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Exploring Social Identity through Stable Isotope Analysis in the Kellis 2 Cemetery

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EXPLORING SOCIAL IDENTITY THROUGH STABLE ISOTOPE ANALYSIS IN THE
KELLIS 2 CEMETERY

by

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B.A. Brown University, 2012

A thesis submitted in partial fulfillment of the requirements
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ABSTRACT

The material remains of ancient Egypt provide extensive and wide ranging data about the empire throughout its history. However, little evidence is available from ancient Egypt, or any past culture, with which to rebuild an image of social identity or individual experiences. This is especially problematic when the dominant narrative ignores experiences of minorities and minimizes the variation existing throughout the empire. Stable isotope analysis has the potential to reveal variability in lived experience of past peoples by acting as a proxy for behavior that can be analyzed from bone. Such an approach has been applied on individuals from the Romano-Christian Kellis 2 cemetery in the Dakhleh Oasis to explore diversity of lived experiences in relation to age, sex, and gender. Analysis of stable carbon and nitrogen values from bone collagen of 138 adults revealed a predominately C₃ plant based diet with the addition of some animal protein. Statistical analysis of these values uncovered discernable differences in the values of young males and older adults which may suggest differences in the biological experiences of these groups and unique social experiences for those individuals. These findings offer a starting point with which to explore social organization at this site and others in ancient Egypt and the methods provide a useful approach to exploring individual experience in the past in ways not possible from other sources.

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“The past, like the future, is indefinite and exists only as a spectrum of possibilities.”

-Stephen Hawking

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CHAPTER 1: INTRODUCTION

Ancient Egypt is one of the most studied ancient civilizations in the world resulting in a wealth of information about the empire and its people. Historically, much of the data existing about life in ancient Egypt has been limited to traditional data such as literary sources, iconography, or material culture which tend to reproduce the dominant narrative of the time. As such, the experiences of certain groups, especially women, children, and commoners, tend to be ignored or idealized and variations across the empire, especially in border zones, are minimized. From these sources, it is often impossible to look below this narrative to reveal information about the reality of lived experience in a particular place and time in ancient Egypt.

This study seeks to explore these otherwise silenced experiences from ancient Egypt. Stable isotope values will be analyzed to examine dietary and health patterns within a sample of the Kellis population. As Kellis was located on the peripheries of the Roman Empire, this research will investigate the nature and significance of social groupings relating to age, sex, gender, and status in a settlement on the fringes of an empire. Such an approach offers a unique tactic to understanding social identities in past cultures and could provide a new perspective on the appearance and significance of such divisions in other societies.

Researchers have begun to study the human remains from ancient Egypt to shed light on the full range of human experiences across the Egyptian empire at any particular time. Nowhere is this truer than at the Romano-Christian settlement of Kellis. The site is unique in its location at the edge of the Greek and Roman empires and occupation during a period of social change. Here, researchers have examined a wide range of bioarchaeological topics to explore the lives of the population at the site. Such work has explored topics of disease, childhood, and paleodemography through skeletal analysis. Much research has also focused on stable isotope

analysis and has revealed information about diet, health, environment, migration, and seasonality of death. These studies have revealed variability in diet in relation to age and sex (Dupras 1999; Dupras and Tocheri 2007). This research will continue this trend by thoroughly examining patterns in stable isotope values to explore variations in lived experience across the population in Kellis.

Stable isotope analysis and bioarchaeology more broadly, frames the study of the human skeleton as a product of lived experiences (Sofaer 2006a). Specifically, these lived experiences can be recorded in bone through stable isotopic values, which are tied to diet, health and migration. Health is defined as the metabolic condition of an individual which accounts for periods of stress that may alter normal metabolic functions. Stable isotopic analysis involves the measurement of ratios of variations of elements which are incorporated into skeletal tissues in various manners. Carbon and nitrogen are the most common elements analyzed and, because they are incorporated from food and water, can reveal information about diet, residency, and health (Katzenberg 2007). Researchers in many areas of the world have begun to employ stable isotopic analysis to examine social identities relating to age, sex, gender, and status (White et al. 2001; Privat and O'Connell 2002; White 2005). Each of these categories represents a complex interplay between biology and culture that must be examined carefully from numerous perspectives and so in these instances, stable isotopic values are interpreted as a proxy for diet, health, and movement which may inform about individual's lived experiences or behaviors.

The ancient settlement of Kellis, located in the Dakhleh Oasis in the western desert of Egypt, provides a rare and complex environment in which to investigate stable isotopes and social identity. Located on the fringes of the Ptolemaic, and then Roman, Empire, the settlement was a prosperous administrative and trade center that developed its own unique, hybrid identity

(Bowen 2001). During the period on which this study will focus, from approximately 100 AD to 450 AD, the culture of the settlement combined aspects of Roman and Christian culture and tradition with Pharaonic elements to produce a vibrant and complex identity. Its people were likely equally diverse and complex. Literary and iconographic resources do identify differences in experiences based on sex and age during the Ptolemaic and Roman periods although the lived consequences of such differences at Kellis is not well known, especially considering its location on the fringes of the empire (Robins 1993; Rowlandson 1998; Meskell 1999).

Although the information available about ancient Egypt is extensive, little research has focused on the reconstruction of ancient social identities from the human skeleton, especially in areas and times in which cultures, traditions, and identities were in flux. Most analyses have focused on analysis of binary gendered groups based on sex or only examined broad age differences between juveniles and adults (Dupras 1999; Wheeler 2009). Additionally, although strides have been taken in the nuanced analysis of stable isotopic data to reveal social patterns, too often these values are oversimplified in order to produce a generalized account of a population or area.

The study will address these voids in the literature by examining stable isotopic values of carbon and nitrogen from bone collagen in a sample of adults from the Kellis 2 cemetery. Stable isotope values in this human tissue will be examined as a proxy for lived experiences and human behavior. As such, variation in values across a sample of the population will tentatively be interpreted as real differences in experience. In this way, meaningful differences in the social and biological lives of subgroups within the sample can be identified and analyzed to explore social identity. Social identity will be defined as the ways in which individuals perceive themselves and

was perceived by their society in relation to themselves and others. It is contextual, reflexive, and complex (Sofaer 2006a).

The main purpose of this study is to apply stable isotope analysis to the exploration of dietary and health patterns within a sample of the Kellis population from the Romano-Christian period in order to determine the nature and significance of social groupings relating to age, sex, gender, and status in a settlement on the fringes of the Roman Empire. To do so, five questions will be examined:

1. Did dietary or health differences exist between males and females?
2. Did dietary or health differences exist at different stages across the life course?
3. Did diet or health vary according to gendered subgroup as partially defined by subdivisions within sex and age groups?
4. Did social rank influence diet or health?
5. Can stable isotope analysis, as a proxy for diet and health, offer insight about social identities at Kellis?

Because an individual's position and experiences in society are influenced by their sex, age, gender, and status, it is expected that experiences will vary across the site according to these groupings, and will be identifiable from stable isotope values which are a proxy for diet and health.

To investigate these questions, stable carbon and nitrogen isotope values from bone collagen of 138 adults will be examined through the analysis of descriptive statistics and an analysis of variance (ANOVA) in relation to arbitrary groups defined by estimated sex, approximate age at death, and sex and age. Only those comparisons that reveal significant differences will be examined further as socially meaningful. These will then be compared to the

values of available foodstuffs from the site to draw inferences about the nature of dietary differences between defined groups. Discrepancies between values will be examined in relation to expected effects of metabolic stress, illness, trauma, pregnancy, or growth to reveal information about variations in health. Stable isotope values will also be examined in relation to burial treatment in order to explore possible patterns in social rank. Identified patterns according to sex will offer a starting point to examine gender.

The chapters that follow will explore these questions and discuss their significance. Chapter 2 will provide a background on the mechanism and theory of stable isotope analysis, a description of the ancient settlement of Kellis, and a review of past bioarchaeological research from Kellis, Egypt. Chapter 3 will set out the theoretical background for the ensuing analysis, highlighting the social and biological construction of the human skeleton and the ways in which the body influences and is influenced by social categories of age, sex, gender, and status. This chapter will also provide support for the application of stable isotopic analysis to these topics in ancient Egypt with a review of stable isotopic studies of age, sex, and gender as well as a summary of research in age, sex, and gender from ancient Egypt, focusing on the Roman period. Chapter 4 will delineate the research sample while providing an outline of the methods to be applied. Chapter 5 will present the results of the stable isotopic analysis and statistical investigation. Chapter 6 will explore the social and biological significance of the results generated. Chapter 7 will conclude the study by offering insight about social identities in Kellis, Egypt during the Roman period and will discuss future directions for this research. The chapter will close with a suggestion of the implications of this study to further work at Kellis, in Egypt, and in Anthropology more broadly.

Despite the plethora of research on ancient Egypt, the reality of lived experiences of individuals and subgroups has remained largely impenetrable with traditional sources, especially in cities on the border of the empire. The application of bioarchaeology, and specifically stable isotope analysis, provides a valuable tool to overcoming these previous shortcomings. However, such data must be interpreted cautiously with an eye to diversity and variation and an understanding of its relationship to diet, health, and migration as well as lived experience. By examining stable carbon and nitrogen values in a sample from the city of Kellis located on the fringes of the Roman Empire, this study will investigate variations in lived behavior across the population to identify and explore the nature of possible social divisions and identities at a site and time of social change. The results will provide insight into the diverse lives of people in ancient Kellis and will emphasize the biological consequences of differences in lived experience. As such, it may provide a new approach to the examination and investigation of meaningful social identities within past cultures which could be used to shed light on the very nature and consequences of such divisions in human society.

CHAPTER 2: LITERATURE REVIEW

Stable isotope analysis at the Kellis 2 cemetery draws on a long history of such studies in the Dakhleh Oasis and elsewhere (Dupras 1999, Dupras and Schwarcz 2001; Dupras et al. 2001; Aufderheide et al. 2003;; Dupras and Tocheri 2007; Williams 2008). To fully comprehend the nature of the variation being examined in this population, it is first necessary to review the nature of the data being analyzed and the archaeological site under investigation. As such, a background of carbon and nitrogen stable isotope values from bone collagen will be provided and will focus on the chemical basis of such analysis, the methods of analysis, and sources of variation in the analysis of these values. A thorough discussion of the current data available from ancient Kellis will then be provided. This review will focus on the lives of the inhabitants available from other traditional material culture resources as well as bioarchaeological analysis. Together, these reviews reveal the need for the current study and provide a foundation for the ensuing analysis and discussion.

Stable Isotope Analysis

Isotopes are variations of elements that differ in neutron number but remain identical in proton and electron number (Van der Merwe and Vogel 1983). While they may be able to fill the same roles biologically they tend to differ in quantity within living systems due to the isotope effect. This refers to the difference in physical and thermodynamic properties due to mass differences, and affects the rate of incorporation in physical and chemical processes (Katzenberg 2007; Lee-Thorp 2008; Van der Merwe and Vogel 1983). For example, atmospheric CO₂ has a carbon ratio value of -7‰ but when dissolved in water to become bicarbonate, the value increases to 0‰ (Van der Merwe and Vogel 1983). In general, those molecules with the higher mass tend to concentrate in the most stable compounds and are slower to react when mass is a

determining factor of reactivity (Lee-Thorp 2008). Isotopic values are reported in ratios of the heavy isotope to the light and compared to a standard to reveal the relative content of the heavy isotope in a material (Van der Merwe and Vogel 1983). This distance from the standard (δ) is expressed in parts per thousand (‰) (Van der Merwe and Vogel 1983).

Although the ratio of stable isotopes in a system are influenced by chemical and mechanical processes, certain isotopic ratios including those of nitrogen, are altered more severely when incorporated in biological processes, especially during photosynthesis (Van der Merwe and Vogel 1983; Katzenberg 2007). Through these processes, including deamination and transamination during the synthesis of amino acids, fractionation occurs resulting in the enrichment of isotopic values of consumers in relation to their diet (Ambrose and Norr 1993). As such, the values of plant material incorporated by herbivores are passed down the food chain with some alteration. If enrichment and fractionation values are known, the values of consumers can be related to diet (Vogel 1978). However, analysis may be complicated by numerous factors including diet, individual physiological variability, effects of stress, difficulty in creating baselines, and the averaging of values over a period of time (Vogel 1978).

The analysis of stable isotopes was initiated in geochemistry, with the earliest attempts at chemical bioarchaeology focusing on ageing methods that failed to consider diagenesis or contamination (Ambrose and Krigbaum 2003). The application of stable isotope analysis to broader anthropological questions built upon this work as well as research on plant photosynthesis, controlled animal feeding experiments, and observations of animals in the wild (DeNiro and Epstein 1981). In the 1970s ^{13}C values were examined in humans for the first time to investigate maize consumption in the New World (Van der Merwe and Vogel 1983;

Katzenberg 2007; Lee-Thorp 2008). Since these breakthroughs, numerous other stable elements have been analyzed to address a range of anthropological questions.

Isotopic analysis has been used to examine diet, climate, health, life history, population movements, paleoenvironments, and habitat reconstruction through the examination of oxygen, carbon, nitrogen, strontium, barium, and calcium in individuals to develop a picture of population patterns (Vogel 1978; Ambrose and Krigbaum 2003; Katzenberg 2007). Most commonly, ratios of carbon stable isotopes have been employed to examine dietary components; nitrogen analysis has revealed data on diet and health; and oxygen ratios have been examined to analyze migration (Katzenberg 2007).

The value of this analysis lies in its ability to reveal information about past lifeways unavailable from other sources. The types, amount, and proportion of food consumed by an individual in the past cannot be gleaned from material remains alone (Lee-Thorp 2008). Such sources, including botanical remains, material culture, or iconography can reveal the foodstuffs available to a population, but cannot indicate which items were consumed and by whom (Katzenberg 2007). However, in the investigation of diet, stable isotopic analysis of carbon and nitrogen can reveal the contribution of C₃ and C₄ plants, protein versus not protein resources, trophic level, and marine or terrestrial foodstuffs (Harrison and Katzenberg 2003).

Despite the plethora of information gained from such studies, numerous obstacles exist in the analysis of stable isotopes. Interpretation of isotope value may be complicated by spatial and temporal variability in the values of available resources in an environment (Chisholm et al. 1983; Schwarcz 1991; Lee-Thorp 2008). For example, swings in nutrient availability may alter nitrogen values over time and space, necessitating the use of temporally and spatially similar baselines for comparison with samples (Hedges and Reynard 2007). However, creating a

comparative baseline can be difficult because values of food sources, especially in the past, are often uncertain.

Additionally, interpretation of stable isotope values is complicated by variation between individuals due to both dietary and geographic deviation as well as poorly understood physiological differences (Milner et al. 2004). Tissues within the same individual may also vary due to different turnover rate and portion of diet reflected (Chisholm et al. 1983; Schwarcz 1991; Lee-Thorp 2008). Furthermore, due to relatively slow turnover rates in bone, especially following maturity, isotopic values represent averages of diet over an extended period of time, precluding attempts to refine the association between variation in external factors and internal responses (Lovell et al. 1986; Lee-Thorp 2008).

Further obstacles can be introduced after death. Diagenesis including the action of fungi and bacteria may alter isotope ratios when by breaking down organic matter and introducing trace chemicals (Schoeninger and Moore 1992). Post-mortem contamination from curation may also influence the isotopic composition of tissues, including the application of consolidants (Chisholm et al. 1983; Schoeninger and Moore 1992; Naito et al. 2003). Variability and uncertainty may also be introduced through variation in extraction and measurement procedures (Chisholm et al. 1983). Therefore, replicated measurements must have a standard deviation within 0.1‰ for carbon analysis and a range of 2‰ for nitrogen to be considered valid (Chisholm et al. 1983; Lee-Thorp 2008).

Carbon and nitrogen from bone collagen are analyzed in the current study to examine diet and health. Health will be taken to describe metabolic condition of an individual and will account for periods of metabolic stress that may alter normal body functions. Although these values represent a complex interaction of different factors they can still be analyzed to elucidate patterns

of dietary variation or residency patterns if these factors are accounted for in the analysis. The reconstruction of diet or migration patterns from stable isotope analysis is dependent upon an understanding of the range of isotopic values of resources available, especially the dietary extremes of exclusively marine and terrestrial diets in the area, as well as the local environment and physiology and requires the existence of natural differences in the possible food options (Chisholm et al. 1982; Schwarcz 1991; Ambrose and Norr 1993; Milner et al. 2004). Ultimately, the interpretation of stable isotopic values requires an in depth knowledge of their role and distribution in the environment, the methods of their incorporation, and the factors affecting metabolism of the element.

Carbon

Environment

Carbon was the first element employed in stable isotope analysis for the purpose of dietary reconstruction (Van der Merwe and Vogel 1983; Katzenberg 2007; Lee-Thorp 2008). Carbon is found in the environment in the stable forms of ^{12}C and ^{13}C . To determine relative carbon values, the following equation according to Chisholm et al. (1982) is employed:

$$\delta^{13}\text{C}\text{‰PDB} = \left[\frac{[(^{13}\text{C}/^{12}\text{C sample}) - (^{13}\text{C}/^{12}\text{C standard})]}{^{13}\text{C}/^{12}\text{C standard}} \right] * 1000$$

The accepted standard for carbon is marine limestone or Pee Dee Belemnite (PDB), which is used as the 0‰ carbon mark and has a higher carbon ratio than the majority of terrestrial materials (Chisholm et al. 1982; Van der Merwe and Vogel 1983).

The ultimate source of terrestrial carbon is atmospheric CO_2 with a modern value around -7‰ and an ancient value closer to -8‰ as a result of the burning of fossil fuels (Katzenberg 2007). In marine ecosystems, the main source of carbon is dissolved carbonate that has a value of

0‰ (Katzenberg 2007). The concentration of carbon isotope in plants is dependent upon both the carbon available in the environment as well as the method of carbon fixation and so will differ between marine and terrestrial vegetation and C₃, C₄, and plants employing crassulacean acid metabolism (CAM plants) (Katzenberg 2007).

The isotopic values in plant matter are reflected in consumer tissues as the signatures are passed down the food chain. Differences between marine and terrestrial diets may be identified in consumer carbon if the expected values for each are known in the specific environment (Chisholm et al. 1982). Diets that contain different proportions of each are then scaled linearly between these two extremes (Chisholm et al. 1982). Furthermore, because the incorporation of carbon does not differ based on age or sex, variation greater than $\pm 0.3\text{‰}$ can represent real dietary differences (Lovell et al. 1986).

Terrestrial plants exhibit numerous methods of carbon fixation during photosynthesis. As such, although they each fix carbon from atmospheric CO₂, diversity in carbon isotope values is introduced between classes of plants. (Van der Merwe and Vogel 1983). The methods of carbon fixation include C₃, C₄, and CAM pathways and are named for the photosynthetic products they produce (Lee-Thorp 2008).

C₃ plants employ the Calvin photosynthetic pathway and so rely on rubulose biphosphate carboxylase/oxygenase (RUBISCO) to fix carbon in the form of phosphoglyceric acid which discriminates against ¹³C (Van der Merwe and Vogel 1983; Lee-Thorp 2008). As such, these plants display variable $\delta^{13}\text{C}$ values between -24‰ and -36‰ with an average globally of -26.5‰ and a depletion from atmospheric CO₂ of -15‰ on average (Ambrose and Norr 1993; Hedges 2006; Katzenberg 2007; Lee-Thorp 2008). However these values are sensitive to environmental variables including light availability, temperature, humidity, moisture, and CO₂ recycling

(Ambrose and Norr 1993; Lee-Thorp 2008). C₃ plants include wheat, rice, grasses, dicotyledonous plants, barley, oats, rice, potatoes, manioc, root crops, legumes, vegetables, trees, and shrubs (Ambrose and Norr 1993; Lee-Thorp 2008). Herbivores that consume solely C₃ resources will display an average $\delta^{13}\text{C}$ value of -21.4‰ in collagen (Figure 1) (Van der Merwe and Vogel 1983).

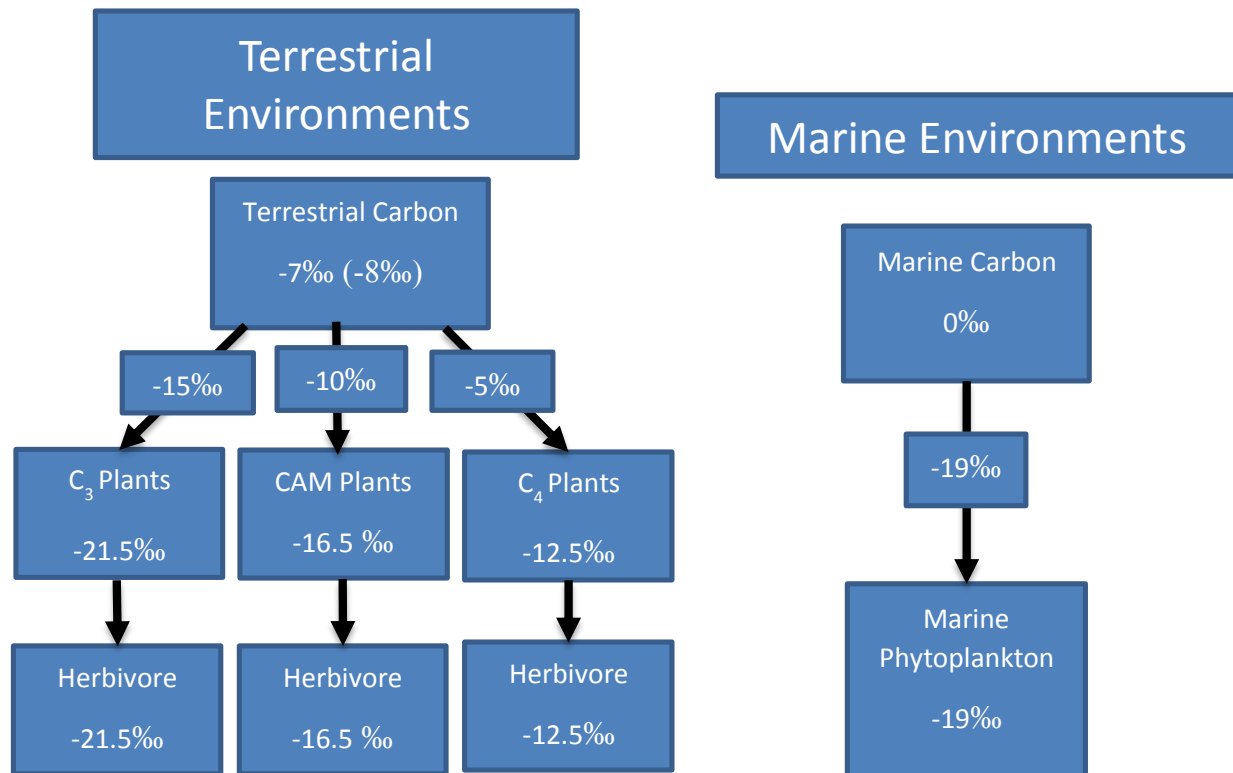


Figure 1: Movement of carbon through terrestrial and marine environments (Chisholm et al. 1982; Van der Merwe and Vogel 1983).

C₄ plants minimize stomata opening to conserve water and first arrange carbon atoms in bundle sheath cells prior to the initiation of the RUBISCO cycle to form malic or aspartic acid (Lee-Thorp 2008; Van der Merwe and Vogel 1983). As a result, they discriminate less against heavy isotope and fractionation is less extreme with only a -5‰ depletion from atmospheric CO₂ (Hedges 2006; Katzenberg 2007; Lee-Thorp 2008). The resulting $\delta^{13}\text{C}$ values are less variable and range from -9‰ to -14‰ with a global average of -12.5‰ (Ambrose and Norr 1993;

Katzenberg 2007; Lee-Thorp 2008). C₄ plant carbon values are the least sensitive to environmental variability (Ambrose and Norr 1993). C₄ plants include sorghum, some millets, maize, sugar cane, and tropical pasture grasses (Ambrose and Norr 1993; Lee-Thorp 2008). Herbivores that exclusively consume C₄ plants will display collagen $\delta^{13}\text{C}$ values of approximately -7.4‰ (Figure 1) (Van der Merwe and Vogel 1983).

CAM plants use an alternative pathway of carbon fixation that produces crassulacean acid. They employ a C₃ procedure during the day and a C₄ approach at night, maintaining $\delta^{13}\text{C}$ values between C₃ and C₄ plants with an average of -16.5‰ but are not normally distributed and contain peaks at the mean values for C₃ and C₄ metabolism (Van der Merwe and Vogel 1983; Katzenberg 2007). The response of CAM plants to environmental change is intermediate between C₃ and C₄ plants (Ambrose and Norr 1993). CAM plants include cacti, euphorbias, agaves, and bromeliads (Figure 1) (Ambrose and Norr 1993; Lee-Thorp 2008).

Specific terrestrial ecosystems may display unique carbon values. In rainforests, for example, the enclosed nature of the ecosystems and restricted air circulation leads to the canopy effect. CO₂ depleted in ^{13}C is released by the breakdown of organic plant matter and is recycled in the closed environment (Van der Merwe and Vogel 1983; Ambrose and Krigbaum 2003). Along with the high humidity in these areas, these factors result in depleted carbon values than otherwise expected (Ambrose and Krigbaum 2003). In contrast, hot, open, dry habitats exhibit enriched carbon signatures (Ambrose and Krigbaum 2003).

In marine environments the primary source of carbon is dissolved bicarbonate which has a higher isotopic value than atmospheric CO₂ (Lee-Thorp 2008). As such, primary producers tend to have $\delta^{13}\text{C}$ values around -20‰ (Hedges 2006; Lee-Thorp 2008). Carbon is also recycled back into the ecosystem from scavengers feeding on marine detritus (Milner et al. 2004).

Furthermore, seawater is enriched in ^{13}C (Milner et al. 2004). Temperature may also alter fractionation in producers during photosynthesis thereby, effecting isotopic ratios (Van der Merwe and Vogel 1983). Marine phytoplankton fractionates carbon at 19‰ relative to the environment which is similar to terrestrial C_3 plants (Figure 1) (Chisholm et al. 1982).

Carbon sources for freshwater plants include dissolved CO_2 in water, bicarbonate from rocks and soils, and organic carbon from waste and decomposition. As such, different habitats may display different carbon signatures such as higher ^{13}C in animals from shallow water habitats (Katzenberg 2007). Furthermore, freshwater fish often maintain slightly elevated carbon levels as a result of a longer food chain (Katzenberg 2007). In general, the carbon value of marine food webs falls between and overlaps both C_3 and C_4 plant values (Ambrose and Norr 1993).

Variability in Carbon Isotope Values

There are a number of obstacles to the successful determination of diet from carbon values (Katzenberg 2007). The same species within an ecosystem may differ in carbon values due to micro-environmental differences and seasonal variations which may be obscured or over emphasized by sampling methods (Zohary et al. 1994). This complicates baseline creation as does the effects of the introduction of fossil fuels which adjusted atmospheric carbon by approximately -1.5‰ and needs to be accounted for when comparing modern standards or baselines to ancient samples (Aufderheide et al. 2003).

Interpretation of carbon values is also influenced by the intricacies of fractionation. Most authors have identified at most 1.0‰ enrichment between diet and consumer carbon values (Aufderheide et al. 2003). However, spacing is also different between carnivores and herbivores because of different methods of incorporation (Ambrose et al. 2003). Ruminant digestion, for

example involves the bacterial production of methane that contains very low $\delta^{13}\text{C}$ values around -44‰. As a result of methanogenesis resulting in blood and respired CO_2 enriched relative to diet by 15‰ (Ambrose et al. 2003).

Furthermore, significant variation may exist within the same plant. This includes differences between seed and vegetable of -1.3‰ for grains, vegetables, legumes, and fruits; of -1.0‰ for wheat; and -4.5‰ for corn (Ambrose and Norr 1993). There may be further differences between protein and non-protein components in plants of 1.2‰ and between seed protein and leaves of 3.8‰ (Ambrose and Norr 1993). In general, the carbon value of carbohydrates is similar to that of the whole plant while lipids differ by -5‰ (Ambrose and Norr 1993).

Carbon values may also differ within a single individual consumer. Carbon is incorporated into different tissues from dietary proteins, lipids, and carbohydrates. The methods by which carbon is included into these tissues from the environment differs, and will be discussed in greater detail below but may be directly routed from protein or mixed from all dietary fractions resulting in different isotopic values (Ambrose and Norr 1993). Furthermore, although intraskeletal variation in carbon is minimal at $0 \pm 0.1\text{‰}$, this may increase in the face of trauma or infection, although not to the same degree as nitrogen (Olsen et al. 2014). Fractionation values are not constant and at times of greater tissue synthesis, as during growth, enrichment may be reduced (Ambrose and Norr 1993).

In addition to the many sources of variation, different food items may have similar carbon values. The carbon value of C_4 plants can be very similar to certain marine protein requiring other evidence to ensure proper interpretation of the data if the diet is known to contain C_3 , C_4 , and marine elements (Chisholm et al. 1982; Ambrose and Norr 1993; Katzenberg 2007).

These factors can introduce even more confusion in the use of marine products as manure or fodder in terrestrial ecosystems may complicate interpretation of carbon values (Milner et al. 2004). In contrast, marine environments may contain carbon from terrestrial sources as a result of the breakdown of terrestrial detritus or the dissolution of inorganic carbon from pre-quaternary carbonate in geologic features of the environment (Milner et al. 2004). These influxes of terrestrial carbon are especially noticeable in stationary marine organisms as their access to alternative resources is limited (Milner et al. 2004). As such, it is especially difficult to interpret carbon values of human populations known to gather resources from lagoon or estuary environments (Milner et al. 2004).

Complicating matters further, environment may change over time. In instances in which carbon values from consumers do not match those expected from the environment, these values may be indicative of environmental change. Such values can then be used to reconstruct the ancient environment (Chisholm et al. 1982; Milner et al. 2004; Katzenberg 2007).

Carbon values may be analyzed to reveal a great deal of information about diet and environment in the past. However, the interpretation of such values is complex. Furthermore, carbon values only reveal one piece of information about diets in the past. As such, it is necessary to incorporate other elements in any rigorous analysis. Nitrogen values are especially useful when analyzed in conjunction with carbon values.

Nitrogen

Environments

Nitrogen is another element that has been traditionally used in reconstructing diet of ancient human societies (DeNiro and Epstein 1981). Nitrogen is consumed from protein resources in the forms ^{14}N and ^{15}N and ratios are measured relative to Ambient Inhalant

Reservoir (AIR) (Katzenberg 2007; Lee-Thorp 2008). Nitrogen availability in an ecosystem is related to the balance of nitrogen fixation by producers coupled with the recycling of nitrogen and the re-release of N_2 (Lee-Thorp 2008). Atmospheric N_2 displays a nitrogen value of 0‰ (Lee-Thorp 2008). The fixation of nitrogen by producers generally results in a 1- 4‰ increase in nitrogen depending on aridity, leaching of nutrients, anoxia, and salinity (Lee-Thorp 2008).

A relationship between nitrogen values and humidity, precipitation, and temperature has been found. Greater fractionation resulting in enrichment of nitrogen values has been noted in hot, dry habitats and soil nitrogen values are often found to be inversely related to precipitation at amounts less than 400mm (Ambrose 1991; Cormie and Schwarcz 1996; Lee-Thorp 2008; Bocherens et al. 2014). Heaton et al. (1986) were the first to identify the quasilinear relationship between the elevated nitrogen values and decreased rainfall. Some have suggested the enrichment of animal tissues in dry habitats may be related to the different methods of urea excretion in drought resistant animals (Ambrose 1991). Others suggest that changes in isotope values with rainfall may be a result of differences in metabolism triggered by a switch in food sources from C_3 to C_4 plants (Cormie and Schwarcz 1996). Enrichment can also occur in animals as ^{15}N depleted urea is excreted to increase the osmolality of urine (Schwarcz et al. 1999). However, another source of enrichment could be nitrogen enrichment in the soil as a result of the volatilization of isotopically light ammonia, especially near the soil surface (Schwarcz et al. 1999). Regardless, populations in hot, open, dry habitats often exhibit higher nitrogen values (Ambrose and Krigbaum 2003).

In contrast to terrestrial environments, ocean nitrogen is introduced to the ecosystem in the form of recycled nitrate with a value of +5‰ or +6‰ (Lee-Thorp 2008). As such, high nitrogen values are found in marine food webs (Lee-Thorp 2008). Freshwater food webs also

display high nitrogen values but can usually be distinguished on the basis of carbon values (Lee-Thorp 2008).

Diet

Nitrogen displays a shift of 2‰ to 6‰ between diet and consumer or trophic level due to the excretion of nitrogen depleted urea at each stage, although some claim a general shift of 3.3‰ between levels (Ambrose et al. 2003; Lee-Thorp 2008). Variation in enrichment is a result of differences in physiology and nitrogen incorporation between species (DeNiro and Epstein 1981; Lee-Thorp 2008). As such, nitrogen values differ based on the source of protein with diets high in invertebrates having lower nitrogen enrichment and those dependent on plants and algae being intermediate (Hedges and Reynard 2007; McCutchan et al. 2003). Additionally, omnivorous diets, diets based on freshwater and marine animals, or diets incorporating nursing animals are elevated in nitrogen values (Hedges and Reynard 2007; Muldner and Richards 2005). For example, in the case of marine and aquatic diets, nitrogen values may be enriched by +3‰ relative to terrestrial diets (Schwarcz et al. 1999). Elevated nitrogen values are also associated with breastfeeding and weaning as the consumption of human breast milk represents a trophic shift in diet, resulting in a +3‰ enrichment (Henderson et al. 2014).

Nitrogen values in consumer tissue may also vary in regards to the source of protein, and therefore nitrogen, in the diet. Plants contain very little protein, roughly 10-25% by weight, while meat contains up to 85-90% protein (Ambrose et al. 2003). As such, even a small amount of protein-rich meat will dominate the nitrogen ratios (Ambrose et al. 2003). For example a diet containing 15% meat will have 50% of protein originating from that dietary fraction which will result in a 1.5‰ increase in nitrogen values (Ambrose et al. 2003). A diet of 50% meat will gain 85% of its nitrogen from that resource and will have $\delta^{15}\text{N}$ values enriched by 3.5‰ (Ambrose et

al. 2003). However, the relationship is not generally linear and so cannot be used to determine the contribution of animal versus plant protein (Ambrose et al. 2003). In the case of very high protein diets ^{15}N may increase as the body preferentially breaks down ^{14}N amino acids to rid the body of excess (Fuller et al. 2005).

Metabolic Stress

Although nitrogen ratios reflect diet they are also influenced by a number of other factors including growth, nutritional stress, and disease that may alter metabolic functions (Katzenberg and Lovell 1999). Due to the variation introduced by pathological conditions, most researchers agree that visibly pathological bone should be avoided during sampling. However, systemic conditions may not be directly visible in the bone and may also alter nitrogen values throughout the skeleton (Katzenberg and Lovell 1999). These obstacles are problematic because nitrogen values are indirect marker of diet to begin with and so the influence of any factors may alter them in significant ways (Reitsema 2013).

Although the effects of stress on the body may produce dramatic changes in the body's nitrogen pool, bone is the last affected by such variation with cortical bone turnover around 25 years and trabecular bone around 3-4 years (Katzenberg and Lovell 1999; Olsen et al. 2014). As such, periodic episodes of short and moderate term stress may not be revealed through the analysis of bone nitrogen values (Reitsema 2013). Furthermore, the human body contains numerous methods of mediating the effects of stress and so not all episodes may leave an identifiable signature (Reitsema 2013).

In a healthy individual, nitrogen values vary throughout the skeleton by $-0.1 \pm 0.4 \text{ ‰}$ (Olsen et al. 2014). In the case of individuals afflicted with injury, illness, or degenerative disease, intraskeletal variation may be as great as 2.5 ‰ (Olsen et al. 2014). Bone infected with

osteomyelitis have ^{15}N values 2‰ greater than normal bone in the same individual, as the collagen within those segments is formed from recycled amino acids and possibly because of dietary shifts during infection (Katzenberg and Lovell 1999; Olsen et al. 2014). While affected bone shows alteration, bone near the infected area also shows similar variation in nitrogen values as that of bone from further away (Olsen et al. 2014). However, while systematic pathological conditions such as rickets or osteomalacia may alter nitrogen values and lead to a negative nitrogen balance, little intraskeleton variation is present (Olsen et al. 2014).

During tissue maintenance nitrogen is at equilibrium within the body, and the collagen nitrogen values will reflect that of the diet at the time of formation (Katzenberg and Lovell 1999). Growth requires greater nutrient consumption and introduces metabolic stress to a body resulting in an anabolic state in which tissue is gained and a positive balance of nitrogen occurs within the body (Katzenberg and Lovell 1999; Fuller et al. 2005; Henderson et al. 2014). As more protein is consumed and employed in tissue construction than excreted, an increase in ^{14}N occurs (Katzenberg and Lovell 1999; Fuller et al. 2005). Stress from inadequate water consumption increases nitrogen values as light nitrogen is excreted and heavy nitrogen is recycled from bodily protein (Ambrose 1991; Hobson and Clark 1992). Malnutrition, disease, injury, and pregnancy also stress the body and can dramatically alter normal metabolism (Katzenberg and Lovell 1999).

Nutritional Stress

Lack of adequate nutrition, especially in regards to protein may have a dramatic effect on body metabolism and ultimately nitrogen balance and values. Such inadequacies may result from disease or social factors and can be short term, such as in the case of morning sickness associated with pregnancy and so may not be identifiable from bone (Fuller et al. 2005; Norman et al. 2008). However, longer term episodes of stress may be reflected in bone.

Starvation is associated with catabolism of nitrogen reserves from preexisting tissue, resulting in an anabolic state and a nitrogen shift similar to a trophic level shift (Fuller et al. 2005; Mekota et al. 2006). In the case of protein stress it may be necessary for the body to acquire energy from other nutrients which requires more steps, thereby increasing fractionation and ^{15}N values (Olsen et al. 2014). Specifically, the breakdown of skeletal muscle to access amino acids relies on deamination and transamination resulting in fractionation and the excretion of ^{14}N (Fuller et al. 2005). The body breaks down amino acids to gain access to NH_2 and preferentially targets ^{14}N as less energy is required to break those bonds (Hobson et al. 1992; Katzenberg and Lovell 1999; Fuller et al. 2005; Hatch et al. 2006). As such, the waste products of this breakdown are depleted in ^{15}N while the amino acids produced through the incorporation of recycled molecules are enriched. Ultimately, a positive nitrogen balance results from the decrease in the excretion of ^{15}N and an increase in the incorporation of ^{15}N in protein synthesis (Mekota et al. 2006). The preferential excretion of ^{14}N combined with the recycling of ^{15}N to produce tissue results in the enrichment of tissues (Fuller et al. 2005). Additionally, amino acids normally received directly from protein may be synthesized from other dietary fractions including carbohydrates and so may reveal a confused dietary signature (Reitsema 2013).

Due to the effects of starvation, ^{15}N values are high and inversely associated with body mass. In individuals suffering from anorexia, nitrogen values may be .5 to 2‰ higher at their sickest point than healthy individuals (Reitsema 2013). However, as the process of nutritional stress continues, the catabolism of the body's protein can slow down to a shift to gluconeogenesis, or glucose synthesis relying on non-carbohydrates, resulting in a depletion in nitrogen values that mimics recovery (Mekota et al. 2006).

Infection and Disease

Infection may affect nitrogen values through the alteration of nutritional status but also through additional processes introduced as a result of the disease process (Reitsema 2013). The biological consequences to the infected organism may result from the direct effects of the pathogen as well as secondary factors including toxic products, inflammation, fever, nutritional stress and damage to neural, cardiovascular, and immunological systems (Beisel 1975). Physiological responses to infection may be initiated within hours of infection, become widespread, and differ throughout the course of the disease (Beisel 1975). As such, the response of the host is influenced by the severity, duration, and localization of the infection as well as effects of treatment, preexisting pathological conditions, and nutritional status (Beisel 1975; 1977). Nitrogen loss may also vary in an individual day by day (Grossman et al. 1945). As such, the effects of infection on a body's nitrogen profile may be variable (Beisel 1975).

The body's response to infections usually peaks within five to ten days after infection or injury (Long 1977; Exton 1997). Energy requirements increase to produce fever as the body enters a hyper-metabolic state. At the same time food intake decreases, the body's ability to employ nutrients is compromised, and nutrients are lost, especially nitrogen. This results in a catabolic state and a negative nitrogen balance (Beisel 1975; Long 1977; Coss-Bu et al. 2001; Hatch et al. 2006). The body ultimately enters a state of cachexia as it consumes its own protein and energy stores (Beisel 1975; Hatch et al. 2006). The greatest loss of nitrogen occurs during a fever response (Grossman et al. 1945). Furthermore, the amount of protein necessary to maintain nitrogen balance varies with the amount of stress and degree of inflammation as well as the functioning of different organs throughout the period of infection (Coss-Bu et al. 2001).

Preexisting pathological conditions may also affect immunological defense including diabetes, anemia, cardiac conditions, trauma, and cirrhosis (Beisel 1977). The loss of nitrogen

may be limited by adequate nutritional and caloric intake but may be compounded with weight loss associated with long term illness (Beisel 1977; Long 1977). Furthermore, the loss of nutrients as a result of a primary infection may result in secondary conditions which further alters nitrogen metabolism (Beisel 1977).

As such, infection affects protein metabolism, the usage of specific amino acids, the incorporation of nutrients, and the production and utilization of cellular energy (Beisel 1977). To meet the demands of defense, muscle protein, especially skeletal muscle, is dismantled through oxidation and the amino acids are redistributed (Beisel 1975; 1977; Coss-Bu et al. 2001). As such, enriched ^{15}N is recycled in the production of new proteins, enriching tissue in ^{15}N and waste products in ^{14}N (Beisel 1977; Hatch et al. 2006; Reitsema 2013). The body prioritizes the value of immediate energy over long term nitrogen debt (Long 1977). As the body recovers, the nitrogen pool is rebuilt and the negative nitrogen balance is reversed. However, the process is a slow one and so the negative nitrogen balance may persist as the patient becomes asymptomatic (Grossman et al. 1945; Beisel 1975; 1977).

Injury

The effect of injury on a body's nitrogen pool is similar to that of other forms of stress. Skeletal tissue collected from osseous calluses resulting from injury and localized periostitis likely reflect diet and limited metabolic alteration at the time of remodeling and so may reflect short term dietary change (Katzenberg and Lovell 1999; Olsen et al. 2014). Severe fractures may result in an inflammatory response and catabolism of muscle protein for repair leading to a negative balance of nitrogen and enrichment in ^{15}N (Olsen et al. 2014). Atrophied bone only shows variation from normal levels if resulting from nutritional stress, otherwise nitrogen values were unaffected (Katzenberg and Lovell 1999).

Pregnancy

Pregnancy is a source of metabolic stress limited to females. Pregnancy results in greater energy requirements and, occasionally a decrease in intake due to morning sickness (Reitsema 2013). Similar to other forms of stress, this results in the recycling of ^{15}N and the excretion on ^{14}N leading to an enrichment in the body's nitrogen pool (Fuller 2005). Although this stress is usually short term, repeated pregnancies, including those ending in miscarriages may sufficiently alter the body's nitrogen pool for an extended enough period of time that the signature may be recognizable in bone (Reitsema 2013).

Other Sources of Variation in Values

In addition to the complexity introduced in the analysis of nitrogen ratios from environment, diet, and metabolic stress, the study of nitrogen values is also limited by numerous obstacles. First of these is a lack of understanding of the process of fractionation. Some research has identified greater trophic shift in diets with high nitrogen content and when plants are the main source of protein, as the nutrients are less efficiently used (Focken 2001; Hedges and Reynard 2007; McCutchan et al. 2003; Schoeninger and Moore 1992). Other studies have identified variation in fractionation between fish, herbivores, and carnivores because of differences in the nitrogen content of food, method of assimilation, and range of sources (Hedges and Reynard 2007; Vander Zanden and Rasmussen 2001). Some investigations have found a correlation between nitrogen value and consumer body mass or “prey quality”, although the term is not well defined (Focken 2001; Oelbermann and Scheu 2002). In contrast, other researchers have found no difference in fractionation values between aquatic or terrestrial animals, carnivores, herbivores, or body mass (Post 2002; Schoeninger and Moore 1992).

Nitrogen values are a valuable source of information about the protein component of human diet in the past. However, these values are altered by a vast array of factors relating to

health, stress, environment, degradation and others. As such, the suggested fraction between trophic levels of 3‰ is not universally acceptable. Instead, the interpretation of nitrogen values must consider the composition of the diet, especially the protein component and nitrogen balance (Fuller et al. 2005).

Tissues

The behavior and interpretation of stable isotopes differs between human tissues. Seventy percent of human bone consists of a mineral fraction (hydroxyapatite) and thirty percent is made up of an organic component (collagen) (Katzenberg 2007). Stable isotope values can also be examined from tooth enamel and dentin as well as hair and other soft tissues. Each aspect incorporates different stable isotopes in variable fashions and has different turnover rates. As a result, they provide different information about an individual's life (Lee-Thorp 2008). These differences are especially complex if components of the diet come from diverse sources (Ambrose and Norr 1993; Katzenberg 2007). Specifically, tooth enamel and dentin do not experience remodeling after formation and so stable isotope values will represent diet at the time of tooth formation (Katzenberg 2007). Soft tissues turnover at a much faster rate and so only provide a window into short periods of time before death (Williams 2008). Bone apatite incorporates carbon and oxygen and is related to bulk diet (Harrison and Katzenberg 2003) Harrison and Katzenberg 2003. Lastly, bone collagen is composed of both carbon and nitrogen and remodels slowly providing a window primarily into protein resources but also health status over an extended period of an individual's life (Harrison and Katzenberg 2003). Therefore, this study focuses on the analysis of collagen from bone.

Collagen is the organic component of bone that is made up of approximately 35% carbon and 11-16% nitrogen (Ambrose and Norr 1993; Katzenberg 2007). Collagen is “composed of

multiple helical peptide fibrils stippled with a fine, poorly crystalline ‘cement’ of minerals” (Lee-Thorp 2008: 2). It consists of amino acids which are incorporated directly from dietary protein; including especially glycine, proline, and hydroxyproline (Ambrose and Norr 1993; Tieszen and Fagre 1993; Jim et al. 2006).

In early studies, turnover in human collagen was believed to take approximately 25-30 years representing a life time average of nutrient intake (Chisholm et al. 1982; 1983; Lovell et al. 1986). Other studies claimed that collagen turned over at a rate of closer to 5-10 years (Milner et al. 2004). Hedges et al. (2007) suggest that the rate of collagen turnover differs between males and females and throughout the life course. Specifically they found a 4% to 3% yearly turnover between the ages of 20 to 80 for females and 1.5% to 3% for males in the same period (Hedges et al. 2007). Between the ages of 10 and 15 they found a yearly replacement of 10- 30% with males exhibiting rates twice as fast as females (Hedges et al. 2007). In general, before the age of 20, male turnover rates can be twice as fast as that of females (Hedges et al. 2007).

Nitrogen is incorporated into collagen with a spacing from dietary protein of 3‰ (Milner et al. 2004). Carbon is also present in collagen with approximately 65% of the carbon ingested from protein directed to collagen (Ambrose et al. 2003). The spacing between collagen and diet carbon values is approximately 5‰ in humans (Ambrose and Norr 1993). Although some studies have identified a small trophic effect of 1 to 2‰ in omnivores and carnivores, it has been recognized for some time, that the spacing is inconsistent (Lovell et al. 1986; Ambrose et al. 2003; Milner et al. 2004; Hedges 2006; Lee-Thorp 2008). Therefore, the collagen $\delta^{13}\text{C}$ values in human diets based on C_3 plants fall around -19‰ while those consisting of C_4 plants are around -8‰ (Dupras and Tocheri 2007).

The isotopic ratio of carbon in collagen is determined by the $\delta^{13}\text{C}$ values of dietary protein, the proportion of protein in the whole diet, and the difference in $\delta^{13}\text{C}$ values between the protein and non-protein elements of the diet (Ambrose and Norr 1993). Because the composition of collagen is dependent on a number of factors, the often cited 5‰ collagen to diet spacing may be inaccurate because it does not take into account the composition of the diet and so may vary from <1‰ to 8‰ or 2‰ to 10‰ (Ambrose et al. 2003; Harrison and Katzenberg 2003; Jim et al. 2006; Katzenberg 2007; Tieszen and Fagre 1993). When protein and non-protein aspects of the diet contain the same carbon values, only then collagen will be enriched by 5‰ relative to diet (Ambrose and Krigbaum 2003; Harrison and Katzenberg 2003). Therefore, the assumption that protein carbon is incorporated into collagen and non-protein is directed to apatite, is overly simplistic (Schwarcz 2002; Ambrose et al. 2003).

Protein is comprised of amino acids. Amino acids can be described as indispensable, conditionally indispensable, or synthesized (Harrison and Katzenberg 2003). Essential or indispensable amino acids account for 21.7 % of carbon in collagen and must be consumed from plant or animal matter (Harrison and Katzenberg 2003; Jim et al. 2006). Conditionally indispensable amino acids account for 29.6% of carbon in collagen and are similar to indispensable amino acids, with growth delays resulting if insufficient amounts are present (Ambrose et al. 2003; Jim et al. 2006). In total, 51.3 % of amino acids are routed to collagen (Jim et al. 2006).

Essential amino acids used in the synthesis of collagen are available from protein sources and account for 12% of collagen material but 18% of the carbon (Chisholm et al. 1982; Ambrose and Norr 1993; Ambrose et al. 2003). These amino acids are absorbed directly from dietary protein without significant alteration in isotopic values and routed directly to collagen (Harrison

and Katzenberg 2003; Milner et al. 2004; Hedges 2006). Non-essential amino acids, including proline, glycine, and hydroxyproline, account for 78% of amino acids in collagen and are available from other components of the diet including lipids and carbohydrates or must be synthesized internally (Ambrose and Norr 1993; Schwarcz et al. 1999; Dupras et al. 2001; Jim et al. 2006). Nearly 50% of amino acids must be synthesized within the consumer (Hedges 2006).

Therefore, in very low protein diets, only 18% of carbon will come from protein with the remainder of amino acids for collagen construction coming from lipids and carbohydrates resulting in carbon values more similar to overall diet (Ambrose and Norr 1993; Harrison and Katzenberg 2003; Milner et al. 2004). If enough protein, and therefore non-essential amino acids, are available from the diet, the pathways responsible for the construction of non-essential amino acids from endogenous sources such as lipids and carbohydrates are inhibited (Schwarcz 2002). If adequate protein is available from the diet, the source of carbohydrates and lipids will be underrepresented in collagen carbon values, these values will instead be biased towards the protein fraction of the diet (Schwarcz 2002; Ambrose et al. 2003; Harrison and Katzenberg 2003; Milner et al. 2004). Furthermore, if protein and non-protein dietary fractions differ markedly, collagen will not be representative of whole diet (Harrison and Katzenberg 2003).

If a diet contains a high proportion of plant matter and low occurrence of meat, carbon values will be lower, especially because the carbon value of carbohydrates is depleted in relation to proteins (Milner et al. 2004). Similarly, diets rich in ^{13}C from plants may lead to overestimation of the importance of protein while those low in protein may underrepresent ^{13}C enriched plant foods (Harrison and Katzenberg 2003). For example, marine diets tend to be protein rich while terrestrial based diets are largely dependent on vegetal resources that lack

protein. As such, the analysis of diets that incorporate marine resources may underestimate the role of lipids and carbohydrates incorporated from plant material (Ambrose and Norr 1993).

There is also debate about how reliably collagen may reflect input from marine protein sources (Milner et al. 2004; Hedges 2006). The relationship between the amount of marine carbon incorporated into collagen and the frequency of marine resources in diet is not linear but instead tends to highlight extremes (Milner et al. 2004).

Diagenesis is related to a sample's collagen content, structural integrity, porosity, and crystallinity (Hedges 2002). It is also related to moisture availability, acidity of burial environment, microbial activity, temperature, and time (Lee-Thorp 2008). Collagen is more susceptible than apatite to changes brought about through diagenetic processes. Collagen will denature if the structural hydrogen bonds are dissolved during diagenesis resulting in disaggregated pseudomorphs and excess proteins (Hedges 2002; Lee-Thorp 2008). Therefore, even if collagen molecules are destroyed by diagenesis, the general isotopic ratios and composition will remain (Chisholm et al. 1983; Lee-Thorp 2008). This is because the loss of individual carbon atoms will dissolve the protein in its entirety, thereby maintaining the isotopic ratios of the remaining molecules (Chisholm et al. 1982).

A lack of diagenetic alteration is most commonly identified by a carbon to nitrogen ratio (C:N) that falls within the range of 2.9 to 3.6 and high collagen yields (Tieszen and Fagre 1993; Lee-Thorp 2008). The percent of collagen composed of carbon and nitrogen can also be examined to determine the quality of the sample. Carbon percentages (%C) between 26 -44% and nitrogen percentages (%N) between 11 and 16% are considered acceptable and indicative of good preservation (Van Klinken 1999). Furthermore, the presence of hydroxyproline, an amino acid only found in collagen and intact pseudomorphs may be analyzed to determine preservation

(Tieszen and Fagre 1993; Ambrose and Krigbaum 2003). In cold, dry cave habitats, bone collagen has been found to survive for up to 10,000 years and 5,000 years in open savannah (Lee-Thorp 2008; Van der Merwe and Vogel 1983).

Summary

Stable Isotope analysis is a valuable tool in revealing dietary and health patterns in the past. Although obstacles exist from variations resulting from environment, diet, stress, and diagenesis proper precautions ensure that the results of analysis are authentic. A thorough understanding of the behavior of the varying elements under investigation and comparison to appropriate baselines allows refined investigation of diet and health to take place. These methods have been applied to great success in the Dakhleh Oasis, and especially at the site of Kellis.

Kellis Background

Dakhleh Oasis

The settlement of ancient Kellis, also known as Ismant el-Kharab, lies in the Dakhleh Oasis in the western desert of Egypt, approximately 300 km west of the Nile River, or an eight-day excursion in ancient times and 750 km south of modern day Cairo (Figure 2) (Thanheiser et al. 2002). The area was hyper-arid and hot in antiquity, relying primarily on underground aquifers originating from the Nubian Sandstone Series aquifer (Dupras and Schwarcz 2001).



Figure 2: Map depicting location of the Dakhleh Oasis relative to major cities in ancient Egypt. The open circle indicates the Dakhleh Oasis and the square outlines the area of Kellis.

Maximum temperatures range from 20-25°C in the winter to 40- 50 °C in the summer while minimum temperatures at night may drop as low as 0-2 °C (Dupras and Schwarcz 2001). Rainfall in the region ranges from 0.3mm to 0.7mm a year with humidity of less than 50% (Schwarcz et al. 1999). The easy access to underground sources of water resulted in productive, farmable land and encouraged early settlement and diverse resource production as early as the Holocene period, about 6,000 years ago (Mills 1984; Knudstad and Frey 1999).

Kellis

Excavation has been ongoing at the ancient settlement of Kellis since the 1980s and at the Kellis 2 cemetery since 1992 (Dupras 1999; Dupras et al. 2016). Ancient Kellis was not settled permanently until the Ptolemaic period around the 1st century BCE (Schwarcz et al. 1999). It became a vibrant and dynamic center of agriculture, industry, trade, and religion during the late Ptolemaic period through the Romano- Christian period from the mid-1st century BCE until its abandonment around 400 CE (Knudstad and Frey 1999; Hope 2001; Bowen and Marchini 2002; Molto 2002). Because of its location, Kellis was simultaneously isolated from severe administrative pressures and exposed to widespread cultural and social changes through trade, religious, and kinship connections to the Nile Valley (Knudstad and Frey 1999; Hope 2001; Bowen and Marchini 2002; Molto 2002). During the Roman period from the 1st century BCE to the 4th century CE, evidence suggests residents were bilingual, produced items in demand by major powers, and selectively adopted architecture, religion, and dress to highlight Roman associations. As such, the population manipulated their position on the fringes of the empire to increase their economic and political power (Bowen 2001; Thanheiser et al. 2002).

Subsistence and Trade

Since its foundation, Kellis boasted a diverse resource base (McDonald 2002). Roman rule brought new technology, including the *saqiya*, or oxen driven water wheel, and cofferdams to raise water tables. It also introduced new markets and a larger population (Bagnall 1996; Molto 2002; Thanheiser et al., 2002). The year-round water supply supported crops nearly year round as well as small domestic gardens resulting in a variety of food items for domestic use as well as local and regional trade (Thanheiser et al. 2002).

Crops included flax and cotton for trade and production, wheat and barley for beer and animal feed, and pearl millet, lentils, beans, safflower, artichoke, bottle gourds, dates, grapes, and olives for consumption and trade (Bowen 2002; Thanheiser et al. 2002). Locally grown exotic foodstuffs included apricots, peaches, apples, pine kernels, pistachios, hazelnuts, walnuts, onions, and garlic (Thanheiser et al. 2002). Young pigs were commonly consumed, followed by cows, goats, and chickens (Churcher 2002). Sheep, donkeys, camels, rabbits, ducks, geese, and pigeons were also raised, and gazelle was hunted (Bowen 2002; Churcher 2002). The foodstuffs available for consumption were extensive and varied (Table 1).

Table 1: List of animal and plant resources available for consumption at Kellis. Adapted from Dupras 1999 and Churcher 2002.

ANIMALS	FIELD CROPS	HOUSEHOLD PLANTS	FRUIT AND NUTS	OTHER
Cows	Wheat	Turnips	Dates	Honey
Pigs	Barley	Garlic	Doum Palm Nuts	Coriander
Goats	Oats	Legumes	Figs	Cumin
Donkeys	Sesame	Onions	Olives	Dill
Camels		Cucumber	Pomegranates	Fennel
Pigeons		Gourds	Jujubes	Marjoram
Geese		Artichokes	Carob	Mint
Ducks			Almonds	Rosemary
Eggs			Apricots	Safflower
Fish			Peaches	Thyme
Gazelle			Pears	Mustard
Oryx			Cherry	Ami
Hartebeest			Citron	Anise
Hare			Apples	Caper
Chickens			Walnuts	Laurel
			Pistachios	Pepper
			Hazelnuts	
			Pine Nuts	

Kellis also received fish and shellfish from the Nile Valley, cowrie and clam shells from the Mediterranean or Red Sea, and elephant ivory from Sudan (Churcher 2002). In return, the city exported wool, purple dye, alum used in tanning and dyeing, cotton, wine, olive oil, and wheat (Bagnall 1996; Bowen 2001; Bowen 2002; Thanheiser et al. 2002). A well-developed

industrial sector produced fine linen, textile, leather goods, ceramics, and metal goods for domestic use and trade. Most production was household-based but specialization was not uncommon (Bowen 2002).

Population Structure

The population of Kellis was influenced by migrant farmers and trade caravans in the Roman period (Parr 2002). Studies have found isotopic evidence of migration from the Nile Valley or Nubia and textual evidence of mobile Manichaean missionaries and kinship ties to the Nile Valley (Dupras and Schwarcz 2001; Molto 2002; Gardner 2008). Further research has revealed diversity in mitochondrial DNA suggesting a diverse population (Parr 2002).

In addition to its diversity, Kellis was characterized by marked social stratification as indicated in differing qualities of household architecture, goods, and mortuary treatments (Aufderheide et al. 1999; Bowen 2005). Slaves occupied the lower tiers of society while religious and administrative officials occupied the upper (Bowen 2001; 2002). While men occupied administrative roles and most positions of authority, women were fairly independent, choosing employment and carrying out legal and business transactions (Bowen 2001; 2002).

Religion

Kellis was a site of intermingling religious traditions as a result of its locations on the outskirts of the empire (Kaper 2002). Traditional Egyptian beliefs, Classical traditions, Christianity, and Manichaeism were all present at the site and interacted in complex ways. Traditional Egyptian temples contained both Pharaonic elements and Classical geometric panels (Berry 2002). During the 3rd and 4th centuries CE, Christianity and Manichaeism spread quickly, with evidence of the adoption of Christian names in 250 CE (Bowen and Marchini 2002; 2003; Gardner 2008). Manichaeism centered on a worship of Christ and condemnation of paganism,

focused on spirituality, and interpreted Christ as a solely divine, tripartite figure (Lieu 1992). However, at the same time, one of the latest built temples in Egypt dating to the late 2nd or early 3rd century CE resides on site (Hope 2001; Kaper 2002). Intermixing of traditions was encouraged by flexible religious doctrine in the area (Bowen 2003; Gardner 2008).

The unique religious patterns in Kellis were reflected in mortuary practices at the site. The Kellis 1 cemetery included rock cut tombs, anthropogenic mummification, grave goods, and flexibility in alignment (Molto 2002; Bowen 2003; 2005). These Egyptian burial practices and use of Kellis 1 overlapped with the use of the Kellis 2 cemetery. Although Kellis 1 was likely in use during the Ptolemaic and early Roman periods, the history of use of the site is expected to be much more complicated (Schwarcz et al. 1999).

Kellis 2 Cemetery

The Kellis 2 cemetery is located to the northeast of the settlement of Kellis (Molto 2002; Thanheiser et al. 2002; Bowen et al. 2005). Due to the Christian style of burial, few artifacts are associated with the graves, complicating attempts to develop an exact chronology for the use of the cemetery (Stewart et al. 2003). Radiocarbon dates suggest a range of 100 to 450 AD, although further radiocarbon dating is planned to refine and support these assertions (Stewart et al. 2003). The arid conditions result in excellent preservation including skeletal materials as well tissues such as hair, nails, skin, and even textiles (Dupras and Schwarcz 2001; Bowen 2002; Dupras and Tocheri 2007).

Kellis 2 was characterized by wrapped individuals, including fetuses, interred in supine positions, and placed in individual burial pits, oriented west to east indicative of Christian beliefs (Bowen 2003). Limited grave foods are present but include ceramic pottery, jewelry, and plant remains including rosemary and myrtle (Wheeler 2009). Burial contexts differ on the basis of the

presence of mudbrick superstructures and substructures including tombs, mastabas, false floors, and vaulted crypts (Wheeler 2009). About one-third of the population was interred in some form of tomb structure (Wheeler 2009). However, this number could be dramatically altered by the effects of wind erosion in destroying many tomb superstructures (Wheeler 2009). The presence of a granular, red clay that differs markedly from the surrounding sand was also present inconsistently (Wheeler 2009). It is unclear if this was employed for the purpose of preservation or served a purely ritualistic purpose (Wheeler 2009).

To date 770 individuals have been excavated from the Kellis 2 burial ground although it likely holds between 3,000 and 4,000 individuals (Molto 2002; Williams 2008; Dupras et al. 2016). The main features of the cemetery are mud brick tomb structures surrounded by simple pit graves, some of which possess mudbrick superstructures (Figure 3) (Birrell 1999). A kin based organization centered on these tombs has been suggested (Dupras et al. 2016).

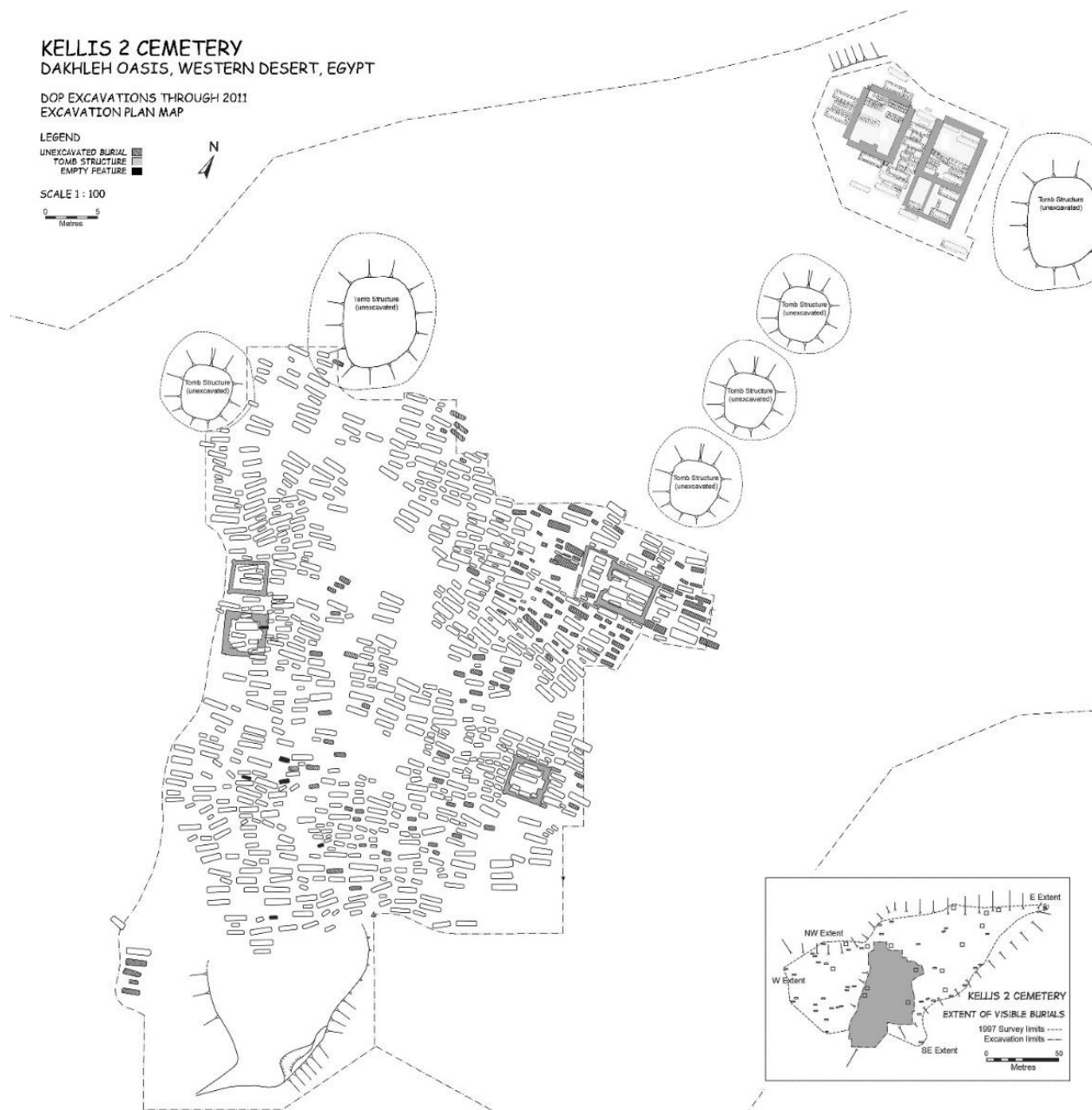


Figure 3: Map of features excavated from the Kellis 2 cemetery as of 2011 (Courtesy of the DOP Bioarchaeology Team).

The analysis of 724 individuals reveals a distribution of 64% juveniles and 36% adult (Williams 2008). Fifty-nine percent of the adults are female and 40% are male (Dupras et al. 2016). Individuals range from 16 weeks gestation to 72 years (Figure 4) (Dupras et al. 2016).

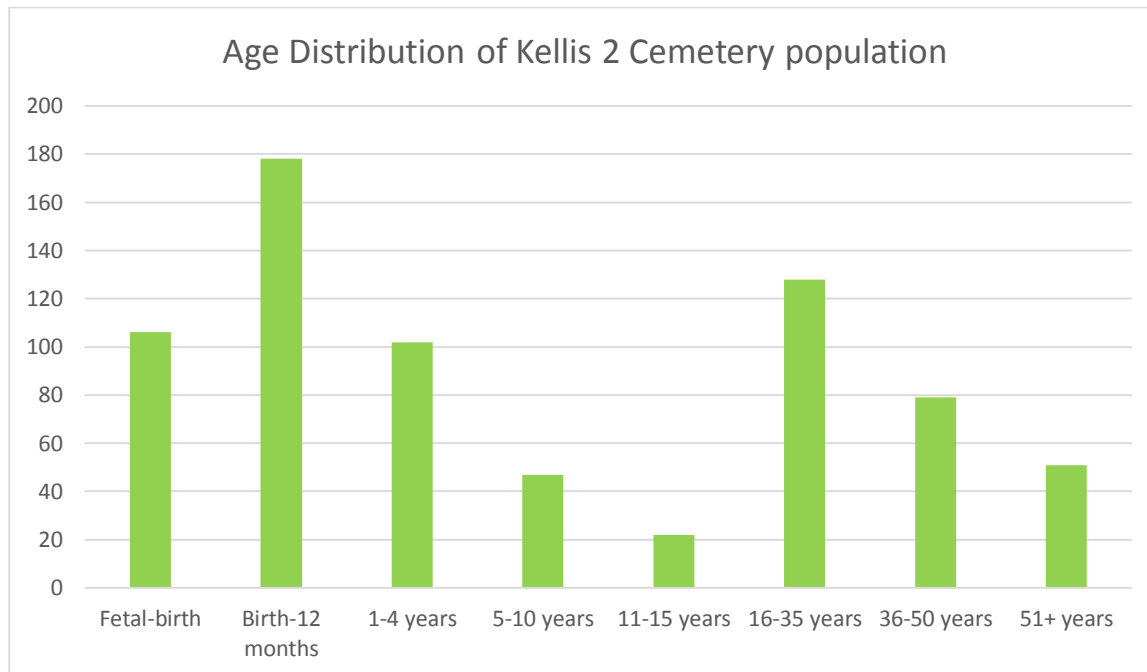


Figure 4: Demographic composition of Kellis 2 cemetery.

Previous Bioarchaeological Studies from the Dakhleh Oasis

Research in the Dakhleh Oasis as part of the Dakhleh Oasis Project has been ongoing since 1978 (Mills 1984). The focus of the project has been both biological and cultural adaptation in the region (Dupras and Schwarcz 2001). As such, the bioarchaeological research in the Dakhleh Oasis and in Kellis in particular, has explored a vast array of topics.

Research has focused on the mummies of Kellis and the mummification techniques used to create them (Cook 1994; Aufderheide 2009). Bioarchaeological research has also examined disease through histology, genetic analysis, and osseous markers, and have found evidence of osteogenesis imperfecta (Cope and Dupras 2011), tuberculosis (Donoghue et al. 2005), humerus varus deformity (Molto 2000), cribra orbitalia (Fairgrieve and Molto 2000), leprosy (Molto 2002; Donoghue et al. 2005), and osteoarthritis (Cook and Sheldrick 2001). Body shape (Bleuze et al. 2014), parasitic infections (Horne 2002), and tetracycline levels (Maggiano et al. 2004) have also been investigated. Juveniles and subadults have been a main focus of research at Kellis

with projects analyzing miscarriages and infant burials (Marlow 2001), fetal skeletons (Tocheri et al. 2005), nutritional stress (Wheeler 2012), childhood (Wheeler 2009), and child abuse (Wheeler et al. 2013). In addition to the diverse studies listed here, stable isotope analysis has been employed to reconstruct diet, weaning patterns, environment, migration, tissue spacing, individual histories, and seasonality of death (Dupras 1999; Schwarcz et al. 1999; Dupras and Schwarcz 2001; Dupras et al. 2001; Williams 2008; Johns 2012; Norris 2012). Due to the thorough work already completed in the Dakhleh Oasis, sufficient data exists to create a baseline of comparison for future isotope studies. This study will build off of these previous findings and address gaps in the current literature to provide a more nuanced and comprehensive understanding of patterns of lived experience across the cemetery.

Diet

Diet at Kellis has been examined in a number of ways. Faunal and botanical analysis has recovered the remains of pigs, cows, goats, chickens, rabbits, dogs, ducks, geese, gerbils, ostrich, mice, camel, fish, and oyster (Churcher 2002). Excavated botanical remains include wheat, barley, dates, grapes, apricots, pomegranates, peaches, squash, beans, and olives (Thanheiser 1999). Further evidence of diet comes from the Kellis Agricultural Account book which identifies the presence of wheat, barley, figs, dates, grapes, onions, turnips, radishes, and olives (Gardner 2008). Additionally, coprolite analysis has discovered evidence of grape seeds and a lack of animal bone (Aufderheide et al. 2003).

Stable isotope analysis has also been applied in the Dakhleh Oasis to examine diet. A study of mummies from tombs in the Kellis 1 cemetery dating to the end of the 2nd century to the beginning of the 3rd century by Aufderheide et al. (2003) examined carbon and nitrogen stable isotope values from carbonate and bone collagen. They found apatite carbon values of -14.8‰

suggesting a food source of -24.2‰ given a carbonate to diet spacing of +9.4‰ (Aufderheide et al. 2003). They cite previous studies from White (1993) carried out on modern plants from Nubia and the Nile Valley which show a mean value of C₃ plants at -26.5‰ and apply a +1.5‰ shift as a result of modern burning of fossil fuels and a +1‰ trophic shift to claim that the expected values of consumers would be -24‰ (Aufderheide et al. 2003). By examining spacing in carbon values between carbonate which largely reflects whole diet and collagen which includes protein values, he suggests that both fractions are coming from the same source. This is because the spacing is 4.9‰ and a spacing of 4.4‰ (5-7 ‰) would be expected if the values of the diet and protein fractions are the same as is the case for herbivores (Aufderheide et al. 2003). Additionally, the nitrogen values of +18.4‰ could suggest that wheat was the major source of protein based on base lines provided from past studies (Aufderheide et al. 2003).

Overall, the authors suggests that the people of Kellis were consuming a primarily C₃ plant based diet supplemented by the meat of animals consuming C₃ foods (Aufderheide et al. 2003). However, the plants examined for the study were not from the Dakhleh Oasis and were not ancient specimens, drawing concern about the reliability of their findings.

Further stable isotope analysis from Kellis 1 found values from bone collagen of -19.3‰ for carbon and +17.7‰ for nitrogen (Dupras 1999). Analysis of bone collagen from the later Kellis 2 cemetery revealed a mean nitrogen value of +18.6‰ and mean carbon value of -18.8‰ (Dupras 1999). The analysis of excavated foodstuffs where possible from Kellis also found carbon values of -18.0 ‰ ± 0.42‰ for non-dairy animals, -15.4 ‰ ± 0.42‰ for dairy animals, -23.2 ‰ ± 1.4‰ for C₃ plants, and -9.9‰ for C₄ plants (millet) (Dupras 1999; Dupras et al. 2001; Williams 2008). The main components of the diet at Kellis and their carbon values were then

inferred as wheat (−22.9‰), barley (−23.3‰), pigs (−17.4‰) and goats (−15.7‰) (Table 2) (Dupras 1999; Williams 2008).

Nitrogen values for animals at the site were $+14.0 \pm 1.47\text{‰}$ for non-dairy animals and $+13.3 \pm 0.21\text{‰}$ for dairy animals (Dupras 1999; Dupras et al. 2001). In general animals exhibited an average nitrogen value of $+13.3\text{‰}$, and plants an average value of $+15.2\text{‰}$ (Table 2). These values support the assertion that the main resource staples were C₃ plants with the addition of C₃ fed animal protein (Dupras 1999; Williams 2008). However, the enriched carbon values of the Kellis 2 cemetery population may indicate greater reliance on C₄ plants, mainly millet, or the consumption of partially C₄ fed animals than the earlier cemetery (Kellis 1) (Dupras 1999).

Table 2: Stable carbon and nitrogen values of foodstuffs available at Kellis. Taken from Dupras (1999), Dupras et al. (2001); and Williams (2008).

Class	Item name	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)
Animals	Gazelle ¹	-17.9	13.2
	Cow ¹	-15.1	13.1
	Goat ¹	-15.7	13.4
	Chicken ¹	-18.4	16.2
	Pig ¹	-17.4	13.3
	Donkey ¹	-18.1	13.3
Plants	Wheat (shaft) ¹	-22.9	16.1
	Fava bean (shell) ¹	-23.1	12.1
	Barley (shaft) ¹	-23.3	14.4
	Grape (seed) ¹	-22.5	16.8
	Olive (seed) ¹	-21.9	18.8
	Date (seed) ¹	-22.2	14.9
	Fig (stem) ¹	-23.8	17.8
	Doum palm nut (seed) ¹	-26.4	11.7
	Peas (seed)	-27.7	-0.7
	Turnip (leaf)	-25.3	10.4
	Garden rocket	-27.8	
	Millet ¹	-9.9	

¹ indicates archaeological specimen was available for analysis.

Weaning

Patterns of weaning at Kellis have been examined in a number of studies in the Dakhleh Oasis. Dupras et al. (2001) examined 49 infant juvenile bone samples from Kellis 2 and

identified a weaning period between 6 months to 3 years (Dupras et al. 2001). Stable nitrogen values exhibited a maximum +3‰ enrichment from the mean at 6 months old with a gradual decline until 2.5 years (Dupras et al. 2001). Adult female nitrogen values of +18‰ were reached by children at 3 years (Dupras et al. 2001).

Carbon values indicated enrichment after 0.5 years with a peak of -17.8‰ at 1.5 years (Dupras et al. 2001). By 3.5 years all individuals had depleted values between adult males (-18.8‰) and adult females (-19.1‰) (Dupras et al. 2001). This enrichment is unusual given that typical breastfeeding infants are depleted in carbon values relative to their mothers (Dupras et al. 2001). Assuming a 5‰ spacing between diet and collagen, the authors claim the enrichment of carbon values is likely related to the incorporation of goat or cow milk as a supplementary food during weaning (Dupras et al. 2001). Both animals are known to have elevated carbon values of $-15.4 \pm 0.4\text{‰}$ which is 2.6‰ enriched relative other animals (-18‰) likely as a result of a millet (C₄ plant) based diet (Dupras et al. 2001).

The authors suggest that more than half of an infant's diet during weaning may have consisted of cow and goat milk (Dupras et al. 2001). The assertion of an extended weaning period is supported by historic evidence and the claim of milk based weaning foods is supported by evidence of nutritional deficiencies in juveniles (Dupras et al. 2001). Follow up studies employing a simulated longitudinal approach examining dentition have largely supported these findings (Dupras and Tocheri 2007). Analysis of collagen and enamel nitrogen and carbon supports assertions of weaning being completed by 3 years and partially addresses the issues of mortality bias in the sample under investigation (Dupras and Tocheri 2007).

Environment

The effects of environment on isotope values in the Dakhleh Oasis have also been examined. Such work has examined samples from Kellis 1, Kellis 2, and ein-Tirghi and found average nitrogen values from human bone collagen of +18‰, +18‰, and +17‰ respectively (Schwarcz et al. 1999). Given a rainfall in the Dakhleh Oasis of 0.7mm, a humidity of less than 50%, and a temperature of between 21.5 and 39 ° C these values fall along a quasi-linear relationship between nitrogen and rainfall defined by Heaton et al. (1986) (Schwarcz et al. 1999). The nitrogen enrichment between diet and humans remains 3‰ suggesting reinforcing the assertion that the effects of aridity are acquired by humans from the environment through consumption of animal and plant protein (Schwarcz et al. 1999).

Some have suggested that such enriched ^{15}N values are related to excretion of excess ^{15}N depleted urea as a result of water stress (Ambrose and DeNiro 1981; Schwarcz et al. 1999) or lower protein content of available foods (Sealy et al. 1987). However, the magnitude of the +15‰ enrichment in the Dakhleh Oasis samples would require a loss of 95% of the nitrogen within an organism if the effect was a result solely of physiology (Schwarcz et al. 1999). Furthermore, the constant availability of water from aquifers would limit water stress (Schwarcz et al. 1999). Therefore, Schwarcz et al. (1999) suggest that the enrichment of plants is related to the evaporative loss of ammonia in the soil resulting in an enrichment of soil nitrogen values (Schwarcz et al. 1999). In addition, desert soils tend to have poor nitrogen content leading to a lack of fractionation when incorporated by plants. The enriched nature of a small amount of available nitrogen leads to an enrichment in nitrogen values in plants which is passed through the food chain to animals and humans (Schwarcz et al. 1999). These effects could have been

emphasized by the addition of animal waste fertilizers which tend to be enriched in ^{15}N (Schwarcz et al. 1999).

As such, many plants display nitrogen values within a range of +12.0 to 19.0‰. These values are especially unusual as they are close to humans and higher than some animals. This could be related to sampling plants not consumed by animals or the effects of diagenesis. It could, however, also be a result of the lack of fractionation during the initial incorporation from the environment by plants and normal fractionation at later stages (Schwarcz et al. 1999).

Migration

Stable oxygen isotope values from bone apatite in conjunction with nitrogen values from collagen have been examined from samples in Kellis 2 to analyze mobility and variation in origins (Dupras and Schwarcz 2001). The authors suggest migration could be identified from changes in nitrogen values when individuals immigrated into the more arid Dakhleh Oasis with elevated nitrogen values from more humid regions with depleted nitrogen values (Dupras and Schwarcz 2001). A sample of the population presented a mean nitrogen values of $17.9 \pm 1.1\text{‰}$ (Dupras and Schwarcz 2001). Depleted nitrogen values and more enriched oxygen values relative to the overall sample mean were found in two males (Dupras and Schwarcz 2001). One of these individuals, individual 116 displayed nitrogen values of +14.5‰, which is similar to the Nile Valley (+9.2‰ to +15.1‰) (Dupras and Schwarcz 2001). This individual also represented a unique maternal lineage in the area as interpreted from his mtDNA sequence (Parr et al. 1998). Skeletal characteristics consistent with leprosy were identified as well. Given that pathological bone associated with osteomyelitis often results in enriched nitrogen values, the depleted values represented by this individual indicate that he was consuming food from a dramatically different

food chain, and likely from a different area (Katzenberg and Lovell 1999; Dupras and Schwarcz 2001).

The average oxygen value for the Kellis sample was +28.2‰ (Dupras and Schwarcz 2001). Individual 116 presented oxygen values 2 standard deviations above the mean at +33.0‰ which is similar to values reported for Nile Valley Dynastic sites (+31.0± 1.0‰) (Dupras and Schwarcz 2001). The findings of individuals with anomalous nitrogen and oxygen values suggests that adult males were the group most likely to migrate between the Dakhleh Oasis and the Nile Valley (Dupras and Schwarcz 2001).

Multiple Tissues

Many stable isotopic analyses from the Kellis 2 cemetery involves the examination of multiple human tissues to provide information about growth and individual life histories. One such study examined tissue spacing in subadults (Norris 2012). In this study, carbon values from hair, nail, skin, and bone collagen were analyzed from 52 juveniles. Each of these tissues forms at a different rate and so may reflect different periods of an individual's life. The results revealed that individuals between 11 and 15 years of age experienced significantly different spacing between bone collagen and skin, bone collagen and nail, and bone collagen and hair in relation to other age groups. The author suggests that this could indicate a unique biological or social process, such as growth, affecting the tissues within these individuals (Norris 2012).

Another study examining multiple tissues sought to create life-histories for 15 individuals through the analysis of stable carbon and nitrogen values from tooth dentin, bone collagen, hair, nail, skin, and gut content (Johns 2012). The investigation of multiple tissues with differing turnover rates allowed the analysis of diet as well as health, in terms of metabolic stress affecting nitrogen stores, at different stages in each individual's life. She found some changes in nitrogen

values as the individuals neared death and relative consistency in carbon values. Furthermore, no discernable differences between males, females, or juveniles were observed for carbon or nitrogen values (Johns 2012).

Seasonality of Death

Stable isotope analysis from the Kellis 2 cemetery has also been used to examine seasonality of death. Williams (2008) investigated solar alignment of graves to suggest a pattern of seasonal mortality in which peak mortality was reached in March-April and was minimal between October- December. Williams (2008) claims that this pattern could be related to seasonal sandstorms, extreme temperature variation, food shortages, or cycles of infectious disease. Furthermore, a comparison with findings from the analysis of subadult remains revealed a maximum in births in April and a minimum in December suggesting a maximum period of conception in August. This period is associated with Egyptian fertility festivals suggesting the retention of traditional Egyptian rituals into the Roman and Christian periods (Williams et al. 2012).

Analysis of stable isotope values from hair was also able to reveal seasonal variations in diet. Findings indicate an enrichment in $\delta^{13}\text{C}$ during peaks of harvest for C_4 plants and where grain stores would have been depleted (Williams 2008). In contrast, $\delta^{13}\text{C}$ was depleted during the harvest period of C_3 plants when those plants would be most plentiful (Williams 2008).

Summary

The analysis of stable carbon and nitrogen isotope ratios from bone collagen is complex and presents multiple limitations. However, if examined carefully, carbon provides detailed information about diet, especially in regards to plant consumption and nitrogen reveals information about meat consumption and metabolic stress not available from other sources. The

past bioarchaeological research in the Dakhleh Oasis has provided expansive and comprehensive data on the lives of the inhabitants of Kellis in the past. This work highlights the excellent resources and preservation at the site. The stable isotopic analysis has provided a baseline of stable carbon and nitrogen values for comparison with the current study. However, a gap continues to exist in the understanding of consumption patterns in the population especially in relation to social identity. As such, this work will build off of previous work by analyzing the similarities and differences in stable isotope values between sex, age, and status groups.

CHAPTER 3: APPROACHES TO AGE, SEX, AND GENDER IN THE ARCHAEOLOGICAL PAST

Introduction

This investigation of differences in the Kellis 2 cemetery sample will rely primarily on stable isotope analysis as a proxy for life experiences that may be influenced by diet, environment, and health. As such, it is necessary to explore the ways in which social identities can be manifested in and interpreted from the human skeleton, and specifically in bone chemistry. Social identity is understood as the role of individuals in society as perceived by themselves and others in relation to particular contexts and bodies (Sofaer 2006a). Age, sex, gender, and status, are key themes that will be examined as explanations for the variability present in the sample.

The analysis of the human skeleton in archaeological contexts is a key piece of evidence in the reconstruction of life in the past. Because of the wide range of interpretations that may be drawn from such material, numerous theoretical frameworks have been applied to its study. This is especially true in the case of the recently problematized topics of age, sex, and gender. These themes may relate to biological features but are social defined. Specifically, age has been analyzed as a socially contingent process, sex has been conceived of as physical differences between bodies, and gender has been interpreted as a social role developed from numerous features including age and sex (Sofaer 2006a). These features both influence and are influenced by an individual's experience and identity. By framing the human skeleton as a product of lived experiences, each of these categories can be manifested in the skeleton and be interpreted from it to understand how social identity is shaped in the past.

Food consumption and access to resources are key features of individual experience that can be analyzed from the skeleton, especially in relation to age, sex, gender, and status (Gumerman 1997). Consumption choices and access to food resources are influenced by broad social patterns which can create and reflect individual and group identities. These patterns in diet can be examined through stable isotope analysis. Past work has explored the topics of age, sex, gender, and status through such methods (Ericson et al. 1989; Privat and O'Connell 2002; White 2005; Bentley et al. 2005, 2007; Halcrow and Tayles 2008; White et al. 2001). In light of the limited but encouraging bioarchaeological research in age, sex, gender, and status in ancient Egypt, this approach will be used to examine a sample from the Dakhleh Oasis in Egypt. The examination of varying theoretical and methodological approaches to age, sex, and gender from human skeletons in the past will provide a foundation to explore the variability in the Kellis 2 cemetery samples in ways that are biologically and socially meaningful for the ancient population of Kellis and Roman Egypt more broadly.

Materiality of the Body

The human skeleton has been variably conceived of as a “cumulative product of life-history experiences” (Agarwal 2012: 331), as “a biological and social product” (Sofaer 2011: 286), and “a cultural concept and a lived reality” (Geller 2008: 114). It is a product of biological as well as cultural factors including status, power, gender, and age (Agarwal 2012). However, it has also been noted that these experiences do not interact in straightforward and simplistic fashions, specifically, “sociocultural influences on the body are not layered on top of the primary influences of sex and age” (Agarwal 2012: 331). Rather, the human skeleton is situated at the heart of a series of complex networks including age, sex, social status, predispositions, space, and time (Sofaer 2006a). According to Sofaer (2006a), “different kinds of bodies learn different

things and act in different ways at different points in the lifecourse” (136). These practices can leave traces on the skeleton and so changes in the skeleton can reveal real changes in life (Sofaer 2006a; Holliman 2011). Furthermore, because each individual skeleton is a product of experiences shaped by larger social structures, they must be analyzed from multiple angles within the context wider social groups and patterns (Sofaer 2006a).

Bioarchaeology examines the skeleton within these contexts and investigates the relationship between bone biology, behavior, and environment (Agarwal 2012). It has also been approached as a “way of dealing with differences between bodies by providing categories that can be investigated in terms of their social relevance in the past” (Sofaer 2006: 97). Recent developments in the field have focused on exploring the full range of complexity in the relationship between biological categories identified from bone and social experiences, especially in terms of age and sex (Knudson and Stojanowski 2008; Holliman 2011). These advancements have required a critical reflection on the bias of the researcher in order to limit the effects on the past (Conkey and Spector 1984). Specifically, research has drawn attention to the predominance of biomedical ‘bodyscapes’ in the modern West and cautioned against its application to the past because of the risk of naturalizing modern Western notions about sex, age, and gender in the past (Geller 2009). It is, therefore, necessary to closely examine the concepts of age, sex, and gender as they relate to the human skeleton before such topics may be investigated.

Age

Age classifications have traditionally been a starting point for broader interpretations without being critically examined (Sofaer 2011). However, recent research has emphasized the importance of cultural context in the description of age categories, as ageing is a complex social

and biological process (Sofaer 2006a; Halcrow and Tayles 2008). Although great advancements in identifying age categories have been made through the use of mortuary artifacts, historic evidence, and ethnographic data, it is important to explore this topic with the human skeleton as the main point of reference (Halcrow and Tayles 2008).

Age is a multifaceted process that can be understood as including chronological age based on calendar time, physiological age determined by development progress, and social age which depends on cultural expectations (Gowland 2006; Sofaer 2006a; Halcrow and Tayles 2008). These different categories do not equate with one another, but they interact and are influenced by other social factors including social, economic, or political status as well as gender (Sofaer 2006a; Knudson and Stojanowski 2008). Sofaer claims “bodies emerge through the life-course and modifications to the skeleton as well as mental developments” (2006a: 133). As such, how individuals are perceived in relation to their own changing bodies, in part, determines their experience (Sofaer 2006a). At the same time, experience can affect a body and leave marks of social and physiological changes (Gowland 2006; Sofaer 2011).

Analysis of age in the past is further complicated by the inaccuracy of most chronological age estimations when relying primarily on the identification of broad categories of biological changes in skeletal remains (Roksandic and Armstrong 2011; Sofaer 2011; Agarwal 2012). The calculation of age is often dependent on the “assumption that the investigation of age is about essential or intrinsic categories which can also be identified in the past” (Sofaer 2006a: 127). However, markers of development may differ between populations for a number of physiological and health related reasons and may also be influenced by culture (Gowland 2006).

The investigation of old age, in particular is fraught with difficulties. Although this is partially a result of the complications in estimating chronological age of older skeletons, it is also

because of the imposition of Western notions of age and ageing as well as a lack of focus on the oldest members of society in archaeological and bioarchaeological research (Appleby 2010). Ageing is an important biological and social process in every society and the lack of research on it leaves gaps in the reconstruction of identity, social change, and plasticity (Appleby 2010). In Western- industrialized societies old age is pathologized and even infantilized with the elderly being removed from productive social roles (Appleby 2010). Furthermore, Western conceptions of old age are tied solely to chronological age. Other cultures may exalt or deride their elderly and define old age based on different factors including physical changes, mental capabilities, and accumulated wisdom (Appleby 2010). It is true that in all societies ageing is associated with biological changes that leave individuals more susceptibility to illness and injury and less physically capable (Appleby 2010). However, the identity of these individuals is tied to other social features such as gender, socioeconomic status, kinship, religion and many others (Appleby 2010). Therefore, their position in society varies considerably and is difficult to access with high status not always equating with economic security or vice versa (Appleby 2010).

Because of the many factors that can affect ageing and age classification, age categories, their importance, and how they are represented can vary greatly between groups (Gowland 2006). Furthermore, given the numerous, changing variables involved, age is better understood if contextualized as a gradual biological and behavioral process along with other experiences (Sofaer 2006a; Knudson and Stojanowski 2008; Appleby 2010). Categorization risks creating artificial age cohorts, which cannot truly be known from archaeological contexts, assumes similarity of experiences, and focuses on differences between groups instead of individual experience (Gowland 2006; Roksandic and Armstrong 2011). However, age categories are often a necessary starting point for examining patterns associated with age and ageing. When age

categories must be employed, they should be meaningful to the population being analyzed and the research question being explored, and not try not to reproduce the cultural bias of the researcher (Halcrow and Tayles 2008; Sofaer 2011). Furthermore, these classifications should be flexible and amenable to alteration as the data requires. Unfortunately, the significance of age and categories is unknown for many past societies. As such, multiple lines of evidence, including mortuary data or stable isotope values, must be analyzed to examine changes and their relevance as they may have implications for broader social patterns (Sofaer 2011).

Despite the limitations inherent to assigning individuals to arbitrary age categories, this study will categorize individuals into age groups to provide a starting point for the following statistical analysis. However, the complexity of age as a social category will be accommodated by employing age classification systems that differ in breadth and are based on chronological age, physiological age, and social age which will be discussed in greater detail in the following chapter. This comparison may provide a window into the significance of particular groupings and the differences between them without prioritizing chronological age, especially in the identification of an elderly cohort. Furthermore, the investigation of old age will not rely on pathological conditions but instead on evidence of changing social and biological conditions over time.

Sex

The classification of sex based on biological differences has been employed as a foundation on which to build interpretations about social organization (Geller 2009). Sex has been defined as physiological differences originating at conception and growing through development to fulfill differing reproductive roles (Armélagos 1998). However, the act of sex estimation is a cultural one, which may impose Western conceptions of two sexes onto the past

and obscure other categories of difference (Claassen 1992; Holliman 2011; Agarwal 2012). As such, it is important not to equate these classifications with meaning, especially in relation to gender and particularly in the case of juveniles (Geller 2008; Agarwal 2012). This is especially true because “people do not see each other as genes but as bodies in the world” (Sofaer 2006a: 92). Affording prominence to sex classification may obscure other forms of variation or artificially homogenize the experience of disparate groups (Agarwal 2012).

The presentation of sexual differences as strictly dimorphic, static, equated with social experience, and of preeminent importance in the past, is flawed (Geller 2008; 2009). However, socially meaningful variations in lived experiences resulting from differing physiology do exist (Sofaer 2006a). For example, females tend to exhibit greater immunity to most infectious disease because of the buffering actions of hormones but are faced with different risks in the form of direct and indirect dangers of pregnancy (Armelagos 1998; Ortner 1998). Furthermore, sex may have social implications because of its association with reproduction, health, and its visibility (Sofaer 2006a). As such, “sex functions as a norm, [and] produces the bodies that it governs” (Butler 1993: 1).

However, sexual dimorphism can vary between populations, a small proportion of individuals do not fit into a binary system of classification, and the reflection of physiological sex can change throughout the life course (Gowland 2006; Sofaer 2006a; 2006b). For example, females cannot biologically or socially maintain their role as reproducers throughout their life with the occurrence of menopause. Therefore, while pre- and post-menopausal women may fulfill differing biological and consequently, social roles, men do not have the same biological restrictions (Geller 2008; 2009). As such, “we cannot homogenize or dichotomize males and females” (Geller 2008: 124).

Therefore, while sex classification may prioritize particular kinds of difference, it affords one approach with which to explore biological and social differences between people (Geller 2008). This approach can only be applied if the division is justified by other forms of evidence such as ethnographic sources or statistical analysis (Agarwal 2012). If sex classifications, especially those relying on binary systems of classification, are assumed to be the preeminent factor in social classification, other, social meaningful, differences between bodies that are not associated with sex may be obscured (Geller 2009). If two sex categories must be employed to facilitate analysis, findings must be interpreted cautiously, and other categories of difference must be examined at the same time, with the same rigor.

In this study a binary sex classification will be explored with statistical analysis. If statistical analysis identifies significant differences between the categories indicative of meaningful biological and social division, sex will continue to be examined as an important social division. If such analysis fails to reveal any variations, sex will not be analyzed as a significant, binary social category.

Gender

The definition and identification of gender, especially in past populations, has been, and continues to be a contentious topic in Anthropology. Despite the difficulties inherent to describing this complex and nuanced subject, the gender dynamics of human populations are important organizing structures in societies as they aid in the construction of individual and group social identities (Conkey and Spector 1984). As such, the exploration of gender in the past is a necessary endeavor that may have implications for the understanding of other social structures.

Gender has been described as a culturally specific social classification or “a reflection of what the social system believes to be a biological reality” (Armelagos 1998: 2). Gender can refer to social group, individual identity, or behavioral role and is one factor employed to construct identity along with other features including age, class, ethnicity, race, social status, and others (Conkey and Spector 1984; Sofaer 2006a; Holliman 2011). As a socially meaningful classification it institutes both expectations and limits on behavior (Conkey and Spector 1984).

The association between gender and sex is a complex one. Historically, researchers have assumed a binary gender system with a conflation of sex and gender. However, a direct association between sex and gender is problematic as some suggest that gendered behavior must be learned (Claassen 1992; Geller 2008; Knudson and Stojanowski 2008). At the same time, a “focus on individuals in terms of embodied subjectivities that is not tied to sex runs the risk that they become free-floating from meaningful social discourse, which works by reference to mutually understood social categories” (Sofaer 2006a: 100). Analysis of the human skeleton as a reference point can work to mediate between these extremes as it embodies sex differences but is also a product of gendered differences in behavior and activity (Sofaer 2006a). However, bioarchaeologists must be wary of imposing assumptions about associations between sex and behavior (Geller 2008; 2009).

Age and gender also interact in complex ways. Gender roles are not static in time. Gender identity is a product of accumulated lived experiences and so expectations of gendered behavior vary throughout the life course (Sofaer 2006a; Geller 2008; Holliman 2011; Agarwal 2012). The examination of these changes can indicate when particular gendered behaviors or categories were introduced (Halcrow and Tayles 2008).

Analyses of gender in the past by archaeologists has often focused on the material culture surrounding the body including artifacts, epigraphy, and architecture while largely ignoring the body itself (Nelson and Rosen-Ayalen 2002; Sofaer 2006a). Some even claim that gender in the past can only be accessed in these ways (Claassen 1992). Such an approach limits the influence of biological determinism but fails to recognize that the “skeletal body is socially constructed – gendered actions produce gendered bodies- but this is in the most fundamental *material* way” (Sofaer 2006b: 162). According to Armelagos (1998) “behavior practices that reflect gender expectations may have biological outcomes” (Armelagos 1998: 2). Additionally, Sofaer claims, “gender as a social institution impacts the body” (2006a: 113).

Gender influences the body as a result of performativity or “reiterative and citational practice by which discourse produces the effect that it names” (Butler 1993: 2). For example, gendered differences in behavior may lead to differential exposure to pathogens while disparate access to food may result in patterns of malnutrition which can alter disease susceptibility (Ortner 1998). Gender can be interpreted from the skeleton in other ways including traces of cultural practices such as foot binding, skeletal markers of activity indicating division of labor or occupational specialization, tooth wear, biomechanical variations, mortality, trauma, and stable isotopes (Sofaer 2006a; Holliman 2011). Gender classifications may rely, in part, on physiology but also influence the body through behavior and so can be interpreted from the skeleton if considered in relation to biological sex (Armelagos 1998; Sofaer 2006b). Therefore, bioarchaeology is situated to identify different gendered experiences especially when groups or individuals do not conform to binary differences based on sex (Holliman 2011).

For the purpose of this study gender will be defined as a social category tied to sex and age. Gender is tied to sex, but assuming binary genders associated with physical sex is overly

simplistic. As such, this study will examine gender as though it is a social category grounded in sex that can change over the life course by examining subgroups within each biological sex group. Therefore, statistical analysis will be employed to examine differences between the sexes over the life course. It will be understood that if meaningful differences exist, this may represent distinct social categories that may be related to gender.

Status

An individual's social identity is also defined in part by their status. Status refers to an individual's position in society (Price and Feinman 2010). The differences between individuals and groups of variable statuses results in social inequality (Price and Feinman 2010). Therefore, in a complex, hierarchical society, individuals of differing statuses exist which can lead to "unequal access to goods, information, decision making, and power" between them (Price and Feinman 2010: 2). The determination of one's social position however, is a complex process and relies not just on socioeconomic position but also age, gender, kinship, occupation, and many others (Price and Feinman 2010). The degree and consequences differs dramatically between societies as well, with complex states displaying the greatest degree of inequality (Danforth 1999).

Status may be identified archaeologically from differences in the value of material remains, including those associated with mortuary contexts (Le Bras-Goude et al. 2011). Those with more and finer materials to be used as grave goods or in the construction of mortuary structures are assumed to have greater access to resources, and therefore, higher social status (Richards et al. 1998; Le Bras-Goude et al. 2011). Additionally, because status can have a direct influence on access to resources for individuals and groups, it can have real consequences in the skeleton. This can lead to nutritional stress, growth interruptions, and other health risks that can

be identified osteologically (Sofaer 2006a). Alternatively, status can influence an individual's procurement and consumption of particular foodstuffs, which may be identifiable from stable isotope values.

In this study, status will be defined as differences in access to resources due to social position. Mortuary treatment and stable isotope values will be investigated. However, it will be necessary to identify such patterns in multiple data sets in order to validate claims of social status differentiation. Therefore differences in mortuary treatment will be compared to evidence of diet and health from stable carbon and nitrogen values to examine patterns of access across the site. Statistically analysis will be employed to determine if the differences in stable isotope values between groups is significant.

Examination of diet as a proxy for identity

Social identities are closely tied to patterns of consumption and access to resources. In complex societies, differential access to power, wealth, and goods directly influence food systems (Gumerman 1997). Consumption patterns are therefore intertwined in larger political, economic, environmental, and social structures and help to define and maintain social identities (Gumerman 1997; White et al. 2001).

Practically, "in complex societies individuals from distinct, economic, gender, or age groups often consume different foods because of various economic, political, and ideological factors" (Gumerman 1997: 105). Furthermore, food holds a social message which differs between and within cultures but is associated with cost, access, social value, symbolism, ecology, environment, and nutrition (Gumerman 1997; Jansen 1997; White et al. 2001; Cuellar 2013). As such, food is a marker of identity in as much as it is linked to status, gender, geographic origin, and other social categories (White et al. 2001; Ambrose et al. 2003; Cuellar

2013). Therefore, dietary patterns may partially reflect social inequalities in a society, although the relationship is a complex one, and can have direct implications for nutrition and health (Ambrose et al. 2003).

In addition to differential access to foodstuffs, public and private food consumption is also a socially determined and symbolic performance (Gumerman 1997; Jansen 1997; White et al. 2001; Cuellar 2013). Both the food consumed and the context of consumption identifies and differentiates group and individual identities (Gumerman 1997; Jansen 1997; Mintz and Du Bois 2002). “A meal... is an event that develops and maintains affiliations among participants and non-participants” (Gumerman 1997: 106). Even the order of serving can determine the quality and quantity of resources available for each individual (Jansen 1997). These patterns influence and reproduce notions of identity (Jansen 1997; Mintz and Du Bois 2002).

Patterns of food consumption and production can actively create and reproduce status differences. In certain instances, status may determine access to resources (Gumerman 1997). Conversely, status related activities may expose different groups to different foodstuffs (Gumerman 1997). Additionally, particular foodstuffs may attain their value because of association with particular groups and may be consumed because of preference (Cuellar 2013). In other instances, access to food may be influenced by its value as determined by cost of production (Cuellar 2013).

Diet patterns can also be influenced by sex or gender. “Food helps to draw lines between men and women, and masculinity and femininity in different ways” (Jansen 1997: 88). Dietary differences between males and females may relate to a division of labor, dietary needs, and access (White et al. 2001). Gender relations may be responsible for distribution of resources both within and without the household as a result of division of labor within the family or gender

specific feasting and fasting events (Gumerman 1997; Flynn 1999; Mintz and Du Bois 2002). For example, in some areas of the ancient Andes in South America males are associated with higher maize consumption, especially in the form of chicha beer (Cuellar 2013). However, gendered relations are also intertwined with status, ethnicity, age, sex, marriage status and many other factors which may also influence consumption patterns (Flynn 1999; Mintz and Du Bois 2002).

Stable isotope analysis offers a unique window into diet in the past as it provides direct evidence of consumption of an individual not available from other sources (Gumerman 1997; Ambrose et al. 2003). Such data can be examined in aggregate to investigate patterns between groups such as those distinguished by status, gender, or age (Gumerman 1997). Analyses can also shed light on individual diet which can be used to understand finer-grained patterns of consumption (White et al. 2001). However, in understanding the role of food and diet in identity formation, stable isotopic analysis contains a number of limitations. Firstly, in many instances it is not the food item necessarily that holds value but the recipe, meal structure, or social context (Gumerman 1997). Furthermore, stable isotope analysis cannot determine why a particular foodstuff was preferred especially in the cases where traditionally low status foods have become associated with group identities (Gumerman 1997). Lastly, in the case of market economies, much of the variability in access to foodstuffs may be diminished (Gumerman 1997). As such, close examination coupled with investigation of other forms of evidence when possible are key to creating appropriate interpretations.

Examination of age, sex, gender, and status through stable isotope analysis

Despite the limitations inherent to the study of diet in the past, especially through stable isotope analysis, productive investigations have been carried out. In these instances, stable

isotope values have been interpreted in the context of age, sex, gender, and status to draw conclusions about social groupings as well as individual and group identity. Such studies provide a foundation from which to build a robust investigation of age, sex, gender, and status identities from stable isotope values as a proxy for diet.

Application of stable isotope analysis to questions of age

In the absence of other markers of the social significance of age such as mortuary artifacts, age groups have been explored through stable isotope analysis as a proxy for diet and health. Privat and O'Connell (2002) analyzed carbon and nitrogen in bone samples from Berinsfield, Oxfordshire. Variation in nitrogen values between males younger and older than 30 years of age was significant where older males displayed elevated values. They suggest that this variation was related to status differences between younger and older males (Privat and O'Connell 2002). In another examination of age differences, Halcrow and Tayles (2008) hypothesized that the identification of migration through stable isotope analysis could be associated with moving to a new area and starting a family. This life event, they suggest, represented the start of a new age stage (Halcrow and Tayles 2008).

White et al. (2001) examined stable nitrogen values from a Maya population from Altun Ha. They found that individuals younger than five years exhibited enriched nitrogen values indicative of breastfeeding. This could indicate that breastfeeding ceased by 5 years of age suggesting the commencement of a new age stage at the time of that dietary change (White et al. 2001). Age has also been examined in relation to sex, with Reed (1999) finding an increase in C_3 plants among older women (35 to 50 years) from the Late Classic Period at Copan, suggestive of alteration in social behavior at the time.

The research on diet and health differences across the life course from stable isotope analysis is limited. Despite the paucity of previous work, the success of the studies indicates the validity of the use of stable isotope analysis to identify differences according to age. However, further examination of the social consequences and implications of such changes has been inadequate. This study will examine patterns in stable isotope values across adulthood to explore changing social and biological status throughout the life course.

Application of stable isotope analysis to questions of sex

Examinations of differences between stable isotope values have also been applied to the investigation of binary sex groups. Ericson et al. (1989), found that males on the North Coast of Peru exhibited a more varied diet than females. They suggest this may be related to males eating on the job away from home, while females pooled their food. However, they could not rule out the effects of a gendered division of food, or the effects of food preference (Ericson et al. 1989). White et al. (2001) identified greater C₄ plant consumption among males at Altun Ha although nitrogen values between males and females were similar. The authors suggest the values could indicate more animal protein fed on C₄ plants but that the differences cannot be associated with either unequal status or simply a division of labor (White et al. 2001).

Research has shown that the identification of sex differences from stable isotopic analysis is possible. Furthermore, these authors are careful not to suggest how these differences may relate to gender. This study will adopt a similar approach in investigating stable isotopic values in relation to sex without equating those differences to gender.

Application of stable isotope analysis to questions of gender

Stable isotope analysis has also been employed in the analysis of topics relating to gender. In these cases, sex has been used a starting point from which to draw inferences about gendered behavior where differences do exist. White (2005) analyzed dietary differences between males and females of differing social classes among the Maya. She emphasized that the value of food is dependent both on rarity and belief and determined that, among higher status groups, females consumed less valuable meat resources than men. This gendered division in dietary practice could relate to differences in activities that brought men and women in regular contact with differing foodstuffs, the use of food to establish differences between gendered groups, or differences in the status of gendered groups resulting in differential access to resources (White 2005).

Bentley et al. (2005, 2007) examined patterns of mobility to identify gendered groups in Thailand. They assumed that patterns of residence or migration could provide insight into changing social roles. Through the analysis of strontium, oxygen, and carbon from tooth enamel, they determined that males displayed more variable isotopic signatures than females. This could suggest that subadult males had access to a greater variety of resources than subadult females, or that males were migrating from other regions. The differences in strontium values between males and females further supported the assertion that males were migrants from coastal areas. They suggest that this pattern may correlate with a shift to matrilocality and changing gender relations coinciding with the adoption of agriculture (Bentley et al. 2005, 2007).

The examination of gender from stable isotopic analysis has been overly simplistic. Much of this work has claimed gender as the social reality of sex. However, this work has failed to recognize that gendered behavior and expectations vary throughout life, and that gender is not

static (Sofaer 2006a; Geller 2008; Holliman 2011; Agarwal 2012). As such, although sex differences may be socially meaningful, the static nature of these differences thereby negates the possibility that they represent gendered variation. This paper will address this limitation by examining gender as a social category tied to sex but also to age. By seeking differences within sex groups the exploration of gender can be more fruitful than if it were to rely solely on the differences between sex groups.

Application of stable isotope analysis to questions of status

Social status is equated with differences in access to resources, including dietary foodstuffs. Because of the utility of stable isotopic analysis in revealing patterns in diet, it has been employed extensively in the investigation of status differences. However, the stable isotopic findings were always compared to evidence from other archaeological sources, usually grave goods or mortuary architecture.

Ambrose et al. (2003) applied such an approach to examine stable carbon and nitrogen from bone collagen and apatite between groups with different amounts of grave goods in Mound 72 from Cahokia. They found that those groups with the largest amounts of grave also exhibited the most elevated nitrogen isotope values, which they suggested indicated greater meat consumption and would be consistent with higher status (Ambrose et al. 2003).

Similarly, Le Huray and Schutkowski (2005) found elevated nitrogen isotope values among males buried with iron weaponry at Kutná Hora-Karlov, a Late Iron period site in Bohemia. They also suggest a difference in dietary patterns based on the status of a “warrior” group (Le Huray and Schutkowski 2005).

Differences in stable nitrogen isotope values were also reported by Richards et al. (1998) at the Poundbury Camp Cemetery site. They claimed elevated nitrogen isotope values of

individuals interred in masolea could reflect the consumption of a more Roman style diet associated with higher status (Richard et al. 1998).

Le Bra-Goude et al. (2011) also found status differences in nitrogen isotope values between those in chamber graves and in pits at a Middle Neolithic site in France. They suggest those in chamber pits were higher status because of an increase in terrestrial protein consumption.

Some studies have examined status from a more nuanced perspective. Linderholm et al. (2008) found no difference in the stable isotope values of individuals from the high status chamber burials and low status inhumations in the Birka Cemetery, a Viking site in Sweden. However, a closer study revealed a pattern of elevated nitrogen values among a group of individuals interred with weapons (Linderholm et al. 2008).

In contrast to the trend in associating elevated nitrogen values and high status, Privat et al. (2002) identified depleted nitrogen values of a group of individual buried with weapons in an Anglo-Saxon cemetery in Berinsfield. They claim this could indicate the consumption of freshwater animals or pork (Privat et al. 2002).

Although most research has associated elevated nitrogen values with higher status, it is clear that any assertion of status from stable isotope values need to be made with a thorough understanding of dietary items available as well as other markers of status. This study will follow the well-established approach suggested by these past researchers in comparing tomb architecture with stable isotope values, especially nitrogen values to identify differences in social status across the cemetery.

Examination of age, sex, and gender in Egypt

The examination of age, sex, and gender in ancient Egypt through the lens of bioarchaeology has been surprisingly limited. Most studies have focused on textual or epigraphic sources (Bagnall 1996). Much of the research on age has focused on the youngest individuals while the studies of sex and gender have relied heavily on artifacts. The minimal research that has been completed, however, emphasizes the value of such analysis and the rich potential of such investigation.

Examination of age in ancient Egypt

Most information about age and ageing in Roman Egypt comes from classical literary sources. From these it is suggested that adulthood for males began around age 14 when they were considered liable for taxation (Montserrat 1996). Literary sources suggest that young people in Roman Egypt, primarily slaves, between the ages of 12 and 13 years were most likely to begin an apprenticeship or be sold into an occupation (Rowlandson 1998). The most common areas for apprenticeship included weaving and textile production although nail making, flute playing, metallurgy, and building were also possible (Bradley 1991). The period of apprenticeships can vary from six months to six years (Bradley 1991). Additionally, young adolescent males were identified as unique from children and adults. These individuals range from 13 years old to early 20s and are associated with a lack of or minimal facial hair (Montserrat 1996). This suggests that these ages represent a significant stage in the life course of these individuals. The initiation of a new age stage could introduce biological and possibly isotopic differences which may persist into adulthood given the long rate of bone turnover.

Furthermore, women could be married as early as 16 or 17 years and most were married by their mid-20s while males were often married beginning in their mid-20s (Montserrat 1996).

Following marriage, evidence suggests that a woman could reproduce for 25 years or more, into her 40s with one child born every three years (Montserrat 1996). The early age of first pregnancy, in combination with multiple pregnancies, may indicate a unique biological experience for this group that could be identifiable from stable isotope values.

Research into the mortuary contexts of individuals interred in the Kellis 2 cemetery found that adults 51+ years and infants and young children were most often associated with red clay. Furthermore, of the 18 individuals buried in tomb structures, 10 are children although this more likely a result of the use of these tombs by family groups (Wheeler 2009). Ceramic vessels are the only burial good included with the oldest adults (51+ years) (Wheeler 2009). Adults receive botanical remains twice as often as infants but the existence of tomb structure of coffin does not differ between adults and children (Wheeler 2009). Although patterns in mortuary treatment are present in relation to age, it is difficult to interpret the meanings of such variation.

In the bioarchaeological examination of age differences in ancient Egypt, and specifically at the Dakhleh Oasis, most work has focused on variation between adults and juveniles. In Kellis, adult individuals have been divided according social and biological phases to produce 6 stages (16-21 years, 22-35 years, 36-50 years, 51-59 years, and 60+ years) (Williams 2008). Juveniles have been divided into early childhood (less than 2 years), late childhood (2-5 years), and juvenile (5-15 years) (Dupras 1999). Stable carbon and nitrogen analysis of bone collagen found differences between children younger than 2 years and all other groups, with infants enriched in carbon and nitrogen values indicating a period of breastfeeding and weaning. Even with the added analysis of hair, nail, skin, and gut content, no significant differences were found between adult age categories, except for juveniles under the age of 3 being enriched in nitrogen and carbon (Williams 2008). However, bone collagen was only available for 13 males and 10

females and while the hair was available from the most individuals, only 42 males, and 47 females were represented (Williams 2008).

Significant research has been carried out at Kellis on juveniles and infants. In examining changes over the life course, Wheeler (2009) identified an increase in fractures between younger and older juveniles suggesting behavioral differences between the groups (Wheeler 2009). Dupras et al. (2001) and Dupras and Tocheri (2007) identified significant differences in diet in children 6 months to 3 years. This period was thought to reflect a biologically and socially relevant weaning period which could suggest a socially meaningful age stage.

In the examination of age from a different perspective, Zaki (2009) analyzed bone density across the life course in a sample from an Old Kingdom cemetery at Giza. She classified age in 10 year categories and found a peak bone mass in women around 30-35 years with a decline a few years later. She suggested that the subsequent osteoporosis between the ages of 45 to 70 years is indicative of postmenopausal bone loss, although she failed to draw any conclusions about the social implications of these changes (Zaki 2009).

Investigation of osteoarthritis in the knee in a sample from the Kellis 2 cemetery, indicates a strong correlation with age. Females tend to experience osteoarthritic changes earlier than males although changes among males tend to be more severe. However, age seems to be the main determining factor for the development of such changes with greatest frequency of changes observed by 46 years old (Robin 2011).

Despite the value of the research that has been done, the investigation of age and ageing, especially through bioarchaeology, in ancient Egypt is limited. What work has been conducted has focused on a dichotomy between adults and juveniles. The bioarchaeological research that has been carried out on the elderly has only focused on pathological conditions, thereby limiting

this important sector of the population to a one defined by disability or illness. Even literary sources fail to discuss the experiences of the oldest members of society. This study recognizes, and seeks to address the need for further research on the elderly in Egypt and the investigation of age differences among adults in bioarchaeology. Additionally, the identification of an elderly cohort will rely not on pathological conditions as has been the case in much past work, but instead on changes in biological or social experiences represented through stable isotope values.

Examination of sex in ancient Egypt

Literary sources from ancient Egypt suggest the existence of a male dominated bureaucracy with entrenched gender inequality leaving females, especially unmarried females in a disadvantaged role (Robins 1993). In most classical texts, women were depicted as the weaker sex, unable to control their sexuality, passions, and desires (Montserrat 1996). Despite its association with fertility, menstruation was often viewed as an illness and could limit a woman's activities (Montserrat 1996). Women were primarily responsible for household activities including grinding grain and weaving but could also own land and farm small plots as well as sell their surplus (Robins 1993). However, given that much of the information about women's roles originates from male scribes, it is difficult to truly infer the social role of females in this society (Robins 1993). As such, while it seems that "there was an ideal division of labor based on gender which limited the types of work a woman could do, but which was much less restrictive with regard to men" (Robins 1993: 126) it is unclear how these attitudes manifested in practice. This is especially complicated when considering that status was the main social division with sex playing a secondary role (Robins 1993).

Under Greek and Roman rule, the social value of women decreased in Egypt. Women were still able to own and sell land, lease property, seek employment for competitive wages,

assistant in agricultural management, collect rent, own livestock, petition government officials, make loans, and foreclose on loans (Rowlandson 1998). Weaving was also still a primarily female task carried out by female slaves (Rowlandson 1998). The task of running households, preparing food, baking bread, and collecting water also fell to women (Rowlandson 1998). However, a clear preference for males, and especially male infants was obvious with female children occasionally being left out in the open to die of exposure or be taken in as slaves (Rowlandson 1998). Furthermore, women's sexuality was often feared because of its ability to influence and control men (Rowlandson 1998). Therefore, while females were considered inferior to men, they were not passive players and did have social and legal power in society (Rowlandson 1998).

Investigation of mortuary treatment in the Kellis 2 cemetery indicates that females are associated with red clay almost twice as often as with males, with a distribution most similar to juveniles. Adult males are more often found with tomb substructures and grave goods than females or juveniles. Botanical remains, for example are present three times as often in the burials of males than of females or juveniles (Wheeler 2009). The difference in mortuary treatment could indicate a social division between these groups in the Kellis 2 cemetery.

Research from the Dakhleh Oasis suggests males are enriched in carbon values as compared to females with males presenting carbon values of -18.8‰ and females of -19.0‰ (Dupras 1999). Significant differences in carbon values were also noted in skin and hair (Williams 2008). In light of these values, males may have consumed approximately 18.2% C₄ plants while females only consumed 16.3% C₄ plants. These values also support the assertion that males may have consumed more C₄ fed animal protein (Dupras 1999). No significant differences between nitrogen values was reported with males exhibiting values of +17.8‰ and

females presenting +18‰ suggesting that the differences in animal protein consumption were not great (Dupras 1999).

Much of the work examining sex from ancient Egypt has come from literary sources and so fails to uncover the reality of these categories in the life of the population. Although mortuary archaeology and bioarchaeology has taken steps to examine these issues, an understanding of biological and social consequences of such categorization is necessary, and will be explored in this study.

Examination of gender in ancient Egypt

Literary sources from Roman Egypt stress the importance of masculinity and its association with physical abilities. For example, during rituals of induction for young males, a number of social groups which could be indicative of gendered divisions are attested. These include boys, beardless youths, and a third category comprised of those young males physically unable to compete in physical games or who were aesthetically unattractive (Montserrat 1996). Masculinity was also tied to physical appearance such as facial hair and practices surrounding it, such as shaving (Montserrat 1996). Men and masculinity are associated with action and dominance whereas women and femininity are seen as passive (Montserrat 1996).

Some researchers have explored the nature and implications of gender in Ancient Egypt from mortuary contexts. Meskell (1999) examined differences in grave goods between male and female burials in the Deir el Medina cemetery from the 18th Dynasty through the Greco Roman Period. She interpreted males gaining higher status and greater wealth during the 18th dynasty based on the quality of their grave goods. She also identifies unique burial treatments of some females which she suggests may represent differential status of unmarried or divorced women. During the 19th and 20th centuries at Deir el Medina, the value of grave goods were interpreted to

suggest that women accrued more wealth even into the Greco Roman Period, but that inequality remained. Meskell (1999) notes however, that in less wealthy cemeteries inequalities in grave goods were not as visible. As such, she claims that the primary social divide was along lines of wealth and status and that gender was secondary.

Except for the limited mentions of gendered differences from literary sources, little is known about the reality of gender in ancient Egypt. Mortuary archaeology holds promise for elucidating these patterns, but has not been carried out extensively or with an eye to teasing out other social factors including sex and age. This study will complicate gender in an attempt to identify different in experience indicative of gendered social groups.

Examination of status in ancient Egypt

In addition to the examination of status by Meskell (1999) described above, deeply engrained status differences in Roman Egypt are well attested from literary and archaeological sources. Slaves are a common feature in ancient Egypt and are seen as nothing more than physical bodies, separated from free bodies and spoken about in derogatory and objectifying terms (Montserrat 1996). Clear class divisions also exist between the poor and rich and the city and village and limit access to resources including material wealth and education (Montserrat 1996).

At the settlement of Kellis, similar class divisions certainly existed. The population was comprised of Roman administrators, religious officials, laborers, and slaves each occupying a different social tier (Bowen 2001; 2002). The quality and types of household architecture differed dramatically, reinforcing class distinctions (Bowen et al. 2005). Differences in the qualities of mortuary treatment are attested in the Kellis 1 cemetery and could be indicative of differences in socioeconomic status (Aufderheide et al. 1999). However, in the Kellis 2

cemetery, a predilection for Christian style burials devoid of elaborate grave goods, limits the information available about status differences between individuals in the cemetery.

The highly stratified nature of ancient Egypt is well known. However, the biological consequences of this disparity have not been thoroughly examined bioarchaeologically. This study will investigate the realities of differential access to resources by examining differences in diet and health in relation to markers of wealth.

Summary

This study applies stable isotope analysis to explore patterns of diet and health at Kellis, Dakhleh Oasis Egypt to elucidate patterns in social identity. Past bioarchaeological work has employed such an approach to the examination of age, sex and gender with great success (Privat and O'Connell 2002; White 2005; Bentley et al. 2005, 2007). Furthermore, age, sex, and gender differences have been found previously in Egypt (Dupras 1999; Meskell 1999; Williams 2008; Zaki 2009). However, few studies have examined gender as it changes over the life course in relation to age. Additionally, minimal work in Egypt has applied stable isotope analysis to questions of sex and gender differences and the analysis of age has focused predominately on the youngest segments of society. This study will fill this gap by examining the association between sex and age through a focus on adult individuals.

This approach is underpinned by the theoretical understanding that the skeleton is the product of lived experiences that can be read from the bones, or in this case, isotopic values (Sofaer 2006a). Age-related differences will be examined simultaneously with sex and independently of it. In the examination of age differences, individuals will be assigned to age groups based on chronological ages which will be understood as representing physiological age. Such categorization will allow comparison within the group and facilitate statistical analysis

although it is understood that comparison with other samples might be limited (Roksandic and Armstrong 2011). Because of the difficulties in determining the social relevance of age categories in the past, a number of different classification schemes will be employed and results compared (Gowland 2006).

Biological differences between two primary sexes are accepted here, although they will not be given prominence over other forms of difference between skeletons (Geller 2008). Gender groups refer to subgroups within the population that are socially defined on the basis of a number of features including, in part, sex and age. These categories will only be explored as meaningful where statistical analysis suggests they might be visible from the data under analysis. In an attempt to not homogenize the experiences of individuals within the same arbitrary categories, outliers will be closely examined. Through the investigation of traces of behavior through stable isotope analysis, this study will examine patterns of difference in lived behavior between groups and over the life course in Kellis.

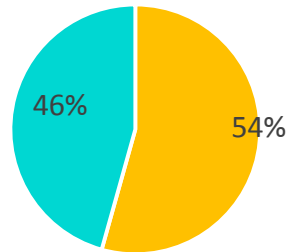
CHAPTER 4: MATERIALS AND METHODS

The analysis of stable isotopic values from bone collagen was carried out on bone samples from Kellis, Egypt. Individuals from the Kellis 2 cemetery dating to the Romano-Christian period in Kellis were chosen for study. These materials were obtained courtesy of Dr. Tosha Dupras and the Dakhleh Oasis Project in Egypt.

Stable isotope values were analyzed for 138 individuals. Samples included both rib and femora fragments. Ten samples were prepared by the author at the University of Central Florida. Twenty five samples were prepared and analyzed by T. Dupras (1999) at McMaster University, and the remaining samples were prepared at the University of Central Florida (Figure 5).

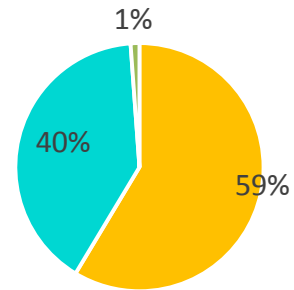
The sample consisted of 63 males and 75 females. Individuals were excavated from variable parts of the cemetery and consisted of adults of both sexes that were complete enough to be reliably and accurately sexed through morphological techniques. Age and sex were estimated by the Dakhleh Oasis Project Bioarchaeology Team using standard methods outlined in Buikstra and Ubelaker (1994). Adults were defined as those individuals older than 15 years on the basis of the social transition to adulthood around this time in ancient Egypt (Wheeler 2009). The balance of males and females is representative of the cemetery thus far ensures reliable results in statistical analysis (Figure 5). The age distribution is also consistent with that of the Kellis 2 cemetery overall and indicates that the findings could be applicable to the total sample (Figure 6). Additionally, the collection of samples from across the cemetery ensures the analysis of variable status and kin groups and the inclusion of only adults ensures the accuracy of sex estimation.

Distribution of Males and Females in Study Sample



Female Male

Distribution of Males and Females in Kellis 2 sample



Female Male Unknown

Figure 5: Distribution of males and females in the sample under analysis in this study and in the Kellis 2 cemetery excavated as of 2011 (Dupras et al. 2016).

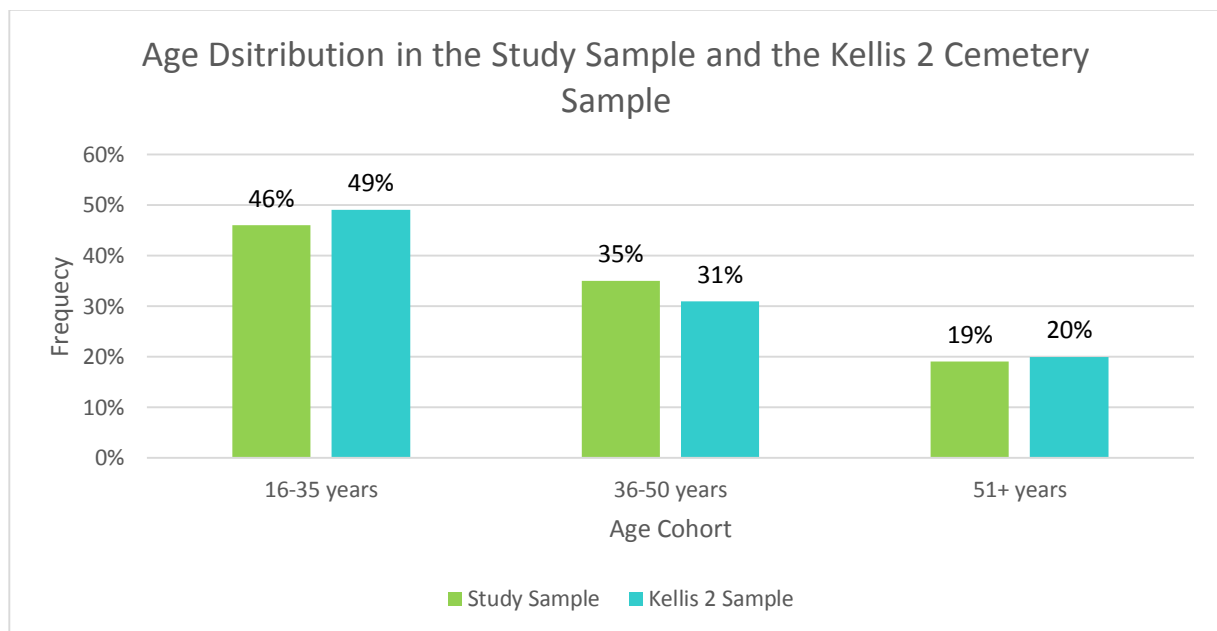


Figure 6: Comparison of age distribution between the study sample and the total sample excavated from the Kellis 2 cemetery as of 2011 (Dupras et al. 2016).

Age Classifications

A number of different age classifications were employed to determine which provided the most refined and nuanced results (Table 3). These categories are not true cohorts as the relationship between these individuals in life is unknown. As such, it is not possible to determine

if these individuals were born at the same time or progressed through life stages together (Gowland 2006). However, these groups do provide a cross-sectional perspective on experience at different stages throughout the life course at the site.

The first system of classification was adopted from Williams (2008) and defined categories on the basis of biological and social processes to delineate six different stages or groups (Figure 7). A three group classification was also tested following approaches proposed by Mays (1998) which suggested three classifications of young adult, middle adult, and post-menopausal/ old adult (Figure 8). A simplistic two group model was employed and adapted from Privat and O'Connell (2002) with groups defined on the basis of less than or greater than 35 years (Figure 9). The last system of classification is based solely on chronological age, was employed by Zaki (2009), and divides the life course into 10 year stages (Figure 10). The most applicable classification scheme for this sample will be determined by the amount of variation revealed by each system.

Table 3: Description of the differing age classification schemes employed and compared in the following analysis.

	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Cohort 6
Social Classification	16 -21 years	22-35 years	36-50 years	51-59 years	60+ years	
3 Group Classification	16-35 years	36-50 years	51+ years			
2 group Classification	16-35 years	36+ years				
10 year increments	10-20 years	21-30 years	31-40 years	41-50 years	51-60 years	61+ years

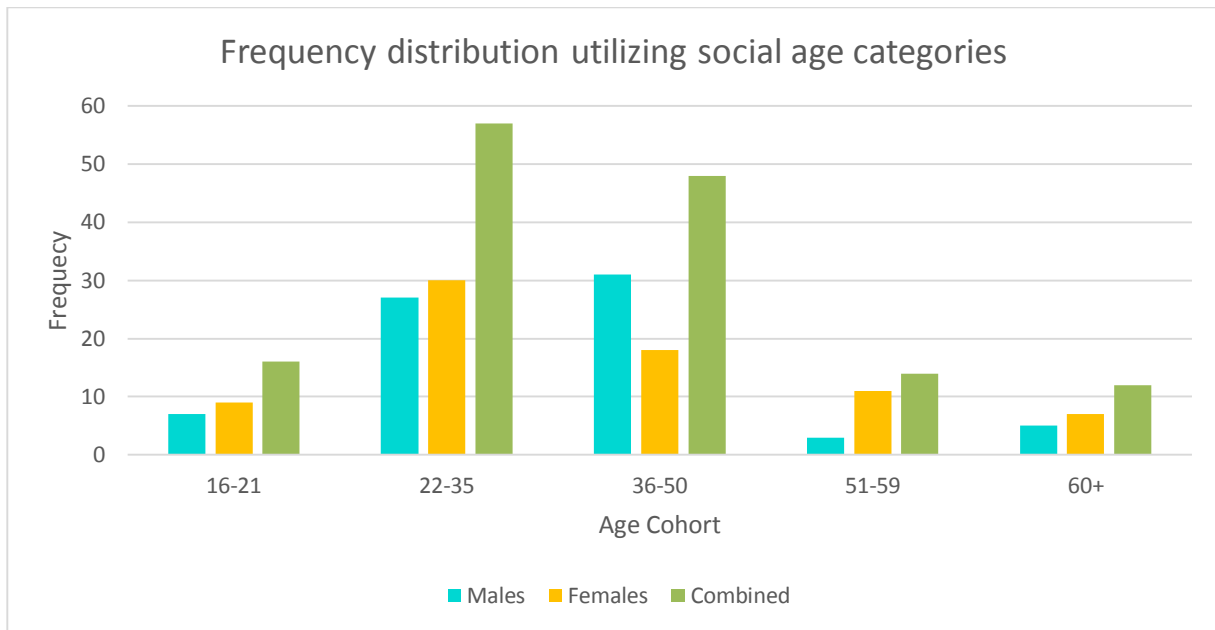


Figure 7: Distribution of the sample when employing the social age categories described above.

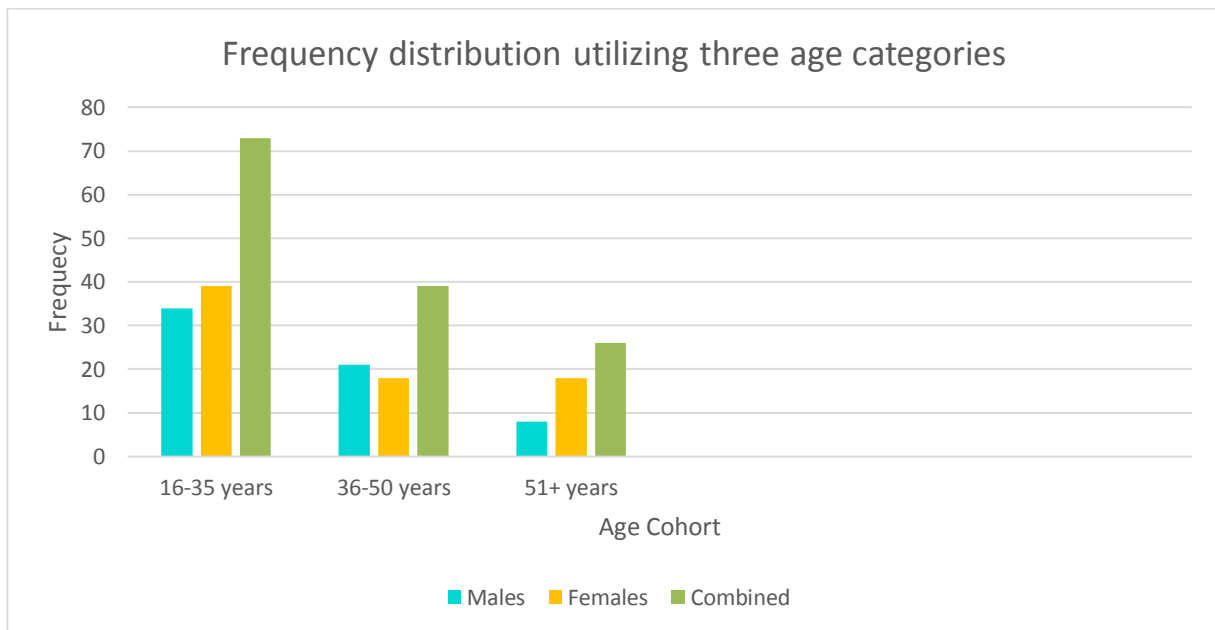


Figure 8: Distribution of the sample when employing 3 age categories.

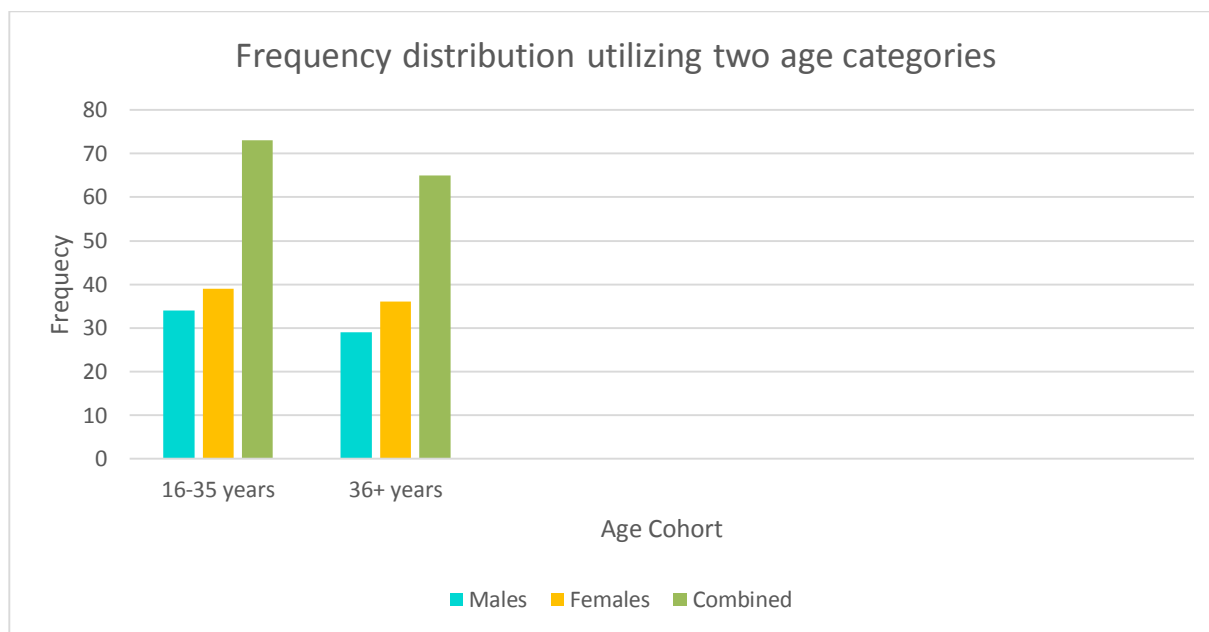


Figure 9: Distribution of the sample when dividing into categories of less than or greater than 35 years.

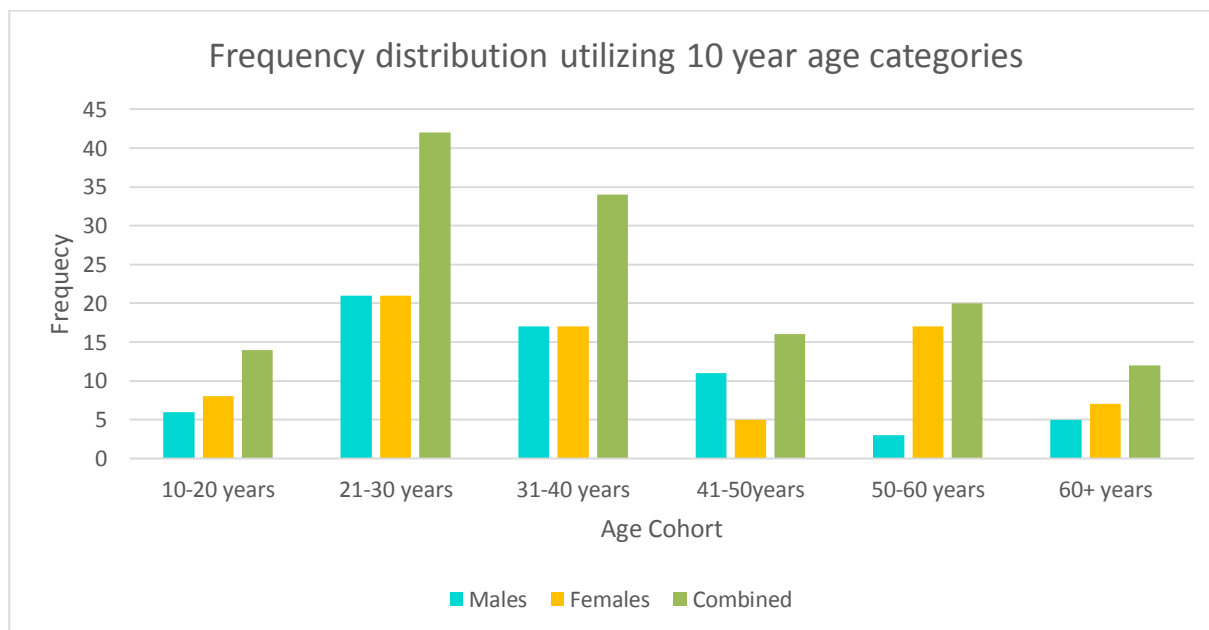


Figure 10: Distribution of the sample when employing 10 year age categories.

Collagen Preparation

Methods for collagen extraction were modified from those outlined by Ambrose and Norr (1993), Hedges et al. (2007); Katzenberg (1989), Longin (1971), and Chisholm et al. (1982). The

10 samples analyzed by the author were prepared at the University of Central Florida and analyzed at the Northern Arizona University Colorado Plateau Stable Isotope Laboratory. The 25 samples prepared and examined by Dr. Tosha Dupras (Dupras 1999) were analyzed at McMaster University by a SIRA mass spectrometer with a precision of 0.08 ± 0.09 ‰ for carbon. The ratios of carbon to nitrogen were analyzed by a Carlo-Erba C,N analyzer (Dupras 1999). The remainder were prepared at the University of Central Florida and analyzed at McMaster University or the Northern Arizona University Colorado Plateau Stable Isotope Laboratory.

The 10 samples by the author and the others analyzed at the University of Central Florida were prepared with the following protocol. They were brushed to remove loose dirt and placed in de-ionized water in a sonicator repeatedly until the water remained clear. After cleaning, the samples were placed in an oven at 60° C overnight to dry. The bone was broken into small, consistent pieces using a mortar and pestle and 1 to 3 grams were weighed out and placed in a 50 mL plastic centrifuge tubes.

The samples were rinsed once with a 2:1 chloroform: methanol solution and dried overnight. The samples were then placed in .5M HCl, agitated, and left overnight. The next day the samples were centrifuged, the acid removed, and new acid added. This process continued until all mineral was dissolved and the bone was soft.

The samples were then washed three times in de-ionized water. After removing the water, the vials were filled with .1M sodium hydroxide (NaOH) up to the 20 mL mark. The tubes were agitated and left to sit for 20 minutes, then centrifuged and the liquid removed. The process continued until the solution was no longer brown or black. A number of washes were then carried out to return the solution to neutral pH and one final wash in .25HCl was done to leave the sample slightly acidic (pH between 2.5 and 3).

At UCF the samples were placed in an oven at 90° C overnight and then transferred to a pre-weighed and labelled glass 2 dram vial. The 2 dram vials were placed back in the oven at 90° C until the sample was dry.

The dry gelatin was then scraped with a dental pick and 0.54 to 0.60 mg were transferred to tin cups and sent for analysis to the Northern Arizona University Colorado Plateau Stable Isotope Laboratory and were analyzed with a Thermo-Electron DELTA V Advantage Isotope Ratio Mass Spectrometer (EA-IRMS) which was configured through a CONFLO II along with a Carlo Erba NC2100 Elemental Analyzer. The instrument has a reported accuracy of $\pm 0.06\%$ for carbon and $\pm 0.06\%$ for nitrogen and in practice exhibited an accuracy of $\pm 0.08\%$ for carbon and $\pm 0.05\%$ for nitrogen.

Collagen yields were not available for all samples. As such, C:N ratios employed to determine the preservation of the samples. In addition to C:N ratios, %C and %N values were analyzed for each sample. Of the 138 samples chosen for further analysis, the collagen C:N ratio was 2.7- 3.5. Although this is slightly outside of the range 2.9-3.6 suggesting good preservation, those with low C:N ratios still exhibited %C values between 26 -44% and %N values between 11-16% (Van Klinken 1999). Those samples that exhibited C:N ratios outside of this acceptable range as well as %C or %N values outside of acceptable ranges, were excluded from further analysis (Figure 11). Of the 176 adult bone collagen samples available for analysis, 138 exhibited appropriate C:N ratios and C and %N values. Of the 39 individuals excluded 16 were female and 22 were male.

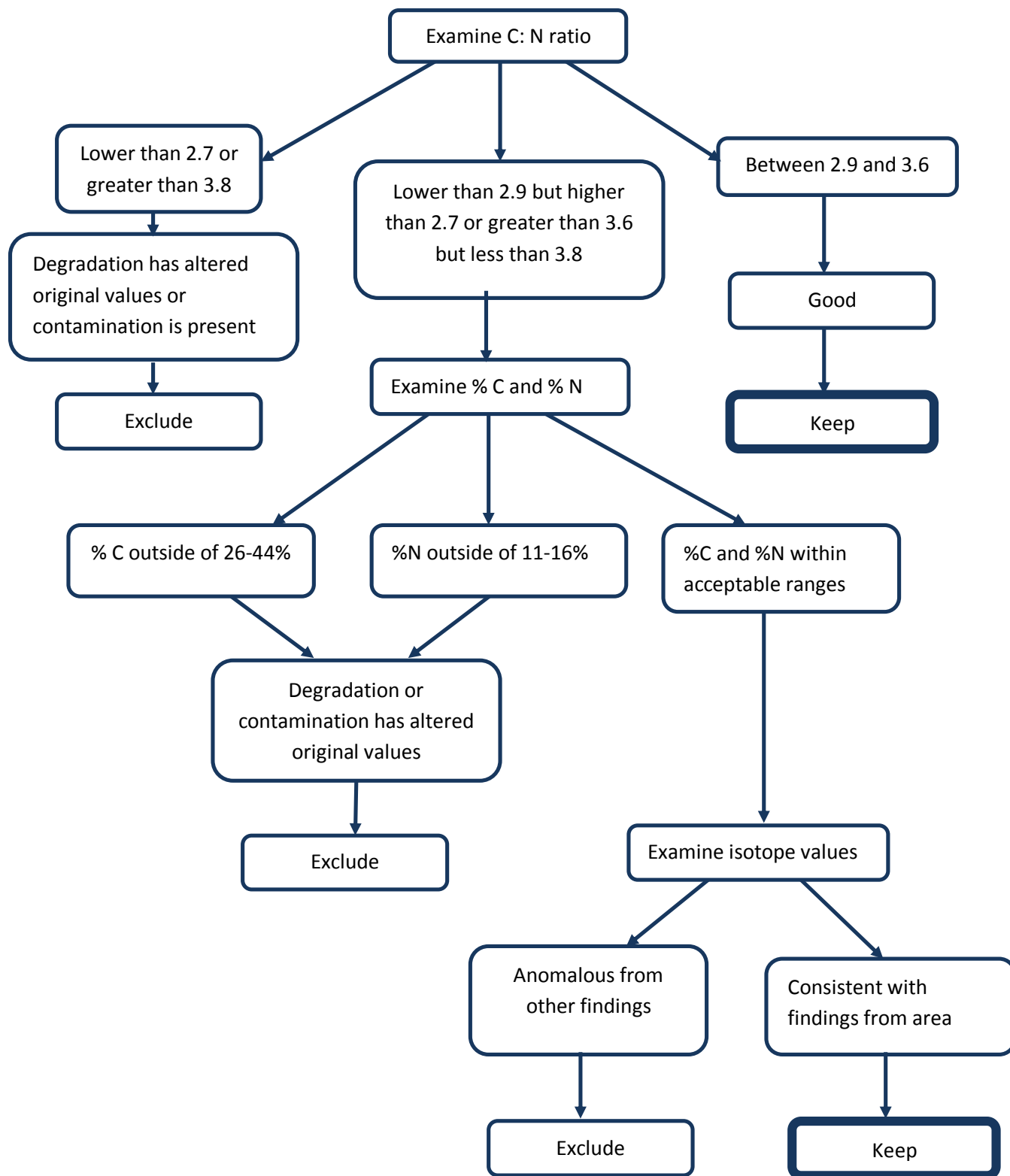


Figure 11: Sequence of steps required to exclude or keep stable isotope values in this study.

Statistical Analysis

All statistical analyses were carried out using SPSS © program software and Microsoft Excel ©. Mean, range, and standard deviations were calculated for the sample as a whole as well as for males and females using SPSS. Box and whisker plots were also created in SPSS to examine range, variance, and outliers within the sample. The mean values for age cohorts were calculated with Microsoft Excel. The associations between carbon and nitrogen values and age, sex, or age and sex were examined with a one- way analysis of variance (ANOVA) in SPSS. ANOVA analyses examine the significance of the difference between the means and variance of different samples. The calculated F values were considered significant at the 0.05 level, and very significant at the 0.01 level.

Dependent variables included age, sex, and age and sex. In the analysis of age, a number of different age classification systems were employed, because the significance of age or the nature of age groupings in this ancient population was not known. As such, a number of different methods were employed to divide the age categories so that the most nuanced and significant results could be revealed and the most meaningful age classification system identified. Point estimates for age were calculated by determining the mean of the age estimation. Individuals were then placed within larger groupings based on age to facilitate statistical analysis.

Four different age classification systems were tested, and each was labeled on a nominal scale between 1 and 2, 1 and 3, 1 and 5, or 1 and 6 (see Table 1). For the purpose of initial analysis, sex was coded as a binary, nominal variable with 1 indicating females, and 0 indicating male. Age and sex were examined by assigning individuals to cohorts on the basis of sex and age with females labelled first, followed by males. For example, when applying 2 age groups, group 1 applied to 16-35 year old females, group 2 indicated 36+ year old females, group 3 indicated

16-35 year old males, and group 4 corresponded to 36+ year old males. The independent variables in this analysis were carbon and nitrogen values from bone collagen which were interval variables.

Summary

This analysis combined stable isotope values of carbon and nitrogen from human bone collagen to create a sample population that could be utilized for statistical analysis to generate meaningful results. The statistical examination of stable isotope values from collagen according to numerous classificatory schemes produced detailed and nuanced data about the sample population. Numerous patterns could be identified from this data to inform an understanding of the lives of the sample population.

CHAPTER 5: RESULTS

General Findings

The total sample exhibited a mean $\delta^{13}\text{C}$ value of -18.8‰ with a range from -21.9‰ to -17.5‰ (Table 4). For a complete list of individual results, see the Appendix. Three outliers were present with more enriched $\delta^{13}\text{C}$ values while two outliers presented less enriched $\delta^{13}\text{C}$ values (Figure 12). The mean $\delta^{15}\text{N}$ value for the sample was $+17.8\text{‰}$ with a range of $+8\text{‰}$ to $+20.5\text{‰}$ (Table 4). Seven outliers were present and all exhibited $\delta^{15}\text{N}$ values significantly lower than the mean value for the total samples. Females presented a mean $\delta^{13}\text{C}$ value of -18.8‰ and $\delta^{15}\text{N}$ value of $+18.1\text{‰}$ while males exhibited a mean $\delta^{13}\text{C}$ value of -18.7‰ and mean $\delta^{15}\text{N}$ value of $+17.5\text{‰}$ (Figure 13 and 14; Table 5 and 6).

Table 4: Descriptive statistics for carbon and nitrogen values for the total population.

	Range (‰)	Minimum (‰)	Maximum (‰)	Mean (‰)	Std. Deviation
$\delta^{13}\text{C}$	4.4	-21.9	-17.5	-18.8	0.449
$\delta^{15}\text{N}$	12.6	+7.9	+20.5	+17.8	1.855

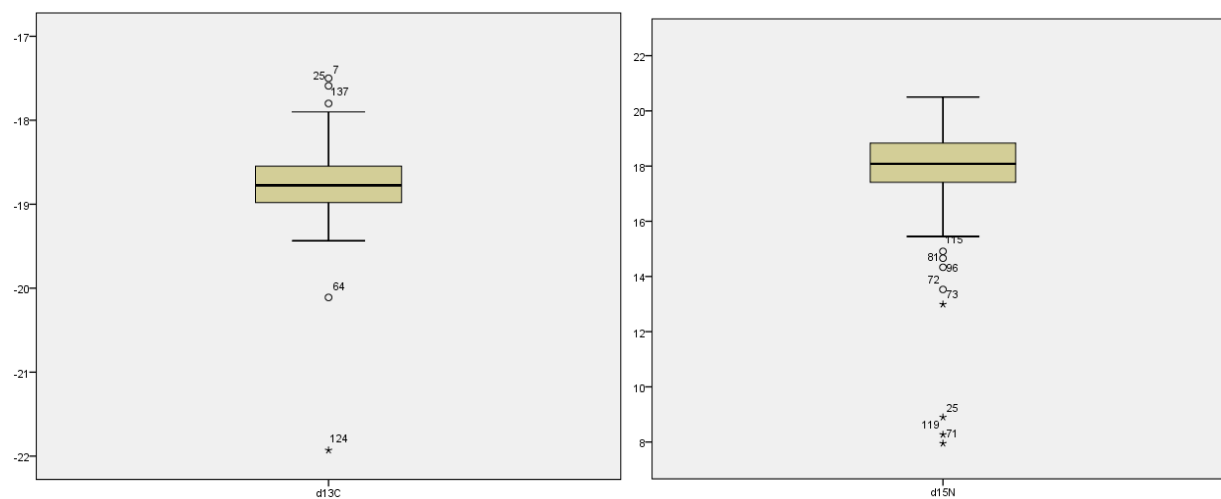


Figure 12: Box and whisker plot depicting the mean and range of $\delta^{13}\text{C}$ (left) and $\delta^{15}\text{N}$ (right) values. A number of outliers are present in each case.

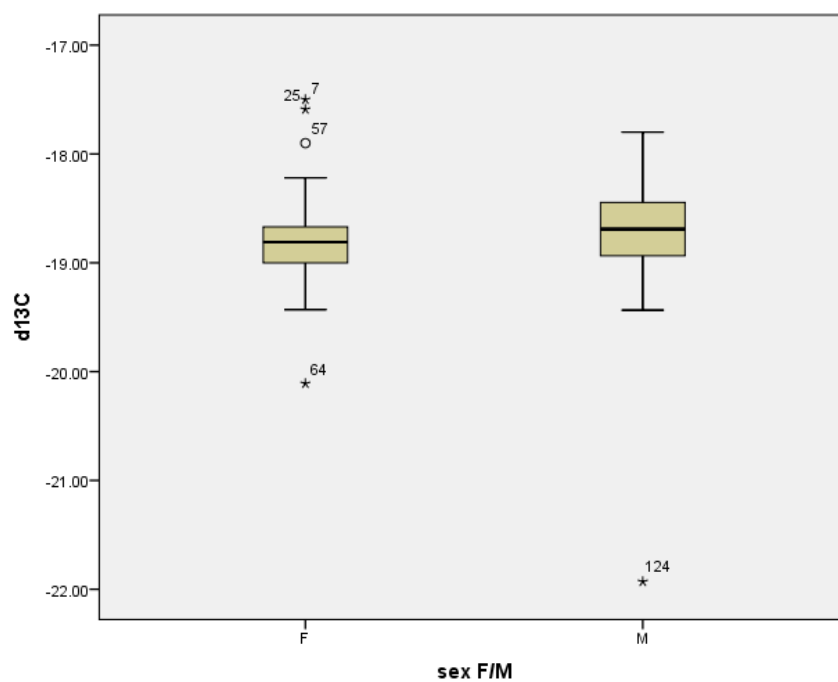


Figure 13: Box and whisker plot indicating the mean and range of the $\delta^{13}\text{C}$ values as well as outliers for females (F) and males (M).

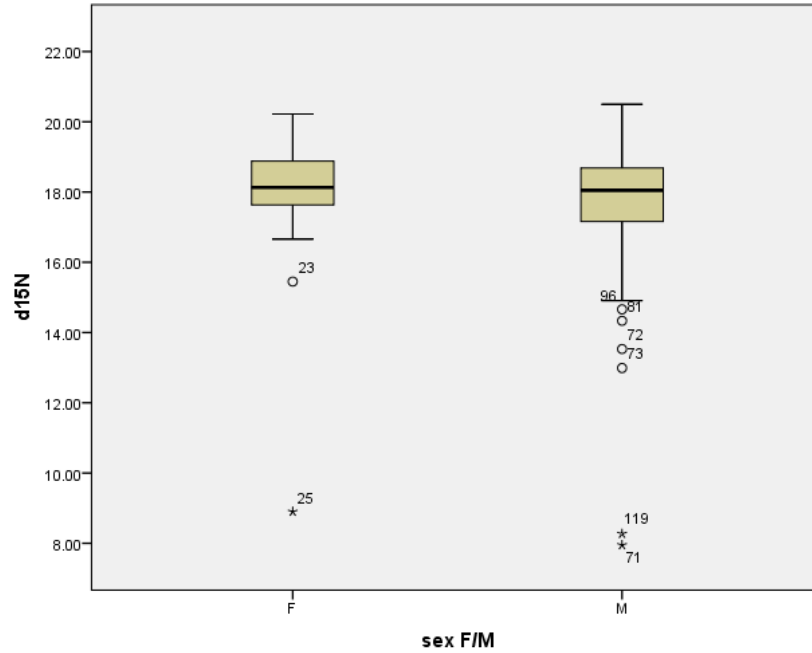


Figure 14: Box and whisker plot indicating the mean and range of the $\delta^{15}\text{N}$ values as well as outliers for females and males.

Table 5: Descriptive statistics for the carbon and nitrogen values for females.

	Range (‰)	Minimum (‰)	Maximum (‰)	Mean (‰)	Std. Deviation
$\delta^{13}\text{C}$	2.6	-20.1	-17.5	-18.8	0.364
$\delta^{15}\text{N}$	11.3	8.9	20.2	18.1	1.418

Table 6: Descriptive statistics for carbon and nitrogen values for males.

	Range (‰)	Minimum (‰)	Maximum (‰)	Mean (‰)	Std. Deviation
$\delta^{13}\text{C}$	4.1	-21.9	-17.8	-18.7	0.531
$\delta^{15}\text{N}$	12.3	7.9	20.5	17.5	2.261

In general males exhibited more variation in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values than females. One female (B267) displayed $\delta^{13}\text{C}$ values one standard deviation outside of the female values, while three females (B082, B320, B411) displayed $\delta^{13}\text{C}$ values outside of the range of two standard deviations around the mean (Figure 13 and 14). Only one male (B379) exhibited $\delta^{13}\text{C}$ values two

standard deviations below the mean for males. One female (B401) exhibited $\delta^{15}\text{N}$ values one standard deviation below the female mean for $\delta^{15}\text{N}$ values and one female (B411) displayed values two standard deviations below. Four males (B286, B274, B116, and B457) displayed values one standard deviation below the mean $\delta^{15}\text{N}$ value for males, and two males fell (B253, B412) outside of two standard deviations of the mean.

Individuals B253, B412, and B411 exhibit suspiciously low nitrogen values. However, the carbon values of these individual are consistent with the range of the sample and C:N ratios as well as the %C and %N are within the normal range for the sample. Despite the lack of clear diagenetic change, these values are nearly impossible given the food available at the site. It should be noted, however, that these individuals are from differing age groups and represent a very small minority of the sample. As such, they are not responsible for the trends observed in the sample and likely resulted from an error and so were not considered in the interpretation of the sample.

Carbon Values

Carbon results indicate no significant differences in mean carbon values between the sexes or between age categories for a two group classification (Table 7 and 8). Furthermore, no significant differences between the means were observed for sex and 10 year increments cohorts or sex and 2 age categories (Table 7). However, a discernable difference was present between groups classified according to age (Table 7 and 8).

Table 7: Differences between mean carbon values for different age and sex categories (*indicate significance below the .05 level; ** indicates significance below the .01 level).

Independent Variable	F value
Sex	1.709
Age (social groups)	2.820*
Age (3 age groups)	3.227*
Age (2 age groups)	1.028
Age (10 year cohorts)	2.808*
Sex and age (Social age cohorts)	1.955*
Sex and age (10 year cohorts)	1.642
Sex and age (3 age groups)	2.367*
Sex and age (2 age groups)	.906

Table 8: Mean $\delta^{13}\text{C}$ values for age groups according to different classification systems.

	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Cohort 6
Social Classification	-18.7‰	-18.7‰	-18.7‰	-18.8‰	-19.2‰	
3 Group Classification	-18.7‰	-18.7‰	-18.9‰			
2 group Classification	-18.7‰	-18.8‰				
10 year increments	-18.7‰	-18.7‰	-18.6‰	-18.7‰	-18.8‰	-19.2‰

A general downward trend in carbon values with values becoming more depleted with age is visible in all of the age classification systems tested (Table 8, Figures 15, 16, 17, 18). Furthermore, significant differences between the mean carbon values for sex and social age and sex and three age categories were observed. Significant differences were also present between

social age categories, three age categories, and 10 year cohorts. All differences were significant at the .05 level.

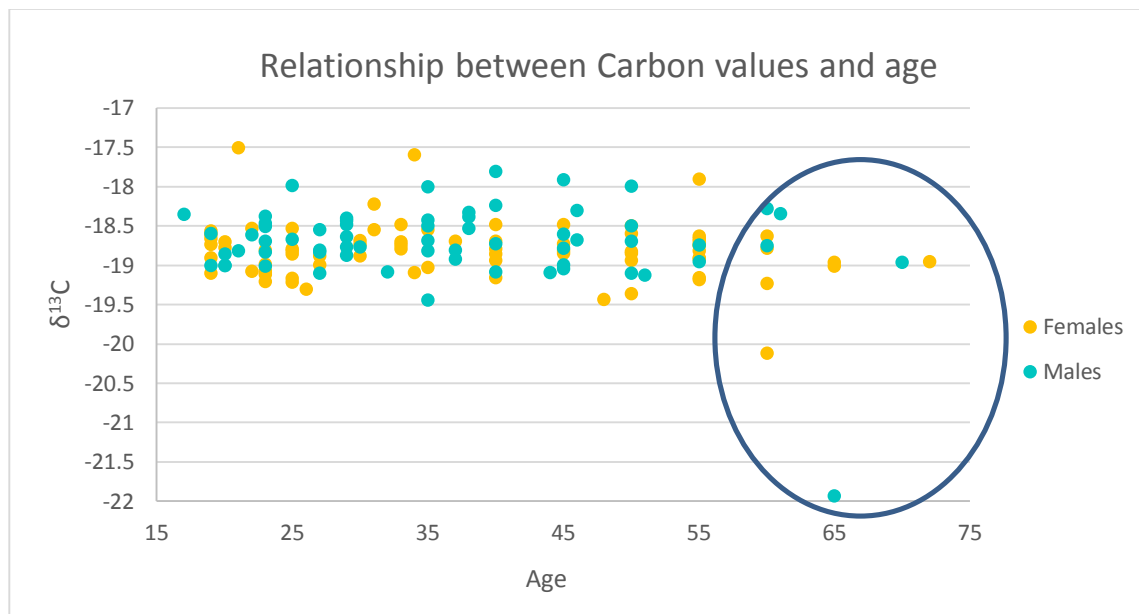


Figure 15: Scatter plot depicting carbon values by sex and age. Note the lack of clear trends in $\delta^{13}\text{C}$ values over age or with sex. Circle indicates distribution of oldest age cohort.

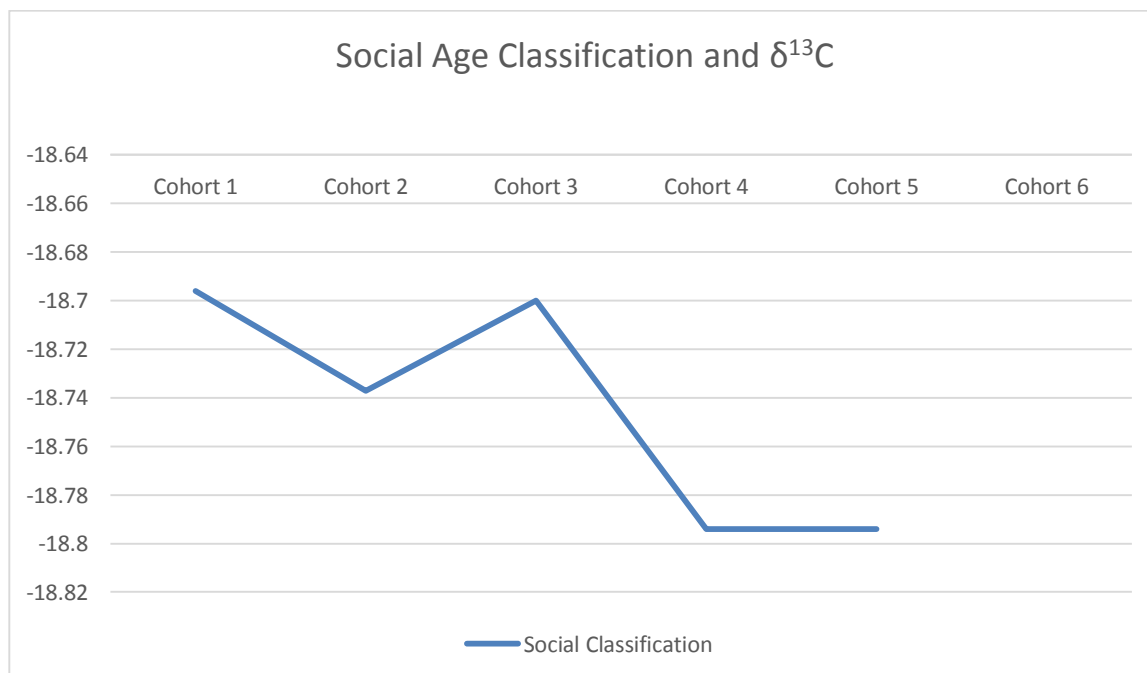


Figure 16: Line graph depicting depletion of $\delta^{13}\text{C}$ as age increases according to social age classification.

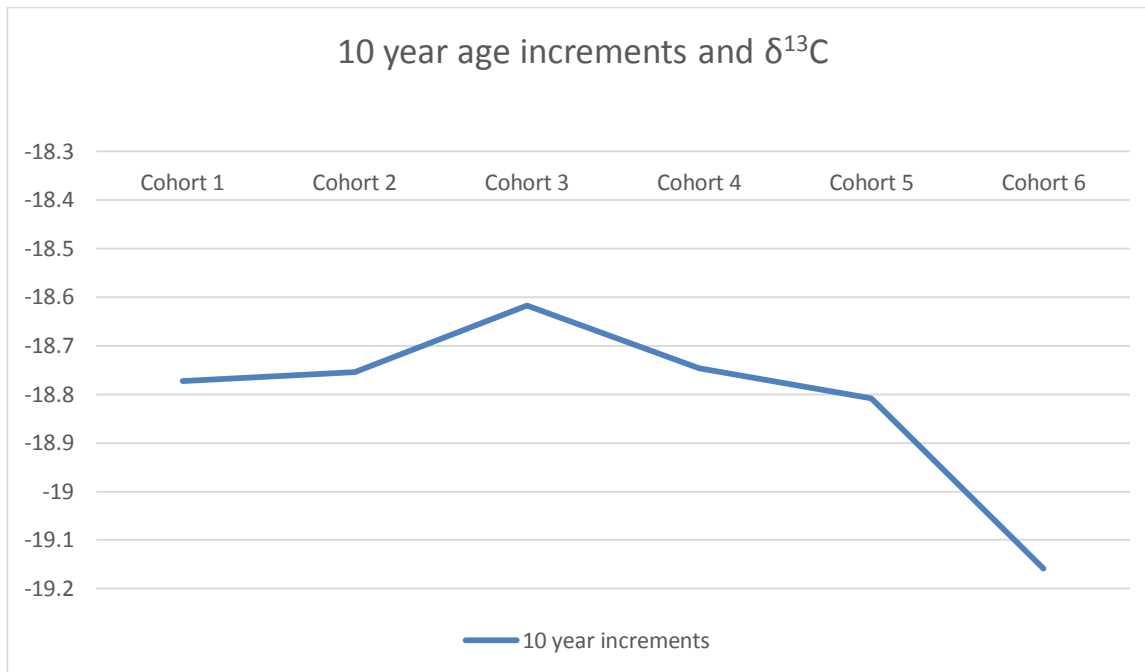


Figure 17: Line graph depicting depletion of $\delta^{13}\text{C}$ as age increases according to 10 year increments.

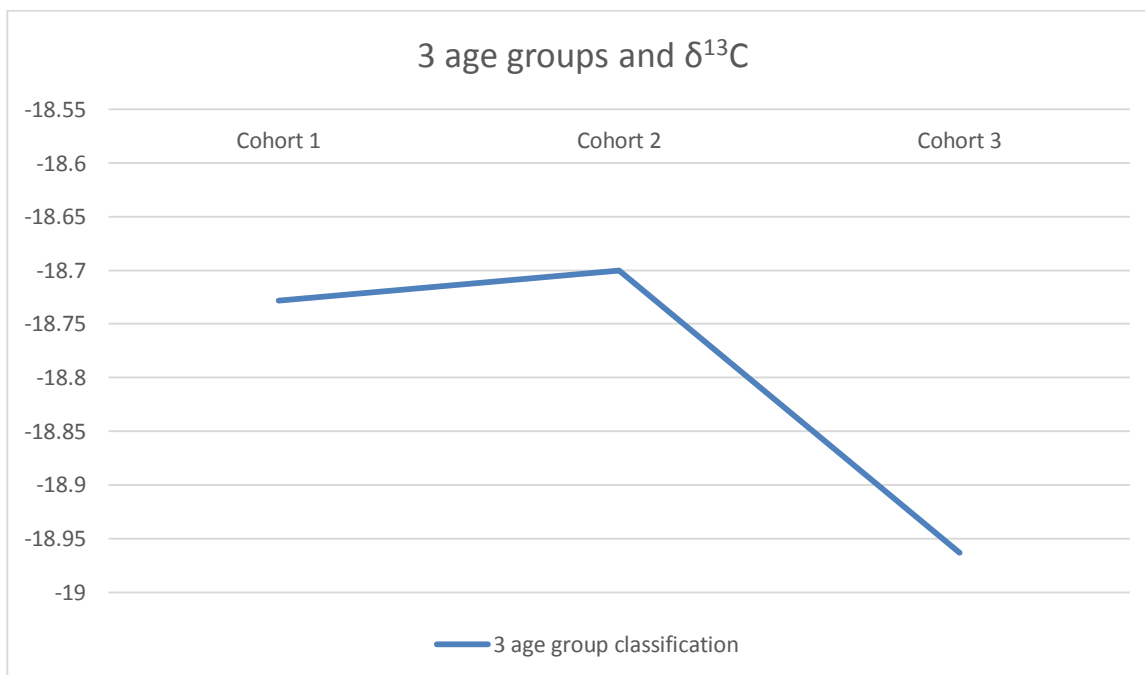


Figure 18: Line graph depicting depletion of $\delta^{13}\text{C}$ as age increases according to 3 age group classifications.

The analysis of differences in mean $\delta^{13}\text{C}$ values between social age categories revealed significant differences. Specifically, the oldest age category of 60+ year olds exhibited

significantly different mean carbon values from all other categories ($p < .01$) (Figure 15; Table 9).

This suggests that the carbon values of the oldest age category are depleted relative to than all others. A similar trend was observed when age was classified in different ways. When age was organized in three age cohorts, the oldest age group of 51+ years exhibited significant differences compared to all other age cohorts displaying more negative carbon values ($p < .01$) (Table 10). When age is classified according to 10 year increments the oldest age group of 61+ years exhibited significantly more negative values than all other age groups ($p < .01$) (Table 11).

Table 9: Results of ANOVA analysis indicating differences between the mean $\delta^{13}\text{C}$ of age groups classified according to social age standards. Note the significant differences at the 0.01 level (**) between the oldest age category and all others.

	16-21 years	22-35 years	36-50 years	51-59 years	60+ years
16 years					
22-35 years	.041				
36-50 years	.004	-.036			
51-59 years	.098	.058	.094		
60+ years	.464**	.422**	.459**	.365**	

Table 10: Results of ANOVA analysis indicating differences between the mean $\delta^{13}\text{C}$ values of different age groups classified by three general age categories. Note the significant differences at the 0.05 level (*) between the oldest age category and all others.

	16-35 years	36-50 years	51+ years
16-35 years			
36-50 years	-.027		
51+ years	.234*	.262*	

Table 11: Results of ANOVA analysis indicating differences between the mean $\delta^{13}\text{C}$ values of age groups classified in 10 year increments. Note the differences at the 0.05 level (*) and 0.01 level (**) between the oldest age group and all others.

	10-20 years	21-30 years	31-40 years	41-50 years	51-60 years	61+ years
10-20 years						
21-30 years	-.019					
31-40 years	-.156	-.137				
41-50 years	-.027	-.008	.129			
51-60 years	.034	.053	.191	.061		
61+ years	.386*	.404**	.542**	.413*	.352*	

In addition to differences observed between age groups, significant levels of difference were observed when sex and social age categories were considered together. Specifically, when classifying age along social categories, older females (60+ years) exhibited significant difference from males between the ages of 22 and 35 years and between the ages of 36 and 50 years ($p < .05$). In these cases the 60+ year old females display more negative values than these other groups. Additionally, old males (60+ years) display significant differences in mean carbon values compared to 16-21 year old females ($p < .01$) and 22-35 year old females ($p < .05$). However, it is important to note that the mean carbon values of the oldest age category 60+ years do not differ significantly between males and females (Table 12).

Table 12: Results of ANOVA analysis indicating differences between the mean $\delta^{13}\text{C}$ values between male and female age groups classified according to social standards. Note the differences at the 0.05 level (*) and the 0.01 level (**) between most old and young age groups and the lack of difference between old males and females.

	16-21 year Females	22-35 year Females	36-50 year Females	51-59 year Females	60+ year Females
16-21 year Males	.185	-.012	-.027	.0445	-.294
22-35 year Males	.039	-.159	-.017	-.102	-.441*
36-50 year Males	-.038	-.220	-.235	-.164	-.502**
51-59 year Males	.322	.125	.109	.181	-.157
60+ year Males	.635**	.438*	.423	.495*	.156

Additionally, when comparing just females across all social categories the only significant variation observed was between the oldest females (60+) and youngest females (16-21 years) with older individuals exhibiting more negative carbon values (Table 13). However, when comparing male values across all social categories, significant differences in mean values were observed between males 60+ years and males 22-35 and 36-50 years ($p < .01$). The older males display more negative values than the other categories (Table 14).

Table 13: Results of ANOVA analysis indicating differences between the mean $\delta^{13}\text{C}$ values of female age groups classified according to social age categories. Note the only significant difference at the 0.05 level (*) between the oldest and youngest age group.

	16-21 year Females	22-35 year Females	36-50 year Females	51-59 year Females	60+ year Females
16-21 year Females					
22-35 year Females	.197				
36-50 year Females	.212	.015			
51-59 year Females	.141	-.056	-.071		
60+ year Females	.479*	.282	.267	.338	

Table 14: Results of ANOVA analysis indicating differences between the mean $\delta^{13}\text{C}$ values of male age groups classified according to social age categories. Note the significant difference at the 0.01 level (**) between the oldest age group and most others.

	16-21 year Males	22-35 year Males	36-50 year Males	51-59 year Males	60+ year Males
16-21 year Males					
22-35 year Males	-.147				
36-50 year Males	-.208	.061			
51-59 year Males	.137	.284	.345		
60+ year Males	.450	.597**	.658**	.313	

In addition to significant differences between mean $\delta^{13}\text{C}$ values when examining social age categories, the classification of age into 3 categories also revealed significant variation. The oldest age category of 51+ years was significantly different from both other categories (Table 8). Furthermore, the oldest females were significantly less negative than middle aged (36-50) males but showed no differences from other female categories (Table 15 and 16). The oldest male

category (51+ years) displays significantly more negative mean carbon values from young females (16-35 years) as well as all other male categories (16-35 and 36-50 year olds) (Table 15 and 17).

Table 15: Results of ANOVA analysis indicating differences between the mean $\delta^{13}\text{C}$ values of male and female age cohorts organized into three broad categories. Note the differences at the 0.05 level (*) between the oldest groups and the younger groups and the similarity between old males and females

	16-35 year Females	36-50 year Females	51+ year Females
16-35 year Males	-.083	-.144	-.204
36-50 year Males	-.174	-.235	-.295*
51+ year Males	.366*	.305	.245

Table 16: Results of ANOVA analysis indicating differences between mean $\delta^{13}\text{C}$ values of female age groups divided into three broad categories. Note the lack of significant variation.

	16-35 year Females	36-50 year Females	51+ year Females
16-35 year Females			
36-50 Females	.061		
51+ year Females	.121	.060	

Table 17: Results of ANOVA analysis indicating differences between mean $\delta^{13}\text{C}$ values for male age groups divided into three broad categories. Note the significant difference at the 0.01 level (**) of the oldest males with all other male groups.

	16-35 year Males	36-50 year Males	51+ year Males
16-35 year Males			
36-50 year Males	-.091		
51+ year Males	.419**	.541**	

The significant difference in $\delta^{13}\text{C}$ values between the oldest age groups and the youngest age groups despite differing classification systems suggests that the variability is meaningful.

Not only do older males and females (60+) display more negative carbon values but also, importantly, that they do not differ between each other. As such, while carbon values differ with age, sex does not seem to play an important role in explaining the variability within the population. Furthermore, these older individuals are buried in various parts of the cemetery without visible patterning suggesting they may not have originated from the same family or social group. This further supports the importance of age in determining differences in nitrogen values as a result of diet or physiological changes.

Nitrogen Values

No significant difference between mean nitrogen values for males and females was observed. Additionally, there were no significant differences in nitrogen values between age groups (Table 18). Furthermore, no significant differences in nitrogen values were found between categories based on the three group classification combined with sex or a two group age classification combined with sex (Table 19). However, discernable differences were identified between groups when classified according to sex and social age classifications as well as sex and 10 year increments (Table 19).

Table 18: Mean $\delta^{15}\text{N}$ values for age groups according to different classification systems.

	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Cohort 6
Social Classification	+16.9‰	+17.9‰	+18‰	+17.4‰	+18.6‰	
3 Group Classification	+17.7‰	+18‰	+17.9‰			
2 group Classification	+17.7‰	+17.9‰				
10 year increments	+16.7‰	+18.1‰	+17.6‰	+18.2‰	+17.6‰	+18.6‰

Table 19: Differences between mean nitrogen values for different age and sex categories (*indicate significance below the .05 level; ** indicates significance below the .01 level).

Independent Variable	F value
Sex	3.670
Age (Social groups)	1.685
Age (3 age groups)	.476
Age (2 age groups)	.919
Age (10 yr cohorts)	1.956
Sex and age (Social age cohorts)	3.538 **
Sex and age (10 yr cohorts)	3.554 **
Sex and age (3 age groups)	1.089
Sex and age (2 age groups)	1.500

No obvious trends in nitrogen across age and sex were visible, however, a significant degree of variation in stable nitrogen values was observed when social age categories were combined with sex (Figure 19, Table 19). The level of significance was below the value of .01. This variability can be explained by the variability observed between the young male samples and other categories. The mean nitrogen values of young adult males between the ages of 16 and 21 years were significantly lower from all female groups and most male groups except the 51-59 years category (Table 20 and 22). In all cases the difference was significant below the .01 level. Despite the small samples size of this age group, the standard error of this group below 1 when compared to all other groups, indicating that the mean adequately represents the sample and that the significant differences with other groups are authentic.

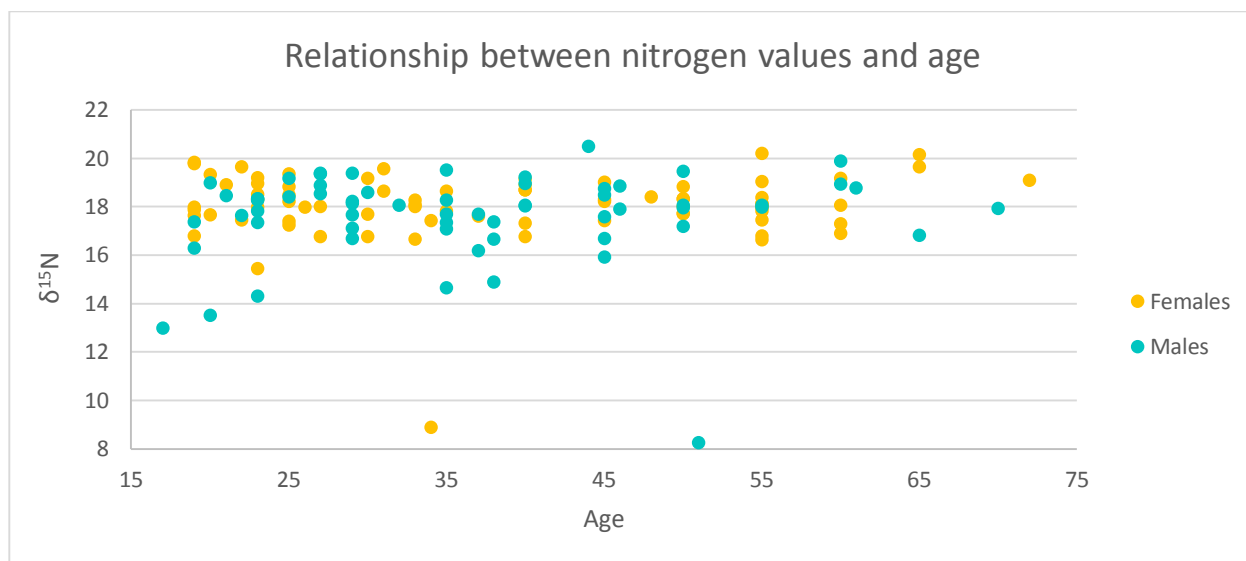


Figure 19: Scatter plot depicting the association between nitrogen and age as well as sex. Note the lack of obvious trends in carbon values with age or sex.

Table 20: Results of ANOVA analysis indicating differences between the mean $\delta^{15}\text{N}$ values of female and male age cohorts divided according to social groups. Note the significant differences at the 0.01 level (**) between the youngest male cohort and all female groups as well as the differences between the older age group (51-59) all others. The small size of the 51-59 year cohort indicates its difference may be inauthentic.

	16-21 year Females	22-35 year Females	36-50 year Females	51-59 year Females	60+ Females year
16-21 year Males	3.345**	2.705**	3.116**	2.974**	3.541**
22-35 year Males	.488	-.151	.259	.117	.685
36-50 year Males	.589	-.050	.360	.218	.786
51-59 year Males	3.655	3.015**	3.426**	3.285**	3.851**
60+ year Males	-.042	-.682	-2.718	-.413	.153

Table 21: Results of ANOVA analysis indicating differences between the mean $\delta^{15}\text{N}$ values of age cohorts divided according to social classifications. Note the significant differences at the 0.01 level (**) between the youngest cohort and nearly all others, as well as the significant variation between the older (51-59) cohorts and nearly all others. The small size of the 51-59 year cohort indicates its difference may be inauthentic.

	16-21 year Males	22-35 year Males	36-50 year Males	51-59 year Males	60+ year Males
16-21 year Males					
22-35 year Males	-2.856**				
36-50 year Males	-2.756**	.101			
51-59 year Males	.310	3.167**	3.066**		
60+ year Males	-3.388**	-.531	-.632	-3.698**	

The lack of variation between young males (16-21 years old) and older males (51-59 years old) may be explained by the very small sample of only three in the latter group. Because of the small sample, the mean for this group may be artificially skewed and may not adequately represent the sample or its relationship to other groups. The small sample may also account for the differences seen between this group and most female groups (except for 16-21 year olds) and most male groups (except for 16-21 year olds). The bias of this small sample is further suggested by a standard error between this group and all other groups of greater than 1.

Despite the significant difference between 16-21 year old males and nearly all other groups, no similar variation was found for young females between the ages of 16-21 years (Table 22). This indicates that both age and sex are important factors in explaining variation in the sample.

Table 22: Results of ANOVA analysis indicating differences between the mean $\delta^{15}\text{N}$ values of female age cohorts divided by social age groups. Note the lack of significant variation between any groups.

	16-21 year Females	22-35 year Females	36-50 year Females	51-59 year Females	60+ year Females
16-21 year Females					
22-35 year Females	.640				
36-50 year Females	.230	-.410			
51-59 year Females	.371	-.269	.142		
60+ year Females	-.196	-.836	-.425	-.567	

A significant degree of variation ($p < .01$) in nitrogen values was also revealed when sex was considered with 10 year age categories. Again, the majority of this variation is present in the differences between the youngest male categories of 16-20 year olds and the remainder of the sample (Table 23 and 24). These males were significantly different from all female groups and most male groups except the 51-60 year old male group. Although the 16-20 year old male sample is small, the standard error with all other groups is less than 1 except for the 51 to 60 year age group, ensuring the consistency of the values and supporting the significance of these results.

The 51-60 year old male group also displays significant variation with all female groups and most male groups except for the 16-20 year old group (Table 24). However, again this sample is very small, consisting of only three individuals. As such, the mean for this group may not adequately represent this sample and therefore the significant differences with other groups may be in error. Additionally, the standard error for this sample in relation to all other groups is greater than 1 supporting the assertion that the mean may not adequately represent the sample and that the findings are not authentic.

Table 23: Results of ANOVA analysis indicating differences between the mean $\delta^{15}\text{N}$ values of female and male age cohorts divided into 10 year increments. Note the significant differences at the 0.01 level (**) between the youngest males and all female groups as well as older males (51-60) and all female groups. The small size of the 51-59 year cohort indicates its difference may be inauthentic.

	10-20 year Females	21-30 year Females	31-40 year Females	41-50 year Females	51-60 year Females	61+ year Females
10-20 year Males	3.848**	3.599**	3.090**	3.765**	3.574**	4.106**
21-30 year Males	.262	.013	-.496	.178	-.012	.519
31-40 year Males	.850	.601	.092	.767	.576	1.107
41-50 year Males	.232	-.017	-.527	.148	-.042	.489
51-60 year Males	3.593**	3.345**	2.835**	3.510**	3.319**	3.851**
61+ year Males	-.104	-.353	-.863	-.188	-.379	1.534

Table 24: Results of ANOVA analysis indicating differences between the mean $\delta^{15}\text{N}$ values of male cohorts divided into 10 year groupings. Note the significant difference at the 0.01 level (**) between the youngest males and nearly all others as well as the significant differences between older males (51-60) and nearly all others. The small size of the 51-59 year cohort indicates its difference may be inauthentic.

	10-20 year Males	21-30 year Males	31-40 year Males	41-50 year Males	51-60 year Males	61+ year Males
10-20 year Males						
21-30 year Males	-3.587**					
31-40 year Males	-2.998**	.588				
41-50 year Males	-3.617**	-.030	-.618			
51-60 year Males	-.255	3.332**	2.743**	3.361**		
61+ year Males	-3.953**	-.366	-.955	-.336	-3.698**	

Due to the effects of bone turnover, the isotopic signatures of the 16-21 year old males may more adequately represent these individuals' lives 5-10 years prior to their death. However,

because of the uncertainty in calculating the rates of bone turnover especially during periods of growth when turnover rates may increase, it is not possible to determine exactly what period of these individual's lives is being represented by these values.

The lack of variation in nitrogen values when just age or just sex is considered indicates that the interaction of age and sex were important factors in determining diet as well as the resulting nitrogen values. Furthermore, the lack of significant differences between young females and the remaining sample underscores that both sex and age are important in explaining the patterns of variation in nitrogen values.

Outliers

Although patterns were present in nitrogen and carbon values, a number of individuals exhibited anomalous values (Figure 20). In each case, despite the unique isotope values, none of the individuals exhibited C:N ratios or %C or %N values outside of the expected range and so could not be excluded on those bases. The outliers are buried in the cemetery in similar fashions to the rest of the population. They are not located in the same area as each other or on the outskirts of the cemetery. This suggests that their dietary or health differences did not equate with differential treatment in death.

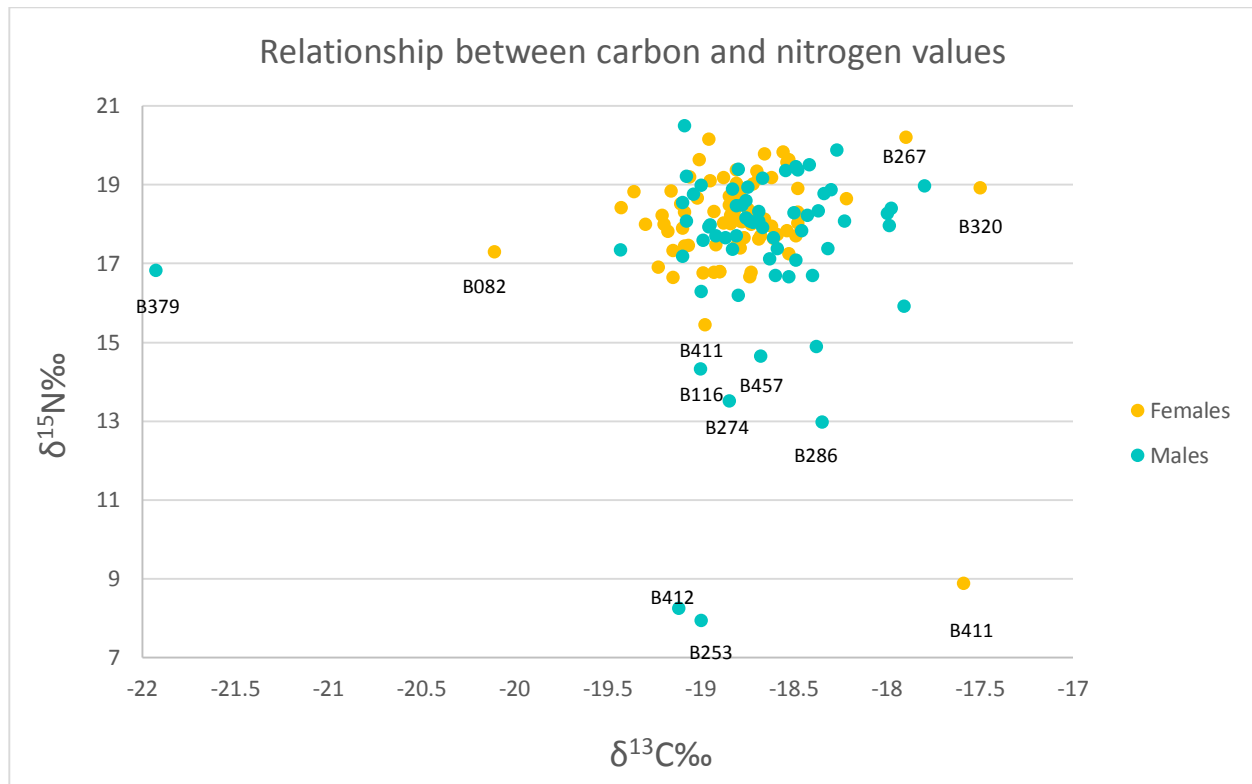


Figure 20. Graph depicting association between carbon and nitrogen for males and females. Note the numerous outliers and the more dispersed nature of the male sample.

A number of outliers were present (Figure 20). Sample B379, a 65 year old male exhibited the lowest carbon values at -21.9‰. The lowest female values belong to B082 a female aged 60 with a value of -20.1‰. A number of females also exhibited values at least one standard deviation greater than the mean for female carbon isotope values. B320 was 21 years old and exhibited a value of -17.5‰, B411 was 34 years with a value of -17.6‰, and B267 was 55 years old with a value of -17.9‰. Although B267 exhibited values outside of the female range, her values were consistent with the male carbon isotope value range.

A number of males exhibited nitrogen values lower than the mean for males. B286 was 17 years old with a value of +12.9‰, B274 was 20 years old with a value of +13.5‰, B116 was 23 years old with a value of +14.3‰, and B457 was 35 years old with a value of +14.7‰. One female exhibited true anomalous values. B401 was 23 years old with a value of +15.5‰.

Although the value of B401 was outside of the female range it was consistent with the male values.

The outliers for carbon are consistent with older people exhibiting more negative values although the more enriched individuals exhibit no pattern in age, they are all female.

Furthermore, while most of the outliers for nitrogen were young males, a few older males were present. No patterns were exhibited by the females. Two outliers, one for carbon and one for nitrogen isotopic values, were females that displayed values more consistent with males at the site than with females.

Age Classifications

In each instance in which variation was present in the sample in regards to age, it was visible when the population was divided by social age. The classification by 10 year increments also successfully reflected variation when it was present. Only in the case of carbon was a three year age classification capable of revealing the source of variation within a sample. A two year classification scheme was not able to identify variability in either nitrogen or carbon isotopic values for the sample analyzed here.

Summary

A fine grained investigation employing statistical analysis examining differences by sex as well as age divided along various different lines, revealed significant variability among carbon and nitrogen isotope values within the sample. The most significant patterns identified in $\delta^{13}\text{C}$ values was between the oldest and youngest cohort suggesting that older people, 60+ years, exhibited more negative carbon values than the remainder of the population. Sex did not seem to influence this pattern greatly.

$\delta^{15}\text{N}$ values varied according to age and sex with the youngest males exhibiting the most depleted values and the greatest variation from all other groups. A number of outliers are also present. Most of these are consistent with the trends seen within the sample. Social age classification and 10 year age categories were capable of revealing the most variation within the sample. The patterns revealed through statistical analysis provide much evidence with which to extrapolate information about these individuals and the society within which they lived.

CHAPTER 6: DISCUSSION

This study was undertaken to explore social identity in a sample of the Kellis population through the analysis of stable carbon and nitrogen isotope values. The intention was to explore patterns in stable isotope values as a proxy for differences in lived experiences between groups. Variation was expected between groups divided by age, sex, gender, and status because of the potential differential access to resources between these groups which could have influenced their diet and metabolic condition, and subsequently, stable isotope values. The findings reveal a much more complex picture of life for those buried in the Kellis 2 cemetery in which differences between groups are nuanced and manifest themselves in unexpected ways.

General Findings

Carbon

The mean $\delta^{13}\text{C}$ value exhibited by this Kellis 2 cemetery sample is -18.8‰. These values are consistent with previous findings from the site of -18.9‰ that indicate a diet consisting primarily of C_3 plants (Dupras 1999). After considering a diet to tissue spacing of approximately 5‰ the expected value of the diet would be around -23.8‰. As such, the mean $\delta^{13}\text{C}$ value for the sample is much closer to the site's mean $\delta^{13}\text{C}$ values for C_3 plants at -23.2‰ than to the mean C_4 plant value at -9.9‰ (Ambrose and Norr 1993). C_3 plants that were likely consumed at the site include wheat at -22.9‰ and barley at -23.3‰, the only C_4 plant attested is millet at -9.9‰. Other possible C_3 plants include fava beans (-23.1‰) and figs (-23.8‰). Given the close association between the human values and those of barley, wheat, fava beans, and figs, these could all have been main contributors to the diet.

The human $\delta^{13}\text{C}$ values are most similar to those presented by chickens (-18.4‰) and donkeys (-18.1‰) (Dupras 1999). This may suggest that humans were consuming a diet similar

to these animals. These animals were domesticates that may have lived in close association with humans, supporting the assertion that their diet may have been similar to humans. As such, a diet consisting primarily of C₃ plants, especially barley is most likely.

The narrow range of $\delta^{13}\text{C}$ values for the sample at 4.4‰ with a narrow standard deviation of 0.45‰ that suggests limited variability in the dietary sources of carbon for the sample. This lack of variation in carbon values is consistent with past findings from Kellis and other areas of the Dakhleh Oasis (Dupras 1999). This could suggest limited dietary variation or availability at the site.

Nitrogen

The mean $\delta^{15}\text{N}$ value in the sample was +17.8‰ and is consistent with past research at the site which found a value of +17.9‰ (Dupras 1999). Given a 3‰ trophic shift between diet and consumer, the values of human diet would be expected to fall around 14.8‰. This value is very close to that of barley (+14.4‰), goat (+13.4‰), donkey (+13.3‰), pig (+13.3‰), and gazelle (+13.2‰) (Dupras 1999). Donkeys were unlikely food animals given their role in transport and gazelle were unlikely to have played a significant dietary role due to their few numbers and the high energy requirement to procure them. As such, barley was likely the main source of protein but the diet may have been reinforced with animal protein from goats and pigs.

However, the enriched $\delta^{15}\text{N}$ levels in the area may complicate the assessment of a trophic level shift. For example, plants exhibit nitrogen values of +15.3‰, which is also roughly 3‰ less than the human values at the site (Dupras 1999). As such, it is difficult to determine the degree of animal protein in the Kellis 2 sample diet, but a contribution of animal protein is likely.

The very high $\delta^{15}\text{N}$ values found in the sample are consistent with other research at the site and have been thoroughly discussed elsewhere (Dupras 1999; Schwarcz et al. 1999). The

high values are likely a result of the arid environment leading to increased volatilization of isotopically light nitrogen and enrichment of the nitrogen in the soil and primary producers which is passed to humans through ingestion of plant and animal products (Schwarcz et al. 1999).

The variability in $\delta^{15}\text{N}$ values is much greater than those present for carbon. These values exhibit a range of +12.6‰ and a standard deviation of $\pm 1.86\text{‰}$. The extensive variation is partially a result of the erroneous outliers present in the sample. However, even with these samples excluded, a range of 7.5‰ and standard deviation of $\pm 1.21\text{‰}$ is identified. As such, a great amount of variation is present in $\delta^{15}\text{N}$ values in the sample.

The variability could be suggestive of a diversity of protein consumption. Protein derived from meat sources can have a greater effect on $\delta^{15}\text{N}$ values than protein derived from plant sources (Ambrose et al. 2003). As such, given the limited amount of meat that these individuals were consuming to begin with, any variation would have had drastic effects on their resulting $\delta^{15}\text{N}$ values. The society of Kellis was highly stratified and most likely consisted of both elites and slaves. This differential social status could certainly influenced access to food resources. However, the lack of grave goods associated with the burials and the uncertain organization of the cemetery, limits any attempts to identify status differences at Kellis.

Another possibility is that the degree of variation could be related to the health status of the individuals comprising the sample. The long turnover rate for bone collagen, however, especially in adulthood, precludes the possibility that short term variation in health status would affect $\delta^{15}\text{N}$ values. As such, it is unlikely that short term nutritional stress or pathological conditions could have affected $\delta^{15}\text{N}$ values. Another possibility is that the health status of numerous individuals was influenced by chronic pathological conditions, such as dehydration

(Ambrose 1991; Hobson and Clark 1992). Alternatively, metabolic stress introduced during pregnancy could have effects on nitrogen values in the sample (Fuller 2005). Lastly, given the age distribution of the outliers, nitrogen variation could be accounted for by the presence of growing individuals who display depleted nitrogen values and will be discussed in further detail below.

In light of the reliance on bone collagen, the wide range of variation in nitrogen values can most likely be related to variability in animal protein consumption as well as the effects of growth or pregnancy on certain segments of the population.

Interpretation

Given the close association between human $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values and barley, barley seems to be the most likely, main contributor to human diet at the site. However, $\delta^{15}\text{N}$ values also suggest a limited, and possibly variable, contribution of meat protein, likely from goats/sheeps or pigs. The limited amount of variation in $\delta^{13}\text{C}$ values suggests that access to barley was consistent throughout the site. However, the variation in $\delta^{15}\text{N}$ indicates that access to meat protein may have differed throughout the sample and that other causes of variation were present.

Age

Age Classification

A number of different age classifications were tested in this study. Of the four tested, only two, the social age cohorts and 10 year increment scheme, successfully identified variation in each case it was present. In contrast, the 2 and the 3 age cohort approaches failed to identify most variation and instead masked much of the patterns present in the sample. For this study, the social classification proposed by Williams (2008) was the most effective approach to

investigating variation within the study sample. This classification revealed the greatest amount of variation while also being socially and biologically relevant to the population under study. As such, the ensuing discussion will engage primarily with the findings revealed from the social classification approach.

Carbon

Most of the variability in $\delta^{13}\text{C}$ values that was found in the sample can be explained by age differences. When dividing the sample into social age cohorts, individuals 60 years old and older displayed discernably different carbon values from all other groups. In general $\delta^{13}\text{C}$ values decreased with age in each classification scheme even though the only significantly unique values were present in the oldest age cohorts. Interestingly, the variation between female cohorts is smaller than that displayed for males. However no significant differences between males and females were found overall and males and females in the oldest cohorts displayed similar values. As such, although the age-based variation existed across the sample it was greater among males.

The downward trend in $\delta^{13}\text{C}$ values results in the oldest cohort displaying depleted carbon values suggesting a greater reliance on C_3 plants than the remainder of the sample or the experience of physiological changes associated with ageing. This oldest cohort displays a mean value of -19.2‰. This is significantly different from the mean $\delta^{13}\text{C}$ value for the sample at -18.8‰. If these differences are associated with diet, the expected $\delta^{13}\text{C}$ value of the diet would then be -24.2‰. This is still consistent with the value of barley (-23.3‰), and is similar to that of fig (-23.8‰), turnip (-25.3‰), and doum palm nut (-26.3‰).

^{15}N values for the oldest age group were approximately +18.6‰. The $\delta^{15}\text{N}$ value of the diet would be expected to be around +15.6‰. These values are most similar to barley (+14.4‰), wheat (+16.1‰), grape (+16.8‰), palm date (+14.9‰), and chicken (+16.2‰). However, grape,

palm date, and chicken have very different $\delta^{13}\text{C}$ values than would be expected at -22.4‰, -22.2‰, and -18.4‰ respectively.

The combination of carbon and nitrogen values suggests that these individuals were consuming primarily barley and wheat with the addition of other C_3 plants including fig, turnip, or doum palm nut which may account for the more depleted $\delta^{13}\text{C}$ values. However, the $\delta^{15}\text{N}$ values do not match this explanation well. A combination of barley (+14.4‰), wheat (+16.1‰), fig (+17.8‰), turnip (+10.4‰), and doum palm nut (+11.7‰) could explain these nitrogen values. The shift to wheat, figs, and turnips could also account for the higher than average nitrogen values for this oldest segment of the population. Furthermore, the higher nitrogen values and more depleted carbon values could also be explained by a reduction in animal protein, especially if those animals are partly fed on C_4 plants and given the unique circumstances of the Dakhleh Oasis in which the nitrogen values of plants can be higher than animal protein

Of the 12 individuals constituting the oldest age cohort many display severe dental wear or tooth loss. Given the gritty nature of the diet in Egypt, the extreme nature of these dental pathological conditions are not surprising. In fact, severe wear, the accumulation of dental calculus, and other dental pathologies were very common among most adults at the site (Dupras et al. 2016). It is likely that these pathological conditions would have directly influenced these individuals' diets and life styles. It is possible that meat was too tough to consume and that these individuals were instead forced to rely more heavily on softer foods, such as wheat and barley based foods such as breads and gruel which contain more C_3 plants in addition to soft starchy foods such as turnips and soft fruits such as figs. Wheat was a high value commodity as it was not harvested year round and was used in the payment of taxes. A greater reliance on wheat,

therefore, indicates this group's access to this more valuable commodity year round, in contrast to the rest of the population.

It is interesting to note that these individuals did not turn to millet gruel which has been suggested as an illness and weaning food in the area (Dupras et al. 2001; Dupras and Tocheri 2007). Perhaps this food was associated with a lower status given its relationship to the sick and young, and its use as animal fodder. This would suggest that the avoidance of such foods, despite their ease of consumption and digestion which could have benefitted individuals with extreme dental pathologies, was a purposeful choice. This may, in turn, indicate a preference for particular foodstuffs among older individuals and a higher status of those individuals in being able to acquire such resources.

Furthermore, the lack of distinction between old males and females indicates that, at least at this period of their lives, sex or gender may not have played a key role in access to food stuffs. Given that women were no longer reproducers and were likely not running households, their changes in behavior and occupation could have been associated with a change in status. For males, a possible shift from laboring may have also been accompanied by a change in status.

Nitrogen

Despite the clear trend in $\delta^{13}\text{C}$ values, $\delta^{15}\text{N}$ values do not exhibit any significant variation across age groups. However, as discussed above, the oldest age cohorts do display the highest $\delta^{15}\text{N}$ values for the sample which suggests a greater reliance on C_3 plants and could suggest the possibility that these individuals were consuming less animal meat. However, given the complexity of nitrogen isotope values at the site the possibility of a decrease in animal meat and increase in nitrogen enriched plants cannot be ruled out. Furthermore, the youngest age cohorts exhibit the lowest $\delta^{15}\text{N}$ values, but these are not statistically discernable. This variation can likely

been explained by the presence of young males with low $\delta^{15}\text{N}$ in the sample and will be discussed in greater detail below. Alternatively, the elevated $\delta^{15}\text{N}$ values of older adults could be related to chronic pathological conditions or nutritional stress which would result in a catabolic state and an enrichment of $\delta^{15}\text{N}$ (Hobson et al. 1993; Katzenberg and Lovell 1999; Fuller et al. 2005; Hatch et al. 2006; Olsen et al. 2014).

Interpretation

The results of carbon and nitrogen isotope analysis suggest that the oldest members of the Kellis 2 cemetery sample were experiencing physiological changes or consuming a significantly different diet than the rest of the sample. This could be associated with biological changes such as menopause among women. Their diet likely consisted of more C_3 plants and less meat. The alteration of this diet was a gradual one that may have related to gradual tooth loss and dental wear, which would expose sensitive dentin, and could require a complementary change in diet and lifestyle. The change of diet with age suggests the significance of ageing as part of an individual's social identity, and the significant difference for individuals 60 years and over indicates that this period represented a distinct, socially significant age group that was not influenced by sex. The avoidance of illness and weaning foods may reflect food preferences which distinguish these individuals from the ill or juvenile. In turn, this may suggest that ageing was not seen as a pathological condition and the elderly were not seen as incapable. Instead the reliance on higher quality foods may suggest an elevated status afforded to this age group.

Sex

Carbon

Past research concerning the Kellis 2 cemetery has identified a significant difference in $\delta^{13}\text{C}$ values between males and females and suggested that males consumed more meat and C_3 plants (Dupras 1999). This study examined a larger sample of 138 individuals and found no statistically discernable differences between male (-18.7‰) and female (-18.8‰) $\delta^{13}\text{C}$ isotope values. Males did exhibit a greater range of $\delta^{13}\text{C}$ values at 4.13‰ and standard deviation at 0.51‰ than females with range of 2.6‰ and a standard deviation of 0.36‰. However, none of these differences were statistically significant, suggesting that males and females did not consume dramatically different diets, especially in relation to carbon consumption.

Nitrogen

No significant differences were observed in the $\delta^{15}\text{N}$ values between males (+17.5‰) and females (+18.1‰) in the sample. Males did display a greater range and standard deviation than females with a male range of 12.6‰ versus a female range of 11.3‰ and a male standard deviation of $\pm 2.3\%$ and a female standard deviation of $\pm 1.4\%$. These results further support the assertion that males and females did not consume dramatically different diets but that some variation was present. The variability could be explained by differences in chronic illness, malnutrition, pregnancy, or mobility (Hobson et al. 1993; Katzenberg and Lovell 1999; Fuller et al. 2005; Hatch et al. 2006; Olsen et al. 2014).

Interpretation

The lack of differences in carbon and nitrogen values suggest that division between the sexes were either not socially meaningful, or if so, did not directly influence access to food

resources. It is interesting to note that, despite the fact that females experienced different biological realities, including multiple pregnancies and menopause, no differences in nitrogen values between males and females were observed. The slightly greater variation in male values, however, may suggest that males had access to a greater variety of foodstuffs were involved in more various activities that took them in contact with different foods. It is possible that the lack of variation in females resulted from their association with the household, with little movement or variation.

Gender

In this study, gender was interpreted as a highly complex social category. Gender is often tied to the biological reality of sex but can change throughout the life course. As such, variations in diet and health tied to age and sex can begin to suggest gendered differences in lived experiences in this sample.

Carbon

As discussed previously, $\delta^{13}\text{C}$ values did not differ significantly with age and sex, and so provide no evidence of gendered differences in carbon intake.

Nitrogen

When age and sex were combined, significant variation was found in nitrogen values according to social age categories. Specifically, the youngest males (16-21 years) exhibited lower $\delta^{15}\text{N}$ values than all female and male age groups at +15.1‰ as compared to the sample mean of +17.8‰. With the erroneous outlier removed the mean for the group stands at +16.3‰. Of the six non-outliers in this category, four present values below the mean for the entire sample.

This depletion is significant as it is lower than that expected from the unique nitrogen enriched environment of the Dakhleh Oasis.

If the $\delta^{15}\text{N}$ were only influenced by diet, the expected $\delta^{15}\text{N}$ values of the food would therefore be 13.3‰. This is most consistent with cow (+13.1‰), goat (+13.4‰), pig (+13.3‰), donkey (+13.3‰), gazelle (+13.2‰), fava beans (+12.1‰), and barley (+14.4‰). $\delta^{13}\text{C}$ values are consistent with the overall sample at -18.8‰. The expected value of the diet is therefore -23.8‰ and is most similar to wheat (-22.9‰), barley (-23.3‰), fava beans (-23.1‰) and figs (-23.8‰). Given the association between the carbon and nitrogen values, barley and fava beans seems to be the most likely dietary staple. Because of the disjunction between the $\delta^{13}\text{C}$ values of the sample and the animal protein at the site, despite the close association of nitrogen values, it would suggest that these resources were not a main component in the diet of these individuals. The lower nitrogen values are likely a result of other factors.

Because this age group of males was likely still growing, it is difficult to determine what the bone turnover for these samples might be and therefore what period of these individual's lives might be represented by these depleted nitrogen values. However, bone collagen of males less than 20 years old may turnover at a rate of 10- 30% per year, indicating that the collagen values may reflect a period of 3-10 years before death (Hedges et al. 2007). As such, weaning would not have been a factor in influencing nitrogen values. Instead, these values could be related to migration, growth, or status changes.

Low $\delta^{15}\text{N}$ values in Kellis have been taken as evidence of migration in the past given the very elevated nitrogen values found at the site (Dupras 1999). Nitrogen values reported for the Nile Valley range from +9.2‰ to +15.1‰ (Iacumin et al. 1996). The values of these young males are consistent with these values. Nitrogen values from Nubia have been reported as 11.1‰

± 1.15 which does not encompass the values of these young males (White and Armelagos 1997). If these individuals had migrated to the area as young men, and died shortly after, their bones may retain traces of their earlier life. In this instance, their carbon values could be similar to those reflected by plants at other geographic locations, but the nitrogen values would not be. The migration of young males could be related to a need for young laborers, the beginning of apprenticeships, or participation in trade caravans. This phenomenon would be consistent with literary reports of slaves beginning their apprenticeships around the ages of 12 or 13 years (Rowlandson 1998). The lack of similar findings among young females can be explained by the suggestion from literary sources that apprenticeships were confined to free and enslaved males and, in some cases, enslaved females which would severely limit the number of females experiencing the biological consequences of apprenticeships (Bradley 1991). Alternatively, young males could have moved away from Kellis to seek employment or apprenticeships, and if they died in their time away, could have had their bodies returned to their families, which would account for the retention of anomalous nitrogen values.

The low $\delta^{15}\text{N}$ values of these young males could also be a result of their longer period of growth. This is supported by a lack of similarly low values among females, as females growth begins to slow before males (Hedges et al. 2007). For the youngest males (16-21 years), if collagen represents 3- 10 years before death, this period would be when an adolescent growth spurt can be expected (Hedges et al. 2007). Growth results in a positive nitrogen balance because of an increase in nitrogen –containing tissue and energy requirements. These tissues are enriched in N^{14} resulting in a depletion of $\delta^{15}\text{N}$ isotopic values (Henderson et al. 2014).

Lastly, these depleted $\delta^{15}\text{N}$ isotope values could be related to status differences of young males. The lower nitrogen values could indicate a lack of meat consumption. This could suggest

that young males were in a position of lower socio-economic status and did not have access to meat resources. This status could be related to their age and sex suggesting a gendered dietary division, or could be related to occupation. Perhaps, as young male laborers or apprentices they could not afford the same resources as others in the sample.

However, it must be noted that the young male skeletons in this sample may not be representative of young adulthood for all males in the population, especially considering the mortality bias of the sample. The low nitrogen values could be associated with growth, mobility, status differences, or even metabolic stress which could have differed from the remainder of the population, thereby altered these individual's risk of dying and increasing their representation in the death assemblage (Wood et al. 1992).

Interpretation

Young males exhibited differences from all other groups in the sample. Their depleted nitrogen values did not equate with difference in carbon values. As such, their diet may have been consistent with the remainder of the population but they may have been undergoing metabolic changes due to growth that would lead to lower values. Alternatively, and equally plausible, these individuals could have migrated from another area with less elevated nitrogen values. In either case, it is clear that these individuals represent a distinct group that, for one reason or another, experienced circumstances that differed from the remainder of the population. These differences were either biological in the continuation of a period of growth, or social with the immigration to a new area. If the values were associated with migration, this could indicate a unique social position of young males as the segment of the population that moved from other areas, possibly because of labor requirements or were returned home after dying in other areas. The lack of similar findings among females suggest that females did not experience a social or

biological transition at the same times as males, possibly because of their position in the home of either their fathers or husbands with little time between.

In addition, the uniqueness of young males suggests the existence of a subgroup within the male group. This may suggest that young men represent a gendered group within males. This is because they are defined in part by sex, but their social experience changes across the life course and has real, social and biological consequences.

Status

Tomb 3 is a tomb structure located in the southeast corner of the cemetery. The two adults within the tomb, B522 and B530, exhibit nitrogen values at the upper end of the spectrum for the sample overall at +19.4‰ and +18.9‰ respectively. If a circular area is drawn in this area with the tomb as the central point, roughly 25 adult burials are circumscribed (Figure 21). Isotope values are available for 12 of these individuals plus the two individuals within the tomb. Seven are male, seven are female, with ages ranging from 22 to 60 (Figure 22).

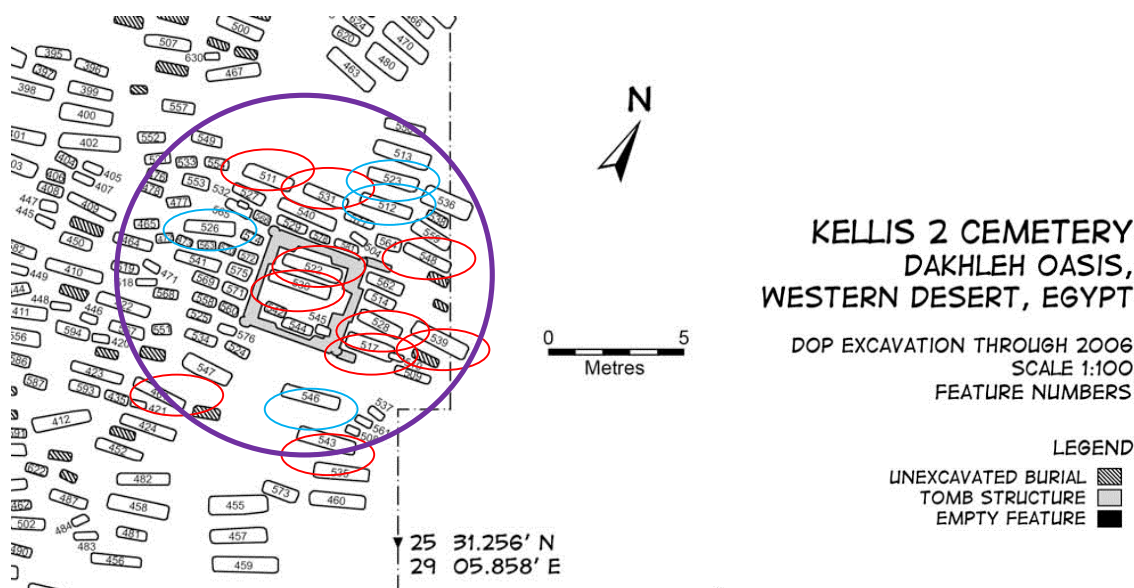


Figure 21: Distribution of samples associated with Tomb 3. Red circles indicate $\delta^{15}\text{N}$ values above the mean, blue circles indicate nitrogen values below the mean. The high mean nitrogen value of these samples could be indicative of status.

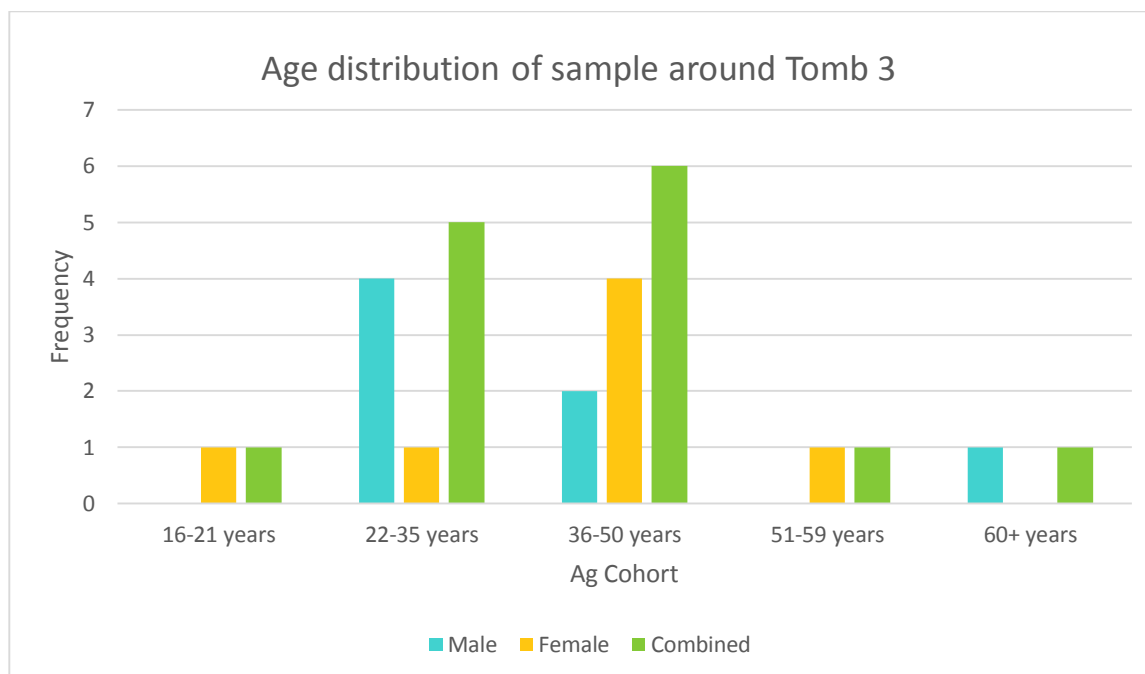


Figure 22. Age distribution of sample in and around Tomb 3.

Carbon

The mean $\delta^{13}\text{C}$ value for these 14 individuals is -18.6‰. This is not significantly different from the $\delta^{13}\text{C}$ values for the sample overall at -18.8‰ and suggests a diet similar to the overall population consuming barley at -23.3‰ with some wheat at -22.9‰ with possible additions of fava beans (-23.1‰) and figs (-23.8‰).

Nitrogen

The mean $\delta^{15}\text{N}$ value for the individuals in and around the tomb is +18.7‰ which is significantly elevated in comparison to the values for the sample overall at +17.8‰ (Table 25; Figure 23). Given a 3‰ trophic shift, food resources for this group would be expected to be +15.71‰. These values are most similar to wheat (+16.1‰), grape (+16.8‰), palm date (+14.9‰), chicken (+16.2‰), and barley (+14.4‰). However, the carbon values of grape, palm date, and chicken suggest that these were unlikely resources. As such, fig (+17.8‰), turnip

(+10.4%), and doum palm nut (+11.7%) may also be present in small quantities to alter the resulting values.

Table 25: Results of ANOVA analysis indicating differences between mean carbon and nitrogen values for those individuals near Tomb 3 and the remainder of the population (* indicate significance below the .05 level).

Dependent Variable	F Value
$\delta^{13}\text{C}$	1.390
$\delta^{15}\text{N}$	3.903*

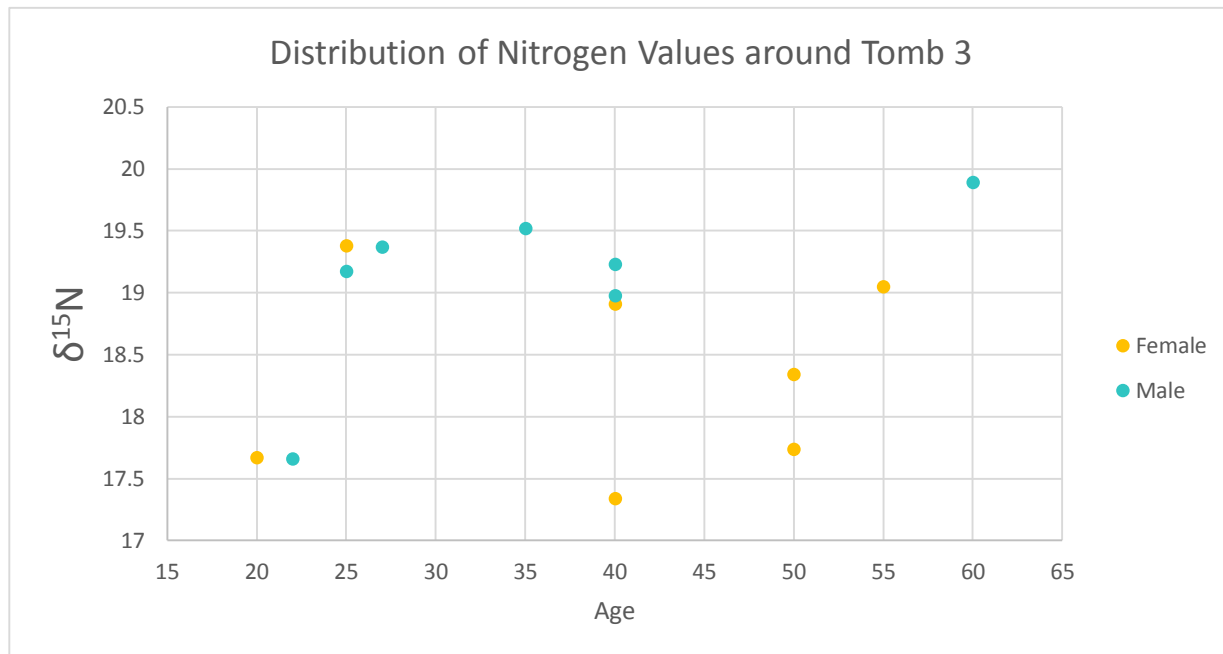


Figure 23. Distribution $\delta^{15}\text{N}$ according to age and sex for individuals in and around Tomb 3.

Although elevated nitrogen values are usually consistent with an increase of meat consumption, it may not be the case at Kellis. Instead, elevated nitrogen values, coupled with carbon values similar to the rest of the population may suggest a reliance on wheat consumption over barley with an addition of fig, turnip, and doum palm nut. Elevated nitrogen values may also be explained by chronic illness, pregnancy, or malnutrition resulting in a catabolic state $\delta^{15}\text{N}$ (Hobson et al. 1993; Katzenberg and Lovell 1999; Fuller et al. 2005; Hatch et al. 2006; Olsen et al. 2014). Migration is an unlikely explanation for elevated nitrogen values as Kellis exhibits the most elevated values in the region (Dupras and Schwarcz 2001).

Interpretation

Given the dietary shift, the location around a tomb, and the range of sex and age for this group, these individuals may represent a distinct social identity. This identity may be related to status, specifically elite status, considering the presence of tomb architecture. It is interesting to note that these $\delta^{15}\text{N}$ values are similar to the older individuals previously discussed (+18.6‰). This could reinforce the higher status of older adults in this sample.

Not everyone in the area surrounding the tomb, however, exhibited elevated values, and numerous individuals in that area have not yet been analyzed. Furthermore, the number of samples analyzed from this section is not equal to other sections, or areas around other tombs. As such, the identification of possible elevated $\delta^{15}\text{N}$ values is preliminary and further evidence and analysis would be required to support these assertions.

Outliers

A number of individuals exhibited $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ values outside the expected range for the sample and their sex.

Individual B379 is a 65 year-old male that exhibited an anomalous $\delta^{13}\text{C}$ value of -21.9‰ and an acceptable $\delta^{15}\text{N}$ value of +16.8‰. These values are consistent with the higher carbon values of older adults found in the sample. However, the depleted $\delta^{15}\text{N}$ values are not consistent with the enriched nitrogen levels found in this age group. This individual's diet displayed $\delta^{13}\text{C}$ values of -26.9‰ consistent with turnip (-25.3‰), peas (-27.7‰), garden rocket (-27.8‰), and barley (-23.3‰). The $\delta^{15}\text{N}$ values of food were 13.83‰ and is consistent with barley (+14.4‰), gazelle (+13.2‰), donkey (+13.3‰), pig (+13.3‰), goat (+13.4), and cow (13.1‰). Peas exhibit $\delta^{15}\text{N}$ values of 0.7‰ and turnip displays nitrogen values of 10.4‰. As such, a greater reliance on peas and turnips than the remainder of the old adults could account for the depletion

of the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. These foods are more often associated with domestic gardens and could indicate a greater reliance on food grown in the home.

Individual B082 is a 60 year-old female presenting a unique $\delta^{13}\text{C}$ value of -20.1‰ and a $\delta^{15}\text{N}$ value within acceptable range at +17.3‰. This individual also displayed an unhealed fracture of the right femoral neck and spina bifida occulta in the first two sacral vertebrae. This individual's food would present $\delta^{13}\text{C}$ values of -26.11‰ and $\delta^{15}\text{N}$ values of 14.31‰. These $\delta^{13}\text{C}$ values are consistent with turnip (-25.3‰), peas (-27.7‰), garden rocket (-27.8‰), and barley (-23.3‰). The $\delta^{15}\text{N}$ values are similar to fava beans (+12.2‰), gazelle (+13.2‰), donkey (+13.3‰), pig (+13.3‰), goat (+13.4), and cow (+13.1‰). Furthermore, the $\delta^{15}\text{N}$ values of turnips (+10.4‰) and barley (+14.4‰) could combine to create a $\delta^{15}\text{N}$ value similar to that represented by this individual. However, as previously discussed, the influence of long term illness or stress cannot be ruled out.

Individual B320 is a 21 year old female displaying an outlier $\delta^{13}\text{C}$ value of -17.5‰ and a high $\delta^{15}\text{N}$ value within the normal range of +18.9‰. These values would leave her diet with a $\delta^{13}\text{C}$ value of -23.5‰ and $\delta^{15}\text{N}$ value of +15.9‰. The $\delta^{13}\text{C}$ value is consistent with barley (-23.3‰), wheat (-22.9‰), fig (-23.8‰), and fava beans (-23.1‰). The $\delta^{15}\text{N}$ values of these items were +14.4‰, +16.1‰, +17.8‰, and +12.1‰ respectively. These values are consistent and suggest that this individual's diet was comprised primarily of C_3 plants including barley, wheat, fig, and fava beans. It is likely that her values are anomalous because she may have been consuming similar foods to the rest of the population in different proportions. This may have been due to access to different foodstuffs or preference for different food items.

Individual B411 is a 34 year-old female with a $\delta^{13}\text{C}$ value outside of the expected range for the sample at -17.6‰. This would suggest a carbon value of the diet at -23.6‰ which is

consistent with barley and fig. However, the $\delta^{15}\text{N}$ value is likely erroneous and so no further conclusions about the diet can be made.

Individual B267 is a 55 year-old female with a $\delta^{13}\text{C}$ value outside of range for the sample at -17.9‰ and a very high $\delta^{15}\text{N}$ value at +20.2‰. The value of this individual's diet is likely to have presented a $\delta^{13}\text{C}$ value of -23.9‰ and $\delta^{15}\text{N}$ value of +17.2‰ which is consistent with barley (-23.3‰), fig (-23.8‰), wheat (-22.9‰), and turnip (-25.3) while the $\delta^{15}\text{N}$ value is consistent with wheat (+16.1‰), fig (+17.8‰), olive (+18.8‰), grape (+16.8‰), and chicken (+16.2‰). The overlap of these results suggests that wheat and fig were the primary sources of the diet. These values are consistent with the pattern of depleted carbon values and elevated nitrogen values found among older adults in the sample. This individual is younger than that cohort and could suggest that the social age cohort of older adult started earlier than identified or that the dietary changes were only related to tooth wear and loss. The difficulties of estimating age of older adults, especially when calculating a point value, could also be responsible for errors in the age estimate. Lastly, it is possible that this individual may have experienced numerous, long term periods of metabolic stress associated with multiple pregnancies.

Individual B286 was a 17 year-old male who exhibited evidence of spina bifida occulta with a $\delta^{15}\text{N}$ value lower than the expected range for the sample at +12.9‰ but a $\delta^{13}\text{C}$ value within the acceptable range at -18.4‰. These values are consistent with the patterns seen in young males with depleted $\delta^{15}\text{N}$ values and acceptable $\delta^{13}\text{C}$ values. This $\delta^{15}\text{N}$ value is most consistent with cow (+13.1‰), goat (+13.4‰), pig (+13.3‰), donkey (+13.3‰), gazelle (+13.2‰), fava beans (+12.1‰), and barley (+14.4‰). The expected $\delta^{13}\text{C}$ value of the diet is therefore -23.8‰ and is most similar to wheat (-22.9‰), barley (-23.3‰), fava beans (-23.1‰) and figs (-23.8‰). As such, much like the other young males, this individual relied primarily on

barley and fava beans despite the fact that he experienced pathological conditions that could have altered his biological experience. This indicates that his pathological condition may not have influenced his access to food resources.

B274 was a 20 year-old male that exhibited a $\delta^{15}\text{N}$ value outside the expected range at +13.5‰ and a normal $\delta^{13}\text{C}$ value of -18.9‰. These values indicate a diet with $\delta^{15}\text{N}$ values of +10.53‰ and $\delta^{13}\text{C}$ values of -23.53‰. Turnip (+10.4‰), doum palm nut (+11.7‰), fava beans (12.1‰) are most similar to the nitrogen values but $\delta^{13}\text{C}$ values are more consistent with wheat (-22.9‰), barley (-23.3‰), fava beans (-23.1‰) and figs (-23.8‰) although turnips are a possibility (-25.3‰). The low $\delta^{15}\text{N}$ value and normal $\delta^{13}\text{C}$ value is consistent with the pattern seen among young males and suggests a reliance on turnips and fava beans.

Individual B116 was a male of 23 years with a low $\delta^{15}\text{N}$ value at +14.3‰ and a normal $\delta^{13}\text{C}$ value of -19.0‰. He has been discussed thoroughly by Dupras and Schwarcz (2001). This individual exhibited skeletal lesions consistent with leprosy, which as a chronic systemic disease could lead to enriched $\delta^{15}\text{N}$ values. The $\delta^{13}\text{C}$ value is consistent with barley (-23.3‰), fig (-23.8‰), wheat (-22.9‰), and turnip (-25.3). Although the $\delta^{15}\text{N}$ value is similar to doum palm nut (+11.7‰) and turnips (+10.4‰) these values do not match precisely, suggesting other factors may have influenced the diet of this individual. Despite the expected enrichment from a chronic disease, this individual's depleted $\delta^{15}\text{N}$ values are within the range reported from the Nile Valley (+9.2‰ to +15.1‰) and so could indicate migration (Iacumin et al. 1996)

Individual B457 was a 35 year-old male with a low $\delta^{15}\text{N}$ value of +14.7‰ and a normal $\delta^{13}\text{C}$ value of -18.7‰. The expected $\delta^{15}\text{N}$ value of the food is therefore +11.66‰ which is similar to fava beans (+12.1‰) and doum palm nut (+11.7‰). The $\delta^{13}\text{C}$ values of the food would be -23.68‰ which is consistent with barley (-23.3‰), fig (-23.8‰), wheat (-22.9‰),

fava beans (-23.1‰) and turnip (-25.3‰). Although the $\delta^{15}\text{N}$ value is still a bit lower than expected, this individual's diet likely consisted of barley, fig, and fava beans. The lower nitrogen values could be consistent with chronic systemic stress, growth, migration, or individual preference. The lack of evidence of pathology and the cessation of growth by this age coupled with the degree of bone turnover, supports migration. However, the close association between the $\delta^{13}\text{C}$ values of the individual and of the food from Kellis suggests that the individual was consuming a diet very similar to that found at Kellis. Alternatively, this individual could have been involved in repeated, short excursion as a part of trade caravans which would have resulted in a confused isotopic signature. As such, the most likely explanations are individual preferences, a pathological condition that is not recorded on the bone surface, migrated from an area with similar carbon signatures, or repeated travel to other regions.

Individual B401 was a 23 year-old female exhibiting a low $\delta^{15}\text{N}$ value of +15.5‰ and normal $\delta^{13}\text{C}$ values of -18.9‰. These values indicate a diet with a $\delta^{15}\text{N}$ value of +12.54‰ and carbon values of -23.9‰. The $\delta^{15}\text{N}$ value is similar to fava beans (+12.1‰) doum palm nut (+11.7‰), barley (+14.4‰), gazelle (+13.2‰), donkey (+13.3‰), pig (+13.3‰), goat (+13.4), and cow (+13.1‰). The carbon values barley (-23.3‰), fig (-23.8‰), wheat (-22.9‰), fava beans (-23.1‰) and turnip (-25.3‰). Although the $\delta^{15}\text{N}$ value is outside of the range for females, it is within the male range and together with the $\delta^{13}\text{C}$ value suggest a diet consisting of barley and fava beans. This could suggest, given the gracile nature of the Kellis population, that this individual's sex was improperly estimated. However, if this individual was biologically female, the stable isotope results indicate a diet is similar to that consumed by young males and could suggest that this individual was facing a similar social experience as that group, because of access to resources, status differences, occupational patterns, or social identity. Alternatively, the

depleted $\delta^{15}\text{N}$ values could be indicative of migration. If this individual had lived in a less arid area and consumed food with depleted $\delta^{15}\text{N}$ values, the signature of that experience could remain in her bone collagen stable isotope values. If this is the case, her $\delta^{15}\text{N}$ value is similar to that reported from the Nile valley at 9.2‰ to +15.1‰ (Iacumin et al. 1996).

Interpretation

Although a number of outliers were present in the sample, their diets, on the whole were similar to the population or the age or sex subgroup to which they belong. The majority of the variation could be accounted for by differences in the proportion of certain foodstuffs rather than in the type of food resources consumed. However, a few individuals exhibited values suggestive of migration, unique social identities, or pathological conditions.

Summary

The investigation of stable carbon and nitrogen isotopic values in a sample from the Kellis 2 cemetery revealed nuanced patterns in lived experience across the population. Unexpectedly, males and females did not exhibit significant differences in mean carbon or nitrogen isotopic values suggesting a similarity in access to food resources. However, a slight difference in standard deviation suggests that males may have had access to, or come into contact with, more diverse foodstuffs. The oldest segments of society exhibited carbon values significantly different from the rest of the population to suggest that they were experiencing physiological changes or dietary changes associated with dental pathological conditions. Their avoidance of illness and weaning foods suggests a preference for wheat that could be associated with their elevated status. Gendered age differences were revealed in nitrogen values with young males exhibiting significantly depleted values likely associated with migration, although the effects of growth cannot be ruled out. Lastly, individuals associated with Tomb 3 display

elevated nitrogen values which could indicate greater access to meat products and wheat which could be indicative of status differences. The identification of these patterns highlights the existence of differences in diet, health, and mobility, across the population which could be associated with variation in biological, and possibly social, experiences.

CHAPTER 7: CONCLUSIONS

Stable carbon and nitrogen values from the individuals interred in the Kellis 2 cemetery indicate a diversity of lived experiences. In general the sample here consumed a diet reliant upon C₃ plants, primarily wheat and barley with the addition of some animal protein in the form of meat from pigs and goats. Most individuals consumed this general diet, although the proportion of wheat, fig, fava beans, or meat differed across the sample.

No notable differences in stable carbon and nitrogen isotope values between males and females existed. While this could suggest that sex differences were not socially meaningful, a more likely explanation is that for the majority of the population, biological sex did not limit their access to food resources, especially for those that were married or part of a family. This is supported by the findings that female values were less diverse than male values. It is possible that females were more often part of a home either as daughters or wives and so their diet was predetermined by the social position of their family. Conversely, males, and young males especially, may have occasionally worked as apprentices or laborers outside of the household at certain ages which could have led to differential access to resources at different stages in their lives.

Stable $\delta^{13}\text{C}$ isotope values of older people were significantly depleted from other age groups, suggesting that the age category of 60+ years was a biologically or socially meaningful life stage. These individuals may have consumed more wheat, fig, and turnip but were likely still consuming a large portion of barley. This shift in diet was likely a result of dental pathology but could also suggest a high status of this age group in that they were not likely constrained to usual illness foods but were afforded these more valued foodstuffs.

A further source of significant variation identified in subgroups of age and sex with young adult males exhibiting significantly depleted nitrogen values in relation to the remainder of the sample. The most likely explanation is the movement of members of this group from a region with less elevated nitrogen values, possibly as part of apprenticeships. The identification of the biological and social significance of this group and a subgroup within sex and age suggests that it may represent a gendered group of young men.

Additionally, a number of individuals exhibiting elevated $\delta^{15}\text{N}$ values are associated with the area surrounding Tomb 3. These individuals were likely consuming more wheat, fig, and turnip. However, given the gaps in and uneven nature of the sample further evidence would be required to support the assertion that these individuals may represent a group of higher status.

The outliers present in the sample consumed diets that were not drastically different in type from that of the rest of the population. Instead, these individuals likely consumed the same or similar foodstuffs in different proportions from the remainder of the sample. A few individuals may have been migrants or experienced a unique social position.

Limitations

Although patterns in stable carbon and nitrogen values were present in the sample, the interpretations of such patterns were limited by the nature of the data and the sample under investigation. Firstly, stable isotope values are indirect proxies for diet, health, and migration and therefore lived experiences. These values can be influenced by innumerable other variables and so must be interpreted with caution. Furthermore, the rate of turnover in adult bone collagen is still unknown and so the period of time reflected by stable isotope values is uncertain as well.

The nature of the sample available for analysis also accounts for some limitations of the findings. The sample is not evenly dispersed across the cemetery, leading to concern about

effects of microenvironment on contamination and raising doubt on any discussions of spatial organization. Furthermore, as is the case in any cemetery sample, the samples were not evenly distributed across all age groupings. The small sample size of young males and older people do raise uncertainty about the validity of the interpretations of this study although the low standard error in each case lends credence to the findings.

While the distribution of the sample complicates statistical analysis, it is consistent with the expectations of samples recovered from cemeteries and likely, accurately represents the age distribution of the cemetery overall (Figure 24). This is because not everyone in the population faced the same risks or experienced the same susceptibility to risk, especially not at the same time. Therefore, the distribution of the sample can reveal information about the experience of risk, but this is biased to those that succumbed to death at any particular age (Wood et al. 1992).

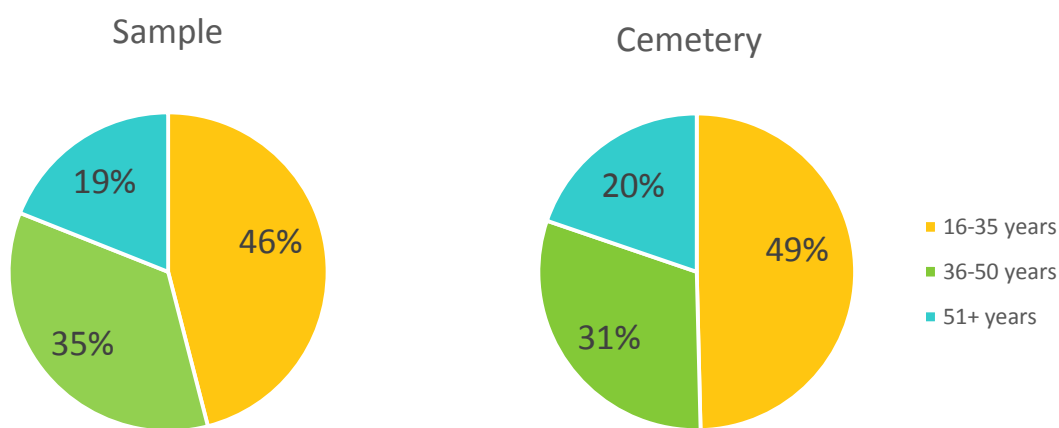


Figure 24. Comparison of age distribution between sample under investigation and total individuals excavated from the Kellis 2 cemetery as of 2011.

Juveniles were not analyzed in this study because they could not be reliably assigned a to biological sex category. Excluding this subgroup limited the ability to track changes over time, especially in the effects of growth on young male nitrogen values. Lastly, assigning an age point

value to individuals was necessary for the sake of statistical analysis; however, it did simplify the difficult and imprecise task of age estimation, especially among older people.

Future Directions

Further research of stable isotope values from Kellis 2 is necessary to validate and support the assertions put forth in this study. Ideally, more samples from all over the cemetery, especially of young males and older people would be analyzed to ensure that the significant differences found are valid. This should be possible given the remainder of individuals previously excavated that have yet to be sampled for stable isotope analysis (Dupras et al. 2016). However, it could inadvertently skew the sample towards these cohorts if they are not present in large numbers to begin with (Wood et al. 1992). Furthermore, the analysis of carbon and oxygen from carbonate could offer further insight into the patterns proposed here. Specifically, it could offer more information about bulk diet and the origin of possible migrants.

Developments in the ability to accurately determine the biological sex of infants and juveniles could reveal a plethora of new information about dietary patterns at the site in relation to sex, age, and gender. Future research could also examine similar patterns in earlier cemeteries in Kellis to determine if the patterns identified were associated with Roman rule. Further research employing other forms evidence should also be carried out to examine the social position of older adults in ancient Egyptian, and specifically Romano-Christian society in Egypt. Lastly, comparison with other samples from Egypt and elsewhere could reveal if the depleted nitrogen values found with young males is a biological or social phenomenon.

Implications

The study has revealed that young males and older adults in this part of Roman Egypt were experiencing different lived experiences than other groups. This is significant in that it may suggest meaningful age or social groups that were important in organizing society at the time and may be relevant to other samples. Furthermore, the success of the social age classification scheme in identifying variability in the sample underscores the validity of this approach in the analysis of individuals from Roman Kellis, and suggests that it should be applied in future study.

Furthermore, this study attempted to examine social and biological meaningful groups in ancient Kellis through the analysis of traces of lived experiences left on bone, namely stable isotope values. This approach is not new, but is a valuable one as it limits the effects of bias introduced from material culture or literary sources and has not been widely implemented. The success of this study indicates the potential of wider application of such an approach.

Additionally, the application of rigorous, statistical examination of stable isotope across different biological and social categories to explore socially meaningful categories through the analysis of values is a valid method that should be applied more broadly in bioarchaeology. It provides an especially useful additional source of information in addition to material culture or literary sources. Approaching stable isotope values as traces of lived experiences is also not new, but has been employed thoroughly in this study, underscoring the utility and validity of such an endeavor.

Conclusion

The application of stable isotope analysis as a proxy for lived behavior written on bone revealed patterns of experience among the Kellis 2 cemetery sample. It revealed a population with access to largely similar foodstuffs although quantities likely differed. Young males and

older adults represented distinct groups based on their biological and possibly social experiences. These findings suggest meaningful social groupings that may provide a starting point for the analysis of wider social structures or comparison with other societies. Additionally, this unique approach underscores the utility of stable isotope values as a proxy to understand individual experience and social identity in other places and times.

APPENDIX: STABLE ISOTOPE DATA

Table 26: Bone collagen isotopic data for samples from the Kellis 2 cemetery. ¹ indicates samples run by Dupras (1999) ² indicates samples prepared by the author. The remainder were prepared at the University of Central Florida

Sample ID	sex F/M	Age	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	C:N Ratio
B002	F	25	-18.5	17.3	2.87
B004	M	50	-17.9	17.9	2.83
B005	F	55	-18.7	18.1	2.84
B006 ²	M	29	-18.6	17.1	3.17
B008	F	72	-18.9	19.1	2.84
B016 ²	M	29	-18.9	17.7	2.81
B019	F	45	-18.7	19.0	2.84
B020	F	55	-18.6	17.9	2.85
B021	F	45	-18.8	17.5	2.85
B022	F	22	-18.5	19.7	2.87
B025	F	19	-18.6	17.6	2.81
B026	F	19	-18.7	18.0	2.81
B027	F	30	-18.7	16.8	2.8
B059 ¹	M	45	-18.6	16.7	3.2
B060 ²	M	37	-18.9	17.7	3.17
B068 ¹	F	30	-18.9	19.2	2.8
B069 ¹	M	29	-18.5	19.4	2.84
B072 ¹	F	65	-18.9	20.2	2.8
B076 ¹	F	50	-18.8	18.0	2.82
B079 ¹	M	55	-18.9	17.9	2.83
B080 ¹	F	50	-18.9	18.3	2.84
B081 ¹	M	40	-18.7	18.1	2.83
B082 ¹	F	60	-20.1	17.3	3.363
B085 ¹	F	48	-19.4	18.4	2.88
B087 ²	M	70	-18.9	17.9	2.81
B091 ¹	F	55	-18.8	18.4	2.8
B093 ¹	M	23	-18.8	17.4	2.8
B107 ¹	M	27	-18.8	19.4	3.3
B111 ¹	M	37	-18.8	16.2	3.2
B116 ²	M	23	-19.0	14.3	3.16
B124 ²	M	30	-18.8	18.6	3.16
B131 ¹	F	23	-19.2	18.0	3.5
B132 ¹	M	19	-19.0	16.3	3.2
B138 ¹	M	46	-18.7	17.9	2.85
B139 ¹	M	29	-18.4	16.7	2.82
B159 ¹	M	20	-19.0	19.0	3.2
B168 ¹	F	19	-18.9	16.8	3.4
B170 ¹	F	26	-19.3	18.0	3.4
B177 ¹	F	55	-18.9	16.8	3.5
B190 ¹	F	19	-19.1	17.9	3.5
B211 ¹	M	50	-19.1	17.2	3.4
B228 ¹	M	35	-18	18.3	2.85
B242	M	25	-17.9	18.4	2.95
B250	M	45	-18.8	18.5	2.84
B251B	M	61	-18.3	18.8	2.84

Sample ID	sex F/M	Age	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	C:N Ratio
B253	M	20	-19.0	7.9	2.86
B254	F	31	-18.2	18.7	2.82
B257	F	19	-18.6	19.8	2.86
B259	M	44	-19.1	20.5	2.79
B262	M	23	-18.5	17.8	2.81
B264	M	23	-18.4	18.4	2.86
B265	M	50	-18.5	19.5	2.79
B266	F	55	-18.9	17.5	2.78
B267	F	55	-17.9	20.2	3.07
B268	M	23	-18.7	18.3	2.81
B271	F	31	-18.5	19.6	2.82
B274	M	20	-18.9	13.5	2.82
B275	F	55	-18.7	18.0	2.89
B279	F	23	-19.1	18.5	2.91
B280	F	60	-18.6	19.2	2.86
B281	M	60	-18.8	18.9	2.85
B282	F	27	-18.9	18.0	2.81
B283	F	55	-18.7	18.2	2.82
B284	F	33	-18.7	18.3	2.83
B285	F	19	-18.7	19.8	2.88
B286	M	17	-18.3	12.9	2.84
B289	F	34	-19.1	17.5	2.84
B291	F	50	-18.5	17.7	2.84
B293	M	45	-17.9	15.9	3.19
B294	F	45	-18.5	18.3	2.85
B300	F	60	-18.8	18.1	2.9
B301	M	19	-18.6	17.4	2.9
B303	M	23	-18.5	18.3	2.86
B305	M	29	-18.4	18.2	2.83
B306	F	65	-19.0	19.7	2.84
B307	F	23	-18.8	18.9	2.85
B308	M	35	-18.5	17.1	2.84
B309	M	32	-19.1	18.1	2.85
B310	M	21	-18.8	18.5	2.84
B312	F	37	-18.7	17.6	2.82
B320	F	21	-17.5	18.9	2.7
B379	M	65	-21.9	16.8	2.96
B380	M	38	-18.3	17.4	2.81
B385	M	27	-18.8	18.9	2.85
B388	M	45	-19.0	18.8	2.8
B400	F	23	-19.1	18.3	2.8
B401	F	23	-18.9	15.5	2.85
B402	M	29	-18.8	18.2	2.85
B410	F	25	-18.9	18.5	2.85
B412	M	51	-19.1	8.3	2.83
B414	M	55	-18.7	18.1	2.8
B415	F	40	-18.9	16.8	2.83
B417	F	27	-18.9	16.8	2.79

Sample ID	sex F/M	Age	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	C:N Ratio
B423	F	23	-19.1	19.2	2.81
B425	F	40	-18.9	18.7	2.78
B426	M	27	-19.1	18.6	2.78
B434	F	33	-18.5	18.0	2.81
B437	F	40	-18.7	19.2	2.8
B440	F	20	-18.7	19.4	2.8
B441	F	25	-18.8	17.4	2.93
B452	F	60	-19.2	16.9	2.88
B453	M	38	-18.5	16.7	2.75
B455	M	40	-18.2	18.1	2.84
B456	F	30	-18.7	17.7	2.73
B457	M	35	-18.7	14.7	2.75
B459	F	55	-19.2	16.7	2.79
B460	F	25	-19.2	18.2	2.76
B461	M	40	-19.1	19.2	3.39
B463	F	35	-19.0	18.7	2.78
B466	M	35	-18.8	17.7	2.94
B467	F	55	-19.2	17.8	2.81
B469	M	38	-18.4	14.9	3.13
B470	F	50	-19.4	18.8	3.16
B474	F	33	-18.8	18.2	2.8
B475	F	35	-18.5	17.8	2.73
B482	M	45	-18.9	17.6	2.75
B486	F	33	-18.7	16.7	2.74
B488	M	50	-18.7	18.1	2.97
B491	F	40	-18.8	18.7	2.75
B496	F	22	-19.1	17.5	2.79
B500	F	45	-18.8	18.2	2.74
B506	F	25	-19.2	18.9	2.79
B511	F	25	-18.8	19.4	2.8
B512	M	22	-18.6	17.7	2.76
B517	M	60	-18.3	19.9	2.75
B522 ³	M	27	-18.6	19.4	3.27
B523	F	20	-18.8	17.7	2.87
B526	F	40	-19.2	17.3	2.73
B528	F	55	-18.8	19.1	2.81
B530	F	40	-18.5	18.9	2.78
B531	M	35	-18.4	19.5	2.82
B535 ²	M	35	-19.4	17.4	3.17
B539 ²	M	40	-17.8	18.9	2.8
B543 ²	M	25	-18.7	19.0	3.16
B546	F	50	-18.6	17.7	3.15
B548	F	50	-18.8	18.3	2.83

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