23 males is 10.74‰ ± 0.89‰ (SE= 0.19‰) and range from 9.08‰ to 12.43‰ (Table 15). There are no significant differences in $\delta^{15}N$ values for dentin collagen between juvenile males and juvenile females (p= 0.239), between juvenile males and the overall dentin sample (p= 0.360), or between juvenile females and the overall dentin sample (p= 0.320) for dentin collagen samples (Table 16). There are no significant difference in $\delta^{15}N$ values between mandibular and maxillary dentin (p= 0.384) for the dentin collagen samples.

Table 20. Dentin collagen samples and corresponding $\delta^{15}N$ values

Sample ID	$d^{15}N$(‰)
K10	9.74
K58	12.02
K155	10.97
K156	9.68
K214A	10.81
K269	9.62
K426	11.32
K428	10.62
K484	10.03
K523	9.54
K543	10.32
K563	11.13
K617	10.84
K622	10.76
K706	10.06
K727	9.36
K770	11.20
K785	11.31
K833	9.09
K849	11.64
K862	12.28
K863	9.44
K867	10.73
K888	12.43
K933	9.08
K934	10.91
K940	10.45
K1009	10.26
K1010	10.89
K1030	10.33
K1049	11.03
K1080	11.45
K1087	9.45
K1090B	11.01
K1115	12.42
K1127	11.73
K1150	10.66
K1152	10.37

The mean $\delta^{15}N$ values and $\delta^{15}N$ ranges for dentin collagen in each of the age at death cohorts are presented in Table 15. The mean $\delta^{15}N$ value for dentin collagen in the 16 individuals in the YA age at death cohort is 10.60‰ ± 0.89‰ (SE= 0.22‰) and range from 9.09‰ to 12.43‰ (Table 15). The mean $\delta^{15}N$ value for dentin collagen in the 15 individuals in the MA age at death cohort is 10.93‰ ± 0.96‰ (SE= 0.25‰) and range from 9.08‰ to 12.42‰ (Table 15). The mean $\delta^{15}N$ value for dentin collagen in the seven individuals in the OA age at death cohort is 10.20‰ ± 0.70‰ (SE= 0.26‰) and range from 9.44‰ to 11.01‰ (Table 15). There is a significant difference in the $\delta^{15}N$ values for dentin collagen between the MA and OA age at death cohorts (p= 0.045) for dentin collagen samples (Table 21). There are no other significant differences in $\delta^{15}N$ values between age at death cohorts for dentin collagen (Table 21).

Table 21. t-test results for $\delta^{15}N$ of dentin collagen for age at death cohort subsamples

	YA	MA	OA
YA	-	0.169	0.151
MA	-	-	**0.045**
OA	-	-	-

Significance level was set to ≤0.05
Significant differences are bolded

$\delta^{13}C$ and $\delta^{15}N$ Values

Overall the dentin collagen sample has a greater range in $\delta^{15}N$ values than in the $\delta^{13}C$ values (Figure 11). Dentin collagen samples generally follow a linear trend. Individuals with more positive $\delta^{15}N$ values also tend to have more positive $\delta^{13}C$ values,

and individuals with more negative $\delta^{15}N$ values tend to have more negative $\delta^{13}C$ values. However, this trend is less substantial in the dentin collagen sample (r^2=0.20) than the linear relationship between $\delta^{13}C$ and $\delta^{15}N$ values in bone collagen (r^2=0.44). No individual appears to be a clear outlier in the overall adult sample.

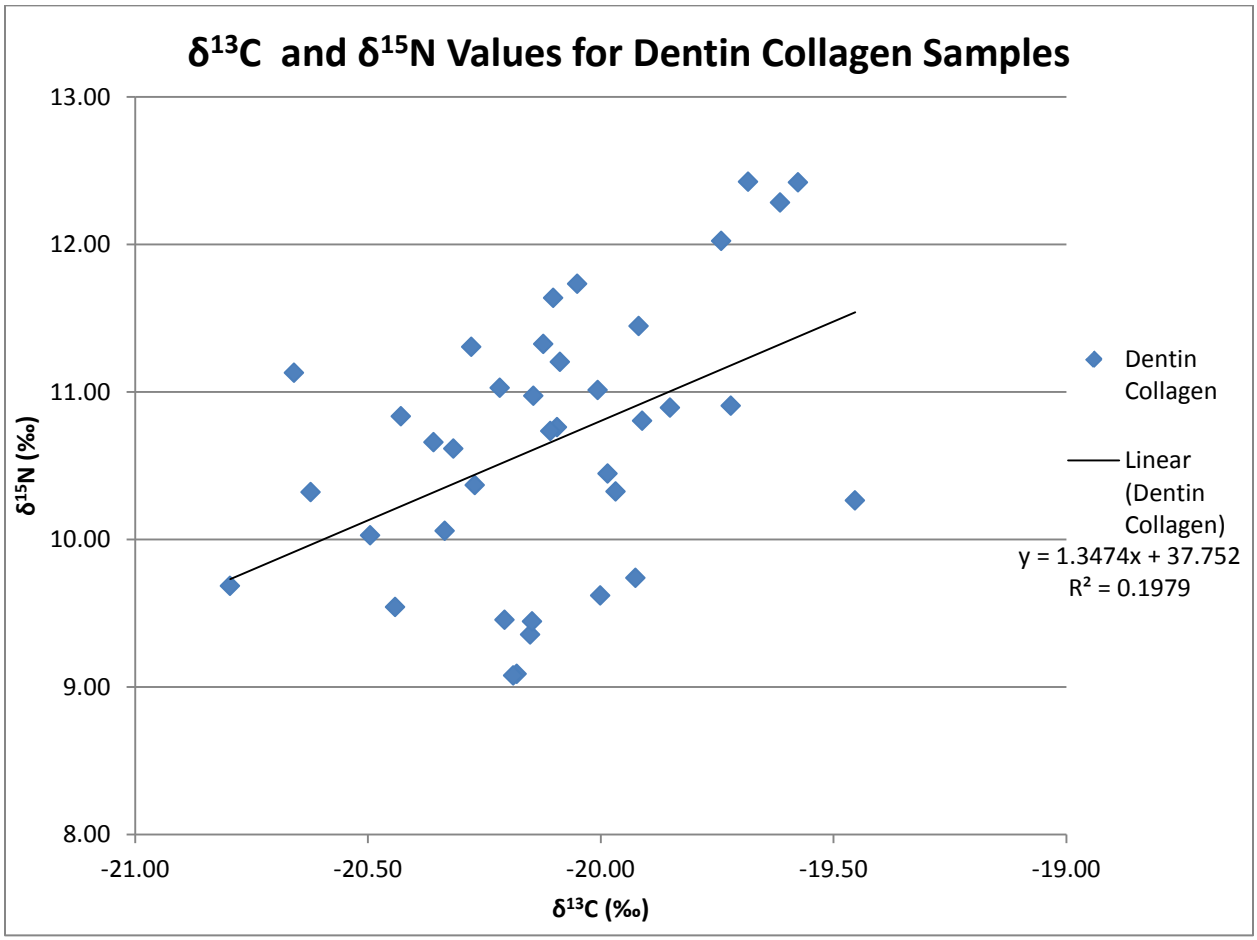

Figure 11. $\delta^{13}C$ and $\delta^{15}N$ values for all individuals in the dentin collagen sample

Males in the dentin collagen sample are represented throughout the entire range of $\delta^{13}C$ and $\delta^{15}N$ values in the overall Alytus sample (Figure 12). Males do not cluster and appear to be fairly evenly distributed throughout the entire sample. The most positive $\delta^{13}C$ value for dentin collagen is from a male individual (-19.45‰); however, a

more positive $\delta^{13}C$ value is not characteristic for the males in the sample. Females in the dentin collagen sample are represented throughout the entire range of $\delta^{13}C$ and $\delta^{15}N$ values in the overall Alytus sample (Figure 12). The most negative $\delta^{13}C$ value for dentin collagen is from a female individual (-20.80‰); however, a more negative $\delta^{13}C$ value is not characteristic for the females in the sample.

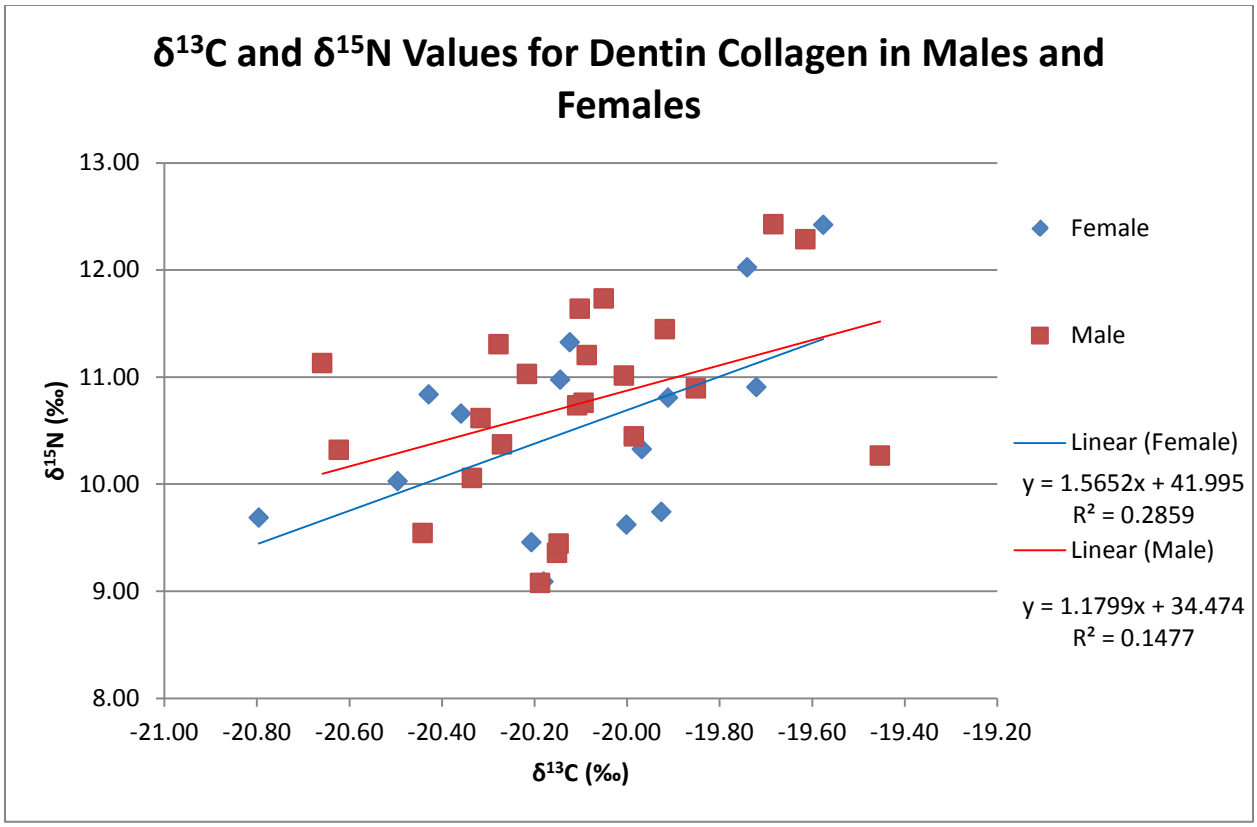

Figure 12. $\delta^{13}C$ and $\delta^{15}N$ values for males and females in the dentin collagen sample

In general, most of the age at death cohorts are found throughout the entirety of the ranges of $\delta^{13}C$ and $\delta^{15}N$ values for dentin collagen (Figure 13). This data reflects whether age at death cohort was related to $\delta^{13}C$ and $\delta^{15}N$ values during the juvenile period when the dentin of first molars is formed (approximately the first year of life to

seven years of age). Individuals in the OA age at death cohort had generally more depleted $\delta^{13}C$ and $\delta^{15}N$ values compared to individuals in the YA and MA age at death cohorts.

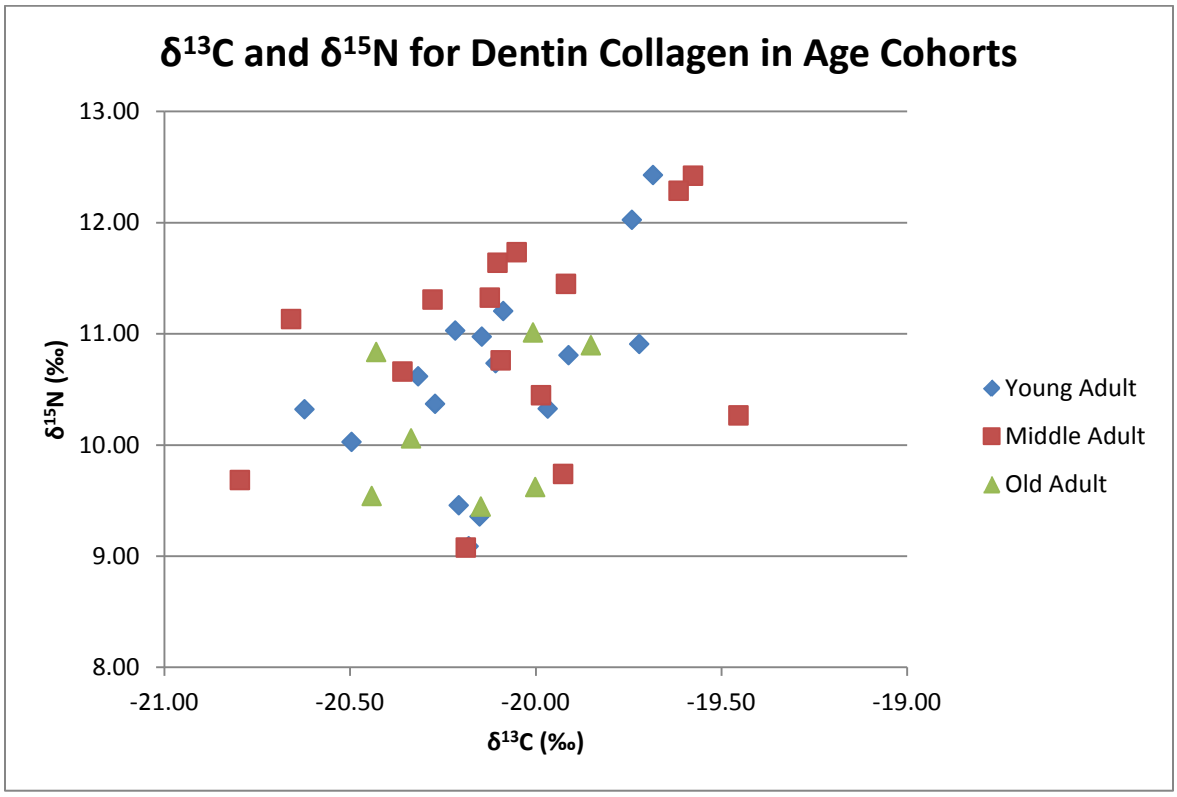

Figure 13. $\delta^{13}C$ and $\delta^{15}N$ values for age cohorts in the dentin collagen sample

Differences between dentin and bone collagen

Overall, there is very little difference between the mean $\delta^{13}C$ and $\delta^{15}N$ values for the dentin collagen samples and the bone collagen samples (Table 22 and Figures 14 and 15). The difference between the mean $\delta^{13}C$ values for dentin and bone collagen was -0.03 and the difference between the mean $\delta^{15}N$ values for dentin and bone collagen was 0.37 (Table 22).

Table 22. Number of individuals, mean $\delta^{13}C$ and $\delta^{15}N$ values for bone and dentin collagen samples and difference in mean $\delta^{13}C$ and $\delta^{15}N$ between dentin and bone collagen samples for the overall sample, males, females

	Dentin Samples			Bone Samples			ΔDentin-Bone	
Sex	**Number of Individuals**	**Mean $d^{13}C$ (‰)**	**Mean $d^{15}N$ (‰)**	**Number of Individuals**	**Mean $d^{13}C$ (‰)**	**Mean $d^{15}N$ (‰)**	**Mean $d^{13}C$ (‰)**	**Mean $d^{15}N$ (‰)**
Male	23	-20.11	10.74	22	-20.03	10.49	**-0.08**	**0.25**
Female	15	-20.1	10.53	13	-20.16	9.95	**0.06**	**0.58**
Overall	**38**	**-20.11**	**10.66**	**35**	**-20.08**	**10.29**	**-0.03**	**0.37**

There is no significant difference in the $\delta^{13}C$ values between the overall dentin collagen and the overall bone collagen samples (p= 0.310) (Table 12). There is a significant difference in the $\delta^{15}N$ values between the overall dentin collagen and the overall bone collagen samples (p= 0.043) (Table 16).

There is very little difference in the mean $\delta^{13}C$ and $\delta^{15}N$ values for females for the dentin collagen samples and the bone collagen samples (Tables 11 and 15). There is no significant difference in the $\delta^{13}C$ values between the female dentin collagen and the overall bone collagen samples (p= 0.371) (Table 12). There is no significant difference in the $\delta^{15}N$ values between the female dentin collagen and the overall bone collagen samples (p= 0.203) (Table 16). There is no significant difference in the $\delta^{13}C$ values between the female dentin collagen and the female bone collagen samples (p= 0.299) (Table 12). There is no significant difference in the $\delta^{15}N$ values between the female dentin collagen and the female bone collagen samples (p= 0.058) (Table 16). There is a significant difference between the $\delta^{15}N$ values between the female bone collagen and the overall dentin collagen samples (p= 0.010) and between the female bone collagen samples and the male dentin collagen samples (p= 0.008) (Table 16).

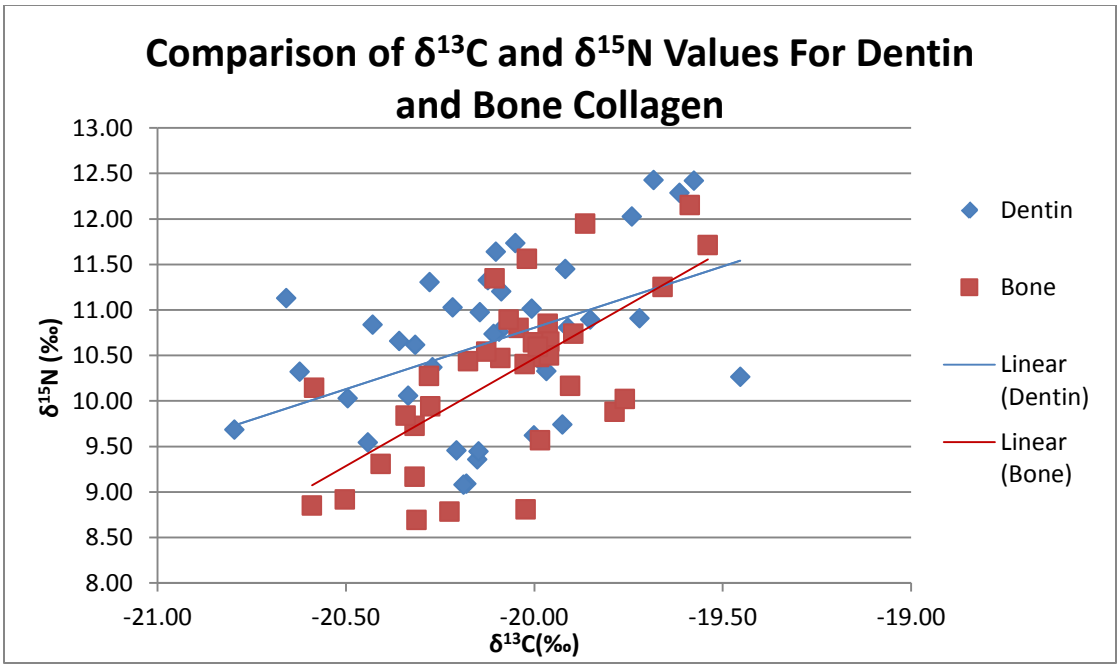

Figure 14. Comparison of the $\delta^{13}C$ and $\delta^{15}N$ values for dentin and bone collagen for Alytus adults.

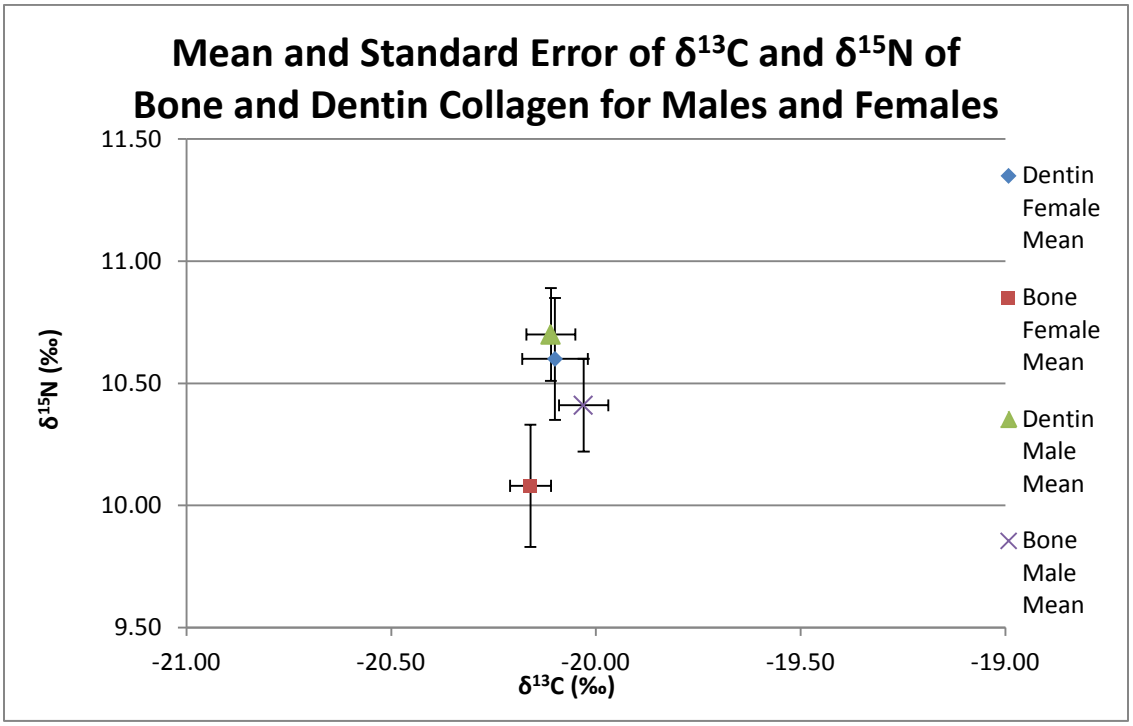

Figure 15. Mean and standard error of $\delta^{13}C$ and $\delta^{15}N$ values for males and females in the dentin and bone collagen samples

There is little difference in the mean $\delta^{13}C$ and $\delta^{15}N$ values for males for the dentin collagen samples and the bone collagen samples (Tables 11 and 15). There is no significant difference in the $\delta^{13}C$ values between the male dentin collagen and the overall bone collagen samples (p= 0.313) (Table 12). There is no significant difference in the $\delta^{13}C$ values between the male dentin collagen and the male bone collagen samples (p= 0.162) (Table 12). There is no significant difference in the $\delta^{15}N$ values between the male dentin collagen and the male bone collagen samples (p= 0.167) (Table 16). There is a significant difference in the $\delta^{15}N$ values between the male dentin collagen and the overall bone collagen samples (p= 0.032) and between the male dentin collagen and the female bone collagen samples (p= 0.008) (Table 16).

Thirty-four Alytus individuals provided both bone and dentin collagen samples which presented the opportunity to compare the juvenile period, as reflected in dentin collagen, and adult period, as reflected in bone collagen, intra-individually. Figures 16 and 17 depict the intra-individual difference in $\delta^{13}C$ values and $\delta^{15}N$ values, respectively, by sex. Figures 18 and 19 depict the intra-individual difference in in $\delta^{13}C$ values and $\delta^{15}N$ values, respectively, by age at death cohort. For the majority of individuals there is very little difference between the juvenile $\delta^{13}C$ and $\delta^{15}N$ values and the adult $\delta^{13}C$ and $\delta^{15}N$. No individual had a difference in $\delta^{13}C$ value greater than 1.00‰. Table 23 presents the difference in $\delta^{13}C$ in bone and dentin collagen intra-individually; data are separated by whether the dentin collagen $\delta^{13}C$ values were less than the bone collagen $\delta^{13}C$ values or vice versa**.**

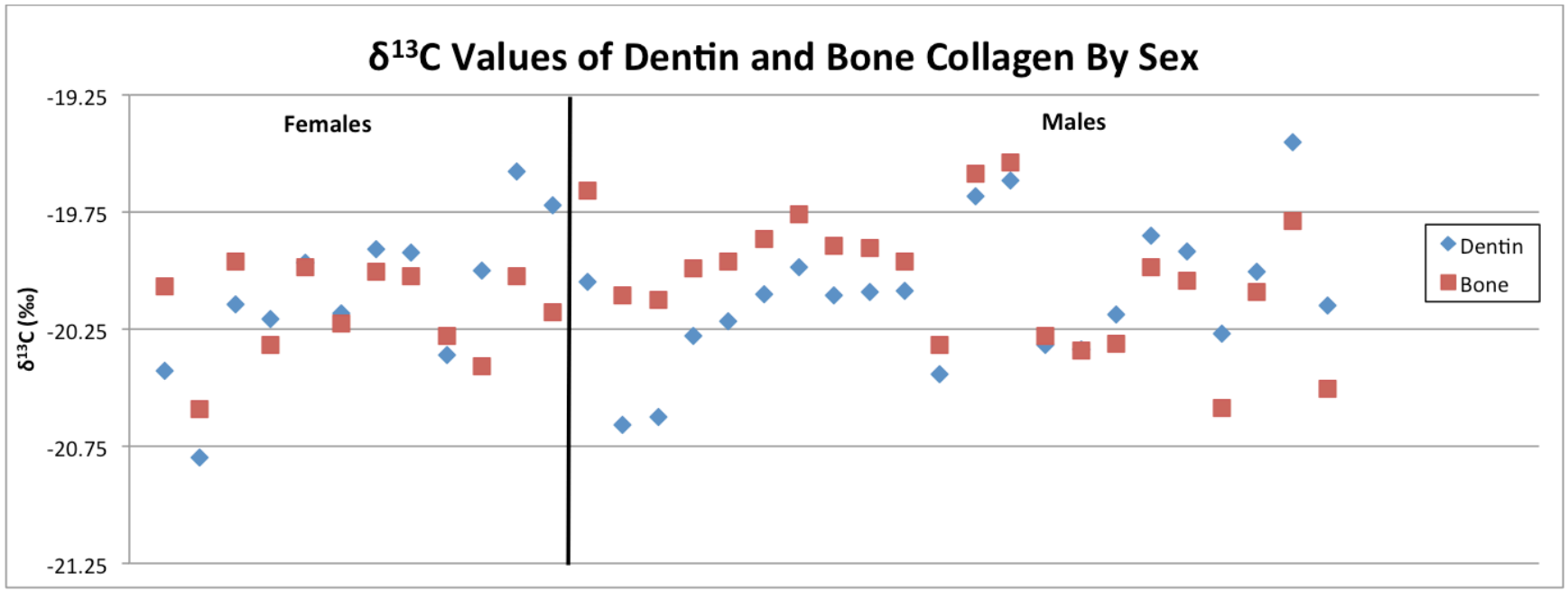

Figure 16. $\delta^{13}C$ values of dentin and bone collagen for each individual providing both dentin and bone samples by sex

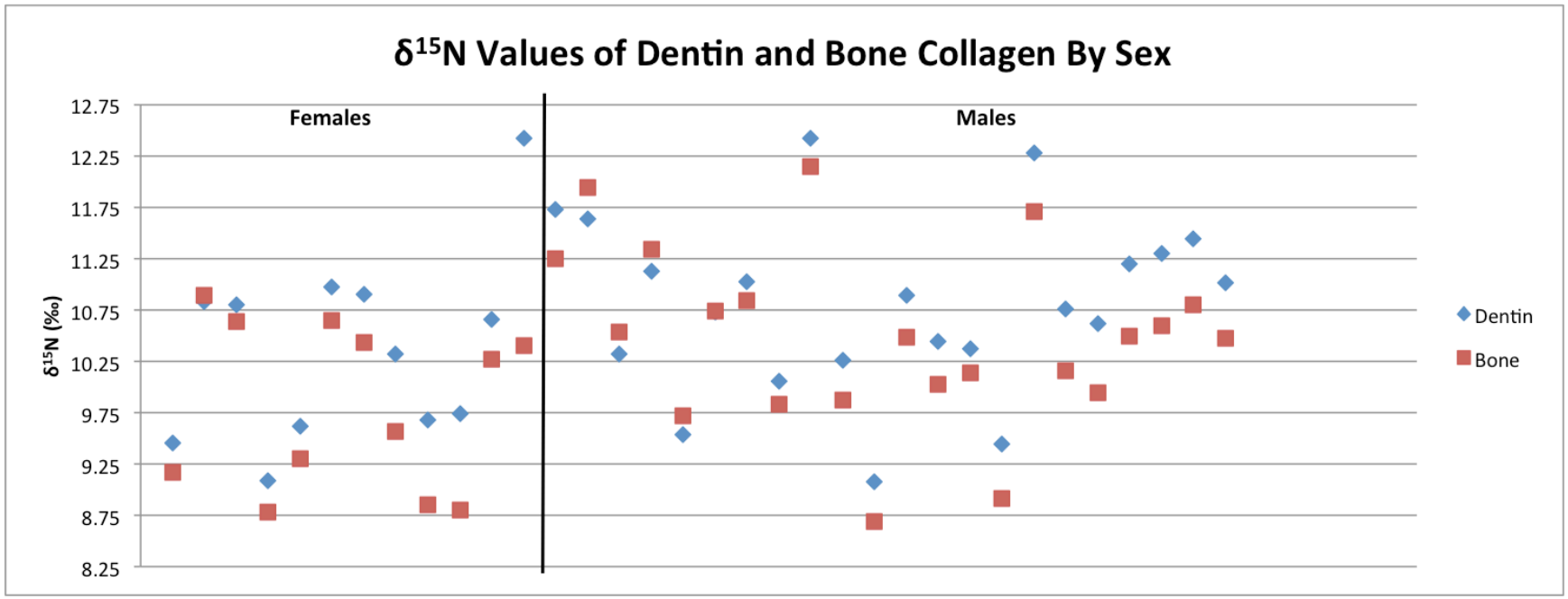

Figure 17. $\delta^{15}N$ values of dentin and bone collagen for each individual providing both dentin and bone samples by sex

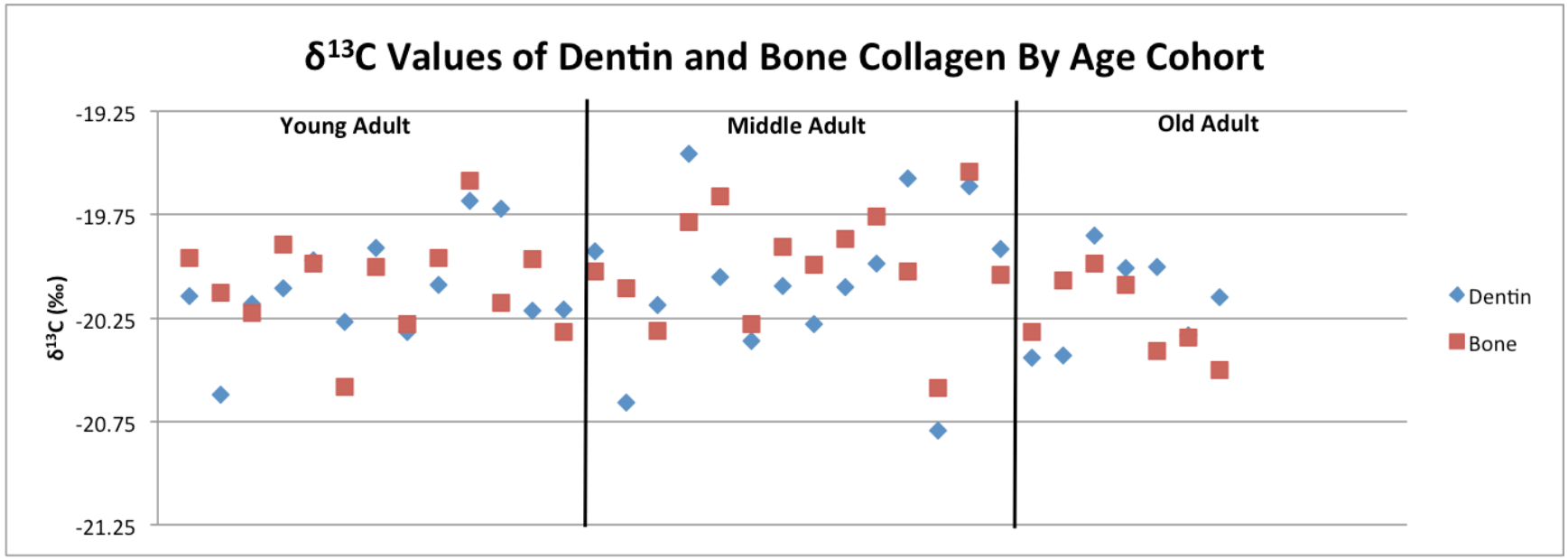

Figure 18. $\delta^{13}C$ values of dentin and bone collagen for each individual providing both dentin and bone samples by age at death cohort

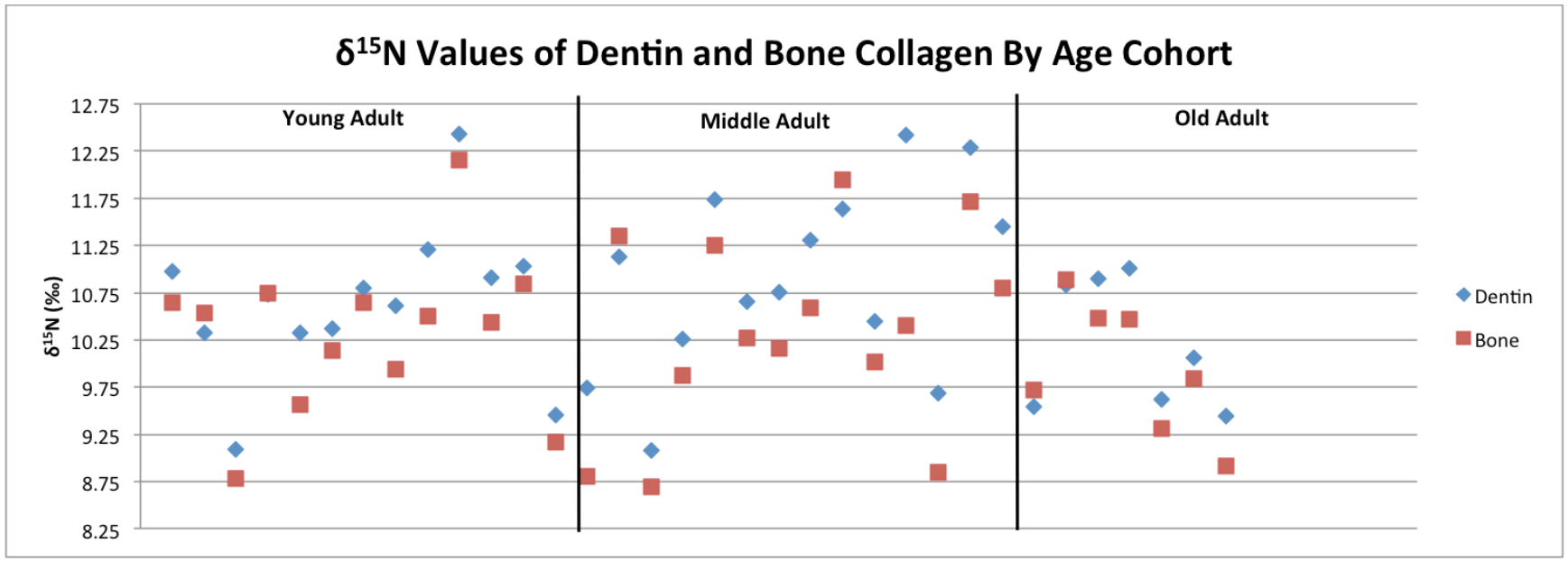

Figure 19. $\delta^{15}N$ values of dentin and bone collagen for each individual providing both dentin and bone samples by age at death cohort

Table 23. Difference between $\delta^{13}C$ values in bone and dentin collagen intra-individually

Sample ID	Sex	Dentin $d^{13}C$ (‰)	Bone $d^{13}C$ (‰)	ΔDentin-Bone
K563	M	-20.66	-20.11	-0.55
K543	M	-20.62	-20.13	-0.50
K1127	M	-20.05	-19.66	-0.39
K617	F	-20.43	-20.07	-0.36
K785	M	-20.28	-19.99	-0.29
K1049	M	-20.22	-19.96	-0.25
K849	M	-20.10	-19.87	-0.24
K940	M	-19.99	-19.76	-0.23
K867	M	-20.11	-19.90	-0.21
K156	F	-20.80	-20.59	-0.21
K622	M	-20.09	-19.91	-0.19
K155	F	-20.14	-19.96	-0.18
K770	M	-20.09	-19.96	-0.13
K523	M	-20.44	-20.32	-0.12
K888	M	-19.68	-19.59	-0.10
K1150	F	-20.36	-20.28	-0.08
K862	M	-19.61	-19.54	-0.07
K428	M	-20.32	-20.28	-0.04
K706	M	-20.34	-20.34	0.01
K1030	F	-19.97	-19.98	0.02
K833	F	-20.18	-20.23	0.04
K1090B	M	-20.01	-20.09	0.08
K214A	F	-19.91	-20.00	0.09
K10	F	-19.93	-20.02	0.10
K1087	F	-20.21	-20.32	0.11
K1080	M	-19.92	-20.04	0.12
K933	M	-20.19	-20.31	0.12
K1010	M	-19.85	-19.99	0.14
K1152	M	-20.27	-20.58	0.31
K1009	M	-19.45	-19.79	0.33
K863	M	-20.15	-20.50	0.36
K269	F	-20.00	-20.41	0.41
K1115	F	-19.58	-20.03	0.45
K934	F	-19.72	-20.18	0.46
		Mean ΔDentin-Bone		-0.03
		Maximum ΔDentin-Bone		0.46
		Minimum ΔDentin-Bone		-0.55

In individuals where the $\delta^{13}C$ value of the dentin collagen sample was more negative than the bone collagen sample resulting in a negative $\Delta_{Dentin\text{-}Bone}$ value, only 22% were female (representing 33% of females in the sample) and 78% were male (representing 64% of the males in the sample) (Table 23). In individuals where the $\delta^{13}C$ value of the dentin collagen sample was more positive than the bone collagen sample resulting in a positive $\Delta_{Dentin\text{-}Bone}$, 50% were female (representing 67% of females in the sample) and 50% were male (representing 36% of the males in the sample) (Table 23). The $\Delta_{Dentin\text{-}Bone}$ for the $\delta^{13}C$ values suggests there might be some differences in the shift from juvenile to adult diet between males and females.

Table 24 presents the difference in $\delta^{15}N$ in bone and dentin collagen intra-individually; data are separated by whether the dentin collagen $\delta^{15}N$ values were less than the bone collagen $\delta^{15}N$ values or vice versa. Only individual K1115 (female, 35-40 age at death category) had a difference in $\delta^{15}N$ value greater than 1.00‰ with a greater dentin $\delta^{15}N$ value than bone $\delta^{15}N$ value (Table 24). In individuals where the $\delta^{15}N$ value of the dentin collagen sample was more negative than the bone collagen sample resulting in a negative $\Delta_{Dentin\text{-}Bone}$ value, only 20% were female (representing 8% of females in the sample) and 80% were male (representing 18% of the males in the sample) (Table 24). In individuals where the $\delta^{15}N$ value of the dentin collagen sample was more positive than the bone collagen sample, 38% were female (representing 92% of females in the sample) and 62% were male (representing 82% of the males in the sample) (Table 24). The $\Delta_{Dentin\text{-}Bone}$ for the $\delta^{15}N$ values suggests there might be some differences in the shift from juvenile to adult diet between males and females. There is

no universal pattern for the differences between juvenile diet and adult diet. For some individuals $\delta^{13}C$ values are greater for the dentin collagen sample and for others the $\delta^{13}C$ values are greater for the bone collagen sample (Table 23). Additionally, for some individuals $\delta^{15}N$ values are greater for the dentin collagen sample, and for others the $\delta^{15}N$ values are greater for the bone collagen sample (Table 24). However, the majority of individuals in the sample have a higher dentin collagen $\delta^{15}N$ value compared to bone collagen $\delta^{15}N$ value.

Table 24. Difference between $\delta^{15}N$ values in bone and dentin collagen intra-individually

Sample ID	Sex	Dentin $d^{15}N$ (‰)	Bone $d^{15}N$ (‰)	ΔDentin-Bone
K849	M	11.64	11.95	-0.31
K543	M	10.32	10.54	-0.22
K563	M	11.13	11.35	-0.22
K523	M	9.54	9.72	-0.18
K617	F	10.84	10.89	-0.06
K867	M	10.73	10.74	0.00
K214A	F	10.81	10.64	0.16
K1049	M	11.03	10.85	0.18
K706	M	10.06	9.84	0.22
K1152	M	10.37	10.14	0.23
K888	M	12.43	12.15	0.27
K1087	F	9.45	9.17	0.29
K833	F	9.09	8.78	0.30
K269	F	9.62	9.31	0.31
K155	F	10.97	10.65	0.32
K1150	F	10.66	10.28	0.38
K1009	M	10.26	9.88	0.39
K933	M	9.08	8.69	0.39
K1010	M	10.89	10.48	0.41
K940	M	10.45	10.02	0.42
K934	F	10.91	10.43	0.47
K1127	M	11.73	11.25	0.48
K863	M	9.44	8.92	0.53
K1090B	M	11.01	10.47	0.54
K862	M	12.28	11.71	0.57
K622	M	10.76	10.16	0.60
K1080	M	11.45	10.80	0.64
K428	M	10.62	9.94	0.67
K770	M	11.20	10.50	0.70
K785	M	11.31	10.59	0.71
K1030	F	10.33	9.57	0.76
K156	F	9.68	8.85	0.83
K10	F	9.74	8.81	0.93
K1115	F	12.42	10.41	**2.02**
		Mean ΔDentin-Bone		0.40
		Maximum ΔDentin-Bone		2.02
		Minimum ΔDentin-Bone		-0.31

Individuals with a difference greater than 1.00‰ are bolded

CHAPTER 5: DISCUSSION

Bone Collagen

Overall the $\delta^{13}C$ values for the Alytus bone collagen samples (mean of -20.08‰) indicate individuals were almost exclusively consuming C_3 plants during the last decade of their adult life. This indicates that adult individuals at Alytus were consuming primarily wheat, barley, flax, and rye, and vegetables, all of which are C_3 plants. Aquatic resources can also affect $\delta^{13}C$ values, and result in more enriched $\delta^{13}C$ values compared to those consuming solely terrestrial resources. Given their $\delta^{13}C$ values, individuals at Alytus were likely consuming marine or freshwater resources. However, due to the large variation in $\delta^{13}C$ values that can occur in freshwater resources (Katzenberg, 2008), the $\delta^{13}C$ values should be used in conjunction with stable nitrogen isotope values to make this determination.

The $\delta^{13}C$ values in the bone collagen also indicate that there is no statistically significant difference between adult males and adult females, adult males and the overall adult population, and adult females and the overall adult population, indicating that there is no difference in the consumption of C_3 plants or aquatic resources for these groups.

A significant difference was found in the $\delta^{13}C$ values of bone collagen between individuals in the MA and OA age at death cohorts. The individuals in the MA age at death cohorts had more enriched mean $\delta^{13}C$ values compared to the mean of the individuals in the OA age at death cohort, which may indicate that the individuals in the

MA age at death cohorts were consuming less C_3 plants during the last decade of life than the individuals in the OA age at death cohort. It is also possible that the individuals in the MA age at death cohorts were consuming a small amount of C_4 plants during the last decade of life or consuming more aquatic resources. There is archaeobotanical evidence of the presence of millet (*Panicum miliaceum*) at Vilnius, Lithuania starting in the latter half of the 14th century (Stančikaitė et al., 2008). It is possible that millet was consumed by some individuals, although the overall stable carbon isotopic signatures for the Alytus sample do not suggest consumption of millet was dominant. It is unclear what is causing the differences in consumption between C_3 and C_4 plants or between aquatic and terrestrial resources at different stages of the adult period. During the medieval period many migrants of varying faiths came to Lithuania, voluntarily and through Lithuanian expansion efforts (Fletcher, 1997). It is possible that differences in the $\delta^{13}C$ values reflect the presence of migrants. Given the archaeobotanical data from medieval Vilnius, it is likely that some individuals are consuming small quantities of millet.

Additionally, there is a statistically significant difference in the $\delta^{13}C$ values of bone collagen between males and females in the MA age at death cohort ($p= 0.021$). Females in the MA age at death cohort have generally more depleted $\delta^{13}C$ values compared to males in the MA age at death cohort indicating that females in this age at death cohort were consuming either more C_3 resources, less C_4 resources, less aquatic resources, or a combination of the above compared to their male, MA age at death cohort counterparts.

It should also be noted that there are only a few individuals included in each of the age at death cohorts (Table 11); there were only seven individuals included in the OA age at death cohort and the largest number of individuals included in a single age at death cohort for bone collagen was only 15. One or two individuals with $\delta^{13}C$ values on the extreme ends of the overall Alytus $\delta^{13}C$ range would have a greater effect on the mean of a cohort with seven individuals than on a cohort with 50 individuals.

Overall the $\delta^{15}N$ values for the Alytus bone collagen samples had a mean of 10.29‰, indicating that individuals were primarily consuming terrestrial fauna during the last decade of their adult life. This indicates that adult individuals at Alytus may have been consuming terrestrial animals such as cows, deer, pig, and sheep. Meat is commonly thought of as a luxury item reserved for the wealthy elite. However, it is clear that at Alytus many individuals had a diet with a large influence of terrestrial animal protein such as meat, milk, eggs, and cheese. Moreover, this diet is found in males and females as well as adults and juveniles. Müldner and Richards (2005) have suggested that by the 14th century meat was more affordable in Europe, so it is not unexpected that at Alytus the majority of individuals were consuming terrestrial animal protein.

The $\delta^{15}N$ values in the bone collagen also indicate that there is no statistically significant difference between adult males and the overall adult population, and adult females and the overall adult population, indicating that there is no difference in the consumption of dietary protein sources, such as meat and freshwater fish, for these groups. There is a statistically significant difference in the bone collagen $\delta^{15}N$ values between adult males and adult females ($p= 0.046$) indicating that there is a difference in

the consumption of dietary protein sources, such as meat and freshwater fish, for these groups. The more depleted bone collagen $\delta^{15}N$ values indicates that adult females were consuming less protein resources, or protein resources of a lower trophic level, compared to their male counterparts.

Interpretation of $\delta^{15}N$ values is much more complicated than the interpretation of $\delta^{13}C$, and it is possible that the depleted bone collagen $\delta^{15}N$ values noted in females are a result of physiological factors which have been documented to have an effect on $\delta^{15}N$ values (Table 3). It would be expected that females that experienced pregnancy would have decreased $\delta^{15}N$ values, on the order of 0.50‰ to 1.00‰ (Duggleby and Jackson, 2002; Fuller et al., 2004). Female YA have statistically significant difference in their bone collagen $\delta^{15}N$ values compared to male YA ($p= 0.039$) which also suggests the possibility that pregnancy might contribute to depleted bone collagen $\delta^{15}N$ values in females. However, it should be noted that there is no statistically significant difference in bone collagen $\delta^{15}N$ values between males and females in the MA or OA age at death cohorts, where it would be expected that females would still be under pregnancy pressures.

The plague and tuberculosis are known to have affected individuals at medieval Alytus (Faerman et al., 1997; Jankauskas, 1998; Kozakaite, 2011). It would be unexpected for the plague to cause depleted $\delta^{15}N$ values as affected individuals would not be living long enough to have the disease cause stable isotopic changes in bone collagen. However, it is possible that individuals suffering from tuberculosis would live long enough to display depleted $\delta^{15}N$ values in bone collagen as Faerman et al. (1997)

found evidence of skeletal manifestations of the disease in the spinal column in individuals at medieval Alytus.

The mean and range of bone collagen $\delta^{15}N$ values for the Alytus adults indicate the consumption of freshwater resources. This is further evidenced by the general linear trend in the bone collagen $\delta^{15}N$ and $\delta^{13}C$ values where more positive $\delta^{13}C$ values are associated with more positive $\delta^{15}N$ (Figure 6). This linear pattern in $\delta^{15}N$ and $\delta^{13}C$ values is found in individuals consuming freshwater resources. Determining whether freshwater resources was a substantial portion of the diet can be difficult given the wide range of $\delta^{13}C$ and $\delta^{15}N$ values found in freshwater resources (Katzenberg, 2008; Reitsema et al., 2013). The large variance in $\delta^{13}C$ and $\delta^{15}N$ values found in freshwater fish can also be found within the same species. For example, Reitsema et al. (2013) found a wide range in the $\delta^{13}C$ and $\delta^{15}N$ values of in a type of freshwater fish known as tench (*Tinca tinca*), with a $\delta^{13}C$ value of -28.20‰ for one sample and -5.60‰ for the other and $\delta^{15}N$ 8.90‰ for one sample and 3.80‰ for the other. Mays (1997) suggests that in populations where the stable nitrogen isotopic signatures suggest some marine resource consumption, but the stable carbon isotopic signatures do not necessarily suggest marine resource consumption, might be indicative of the consumption of freshwater resources. Müldner and Richards (2005) argue that when a high $\delta^{15}N$ ratio is combined with an entirely terrestrial carbon signal, much like what is found in the Alytus data, there are two explanations. The first is that individuals are consuming omnivore protein such as pigs feeding on animal products and the second is freshwater resources are being consumed. Without faunal data from Alytus, it is not possible to determine

whether pigs at the site were omnivores or herbivores. However, pig (*Sus* sp.) data from the early medieval Polish site at Giecz (Reitsema et al., 2010) and the pig (*Sus scrofa* or *Sus suis*) data from Lithuanian Mesolithic, Neolithic, and Bronze Age sites (Antanaitis-Jacobs et al., 2009) indicate that pig and boar were herbivores. The most likely explanation for the $\delta^{13}C$ and $\delta^{15}N$ data at Alytus is the consumption of at least some freshwater resources.

Another issue in determining whether freshwater resources were consumed is that the $\delta^{13}C$ and $\delta^{15}N$ values of some freshwater resources can be very similar to those of terrestrial mammals. At the medieval Polish site of Kałdus, chicken (*Gallus gallus*) and dog (*Canis l. familiaris*) have similar $\delta^{15}N$ values as common bream (*Abramis brama*), catfish (*Silurus glanis*), tench (*Tinca tinca*), and pike (*Esox lucius*). Cow (*Bos taurus*), pig (*Sus scrofa*), and sheep (*Ovis sp*.) have similar $\delta^{13}C$ and $\delta^{15}N$ values to pike (*Esox lucius*) and aspe (*Aspius aspius*) (Reitsema et al., 2013).

Following the model used in Mays (1997), the approximate proportion of marine resources consumed at Alytus can be estimated. The approximate $\delta^{13}C$ value for individuals eating a diet consisting of only terrestrial resources is -21.50‰ (Mays, 1997) and the approximate $\delta^{13}C$ value for individuals eating only marine resources is -13.00‰ (Chisholm et al., 1982; Mays, 1997). Under the assumption that $\delta^{13}C$ values differ in a linear manner from marine to terrestrial contributions to diet, the marine resource contribution to diet can be estimated, where a $\delta^{13}C$ value of -21.50‰ corresponds to 0.0% marine resource consumption and a $\delta^{13}C$ value of -13.00‰ corresponds to 100.0% marine resource consumption. For example, using this model a $\delta^{13}C$ value

of -17.25‰ would correspond to 50.0% marine resource consumption. This indicates that approximately 14.95% of the diet of the overall adult population at Alytus was from aquatic resources. Approximately 14.59% of the diet of the female adult population at Alytus was from aquatic resources, while approximately 16.35% of the diet of the male adult population at Alytus was from aquatic resources. However, using the $\delta^{13}C$ value of -13.00‰ (Chisholm et al., 1982) for the baseline of a solely (100.0%) marine resource diet may artificially reduce the estimated proportion of consumed marine resources at Alytus because the Baltic Sea is less saline. In fact, the Baltic Sea's end-value is 2.00‰ to 4.00‰ more negative than the marine end value (Liden, 1995, as cited in Antanaitis-Jacobs et al., 2009). Without a human model of exclusively marine resource consumption from the eastern Baltic, it is difficult to calculate a more accurate estimation of the proportion of marine resources consumed by individuals at medieval Alytus.

However, using the above estimations for the proportion of marine resources the number of meals that were entirely marine resource based, with no terrestrial resource input, can be estimated. Assuming that individuals consumed two meals a day, individuals at Alytus were consuming 730 meals per year. Of those 730 meals, 14.95% is approximately 109 meals per year, or approximately 54.5 days per year, that meals consisted of exclusively of marine resources. According to Woolgar (2000) approximately 200+ days were fast days during the medieval period. Using the estimation of 200 fast days, 54.74% of the meals each year should be marine resource based. Assuming no terrestrial foods were consumed on these days, following Mays

(1997) model, 54.79% of the diet being marine based would produce a $\delta^{13}C$ value of ~ -16.84‰. The $\delta^{13}C$ value of ~ -16.84‰ provides an estimation of a $\delta^{13}C$ value of an individual participating in Catholic fast days during the medieval period, which is much more enriched compared to the mean $\delta^{13}C$ value of -20.08‰ found for adult individuals at Alytus. The depleted $\delta^{13}C$ values at Alytus indicate that individuals might not have been participating in Catholic fast days. However, the estimation of a $\delta^{13}C$ value of ~ -16.84‰ for an individual participating in Catholic fasting during the medieval period is likely too enriched based on what is observed in the archaeological record. Individuals most likely to strictly adhere to Catholic fasting practices are monastic groups. Table 25 presents the stable carbon isotopic results and contextual information about eight different medieval monastic groups. None of these archaeological groups have mean $\delta^{13}C$ values near the estimated $\delta^{13}C$ value for participation in Catholic fasting practices of ~ -16.84‰. These differences suggest the estimated $\delta^{13}C$ value based off of the Mays (1997) model provides $\delta^{13}C$ values more enriched than what is actually observed in archaeological populations during the medieval period in Europe and the Middle East, especially for those populations that are reliant on C_3 resources or those that consumed primarily freshwater resources rather than marine resources.

Historical documentation notes that with the expansion of Christianity marine and freshwater resources increased in importance in order to meet with Catholic fast day prohibitions on meat and animal products. Archaeological analysis demonstrates through the investigation of fish bones that there was an increase in the utilization of fish in Europe during the 10th and 11th centuries.

Table 25. Summary of a selection of human data from archaeological sites in medieval and post medieval Europe and Middle East including location, time period, and mean, ranges, and standard deviation of $\delta^{13}C$ values and author conclusions

Citation	Group	Location	Time Period	Mean $\delta^{13}C$ (‰)	SD $\delta^{13}C$ (‰)	Range $\delta^{13}C$ (‰)	Conclusions
Gregoricka and Sheridan (2013)	Monastic Males	St. Stephen, Jerusalem	5th to 7th C	-19.10	0.50	-20.60 to -18.20	Affluent monastic community, primarily consuming C3 resources
Mays (1997)	Monastic	York Fishergate, England	1195 to 14th C	-18.29	0.56	-	Diet based primarily on terrestrial foods, but marine resources formed an important source of protein
Müldner et al. (2009)	Bishop and Priests	Whithorn, Scotland	11th to 14th C	-19.20	0.22	-19.40 to -18.90	Consuming C3 dominated foods
Quintelier et al. (2014)	Monastic Males	Carmelite Friary of Aalst, Belgium	16th to 18th C	-19.30	0.60	Approx. -20.50 to -18.90	Not likely consuming C4 plants. Marine resources appear to be an important component of diet.
Regan et al. (2005)	Monastic	St. Stephen, Jerusalem	5th to 7th C	-19.00	0.70	-20.60 to -18.40	Affluent monastic community, likely not consuming any C4 plants
	Monastic Males	St. Stephen, Jerusalem	5th to 7th C	-19.00	0.80	-20.60 to -15.40	Affluent monastic community, likely not consuming any C4 plants
	Monastic Females	St. Stephen, Jerusalem	5th to 7th C	-19.00	0.40	-19.60 to -18.30	Affluent monastic community, likely not consuming any C4 plants
Yoder (2012)	Monastic	1172 to mid-16th C	Om Kloster, Denmark	-19.77	0.47	-	Diet higher in C3 plants like the peasant group but also ate more terrestrial animal proteins and/or freshwater fish

By the 13th and 14th centuries northern and western Europe were meeting increased demands for marine resources by importing from the eastern Baltic (Barrett et al., 2012). These findings are echoed by Orton et al. (2011) who examined 13th to 16th century cod (*Gadus morhua*) bones from archaeological sites around the eastern Baltic littoral, which includes the coastline of medieval Lithuania. Orton et al. (2011) determined that during the 13th to 14th centuries, the majority of cod was imported from Artic Norway, but by the 15th century, eastern Baltic cod dominated the sample. This finding might indicate the development of a late medieval fishery and suggests fish were procured locally in the eastern Baltic.

In combination with the archaeological data that demonstrates the widespread utilization of marine resources from the eastern Baltic, the stable carbon and nitrogen isotopic signatures of the individuals at medieval Alytus suggest the consumption of aquatic resources. Historical documentation of the relationship between the utilization of aquatic resources and the spread of Christianity throughout Europe during the medieval period, and the isotopic evidence of aquatic resource consumption at Alytus, might indicate that individuals at medieval Alytus participated in Catholic fasting practices. However, participation would likely have been limited.

It has been previously suggested that pathological conditions on sampled elements can affect the stable nitrogen isotope signatures (Katzenberg and Lovell, 1999). However, in the Alytus sample there was no statistically significant difference in the $\delta^{13}C$ or $\delta^{15}N$ values between individuals with a noted pathological condition on the sampled element, and no noted pathological condition on the sampled element. This

does not refute the suggestion that pathological conditions have an effect on stable nitrogen isotope signatures. The lack of significant difference between Alytus individuals with and without pathological conditions on the sampled element may be due to avoidance of these areas during sampling or from the masking of disease signatures because isotopic analysis of bone collagen reflects bulk isotopic data over the approximately last decade of life.

Dentin Collagen

Overall the $\delta^{13}C$ values for the Alytus dentin collagen samples (mean of -20.11‰) indicate that individuals were almost exclusively consuming C_3 plants during the juvenile period (birth to seven years of age). This indicates that juvenile individuals at Alytus were consuming primarily wheat, barley, tubers, and vegetables, all of which are C_3 plants. Given their $\delta^{13}C$ values for dentin collagen, juvenile individuals at Alytus were likely consuming a small amount of marine or freshwater resources during the juvenile period after weaning. The $\delta^{13}C$ values in the dentin collagen also indicate that there is no statistically significant difference between juvenile males and juvenile females, juvenile males and the overall juvenile population that survived into adulthood, and juvenile females and the overall juvenile population that survived into adulthood, suggesting that there is no difference in the consumption of C_3 plants or aquatic resources for these groups. There are no significant differences in $\delta^{13}C$ values between any of the age at death cohorts for dentin collagen samples, indicating that age at death was not related to the consumption of C_3 plants or aquatic resources during the juvenile period.

Overall the $\delta^{15}N$ values for the Alytus dentin collagen samples (mean of 10.66‰) indicate that individuals were almost exclusively consuming terrestrial fauna during the juvenile period. This indicates that juvenile individuals at Alytus were primarily consuming terrestrial fauna such as cow, deer, pig, and sheep. The mean and range of $\delta^{15}N$ values of the dentin collagen may also indicate the consumption of freshwater resources during the juvenile period at Alytus. However, this is less likely as there is less of a linear trend in the $\delta^{15}N$ and $\delta^{13}C$ values than is found in the bone collagen signatures. Since dentin collagen reflects the combined diet from about birth to seven years of age, dentin collagen would also reflect the time period when juveniles were breastfeeding and weaning. Medieval Alytus individuals breastfed exclusively through two years of age and were weaned from two to five years of age (Page, personal communication). Thus the stable isotope signatures observed in the juvenile period reflect bulk diet; a combination of breastfeeding, with little to no terrestrial, marine, or freshwater protein resource consumption, and the transition to adult resource consumption, which would include both terrestrial and aquatic protein resources. The $\delta^{15}N$ values in the dentin collagen also indicate that there is no statistically significant difference between juvenile males and juvenile females, juvenile males and the overall juvenile population, and juvenile females and the overall juvenile population, indicating that there is no difference in the consumption of dietary protein sources between these groups. Additionally, there was no statistically significant difference in the $\delta^{15}N$ values for individuals sampled from mandibular permanent first molars and individuals sampled

from maxillary permanent first molars indicating that there is no difference in the diet between these two groups.

A significant difference was found in the $\delta^{15}N$ values of dentin collagen between individuals in the MA and OA age at death cohorts. This indicates that a difference in the dietary protein sources during the juvenile period may have an effect on age at death. In this case the OA age at death cohort has more depleted $\delta^{15}N$ values than the other age at death cohorts for dentin collagen. This may indicate that for individuals that survived into adulthood, depleted $\delta^{15}N$ values in the juvenile period is associated with older age at death, although the causes for this are unclear. There are no other significant differences in $\delta^{15}N$ values between any of the age at death cohorts for dentin collagen samples, indicating that there were no differences in dietary protein sources for during the juvenile period and adult age at death.

Differences between dentin and bone collagen

Dentin collagen reflects the bulk diet of early juvenile period from birth to approximately seven years of age while bone collagen reflects the diet of approximately the last decade of life. Comparison of the two tissues allows for a comparison between adult diet and juvenile diet. The $\delta^{13}C$ and $\delta^{15}N$ values in bone and dentin collagen can be examined overall in the Alytus population, between sexes, between different age at death cohorts, and intra-individually.

Overall there is no significant difference in the $\delta^{13}C$ values between the dentin and bone collagen samples. Overall there is a significant difference in the $\delta^{15}N$ values

between the dentin and bone collagen samples. The mean $\delta^{15}N$ value is enriched for the dentin collagen samples than the bone collage samples. This may be a result of breastfeeding/weaning signatures that contribute to the $\delta^{15}N$ values in the dentin collagen samples as previously discussed. However, there are also significant differences between the male dentin collagen samples and the overall bone collagen samples, between the overall dentin collagen sample and the female bone collagen sample, and between the female bone collagen sample and the male dentin sample. These differences might be a result of the generally depleted $\delta^{15}N$ female bone collagen signatures and the general more enriched $\delta^{15}N$ male dentin collagen signatures. Perhaps male juveniles were incorporating more terrestrial faunal and/or aquatic resources in their diets compared to their female counterparts. Possibly male juveniles were weaned later than female juveniles. Mays et al. (2002) notes historical medical documents during the medieval period recommended the cessation of breastfeeding at around two years of age, but suggests that male juveniles be weaned six to 12 months later than female juveniles. However, there is no statistically significant difference between the male and female dentin collagen values, suggesting that if there were differences in male and female juvenile weaning times or in the consumption of protein resources during the later juvenile period, the difference was not great. Perhaps this difference is caused by adult females consuming less terrestrial faunal and/or aquatic resources in their diets than their male counterparts. Or perhaps physiological factors, such as pregnancy or disease, are contributing to the depleted female $\delta^{15}N$ bone collagen values. There is a statistically significant difference between the male and

female bone collagen values. $\delta^{15}N$ values are significantly different between the males and females in the YA age at death cohort, however they are not significantly different in the MA ($p= 0.123$) or OA ($p= 0.377$) age at death cohorts. The MA and OA age at death cohorts still reflect the reproductive adult period, indicating that if pregnancy had an effect on the $\delta^{15}N$ values of females, the effect was not great. Likely the increased consumption of resources with more enriched $\delta^{15}N$ values in juvenile males in combination with the depleted $\delta^{15}N$ values in adult females, possibly due to dietary or physiological causes, leads to the significant differences between these groups.

In examining individuals that provided both dentin and bone collagen samples there is a noticeable pattern in the difference of $\delta^{13}C$ and $\delta^{15}N$ values between dentin and bone collagen for sex. In individuals where the $\delta^{13}C$ value of the dentin collagen sample was depleted compared to the bone collagen sample, the majority of individuals were male (78%; representing 64% of the males in the total sample), and only 22% were female (representing 33% of females in the total sample). The more depleted $\delta^{13}C$ values in the dentin collagen indicates that the majority of males consumed more C_3 plants, less C_4 plants, and/or less aquatic resources during the juvenile period compared to the adult period. In individuals where the $\delta^{13}C$ value of the dentin collagen sample was enriched, compared to the bone collagen sample, 50% were female (representing 67% of females in the total sample) and 50% were male (representing 36% of the males in the total sample). This indicates that the majority of females consumed less C_3 plants, more C_4 plants, and/or utilized of more aquatic resources during their juvenile period than their adult period.

In individuals where the $\delta^{15}N$ value of the dentin collagen sample was more depleted than the bone collagen sample, only 20% were female (representing 8% of females in the sample) and 80% were male (representing only 18% of the males in the sample). The more depleted $\delta^{15}N$ values in the dentin collagen indicates that about one fifth of males were consuming less protein (aquatic or terrestrial) resources during the juvenile period compared to the adult period, or cessation of breastfeeding was taking place at a younger age. In individuals where the $\delta^{15}N$ value of the dentin collagen sample was more enriched than the bone collagen sample, 38% were female (representing 92% of females in the sample) and 62% were male (representing 82% of the males in the sample). Overall both males and females were more likely to have a more positive $\delta^{15}N$ values during their juvenile period, probably as a result of the breastfeeding signature in $\delta^{15}N$ values of dentin collagen. While the majority of males have depleted $\delta^{13}C$ values during their juvenile period compared to their adult period, they do not have depleted $\delta^{15}N$ values during their juvenile period compared to their adult period. This suggests the statistically significant difference in $\delta^{15}N$ values observed between juvenile males and adult females is due to later weaning of juvenile males and adult females consuming less terrestrial and/or aquatic protein, rather than juvenile males consuming less aquatic protein resources.

Comparison of Alytus to Other Archaeological Sites

A substantial number of stable carbon and nitrogen isotopic research studies have been undertaken at medieval sites throughout Europe (Barrett et al., 2011; Bourbou et al., 2013; Bourbou and Richards, 2007; Bourbou et al., 2011; Czermak et

al., 2006; Fornaciari, 2008; Fuller et al., 2010; 2012; Garvie-Lok, 2001; Herrscher et al., 2001; Kjellstrom et al., 2009; Kosiba et al., 2007; Lightfood et al., 2012; Mays, 1997; Müldner and Richards, 2005; 2007a; 2007b; Müldner et al., 2009; Orton et al., 2011; Polet and Katzenberg, 2003; Reitsema and Vercellotti, 2012; Reitsema et al., 2010; 2013; Richards et al., 2002; Salamon et al., 2008; Schutkowski et al., 1999; Yoder, 2010; 2012), however substantially less research has been conducted in the region surrounding Alytus, Lithuania (Antanaitis-Jacobs et al., 2009; Barrett et al., 2011; Becker and Grupe, 2012; Kosiba et al., 2007; Orton et al., 2011; Reitsema, 2012; Reitsema et al., 2010; 2013; 2014). A selection of research investigating human individuals in the medieval period in Europe through stable isotope research is summarized in Table 26 and a corresponding summary of the faunal data is found in Table 27. Research investigating humans through stable carbon and nitrogen isotopic analysis in the region surrounding Alytus is summarized in Table 28, and studies investigating fauna in the region surrounding Alytus can be found in Table 29.

In terms of $\delta^{13}C$ values the Alytus bone collagen samples do not resemble any of the human isotopic data from comparison sites in the region surrounding Lithuania. In comparison to medieval sites throughout Europe however, there are a few comparison sites with human $\delta^{13}C$ values similar to Alytus. One of the most similar is the site of Om Kloster in Denmark, which dates from 1172 AD to the mid-16th century (Yoder, 2010).

Table 26. Summary of a selection of human data from archaeological sites in medieval Europe including location, time period, sampled tissue, mean $\delta^{13}C$ and $\delta^{15}N$ values, and author conclusions

Citation	Location	Time Period	Tissue Sampled	Human or Faunal?	Subgroup	Mean $\delta^{13}C$(‰)	Mean $\delta^{15}N$(‰)	Conclusions
Bourbou et al. (2013)	Servia, Greece	11th to 15th C	Bone	Humans	Adult females	-18.9	8.5	Primarily terrestrial protein sources with little to no marine resource consumption
Bourbou and Richards (2007)	Crete, Greece	Middle Byzantine (11th C)	Bone	Human		-19.4 to -18.2	7.5-12.1	Diet primarily of terrestrial, C3 protein, probably from animal sources with some marine protein
Bourbou et al. (2011)	Petras, Greece	6th to 15th C	Bone	Human		-19.2	9.5	Terrestrial based C3 diet, significant amounts of animal protein, possibly some C4 plants, no dependence on low, marine protein at coastal and some inland sites. Increased marine usage possibly due to fasting practices
Czermak et al. (2006)	Bavaria	Early Medieval	Bone	Human			8.18 to 11.22	Animal based protein and C3 plants, no consumption of freshwater fish
Fornaciari (2008)	Florence, Italy	16th -17th C	Bone	Human		-19 to -17	11 to 14	Diet rich in meat, some intake of fish.
	Naples, Italy	15th to 17th C	Bone	Human		-19 to -16	10 to 14	Diet rich in meat, intake of fish. Fish consumption related to fasting
Fuller et al. (2010)	Ibiza, Spain	10th to 13th C	Bone	Human	Islamic	-18.1	10.9	Islamic. Increased reliance on C4 plants and/or animals
Fuller et al. (2012)	Sagalassos, Turkey	Middle Byzantine (800-1200AD)	Bone	Human		-19	9.1	Diet was C3 terrestrial based and composed of livestock such as cattle and pigs
Garvie- Lok, 2001	Mitilini, Greece	14-15th C	Bone	Human		-19.3	8.3	No evidence for consumption of legumes, primarily terrestrial protein sources with little to no marine component
	Nemea, Greece	12th to 15th C	Bone	Human		-19.1	8.7	No evidence for consumption of legumes, primarily terrestrial protein sources with little to no marine component
	Servia, Greece	11th to 15th C	Bone	Human		-18.7	8.9	No evidence for consumption of legumes, primarily terrestrial protein sources with little to no marine component

Citation	Location	Time Period	Tissue Sampled	Human or Faunal?	Subgroup	Mean $\delta^{13}C$(‰)	Mean $\delta^{15}N$(‰)	Conclusions
Herrscher et al. (2001)	France	Late Medieval	Bone	Human		-19.1 to -20.6	6.3 to 10.8	Animal protein and no freshwater or marine fish consumption
		Phase 15	Bone	Human			9.2	More access to animal protein
Kjellstrom et al. (2009)	Sigtuna, Sweden. Nunnan block	900-1100AD	Bone	Human	Females	-21.57	10.73	Females. Terrestrial protein, higher input of vegetables at Nunnan
	Sigtuna, Sweden. Nunnan block	900-1100AD	Bone	Human	Males	-21.19	11.3	Males. Terrestrial protein, higher input of vegetables at Nunnan
	Sigtuna, Sweden. Church 1, phase 1	900-1100AD	Bone	Human	Females	-20.7	13.06	Females. Terrestrial protein. Difference to males, consuming more animal protein.
	Sigtuna, Sweden. Church 1, phase 1	900-1100AD	Bone	Human	Males	-20.64	12.39	Males. Terrestrial protein.
	Sigtuna, Sweden. Church 1, phase 2	1100-1300AD	Bone	Human	Females	-20.99	13.89	Females. Difference to Nunnan block could be representative of stricter adherence to fasting
	Sigtuna, Sweden. Church 1, phase 2	1100-1300AD	Bone	Human	Males	-21.54	12.5	Males. Difference to Nunnan block could be representative of stricter adherence to fasting
	Sigtuna, Sweden. St Lawrence	1300-1500AD	Bone	Human	Females	-21.14	12.13	Females. Religious institutions abandoned. Less protein consumption than Phase 2
	Sigtuna, Sweden. St Lawrence	1300-1500AD	Bone	Human	Males	-20.74	12.65	Males. Religious institutions abandoned. Less protein consumption than Phase 2
Kosiba et al. (2007)	Gotland, Sweden	11th to 12th C	Bone	Human		-17.2	11.6	Equal parts terrestrial and marine foods
Lightfoot et al. (2012)	Croatia	Roman	Bone	Human		-18.8	10.1	Incorporation of marine protein, mostly C3 foodstuffs with the incorporation of some C4 plants such as millet.
	Radasinovci-Vinogradine, Croatia	850-900AD	Bone	Human		-17.7	9.7	Marine component seen in earlier time periods lost, and C4 plants were added to the diet, likely millet
	Sibenik-Sveti Lovre, Croatia	800-1000AD	Bone	Human		-18.4	10	Marine component seen in earlier time periods lost, and C4 plants were added to the diet, likely millet

Citation	Location	Time Period	Tissue Sampled	Human or Faunal?	Subgroup	Mean $\delta^{13}C$(‰)	Mean $\delta^{15}N$(‰)	Conclusions
Mays (1997)	York Fishergate, England. Monastic group.	1195 to early 14th C	Bone	Human		-18.29		Diet based primarily on terrestrial foods, but marine resources formed an important source of protein
	York Fishergate, England. Lay group.	1195 to early 14th C	Bone	Human		-19.47		Diet based primarily on terrestrial foods, but marine resources less marine food consumption than the monastic group
	Wharram Percy, England	10th to 16th C	Bone	Human		-19.7		Diet based primarily on terrestrial foods, with some consumption of marine resources
	Hartlepool Greyfriars, England. Lay persons	13th to 16th C	Bone	Human		-18.17		Diet based primarily on terrestrial foods, but marine resources formed an important source of protein
	Newcastle Blackfriars, England. Lay persons	13th to 16th C	Bone	Human		-18.55		Diet based primarily on terrestrial foods, but marine resources formed an important source of protein
	Scarborough, Castle Hill, England. Lay persons	11th to 16th C	Bone	Human		-20.17		Diet based primarily on terrestrial foods, surprising lack of marine resources given that Scarborough had a major deep-sea fishing fleet
Müldner and Richards (2005)	St. Giles, England	12th to 15h C	Bone	Human		-20.1 to -18.3	10.9 to 13.8	Rural Hospital. Carbon suggests a terrestrial C3 based diet and a mixture of terrestrial, freshwater (possibly eel), and marine protein
	Warrington, England	Mid-13th to 17th C	Bone	Human		-20.6 to -18.8	10.6 to 13.9	Urban Friary. Carbon suggests a terrestrial C3 based diet and a mixture of terrestrial, freshwater (eel?), and marine protein
	Towton, England	1461AD	Bone	Human		-20.2 to -18.3	11.8 to 14.0	Mass grave of soldiers from around England. Carbon suggests a terrestrial C3 based diet and a mixture of terrestrial, freshwater (eel?), and marine protein. Freshwater resources consumed throughout England.
Müldner and Richards (2007a)	Gilbertine priory of St. Andrew, Fishergate, England	13th to early 16th C	Bone	Human	Males	-18.9	13	Males. Variation in consumption of marine resources between sexes.

Citation	Location	Time Period	Tissue Sampled	Human or Faunal?	Subgroup	Mean $\delta^{13}C$(‰)	Mean $\delta^{15}N$(‰)	Conclusions
Müldner and Richards (2007a)	Gilbertine priory of St. Andrew, Fishergate, England	13th to early 16th C	Bone	Human	Females	-19.5	12.1	Females. Variation in consumption of marine resources between sexes.
Müldner and Richards (2007b)	Gilbertine Priory at Fishergate, England	13th to 16th C	Bone	Human		-19.1	12.8	Significant but varying amounts of marine protein, possibly related to fasting practices
	All Saints, Pavement, England	Medieval	Bone	Human		-18.8	12.6	Significant but varying amounts of marine protein, possibly related to fasting practices
	All Saints, Pavement, England	Post medieval	Bone	Human		-19.1	12.6	Significant but varying amounts of marine protein, possibly related to fasting practices that were used to promote England's role as a seafaring nation
Müldner et al. (2009)	Withorn Cathedral Priory, Scotland	11th to late 14th C	Bone	Human	Monastic	-20.0 to -18.9	11.5 to13.5	Bishops and priests. Terrestrial foods produced in C3 ecosystem, incorporation of marine foods into diet
	Withorn Cathedral Priory, Scotland	11th to late 14th C	Bone	Human	Lay	-21.1 to -19.4	10.5 to 12.0	Lay persons. Terrestrial foods produced in C3 ecosystem, incorporation of marine foods into diet
Polet and Katzengberg (2003)	Koksijde, Belgium	12th to 15th C	Bone	Human		-19.1	11.1	Diet based largely on terrestrial foods, but marine resources also formed a source of protein
Reitsema and Vercellotti (2012)	Trino Vercellese, Northern Italy	8th to 13th C	Bone	Human	Males	-18.9	8.8	Males. Mostly terrestrial based diet including plant and animal protein. Greater range in nitrogen and small range in carbon could indicate the incorporation of freshwater resources
		8th to 13th C	Bone	Human	Females	-19.5	9.2	Females. Mostly terrestrial based diet including plant and animal protein. Greater range in nitrogen and small range in carbon could indicate the incorporation of freshwater resources

Citation	Location	Time Period	Tissue Sampled	Human or Faunal?	Subgroup	Mean $\delta^{13}C$(‰)	Mean $\delta^{15}N$(‰)	Conclusions
Reitsema and Vercellotti (2012)	Trino Vercellese, Northern Italy	8th to 13th C	Dentin	Human	Males	-19.4	9.5	Males. Mostly terrestrial based diet including plant and animal protein. Greater range in nitrogen and small range in carbon could indicate the incorporation of freshwater resources
		8th to 13th C	Dentin	Human	Females	-19.4	9.2	Females. Mostly terrestrial based diet including plant and animal protein. Greater range in nitrogen and small range in carbon could indicate the incorporation of freshwater resources
Reitsema et al. (2010)	Giecz, Poland	11th to 12th C	Bone	Human	Males	-18.8	9.6	Males. Dietary protein from terrestrial and not aquatic sources. Freshwater fish were not a significant dietary resource for this population. Consuming both C3 and C4 resources, but more C3 resources
Reitsema et al. (2010)	Giecz, Poland	11th to 12th C	Bone	Human	Females	-19	8.8	Females. Dietary protein from terrestrial and not aquatic sources. Freshwater fish were not a significant dietary resource for this population. Consuming both C3 and C4 resources, but more C3 resources
Richards et al. (2002)	Wharram Percy, Yorkshire, UK	10th to 16th C	Bone	Human		~ -19.6	~ 9.0	No input of marine or C4 foods in the average diet, mixed diet with contributions from animal (meat or milk) and plant protein
Salamon et al. (2008)	Castro die Volsci, Italy	Early Medieval	Bone	Human		-20.25 to -19.0	6.5 to 9.0	Predominately terrestrial C3
	Castro die Volsci, Italy	Early Medieval	Dentin	Human		-20.25 to -18.75	7 to 10	Predominately terrestrial C3
	Rome, Italy	Late Medieval	Bone	Human		-19.5 to -18.0	9.0 to 15.0	Incorporation of substantial marine protein, variable within population
	Rome, Italy	Late Medieval	Dentin	Human		-20 to -18	8.75 to 15.75	Incorporation of substantial marine protein, variable within population
Schutkowski et al. (1999)	Weingarten, Germany	6th to 8th C	Bone	Human		-21.7 to 18.1, mean ~ -19.77	7.1 to 10.3, mean ~8.77	Diet based predominantly on C3 plants and terrestrial protein resources

Citation	Location	Time Period	Tissue Sampled	Human or Faunal?	Subgroup	Mean $\delta^{13}C$(‰)	Mean $\delta^{15}N$(‰)	Conclusions
Yoder (2010)	Om Kloster, Denmark	1172 to mid 16th C	Bone	Human		-19.86	11.64	Diet based on C3 plant and terrestrial resources with some freshwater species
	St Mikkel, Viborg, Denmark	12th to 16th C	Bone	Human		-19.24	12.39	Diet based on C3 plant and terrestrial resources with some marine and freshwater species
	Ribe, Denmark	1250AD to early 15th C	Bone	Human		-19.19	12.85	Diet based on C3 plant and terrestrial resources with more marine and freshwater species
Yoder (2012)	Om Kloster, Denmark	1172 to mid 16th C	Bone	Human	Elite	-19.4	12.47	Terrestrial animal protein, C3 plant foods, and marine resources
	Om Kloster, Denmark	1172 to mid 16th C	Bone	Human	Monastic	-19.77	12.25	Diet higher in C3 plants like the peasant group but also ate more terrestrial animal proteins and/or freshwater fish
	Om Kloster, Denmark	1172 to mid 16th C	Bone	Human	Peasant	-19.85	11.63	Diet primarily composed of C3 plant foods and terrestrial animal protein with smaller contributions from marine foods.

Table 27. Summary of a selection of faunal data from archaeological sites in medieval Europe including location, time period, sampled tissue, mean $\delta^{13}C$ and $\delta^{15}N$ values, and author conclusions

Citation	Location	Time Period	Tissue Sampled	Human or Faunal?	Subgroup	Mean $\delta^{13}C$(‰)	Mean $\delta^{15}N$(‰)	Conclusions
Barrett et al. (2011)	England and Belgium (cod from Eastern Baltic Sea)	Medieval	Bone	Fish	Cod	-15 to -17.5	11 to 16	By the 13th- 14th centuries increased demand for fish was met through long distance transport
Kjellstrom et al. (2009)	Sigtuna, Sweden	Medieval	Bone	Fish	Pike	-20.35	10.66	Freshwater fish
Orton et al. (2011)	Eastern Baltic sites are in Poland, Estonia, and Sweden	12th to 16th C	Bone	Fish	Cod	-18.66 to -15.55	9.40 to 12.19	Cod bones from archaeological sites in the Baltic region that are estimated to have been locally (in the Eastern Baltic) procured
Reitsema et al. (2010)	Giecz, Poland	11th to 12th C	Bone	Mammals		-21.9 to -20.5, mean -21.4	5.8 to 6.8, mean 6.3	Indicative of C3 feeders
	Giecz, Poland	11th to 12th C	Bone	Fish		-26.5 to -24.5, mean -25.5	6.4 to 12.3, mean 9.6	Likely freshwater based on carbon signatures. More positive nitrogen values are associated with more positive carbon values
Reitsema et al. (2013)	Kałdus, Poland	12th to 13th C	Bone	Domestic animals		-20.6	7.6	
	Kałdus, Poland	12th to 13th C	Bone	Wild animals		-22	5.3	
	Kałdus, Poland	12th to 13th C	Bone	Fish		-21.9	9.5	
	Kałdus, Poland	12th to 13th C	Bone	Fish	Sturgeon	-16.47	10.6	Migratory (Baltic Sea to river)
	Kałdus, Poland	12th to 13th C	Bone	Fish	Pike	-24.93	9.03	Freshwater, lake, lake- river
	Kałdus, Poland	12th to 13th C	Bone	Fish	European catfish	-23.6	11.03	Freshwater, lake, lake- river
	Kałdus, Poland	12th to 13th C	Bone	Fish	Common bream	-25.05	9	Freshwater, lake, lake- river, river
	Kałdus, Poland	12th to 13th C	Bone	Fish	Aspe	-24	6.6	Freshwater, lake, lake- river, river
	Kałdus, Poland	12th to 13th C	Bone	Fish	Tench	-28.2 to -5.6	3.8 to 8.9	Freshwater, lake, lake- river
	Kałdus, Poland	12th to 13th C	Bone	Fish	Pike-perch	-23.75	11.05	Freshwater

The mean $\delta^{13}C$ value for this group is -19.86‰ and Yoder (2010) concluded individuals at this site were eating a diet based on C_3 plant and terrestrial resources but were also consuming some freshwater resources. The mean $\delta^{15}N$ value at this site is 11.64‰ which is more enriched than the mean $\delta^{15}N$ value of 10.29‰ found at Alytus. However, the mean $\delta^{15}N$ value at Om Kloster does fall within the range of $\delta^{15}N$ values found at Alytus (8.69‰ to 12.15‰). Another similar site is Scarborough, Castle Hill, England, which dates from the 11th to 16th century and represents a community of lay individuals. The mean $\delta^{13}C$ value for this group is -20.17‰ and Mays (1997) concluded the individuals at Scarborough were consuming a diet primarily based on terrestrial resources and overall less on marine resources than would be expected given that Scarborough had a major deep-sea fishing fleet. Unfortunately, $\delta^{15}N$ values are not provided for this site so further comparison to the Alytus sample is not possible. It should be noted that Scarborough is on the coast of the North Sea which is more saline than the Baltic Sea, which is adjacent to Lithuania, and it would be expected that marine resource consumption from Scarborough would result in more enriched $\delta^{13}C$ values.

In terms of $\delta^{15}N$ values, the Alytus bone collagen samples only resemble one of the comparison sites from the region surrounding Lithuania. Donkalnis is a site currently believed to date to the Mesolithic or Neolithic period and has a mean $\delta^{15}N$ value of 10.30‰ (Antanaitis-Jacobs et al., 2009). Antanaitis-Jacobs et al. (2009) concluded these individuals were consuming a diet mostly of terrestrial animal protein with the inclusion of some freshwater fish. However, the mean $\delta^{13}C$ value for this site is -22.60‰ which is more depleted than the Alytus mean and outside the Alytus range.

Table 28. Summary of a selection of human data from archaeological sites around the region of Lithuania including location, time period, sampled tissue, mean $\delta^{13}C$ and $\delta^{15}N$ values, and author conclusions

Citation	Location	Time Period	Tissue Sampled	Human or Faunal?	Subgroup	Mean $\delta^{13}C$(‰)	Mean $\delta^{15}N$(‰)	Conclusions
Antanaitis-Jacobs et al. (2009)	Donkalnis, Lithuania	Mesolithic? Neolithic?	Bone	Human		-22.6	10.3	Freshwater fish, majority terrestrial animal protein; similar signatures between adults and juveniles
	Lithuania*	Late Mesolithic	Bone	Human		-22.7	12.6	Terrestrial animal protein with higher input from freshwater resources
	Lithuania**	Late Neolithic	Bone	Human		-21.9 to -21.4	7.99 to 10.1	Diet of mainly animal protein, meat or milk; unlikely freshwater fish consumed
	Lithuania***	Bronze Age	Bone	Human		-18.4	Similar to Late Neolithic	Carbon indicates marine protein but nitrogen is too low; diet based on domestic animals and the C4 plant millet
Kosiba et al. (2007)	Gotland, Sweden	11th to 12th C	Bone	Human		-17.2	11.6	Equal parts terrestrial and marine foods
Reitsema et al. (2010)	Giecz, Poland	11th to 12th C	Bone	Human	Males	-18.8	9.6	Males. Dietary protein from terrestrial and not aquatic sources. Freshwater fish were not a significant dietary resource for this population. Consuming both C3 and C4 resources, but more C3 resources
	Giecz, Poland	11th to 12th C	Bone	Human	Females	-19	8.8	Females. Dietary protein from terrestrial and not aquatic sources. Freshwater fish were not a significant dietary resource for this population. Consuming both C3 and C4 resources, but more C3 resources

**Includes data from the sites of Spiginas and Donkalnis in Lithuania*
***Includes data from the sites of Gyvakarai, Plinkaigalis, and Spinginas in Lithuania*
****Includes data from the sites of Turlojiškė and Kirsna*

Table 29. Summary of a selection of faunal data from archaeological sites around the region of Lithuania including location, time period, sampled tissue, mean $\delta^{13}C$ and $\delta^{15}N$ values, and author conclusions

Citation	Location	Time Period	Tissue Sampled	Human or Faunal?	Subgroup	Mean $\delta^{13}C$(‰)	Mean $\delta^{15}N$(‰)	Conclusions
Antanaitis-Jacobs et al. (2009)	Lithuania	Mesolithic or Neolithic	Bone		Herbivores	-24.1 to -20.7	2.2 to 5.5	Feeding on C3 plants
	Lithuania	Mesolithic or Neolithic	Bone	Fish	Pike	-21.60	12.60	Freshwater fish
	Lithuania	Mesolithic or Neolithic	Bone	Fish	Pike-perch	-21.80	12.60	Freshwater fish
	Lithuania	Mesolithic or Neolithic	Bone	Fish	Flounder	-16.60	11.60	Marine fish
	Lithuania	Mesolithic or Neolithic	Bone		Carnivores	-20.7 to -18.5	8.8 to 13.3	
Barrett et al. (2011)	England and Belgium (Eastern Baltic Sea)	Medieval	Bone	Fish	Cod	-15 to -17.5	11 to 16	By the 13th- 14th centuries increased demand for fish was met through long distance transport
Becker and Grupe (2012)	Northern Germany (Baltic Sea)	9th to11th C	Bone	Fish	Cod	-15.7	15.6	Marine fish
			Bone	Fish (perch)		-16.7	10.1	Freshwater fish
			Bone	Fish	Pike	-21.5	12.1	Freshwater fish
			Bone	Fish	Sander	-21.7	10.4	Marine fish
	Northern Germany (Baltic Sea)	11th to12th C	Bone	Fish	Cod	-15.5	12.1	Marine fish
			Bone	Fish	Bream	-25.6	7.1	Freshwater fish
			Bone	Fish	Garfish	13.9	9.6	Marine fish
			Bone	Fish	Haddock	-15.7	13.3	Marine fish
			Bone	Fish		-14.4	12.5	Freshwater fish

Citation	Location	Time Period	Tissue Sampled	Human or Faunal?	Subgroup	Mean $\delta^{13}C$(‰)	Mean $\delta^{15}N$(‰)	Conclusions
Becker and Grupe (2012)			Bone	Fish	Pike	-22.3	8.6	Freshwater fish
			Bone	Fish	Plaice	-14.9	10.7	Marine fish
Orton et al. (2011)	Eastern Baltic sites are in Poland, Estonia, and Sweden	12th to 16th C	Bone	Fish	Cod	-18.66 to -15.55	9.40 to 12.19	Cod bones from archaeological sites in the Baltic region that are estimated to have been locally (in the Eastern Baltic) procured
Reitsema et al. (2010)	Giecz, Poland	11th to 12th C	Bone	Mammals		-21.9 to -20.5, mean -21.4	5.8 to 6.8, mean 6.3	Indicative of C3 feeders
	Giecz, Poland	11th to 12th C	Bone	Fish		-26.5 to -24.5, mean -25.5	6.4 to 12.3, mean 9.6	Likely freshwater based on carbon signatures. More positive nitrogen values are associated with more positive carbon values
Reitsema et al. (2013)	Kałdus, Poland	12th to 13th C	Bone	Domestic animals		-20.6	7.6	
	Kałdus, Poland	12th to 13th C	Bone	Wild animals		-22	5.3	
	Kałdus, Poland	12th to 13th C	Bone	Fish		-21.9	9.5	
	Kałdus, Poland	12th to 13th C	Bone	Fish	Sturgeon	-16.47	10.6	Migratory (Baltic Sea to river)
	Kałdus, Poland	12th to 13th C	Bone	Fish	Pike	-24.93	9.03	Freshwater, lake, lake- river
	Kałdus, Poland	12th to 13th C	Bone	Fish	European catfish	-23.6	11.03	Freshwater, lake, lake- river
	Kałdus, Poland	12th to 13th C	Bone	Fish	Common bream	-25.05	9	Freshwater, lake, lake- river, river

Citation	Location	Time Period	Tissue Sampled	Human or Faunal?	Subgroup	Mean $\delta^{13}C$(‰)	Mean $\delta^{15}N$(‰)	Conclusions
Reitsema et al. (2013)	Kałdus, Poland	12th to 13th C	Bone	Fish	Aspe	-24	6.6	Freshwater, lake, lake- river, river
	Kałdus, Poland	12th to 13th C	Bone	Fish	Tench	-28.2 to -5.6	3.8 to 8.9	Freshwater, lake, lake- river
	Kałdus, Poland	12th to 13th C	Bone	Fish	Pike-perch	-23.75	11.05	Freshwater
	Kałdus, Poland	12th to 13th C	Bone	Mammals	Elk	-22.8	3.8	
	Kałdus, Poland	12th to 13th C	Bone	Mammals	Hare	-21.7	5	
	Kałdus, Poland	12th to 13th C	Bone	Mammals	Auroch	-22.2	4	
	Kałdus, Poland	12th to 13th C	Bone	Mammals	Deer	-21.65	4.3	
	Kałdus, Poland	12th to 13th C	Bone	Mammals	Chicken	-18.6	9.1	
	Kałdus, Poland	12th to 13th C	Bone	Mammals	Cow	-21.1	7.22	
	Kałdus, Poland	12th to 13th C	Bone	Mammals	Dog	-19.7	9.6	
	Kałdus, Poland	12th to 13th C	Bone	Mammals	Pig	-21	6.87	
	Kałdus, Poland	12th to 13th C	Bone	Mammals	Sheep	-21.5	7.1	

In comparison to medieval sites in Europe, the Alytus bone collagen samples are most similar to a Roman era Croatian site that has a mean $\delta^{15}N$ value of 10.10‰ (Lightfoot et al., 2012). Lightfoot et al. (2012) concluded the individuals at this site were incorporating marine resources into their diet. However, the mean $\delta^{13}C$ value for this site is -18.80‰ which is more enriched than the Alytus mean and outside the Alytus range. However, the more positive $\delta^{13}C$ values at the Roman Croatian site were attributed to the incorporation of some C_4 foodstuffs such as millet.

The Alytus mean overall, female, and male bone collagen $\delta^{13}C$ and $\delta^{15}N$ values were compared to the mean $\delta^{13}C$ and $\delta^{15}N$ values from five different archaeological sites throughout Europe (Figure 20). The first site is the Gilbertine Priory at Fishergate, England which dates to the 13th to 16th century (Müldner and Richards, 2007b). The mean $\delta^{13}C$ and $\delta^{15}N$ values at the site are -19.10‰ and 12.80‰ respectively. It was concluded that the individuals at this site were consuming a significant amount of marine protein and that the consumption of marine resources may have been related to fasting practices in the Catholic Church during this time period (Müldner and Richards, 2007b). The second site is the 12th to 15th century site of Koksijde in Belgium (Polet and Katzenberg, 2003). The mean $\delta^{13}C$ value at this site is -19.10‰ and the mean $\delta^{15}N$ is 12.80‰. Polet and Katzenberg (2003) concluded that the individuals at this site were eating a diet largely based on terrestrial foods but that marine resources also formed an important source of protein. The third site is the Turkish site of Sagalassos which dates to the Middle Byzantine period, 800-1200 AD (Fuller et al., 2012). The mean $\delta^{13}C$ value at this site is -19.00‰ and the mean $\delta^{15}N$ is 9.10‰. It was concluded that the

individuals at this site were consuming a C_3 terrestrial based diet composed of livestock such as cattle and pig (Fuller et al., 2012). The fourth site is Ribe in Denmark which dates from 1250 AD to the early 15th century (Yoder, 2010). The mean $\delta^{13}C$ and $\delta^{15}N$ values at the site are -19.19‰ and 12.85‰ respectively. Yoder (2010) concluded that the individuals at this site were consuming a diet based on C_3 plant and terrestrial resources with a significant portion of the diet coming from marine and/or freshwater resources. The fifth comparative group is the female individuals from the 11th to 12th century site in Giecz, Poland (Reitsema et al., 2010). The mean $\delta^{13}C$ value for these individuals is -19.00‰ and the mean $\delta^{15}N$ is 8.80‰.

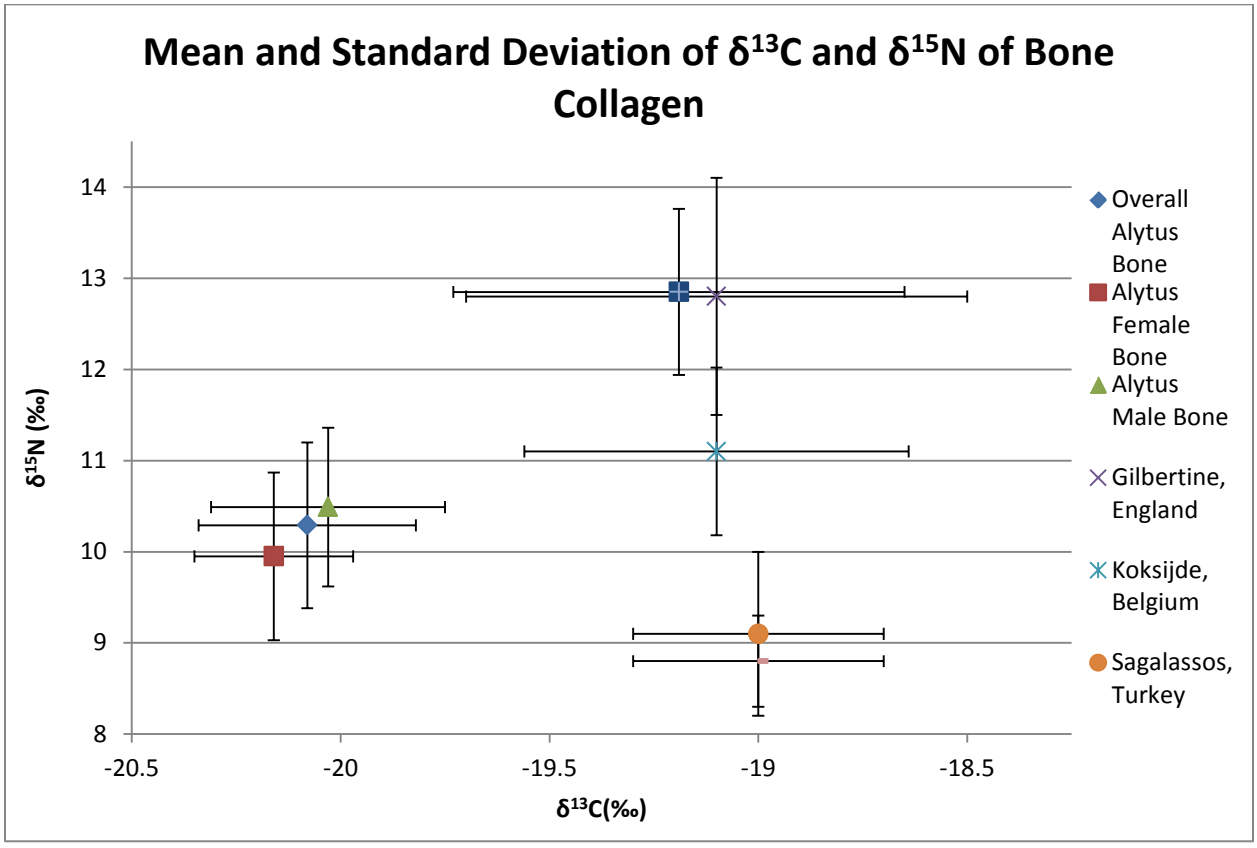

Figure 20. Comparison of the mean overall, female and male $\delta^{13}C$ and $\delta^{15}N$ values bone collagen values to five European archaeological sites.

It was concluded that these individuals were likely consuming both C_3 and C_4 plant based resources and that the dietary protein component of diet was from terrestrial, not aquatic, sources, indicating that freshwater fish were not an important portion of the diet (Reitsema et al., 2010).

The Alytus overall, female, and male mean bone collagen $\delta^{13}C$ values are more depleted than any of the mean $\delta^{13}C$ values for any of the comparison sites, likely indicating a greater reliance on C_3 plant resources and/or less reliance on aquatic resources. The Alytus overall, female, and male mean $\delta^{15}N$ values are not as enriched as the mean values for the individuals from medieval Ribe and medieval Gilbertine Priory where individuals are thought to have consumed significant amounts of marine and/or freshwater resources. The Alytus overall, female, and male mean $\delta^{15}N$ values are more enriched compared to the mean values for the individuals from Middle Byzantine Sagalassos and the female individuals from early medieval Giecz who are thought to have consumed primarily terrestrial animal protein and no marine or freshwater resources. The Alytus overall, female, and male mean $\delta^{15}N$ values are most similar to the mean values for the individuals from medieval Koksijde who are thought to have consumed both terrestrial and marine/freshwater resources. In comparison to other sites from the medieval period, it appears that adults at Alytus were consuming at least some freshwater and/or marine resources, which comprised approximately 15% of the diet.

The $\delta^{13}C$ and $\delta^{15}N$ values from bone collagen of 51 individuals considered to be elites (nobles, bishops, secular elites) from Polish- Lithuanian Commonwealth churches

(15th – 19th centuries) was estimated from Reitsema et al. (2014) and compared to the bone collagen samples from Alytus (Figure 21). The Alytus sample tends to be depleted in $\delta^{13}C$ and $\delta^{15}N$ values compared to the elite individuals from Poland and Lithuania, however overlap is observed in both the $\delta^{13}C$ and $\delta^{15}N$ values. These differences might indicate difference in diet based on social status. Individuals considered being of higher status, or elite, appearing to consume more terrestrial and aquatic protein resources and possibly less C_3 plant resources compared to non-elite individuals such as those found at Alytus. This pattern is also observed when comparing the bone collagen mean $\delta^{13}C$ and $\delta^{15}N$ values from Alytus to the bone collagen mean $\delta^{13}C$ and $\delta^{15}N$ values estimated from Reitsema et al. (2014) (Figure 22). Note that groups with less than three individuals were excluded from this comparison. The observed differences in $\delta^{13}C$ and $\delta^{15}N$ values are likely related to elite individuals having greater access to more protein (terrestrial and aquatic) resources. It is also possible the observed differences are related to differential consumption of aquatic resources in relation to Catholic fasting customs as suggested by Reitsema et al. (2014).

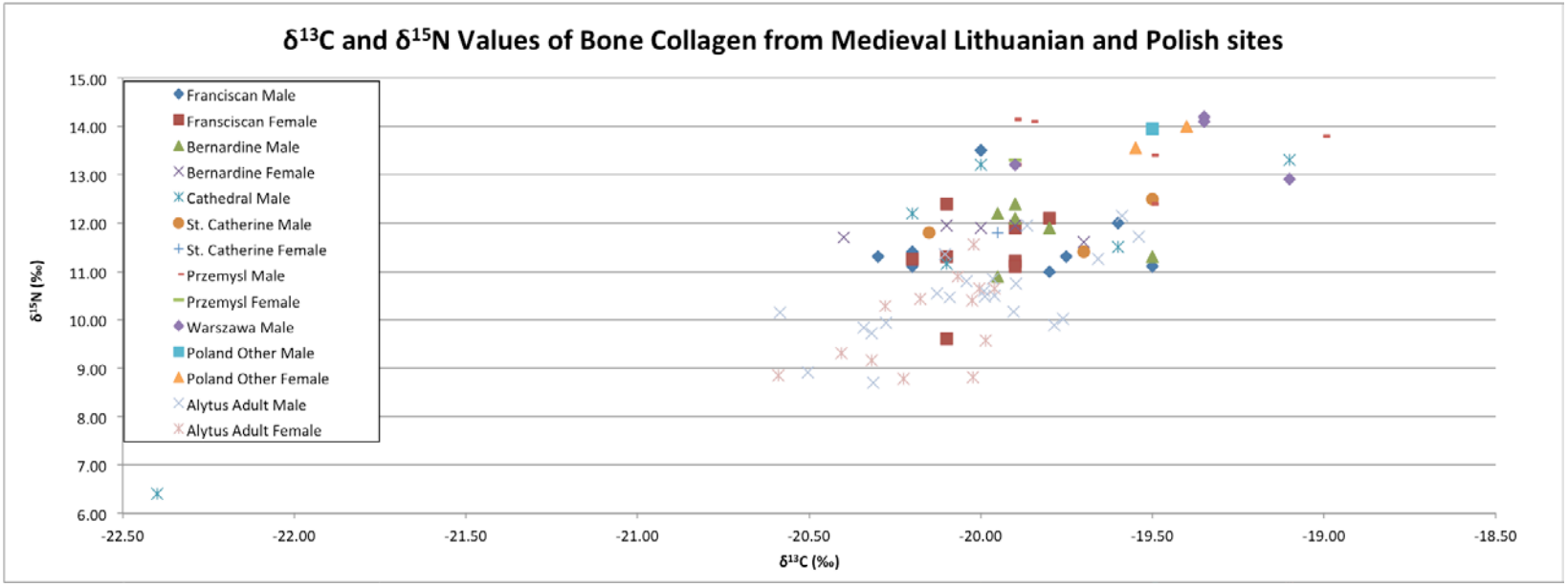

Figure 21. Alytus bone collagen $\delta^{13}C$ and $\delta^{15}N$ values with human $\delta^{13}C$ and $\delta^{15}N$ values from the Polish-Lithuanian Commonwealth elites estimated from Reitsema et al. (2014)

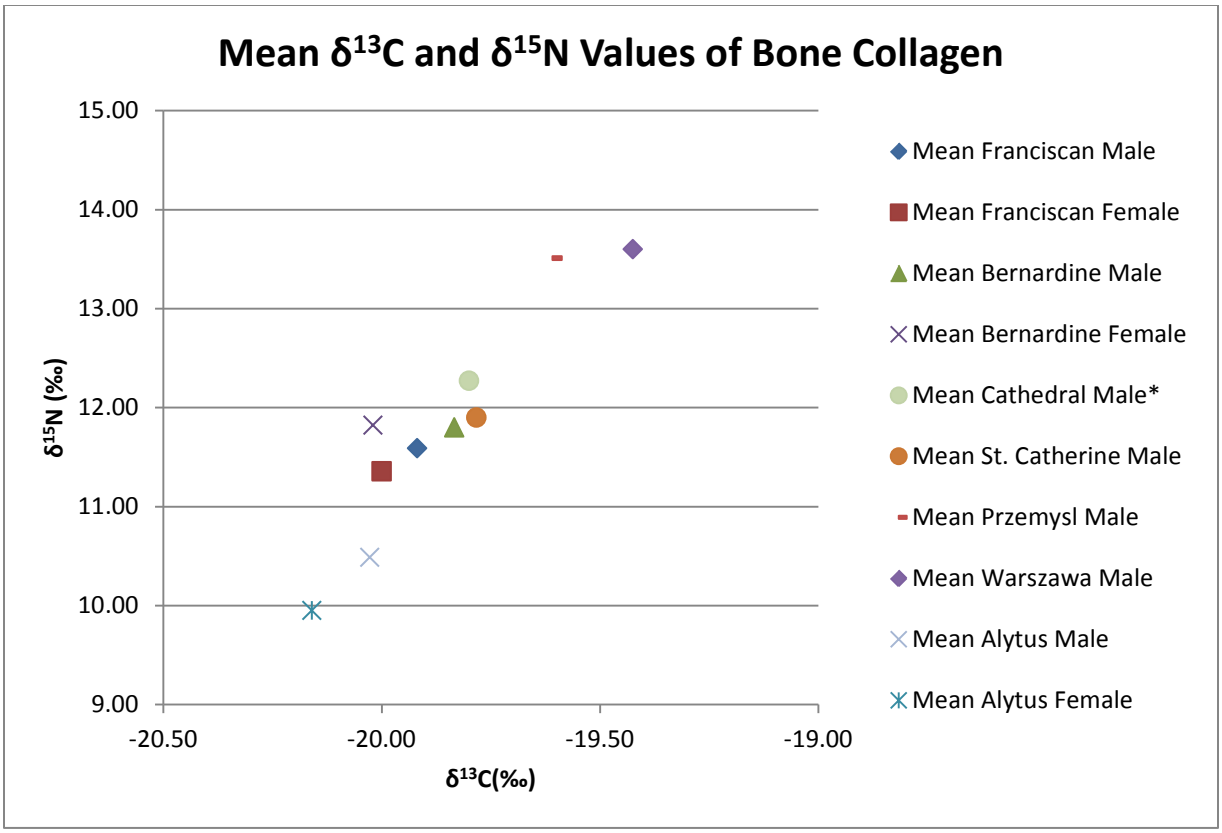

Figure 22. Mean $\delta^{13}C$ and $\delta^{15}N$ values of bone collagen from non-elite Alytus individuals and other elite Polish- Lithuanian Commonwealth individuals estimated from Reitsema et al. (2014)

**A single male individual with $\delta^{13}C$ and $\delta^{15}N$ values (-22.40‰ and 6.40‰, respectively) far outside the range for the other individuals included in this comparison was excluded from the calculation of the mean for Cathedral Males*

The bone collagen $\delta^{13}C$ and $\delta^{15}N$ data from Alytus was also compared to the bone collagen $\delta^{13}C$ and $\delta^{15}N$ data from the sites of Kałdus 1 and Gruczno 2 estimated from Reitsema (2012) (Figure 23). Kałdus 1 is a 12th to 13th century Polish site and Gruczno 2 is a 13th to 14th century Polish site that are representative of non-elite individuals. The Alytus bone collagen $\delta^{13}C$ and $\delta^{15}N$ ranges overlap with the $\delta^{13}C$ and $\delta^{15}N$ ranges from Kałdus 1 and Gruczno 2. The $\delta^{13}C$ values for bone collagen in the

Alytus sample are generally more depleted compared to the $\delta^{13}C$ values for bone collagen from Kałdus 1; however, these two sites have similar ranges in their $\delta^{15}N$ ranges. The $\delta^{13}C$ values for bone collagen in the Alytus sample have similar $\delta^{13}C$ values for bone collagen at Gruczno 2. These two sites overlap in their $\delta^{15}N$ values; however, the $\delta^{15}N$ values of bone collagen for Alytus are generally more enriched than the $\delta^{15}N$ values for bone collagen from Gruczno 2. The similarity in the $\delta^{13}C$ and $\delta^{15}N$ values at Alytus, Kałdus 1, and Gruczno 2 indicate non-elite individuals were consuming a similar diet in the eastern Baltic region during the medieval period.

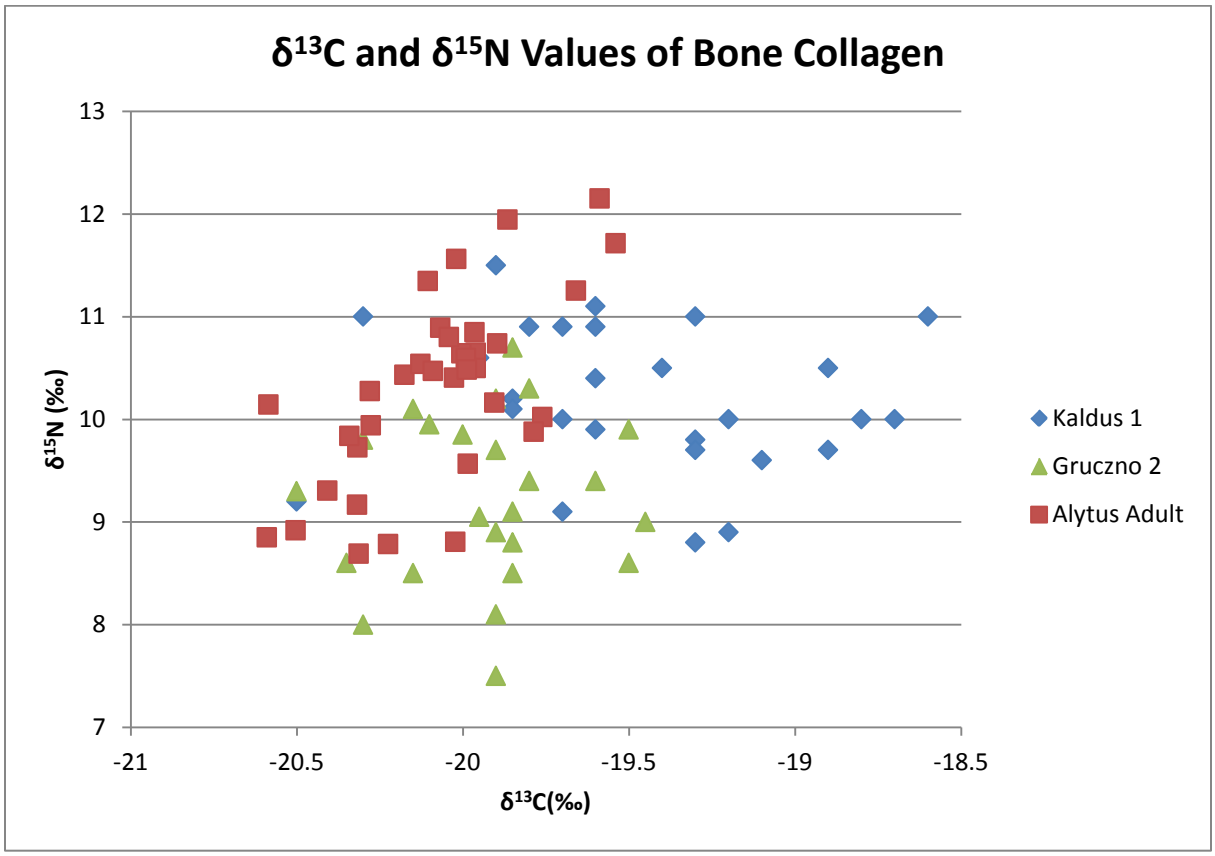

Figure 23. $\delta^{13}C$ and $\delta^{15}N$ values of bone collagen from non-elite Alytus individuals and non-elite Polish individuals from Kałdus 1 and Gruczno 2 estimated from Reitsema (2012)

Unfortunately there is currently no stable isotopic data for faunal remains from Alytus to create a baseline for the human individuals at Alytus. Instead, the Alytus bone collagen $\delta^{13}C$ and $\delta^{15}N$ data was compared to the faunal data published in Antanaitis-Jacobs et al. (2009) (Figure 24) and Reitsema et al. (2013) (Figure 25). The faunal data from Antanaitis-Jacobs et al. (2009) is derived from Mesolithic, Neolithic, and Bronze Age archaeological sites from around Lithuania and includes terrestrial fauna such as red deer (*Cervus elaphus*), elk (*Alces alces*), marten (*Martes martes*), boar (*Sus scrofa*) and pig (*Sus suis*) and aquatic data such as aquatic birds (*Anas platyrchynchos* and *Bucephala clangula*), pike (*Esox lucius*), beaver (*Castor fiber*), flounder (*Pleuronectes platessa*), and seal (*Phocidae*). The mean bone collagen $\delta^{13}C$ and $\delta^{15}N$ data for the overall, female, and male Alytus individuals are plotted and the overall sample $\delta^{13}C$ and $\delta^{15}N$ ranges are indicated with a red box (Figure 24). The Alytus individuals are most similar in their $\delta^{13}C$ and $\delta^{15}N$ values to the badger (*Meles meles*) and marten (*Martes martes*) which are terrestrial omnivores that eat small mammals, birds, eggs, fruits, and nuts. The $\delta^{13}C$ values of the Alytus individuals are also similar to the dog (*Canis familiaris*), and the $\delta^{15}N$ values of the Alytus individuals are also similar to the fox (*Vulpes vulpes*), seals (*Phocidae*), and flounder (*Pleuronectes platessa*). See Table 30 for additional dietary information about the fauna from Antanaitis-Jacobs et al. (2009) with similar $\delta^{13}C$ and/or $\delta^{15}N$ values to the individuals at Alytus.

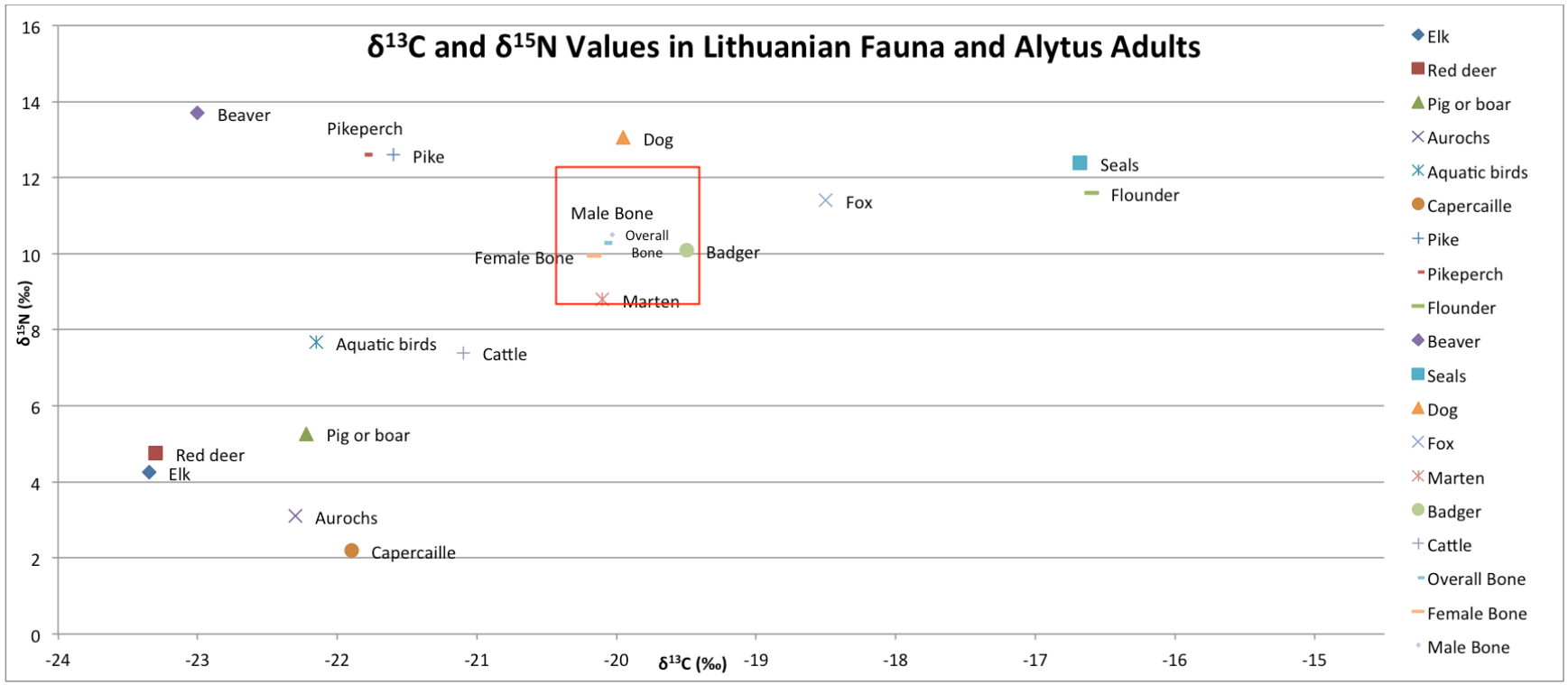

Figure 24. Alytus bone collagen $\delta^{13}C$ and $\delta^{15}N$ values with faunal data from Antanaitis-Jacobs et al. (2009), overall Alytus bone collagen $\delta^{13}C$ and $\delta^{15}N$ range denoted by red box.

Table 30. Additional dietary information about the fauna from Antanaitis-Jacobs et al. (2009) with similar $\delta^{13}C$ and $\delta^{15}N$ values to the individuals at medieval Alytus

Common Name	Species	Additional Dietary Information
Badger	*Meles meles*	Terrestrial omnivores; consumes small mammals, birds, eggs, fruits, and nuts
Marten	*Martes martes*	Terrestrial omnivores; consumes small mammals, birds, eggs, fruits, and nuts
Dog	*Canis familiaris*	Terrestrial and aquatic carnivore
Fox	*Vulpes vulpes*	Terrestrial carnivore
Seals	*Phocidae*	Aquatic carnivores
Flounder	*Pleuronectes platessa*	Freshwater and marine fish that consumes aquatic invertebrates

Comparing the Alytus bone collagen data to the Antanaitis-Jacobs et al. (2009) data indicates that individuals at Alytus were consuming primarily protein from terrestrial resources, and possibly consuming a small amount of freshwater and/or marine resources. Comparison to the Antanaitis-Jacobs et al. (2009) faunal data is not ideal given the large temporal differences between the two sites. Reitsema et al. (2013) found a large difference in the $\delta^{13}C$ and $\delta^{15}N$ values between domestic and wild fauna at medieval Kałdus, Poland, that the authors attribute to the "canopy effect" and anthropogenic effects such as land management techniques and animal husbandry practices. Wild fauna were found to have less^{13}C enriched values because of habitation in closed forest contexts. The use of manure in agricultural fields, as well as fire and plowing, enriches

$\delta^{15}N$ values. Therefore the Alytus data was also compared to faunal data from a medieval Polish site where similar agricultural practices were likely utilized.

The faunal data from Reitsema et al. (2013) is derived from the 12th to 13th century archaeological site of Kałdus in Poland and includes terrestrial fauna such as sheep (*Ovis* sp.), cow (*Bos taurus*), pig (*Sus scrofa*), deer (*Cervus* sp.), and chicken (*Gallus gallus*) and aquatic fauna such as tench (*Tinca tinca*), pike (*Esox lucius*), common bream (*Abramis brama*), catfish (*Silurus glanis*), aspe (*Aspius aspius*), and sturgeon (*Acipenser* sp.). The mean bone collagen $\delta^{13}C$ and $\delta^{15}N$ data for the overall, female, and male Alytus individuals are plotted and the overall $\delta^{13}C$ and $\delta^{15}N$ ranges are indicated with a red box (Figure 25). The Alytus individuals are most similar in their $\delta^{13}C$ and $\delta^{15}N$ values to the dog (*Canis l. familiaris*) which is a terrestrial and aquatic carnivore and likely consuming similar foods as humans given their integration into the community at the household level. The $\delta^{13}C$ values of the Alytus individuals are also similar to the chicken (*Gallus gallus*), catfish (*Silurus glanis*), cow (*Bos taurus*), pig (*Sus scrofa*), sheep (*Ovis* sp.), hare (*Lepus europeaus*), and deer (*Cervus* sp.). Additional dietary information about the fauna from Reitsema et al. (2013) with similar $\delta^{13}C$ values to the individuals at Alytus is provided in Table 31. Comparison of $\delta^{13}C$ values to faunal data indicates that individuals at Alytus were consuming a diet largely based on C_3 terrestrial resources.

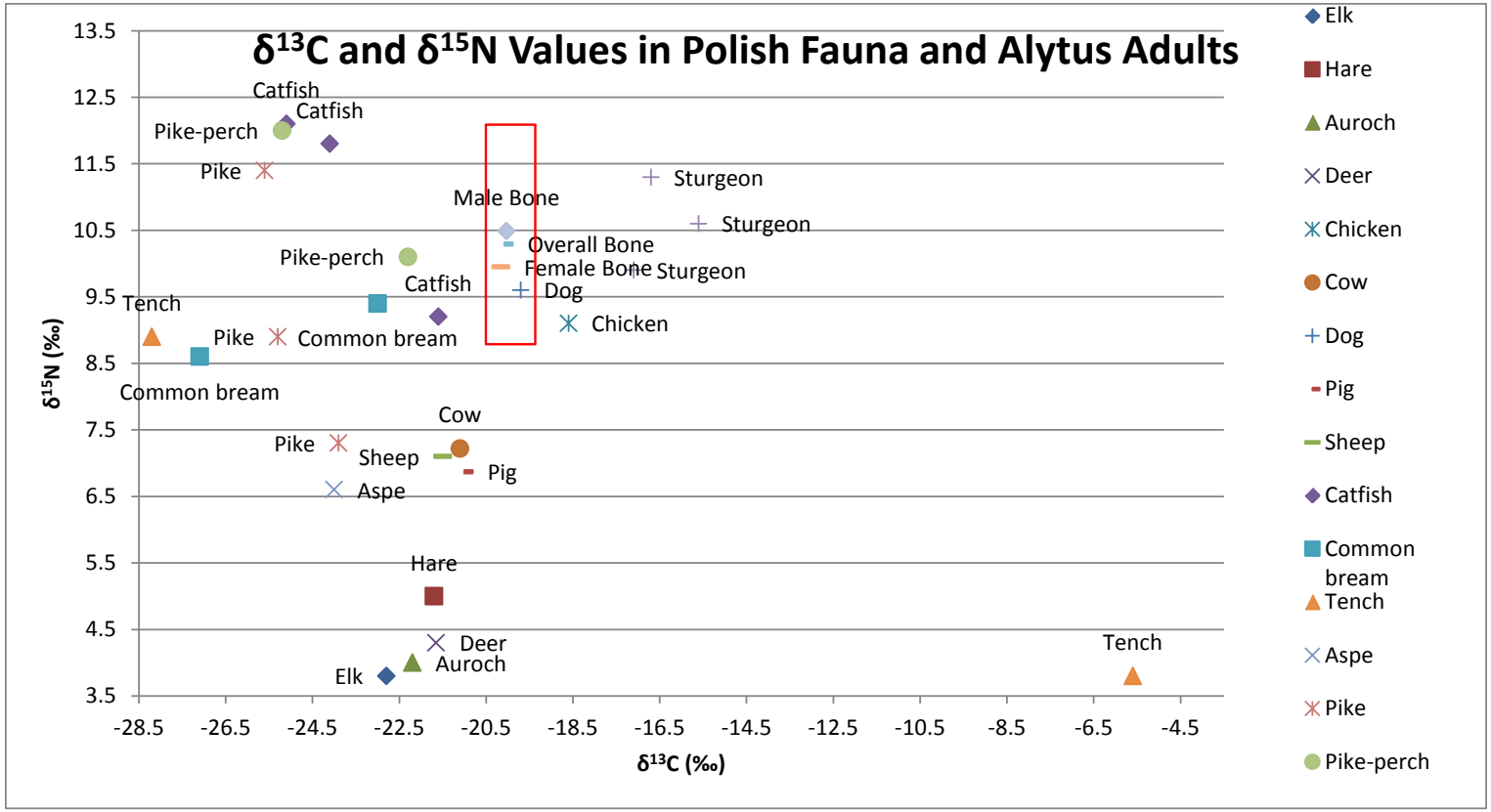

Figure 25. Alytus bone collagen $\delta^{13}C$ and $\delta^{15}N$ values with faunal data from Reitsema et al. (2013) overall Alytus bone collagen $\delta^{13}C$ and $\delta^{15}N$ range denoted by red box.

However, the Alytus $\delta^{13}C$ are also similar to the catfish, a predatory fish that consumes other aquatic fauna including crustaceans and other fish, indicating that individuals at medieval Alytus were possibly incorporating freshwater resources into their diet. The $\delta^{15}N$ values of the Alytus individuals are also similar to the pike (*Esox lucius*), pike-perch also known as sander (*Sander lucioperca*), catfish (*Silurus glanis*), sturgeon (*Acipenser* sp.), common bream (*Abramis brama*), tench (*Tinca tinca*), and chicken (*Gallus gallus*). Additional dietary information about the fauna from Reitsema et al. (2013) with similar $\delta^{15}N$ values to the individuals at Alytus is provided in Table 32. Comparison of $\delta^{15}N$ values to faunal data indicates that individuals at Alytus were consuming a diet with both terrestrial and aquatic protein resources. Overall, comparing the Alytus bone collagen data to the Reitsema et al. (2013) and Antanaitis-Jacobs et al. (2009) faunal data indicates that individuals at Alytus were consuming protein from both terrestrial and freshwater/marine resources.

Table 31. Additional dietary information about the fauna from Reitsema et al. (2013) with similar $\delta^{13}C$ values to the individuals at medieval Alytus

Common Name	Species	Additional Dietary Information
Dog	*Canis l. familiaris*	Terrestrial and aquatic carnivore
Chicken	*Gallus gallus*	Terrestrial omnivore
Catfish	*Silurus glanis*	Predatory, consumes other aquatic fauna including fish
Cow	*Bos taurus*	Terrestrial herbivore
Pig	*Sus scrofa*	Terrestrial herbivore or terrestrial omnivore
Sheep	*Ovis* sp.	Terrestrial herbivore
Hare	*Lepus europeaus*	Terrestrial herbivore
Deer	*Cervus* sp.	Terrestrial herbivore

Table 32. Additional dietary information about the fauna from Reitsema et al. (2013) with similar $\delta^{15}N$ values to the individuals at medieval Alytus

Common Name	Species	Additional Dietary Information
Dog	*Canis l. familiaris*	Terrestrial and aquatic carnivore
Pike	*Esox lucius*	Predatory, consumes other fish and pike
Pike-perch (sander)	*Sander lucioperca*	Predatory, consumes other fish and crustaceans
Catfish	*Silurus glanis*	Predatory, consumes other aquatic fauna including fish
Sturgeon	*Acipenser* sp.	Anadromous bottom feeder
Common bream (carp-bream)	*Abramis brama*	Larvae and insects
Tench	*Tinca tinca*	Freshwater algae and macrophytes
Chicken	*Gallus gallus*	Terrestrial omnivore

CHAPTER 6: CONCLUSION AND FUTURE DIRECTIONS

The stable carbon and nitrogen isotope data from adult individuals at medieval Alytus, Lithuania indicates that individuals during this time period were almost exclusively consuming C_3 plants such as wheat and barley. The protein component of the medieval Alytus diet was from both terrestrial fauna and aquatic resources. The consumption of meat might be a result of the greater access for all individuals to meat after the 14th century. Additionally, the results of the stable isotope analysis indicate that individuals at medieval Alytus were consuming aquatic resources. During the medieval period in Europe the utilization of marine resources, such as fish, became almost ubiquitous, in part due to the fasting practices of the Catholic Church. Consumption of aquatic resources at Alytus might suggest that individuals were practicing Catholics and perhaps following Catholic fasting prohibitions on meat throughout portions of the year. Importantly the stable carbon and nitrogen isotopic data does not indicate that there were significant differences in the diet and access to resources between juvenile males and juvenile females. However, the stable nitrogen isotopic data indicates there were significant differences between adult males and adult females as a result of dietary and/or physiological processes. These differences may be a result of greater access to or consumption of protein, or higher trophic level protein, resources by adult males and/or to depleted stable nitrogen isotopic values relating to pregnancy or disease in adult females.

A difference in the stable nitrogen isotopic data indicates a difference between adults and juveniles, which might be due to the influence of a breastfeeding signature in

the juvenile data. However, there is no difference in male bone $\delta^{15}N$ values and the overall, male, and female dentin $\delta^{15}N$ values. Female bone $\delta^{15}N$ values are not significantly different from the female dentin $\delta^{15}N$ values. The overall difference between juveniles and adults could be a result of male juveniles being weaned slightly later, as was suggested in medieval medical texts. Adult females also have lower $\delta^{15}N$ values compared to juvenile males and adult males, indicating less access to terrestrial and aquatic protein resources or perhaps physiological effects such as pregnancy. The difference between juveniles and adults is likely a result of a combination of factors. Overall, it appears that juveniles and adults were consuming largely the same diet.

To further elucidate the diet consumed by individuals at medieval Alytus, additional stable carbon and nitrogen isotope analysis would be useful. Specifically, botanical and faunal data from the site would allow researchers to create a more accurate and contextually grounded baseline for terrestrial and aquatic resource consumption, especially in relation to freshwater resource signatures. Bogaard et al. (2007) found that anthropogenic activities such as the utilization of manure can result in plant $\delta^{15}N$ values as high as 7.00‰, which can cause purely vegetarian humans to have $\delta^{15}N$ values over 10.00‰. This means that stable isotopic signatures reflecting terrestrial $\delta^{13}C$ values but high $\delta^{15}N$ values, which have been explained as resulting from consumption of freshwater resources, might be better attributed to soil improvement methods. Flora and fauna isotopic data from medieval Alytus would aid in a more accurate human dietary reconstruction at Alytus. Additional information about the individuals and the timing of burials throughout the Alytus cemetery could allow for

the investigation of diachronic dietary changes as well as the impact of the conversion of Lithuania to Catholicism on diet.

A number of models have been proposed to estimate the amount of incorporation of certain types of resources into the diet using stable isotopic data. Originally presented in Wright (2005) and then revised in Fenner and Wright (2014), a model was created that allows for the estimation of the amount of sea salt needed to be incorporated into the diet to shift the stable strontium isotope ratios ($^{87}Sr/^{86}Sr$) from the expected local strontium isotope signature to the observed human signature at the Maya site of Tikal in Guatemala. This two member mixing model could be used in the future to estimate the incorporation of sea salt into the diet at medieval Alytus. A similar type of model could be created to estimate the amount of aquatic resources would have been needed to be incorporated into the diet to produce the enriched $\delta^{15}N$ values seen in some of the Alytus sample. Kellner and Schoeninger (2007) devised a carbon isotope model that allows researchers to us $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$ to identify the dietary energy source, such as C_3, C_4, and marine diet protein. In the future $\delta^{13}C_{apatite}$ could be also analyzed and this model could be used to better understand the incorporation of marine resources into the diet at Alytus. Knudson et al. (2010) proposed a new method in which $\delta^{88/86}Sr$ can be used to investigate the trophic level of consumed marine and terrestrial resources. Additionally, in combination with $\delta^{13}C$ and $\delta^{15}N$ data, $\delta^{88/86}Sr$ can be utilized to determine if the consumed resources were from a higher or lower trophic level. These models would be especially useful at Alytus, and in the future could more precisely

explore the incorporation of aquatic resources into the diet of the individuals from medieval Alytus.

APPENDIX A: DEMOGRAPHIC AND SKELTAL PATHOLOGY DESCRIPTIVE INFORMATION OF INDIVDUALS SAMPLED FOR BONE AND DENTIN COLLAGEN ANALYSIS

Sample ID	Tooth Analyzed ?	Mandibular or Maxillary	Side	Tooth	Bone Analyzed ?	Sex	Age	Dental Pathology	Skeletal Pathology
K10	Yes	Maxillary	Left	M1	Yes	female	30-35	Advanced wear, possible calculus on roots	periostitis of right tibia
K58	Yes	Maxillary	Left	M1	No	female	18-20	Advanced wear, large carries on distal (?) aspect	(1) third condyle of humeri, bilateral; (2) periostitis on the pleural surface of three ribs, left side
K155	Yes	Maxillary	Left	M1	Yes	female	20-25	Two carries, one on lingual aspect on eon buccal aspect, advanced wear	(1) osteochondritis dissecans of left hipbone, left foot thumb; (2) fracture of right nasal bone, well-healed; (3) periostitis of both femora and tibiae; (4) sacralization of caudal bone
K156	Yes	Maxillary	Left	M1	Yes	female	40-45	advanced wear, possible carries obscured by wear, some calculus on roots, carries at CEJ distal (?) aspect	(1) osteochondrosis of L5, sacrum, spondyloarthrosis of Th7, Th9; (2) periostitis of left femur and left tibia
K214A	Yes	Mandibular	Left	M1	Yes	female	25-30	PMD, sever wear, possible carries on occlusal surface obscured by wear	(1) injury with sharp instrument of maxilla, left side; (2) periostitis of both tibiae and right fibula
K269	Yes	Mandibular	Right	M1	Yes	female	50+	Severe dental attrition, small carries on lingual aspect	(1) carries sicca (?) in the frontal bone; (2) nasal bones affected by infection; (3) arthritis of right shoulder joint; (4) subacute periostitis of right femur and tibia; (5) osteophytes of the vertebrae
K426	Yes	Maxillary	Left	M1	No	female	35-40	very slight dental attrition, small amount of bone in roots- removed and saved	No pathology

Sample ID	Tooth Analyzed ?	Mandibular or Maxillary	Side	Tooth	Bone Analyzed ?	Sex	Age	Dental Pathology	Skeletal Pathology
K428	Yes	Mandibular	Right	M1	Yes	male	25-30	Advanced dental attrition, large carries on mesial aspect	(1) cribra parietalia (localized, bilateral); (2) fractures of right side ulna, distal end of fibula, distal end of left side radius, well-healed; 3) periostitis of both tibiae
K484	Yes	Maxillary	Left	M1	No	female	25-30	Severe dental attrition, small carries on lingual aspect	no pathology
K523	Yes	Maxillary	Left	M1	Yes	male	45-50	Advanced dental attrition, large carries on distal aspect, possible carries on occlusal surface, calculus on crown and roots	(1) cribra orbitalia; (2) fracture of nasal bones, bilateral, well-healed; (3) severe arthritis of both hip joints; (4) spondylolysis of L5, osteophytes of many vertebrae; (5) periostitis of both femora and tibiae
K543	Yes	Maxillary	Left	M1	Yes	male	20-25	very slight dental attrition, large carries on mesial aspect, possible beginning of carries on occlusal surface	(1) cribra orbitalia; (2) inflammation reaction due to trauma in left parietal bone, 60x40 mm; (3) periostitis of left femur and both tibiae; (4) osteoma on the right fibula
K563	Yes	Mandibular	Left	M1	Yes	male	30-35	Advanced dental attrition, probable advanced carries on occlusal surface, bone on roots-removed and saved	(1) impressed fracture in the left parietal bone at the lambdoid suture, 20x17 mm; (2) periostitis of right femur, left tibia and fibula

Sample ID	Tooth Analyzed ?	Mandibular or Maxillary	Side	Tooth	Bone Analyzed ?	Sex	Age	Dental Pathology	Skeletal Pathology
K617	Yes	Maxillary	Left	M1	Yes	female	45-50	severe dental attrition, calculus on crown and roots, enamel almost worn away	(1) metal nail (17 mm) fused into right parietal bone (consequences of trauma); (2) periostitis of both femora and tibiae, and right fibula
K622	Yes	Maxillary	Right	M1	Yes	male	35-40	Advanced dental attrition, small carries on distal (?) aspect	(1) cribra orbitalia; (2) button osteoma on the left parietal; (3) fracture of nasal bones, bilateral, well-healed; (4) periostitis of both femora and tibiae; (5) the Schmorl's nodes of T7-T12
K706	Yes	Mandibular	Right	M1	Yes	male	50+	Significant dental attrition, extensive calculus, bone on roots-removed and saved	(1) cribra orbitalia; (2) fracture of nasal bone, right side, well-healed; (3) DJD of both shoulder and elbow joints, right tarsal joint; (4) the Schmorl's nodes of T8-T12, osteochondrosis of T12, spondylolysis of L5, osteophytes of many vertebrae; (5) periostitis of both femora and tibiae; (6) fracture of the midshaft of right fibula, well-healed; (7) fracture of 4th-8th right side and 4th -9th left side ribs, well-healed
K727	Yes	Mandibular	Right	M1	No	male	20-25	Very slight dental attrition	no pathology

Sample ID	Tooth Analyzed ?	Mandibular or Maxillary	Side	Tooth	Bone Analyzed ?	Sex	Age	Dental Pathology	Skeletal Pathology
K770	Yes	Maxillary	Left	M1	Yes	male	25-30	Very slight dental attrition	(1) trauma on the left parietal made by sharp instrument, 25x17 mm, well-healed; (2) myositis ossificans on the left iliac bone
K785	Yes	Maxillary	Left	M1	Yes	male	35-40	Advanced dental attrition, calculus at CEJ and on roots, possible carries on occlusal surface	(1) trepanation with signs of localized inflammation, 35x25 mm, frontal bone, left side; (2) inflammatory-neoblast changes, sternal ends of both clavicles, acromial end of left clavicle, both scapulae, C2, T1, sternum, right side 4th rib (sternal end), left side 5-6th ribs (sternal ends), left 8th rib (body); (3) periostitis of both femora, left tibia, and left fibula
K833	Yes	Maxillary	Right	M1	Yes	female	20-25	very slight dental attrition	(1) cribra orbitalia; (2) osteoma, maxilla, right side; (3) periostitis of left tibia
K849	Yes	Maxillary	Left	M1	Yes	male	35-40	Slight dental attrition, calculus at CEJ/roots on buccal aspect, small carries on occlusal surface small carries on mesial surface	(1) fracture of nasal bones, bilateral, well-healed; (2) fracture, ulna, distal portion, left side, well-healed; (3) fracture, fibula, distal portion, left side, well-healed; (4) the Schmorl's nodes of T8, T10

Sample ID	Tooth Analyzed ?	Mandibular or Maxillary	Side	Tooth	Bone Analyzed ?	Sex	Age	Dental Pathology	Skeletal Pathology
K862	Yes	Maxillary	Right	M1	Yes	male	40-45	Slight wear, slight calculus on crown and CEJ on all aspects	(1) superficial impressed fracture, parietal, right side, 35x11 mm, well-healed; (2) superficial impressed fracture, frontal bone, right side, 16x10 mm, well-healed; (3) fracture, clavicle, acromial end, left side, well-healed; (4) osteoperiostitis of left tibia; (5) osteochondrosis T5-S1; (6) the Schmorl's nodes of T4; (7) lumbalization of S1
K863	Yes	Maxillary	Right	M1	Yes	male	50-55	Severe to slight wear on occlusal surface, bone on roots-removed and saved	cribra orbitalia
K867	Yes	Maxillary	Left	M1	Yes	male	20-25	very slight dental attrition, 2 (?) small carries on occlusal surface and mesial aspect	(1) inflammatory changes, parietal, left side; (2) periostitis, femur, left side, tibiae, bilateral
K888	Yes	Maxillary	Left	M1	Yes	male	25-30	slight dental attrition, medium carries on mesial aspect	(1) injury by sharp instrument, occipital bone, left side, 34x22 mm, partly healed; (2) periostitis, femur, right side, tibiae, bilateral; (3) the Schmorl's nodes T5-L4
K933	Yes	Maxillary	Right	M1	Yes	male	30-35	*lacquer. Advanced dental attrition, large carries at CEJ on mesial aspect and along CEJ towards buccal, possible carries forming on distal aspect	(1) blunt trauma, parietal, right side, well-healed; (2) trauma with edge, parietal, left side; (3) osteochondritis dissecans, humerus, distal end, left side; (4) periostitis, tibia, left side

Sample ID	Tooth Analyzed ?	Mandibular or Maxillary	Side	Tooth	Bone Analyzed ?	Sex	Age	Dental Pathology	Skeletal Pathology
K934	Yes	Maxillary	Left	M1	Yes	female	25-30	very slight dental attrition, carries on occlusal surface	(1) impressed fracture, parietal bone, right side, 15x17 mm, well-healed; (2) periostitis of left tibia
K940	Yes	Maxillary	Right	M1	Yes	male	35-40	Advanced dental attrition, probable carries on occlusal, roots poorly preserved	(1) impressed fracture, parietal bone, left side, well-healed; (2) fracture, fibula, midshaft, right side, well-healed; (3) osteoperiostitis, pleural surface, ribs, left side; (4) periostitis, femora, bilateral, tibiae, bilateral; (5) the Schmorl's nodes T5-T8
K1009	Yes	Maxillary	Right	M1	Yes	male	30-35	slight dental attrition, severe carries all of mesial aspect extending over 50% of tooth, much of the dentin is affected by the carries, bone in roots- removed and saved	(1) impressed fracture near obelion, 25x20 mm, well-healed; (2) periostitis, femora, bilateral, tibiae, bilateral; (3) block T11-T12 due to inflammation; (4) the Schmorl's nodes L1
K1010	Yes	Mandibular	Left	M1	Yes	male	45-50	Advanced dental attrition, slight calculus at CEJ, bone in roots- removed and saved	(1) fracture of nasal bones, bilateral, well-healed; (2) myositis ossificans, humerus, midshaft, left side; (3) periostitis, femora, bilateral, tibia, left side, fibula, bilateral; (4) the Schmorl's nodes T9-T11; (5) osteochondrosis T12; (6) spondylolysis L4-L5
K1030	Yes	Maxillary	Left	M1	Yes	female	20-25	Very slight dental attrition, large (and deep) carries on mesial aspect	-

Sample ID	Tooth Analyzed ?	Mandibular or Maxillary	Side	Tooth	Bone Analyzed ?	Sex	Age	Dental Pathology	Skeletal Pathology
K1049	Yes	Maxillary	Left	M1	Yes	male	25-30	Slight dental attrition, possible carries on occlusal surface	(1) 2 blunt traumas, occipital, left side, 6x7 mm, 18x18 mm, well-healed; (2) fracture, nasal bone, right side, well-healed; (3) periostitis, femora and tibiae, bilateral
K1080	Yes	Maxillary	Left	M1	Yes	male	40-45	Severe dental attrition, possible evidence of a carries that was worn away	No pathology
K1087	Yes	Maxillary	Right	M1	Yes	female	25-30	Slight dental attrition, large carries on mesial aspect, some calculus on distal aspect	(1) fracture, nasal bone, left side, not healed; (2) periostitis, tibiae, bilateral; (3) fracture, tibia, distal end, right side, well-healed; (4) osteochondritis dissecans, tibia, distal end, left side
K1090B	Yes	Maxillary	Right	M1	Yes	male	45-50	very slight dental attrition, some calculus on the CEJ, possible carries on occlusal surface	(1) fracture, nasal bones, bilateral, well-healed; (2) periostitis, tibiae, bilateral; (3) fracture, 2 ribs, right side, well-healed; (4) fusion of 2 ribs, left side; (5) cribra orbitalia; (6) enthesopathies, foot bones, right side; (7) osteophytes of thoracic vertebrae
K1115	Yes	Mandibular	Left	M1	Yes	Female	35-40	Severe wear, possible carries obscured by wear	(1) blunt trauma, frontal bone, bilateral, 48x21 mm, well-healed; (2) periostitis, tibia, fibula, right side; (3) fusion C7-T1; (4) the Schmorl's nodes T7, T10

Sample ID	Tooth Analyzed ?	Mandibular or Maxillary	Side	Tooth	Bone Analyzed ?	Sex	Age	Dental Pathology	Skeletal Pathology
K1127	Yes	Mandibular	Left	M1	Yes	male	30-35	Very sever dental attrition on mesial/buccal half of the tooth possibly due to a large carries? Bone on roots-removed and saved	(1) depression fracture, zygomatic, left side, well-healed; (2) myositis ossificans, humerus, distal portion, left side; (3) fracture, ulnae, distal portion, bilateral, well-healed; (4) fracture, 5th metacarpal, right side, well-healed; (5) fracture, fibula, distal portion, right side, well-healed; (6) fracture, 5th rib, left side, well-healed; (7) degenerative changes, sacrum; (8) enthesopathies, scapula, right side; (9) osteoperiostitis, tibiae, bilateral
K1149	No	-	-	-	Yes	female	35-40	N/A	-
K1150	Yes	Maxillary	Right	M1	Yes	female	30-35	Severe dental attrition, large carries at CEJ on distal aspect, slight calculus on buccal aspect	(1) fracture, nasal bone, left side, well-healed; (2) periostitis, tibiae, bilateral; (3) enthesopathies, foot bones, bilateral; (4) arthritis, hip joint, bilateral
K1152	Yes	Maxillary	Left	M1	Yes	male	20-25	advanced dental attrition, two small carries on occlusal surface, carries (?) along mesial and buccal aspects	(1) cribra orbitalia; (2) impression fracture, frontal bone, right side, 23x17 mm, well-healed; (3) periostitis, tibia, right side; (4) fracture, 10th rib, left side, well-healed; (5) the Schmorl's nodes T6-T9; (6) spondylolysis L5

APPENDIX B: BONE COLLAGEN YIELDS

Sample ID	Element	Side	Dry Crushed Wt. (g)	Empty Vial Wt. (g)	Vial w/ Collagen Wt. (g)	wt% Collagen
K10	Right	Femur	4.553	9.862	10.801	20.624
K155	Left	Femur	4.087	9.877	10.781	22.119
K156	Left	Femur	4.206	9.934	10.827	21.232
K214A	Left	Femur	4.615	9.862	10.853	21.473
K269	Right	Femur	4.958	9.306	9.655	7.039
K428	Left	Femur	4.810	14.016	14.371	7.380
K523	Left	Femur	3.930	9.910	10.716	20.509
K543	Left	Femur	3.774	14.048	14.165	3.100
K563	Left	Femur	4.441	13.996	14.305	6.958
K617	Left	Femur	4.431	9.975	11.002	23.178
K622	Left	Femur	4.388	9.869	10.839	22.106
K706	Left	Femur	4.495	13.997	14.389	8.721
K770	Left	Femur	3.985	9.892	10.199	7.704
K785	Left	Femur	4.092	9.904	10.167	6.427
K833	Left	Femur	4.439	9.845	10.688	18.991
K849	Left	Femur	4.599	9.874	10.772	19.526
K862	Left	Femur	3.591	10.001	10.283	7.853
K863	Left	Femur	4.229	9.915	10.309	9.317
K867	Left	Femur	4.771	7.300	7.725	8.908
K888	Right	Femur	4.295	9.944	10.298	8.242
K933	Left	Femur	4.876	9.905	10.957	21.575
K934	Left	Femur	4.214	9.963	10.882	21.808
K940	Left	Femur	4.683	9.978	10.188	4.484
K1009	Left	Femur	4.889	9.922	10.297	7.670
K1010	Left	Femur	5.063	9.926	10.243	6.261
K1030	Left	Femur	4.268	9.889	10.357	10.965
K1049	Left	Femur	3.913	9.857	10.793	23.920
K1080	Left	Femur	3.586	9.958	10.765	22.504
K1087	Left	Femur	4.859	9.895	10.954	21.795
K1090B	Left	Femur	4.013	14.026	14.377	8.747
K1115	Left	Femur	4.290	9.954	10.307	8.228
K1127	Left	Femur	4.709	9.970	10.456	10.321
K1149	Left	Femur	4.496	9.873	10.837	21.441
K1150	Left	Femur	4.309	9.855	10.818	22.349
K1152	Left	Femur	4.016	9.990	10.897	22.585

APPENDIX C: DENTIN COLLAGEN YIELDS

Sample ID	Combined Initial Vial Weight (g)	Combined Initial Vial and Sample Weight (g)	Combined Initial Sample Weight (g)	Final Vial Weight (g)	Final Vial and Sample Weight (g)	Final Sample Weight (g)	wt% Collagen
K10	1.770	2.789	1.019	7.589	7.723	0.135	13.208
K58	1.737	2.475	0.738	7.350	7.437	0.086	11.687
K155	1.783	2.896	1.113	7.226	7.389	0.163	14.642
K156	1.784	2.458	0.674	7.525	7.626	0.101	15.033
K214A	1.806	2.286	0.480	7.404	7.492	0.088	18.240
K269	1.754	2.473	0.719	7.489	7.587	0.099	13.707
K426	1.781	2.635	0.854	7.586	7.714	0.128	15.001
K428	1.807	2.626	0.819	7.498	7.596	0.098	11.918
K484	1.761	3.328	1.567	7.471	7.670	0.199	12.705
K523	1.769	3.627	1.858	7.101	7.327	0.225	12.134
K543	1.793	2.910	1.117	7.310	7.357	0.047	4.171
K563	1.792	3.769	1.977	7.456	7.701	0.245	12.390
K617	1.770	2.455	0.685	7.538	7.642	0.103	15.098
K622	1.805	3.086	1.281	7.585	7.765	0.180	14.079
K706	1.737	3.368	1.631	7.280	7.477	0.197	12.091
K727	1.765	3.516	1.751	7.044	7.259	0.215	12.276
K770	1.784	3.051	1.267	7.202	7.362	0.160	12.651
K785	1.783	2.714	0.931	7.459	7.540	0.081	8.718
K833	1.767	2.930	1.163	7.533	7.674	0.141	12.144
K849	1.816	3.285	1.469	7.472	7.654	0.182	12.398
K862	1.790	2.867	1.077	7.465	7.603	0.138	12.825
K863	1.760	3.073	1.313	7.298	7.464	0.166	12.611
K867	1.765	2.715	0.950	7.338	7.435	0.097	10.251
K888	1.791	2.838	1.047	7.284	7.378	0.094	8.935
K933	1.787	3.299	1.512	7.358	7.527	0.169	11.209
K934	1.810	2.833	1.023	7.223	7.365	0.142	13.907
K940	1.761	2.958	1.197	7.483	7.586	0.103	8.626
K1009	1.805	2.518	0.713	7.498	7.582	0.084	11.833
K1010	1.789	3.637	1.848	7.286	7.496	0.210	11.363
K1030	1.793	2.839	1.046	7.294	7.401	0.107	10.193
K1049	1.795	3.294	1.499	7.102	7.342	0.239	15.970
K1080	1.809	2.789	0.980	7.620	7.753	0.133	13.573
K1087	1.755	2.634	0.879	7.121	7.240	0.118	13.473
K1090B	1.781	2.873	1.092	7.143	7.278	0.135	12.369
K1115	1.818	2.581	0.763	7.183	7.253	0.070	9.140
K1127	1.733	2.690	0.957	7.470	7.628	0.158	16.542
K1150	1.779	2.737	0.958	7.415	7.568	0.153	15.920
K1152	1.805	3.072	1.267	7.420	7.616	0.196	15.448

APPENDIX D: COPYRIGHT PERMISSION

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Tosha Dupras <Tosha.Dupras@ucf.edu>
Mon 5/19/2014 4:39 AM

From: Rimantas Jankauskas [rimantas.jankauskas@mf.vu.lt]
Sent: Monday, May 19, 2014 4:30 AM
To: Tosha Dupras
Subject: RE: map?

Dear Tosha,
Use of those maps with indication of source (Svetikas E. Alytaus kapinynas: christianizacijos šaltiniai. Vilnius: Diemedis, 2003. 444p.) is OK according to Lithuanian laws. So please consider permission is received,
Sincerely,
Rimas
PS. AND DON'T FORGET GYTIS CONTRACT!
Rimas

From: Tosha Dupras [mailto:Tosha.Dupras@ucf.edu]
Sent: Thursday, May 15, 2014 11:36 PM
To: Rimantas Jankauskas
Subject: Fwd: map?

Hi Rimas,
Katie is working on the final draft of her thesis and she will need permission (as will Katherine) for the use of the images you have provided us (Alytus cemetery map). Can you respond to this email with your permission? I am having Katie make sure there are no formal forms also.

Hope all is well and warming up! :-)

Tosha

Sent from my iPad

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