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FRUITS in Dakhleh: Isotopic and Bayesian Mixed-Model Reconstruction of Food Source Contributions and Diet at Kellis 2 Cemetery, Dakhleh Oasis, Egypt

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FRUITS IN DAKHLEH: ISOTOPIC AND BAYESIAN MIXED-MODEL RECONSTRUCTION OF FOOD SOURCE CONTRIBUTIONS AND DIET AT KELLIS 2 CEMETERY, DAKHLEH OASIS, EGYPT

by

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ABSTRACT

This thesis applies a new methodology to dietary reconstructions of a unique population excavated from Kellis 2, a Romano-Christian era (c.50-450 AD) cemetery located in the ancient city of Kellis, Dakhleh Oasis, Egypt. Previously, stable carbon and nitrogen isotope analyses were conducted on bulk hair keratin from 216 individuals to examine their dietary practices and health status. Although this research identified the presence of specific dietary choices in the community, the researchers were not able to determine what fraction of the diet was composed of those resources. This is the first such study to use *a priori* dietary reconstruction data in combination with the Bayesian mixing-model *Food Reconstruction Using Isotopic Transfer Signals* (FRUITS) to quantify the contributions various food groups make to a diet of age groups within this community. Combining paleodiet stable isotope analysis with FRUITS modeling provides an opportunity to predict and evaluate percentages of food groups consumed in previously identified dietary and social practices, such as weaning, and dietary dynamics between adult males and females and during aging. When C_3 plants, C_4 plants and protein sources were evaluated, FRUITS modeling confirmed that juvenile weaning began around 6 months of age at which time the addition of herbivore dairy and cereal grains were added to their diet. Younger aged adults (~15-35 years) ate a common omnivorous diet with no discernable differences between males and females, while elderly individuals (+50 years) appear to transition to a diet with greater emphasis on protein. The use of FRUITS modeling in this study has added greater clarity to previously identified food practices at Kellis 2 and demonstrated the applicability of this method on archaeological samples when investigating food group quantification and dynamics of diet resources within an ancient community.

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All my love.

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CHAPTER ONE: INTRODUCTION

Bioarchaeologists commonly explore the diet and health of past peoples by analyzing their remaining tissues through biogeochemical analyses. Advances in technology and methodology have enabled bioarchaeologists to delve deeper into stable isotopic analyses by gaining greater insight into the relationships between dietary resources and the isotopic ratios of consumer diets in past populations diet, thereby addressing questions related to health, social status, agricultural seasonality, and life history (Reitsema, 2013).

Studies about ancient Egypt play an important role in providing information on how agricultural and cultural development interact to affect biology during this time period. Much of what is known about ancient Egypt is based on literature relating to pharaonic activities, art, and the archaeology of tombs and remains of those with higher social status, but less is known about the everyday life and diet of non-elite populations living under Egyptian dynastic and Roman provincial rule. This study aims to fill in some of the missing discourse regarding the lives of common men, woman, and children living and working in Roman Egypt during a transitional period in their history.

Dietary experiences within the ancient village of Kellis, now known as Ismant el-Kharab, can offer insight into the changes that were taking place in the Dakhleh Oasis, Egypt during the transition from the Graeco-Roman Period to the Romano-Christian Period, circa C.E. 1-400 (Bowen et al, 2005; Bowen, 2007). Additionally, resulting data from this population can be used to infer dietary differences among various groups of individuals (e.g. women and men, juveniles and the elderly). The proposed study will employ relatively new and accepted methodologies in

stable isotope analysis using the stable nitrogen (δ^{15}N) and stable carbon values (δ^{13}C) of the Kellis individuals and their food resources to explore dietary patterns and food source contributions between and among groups.

Food Reconstruction Using Isotopic Transfer Signals (FRUITS; Fernandes, 2014) is a Bayesian mixing-model that can incorporate prior information about the dietary choices of past people and combine it with isotopic signals sampled from the remains of humans, plants, and animals. This is considered a pilot study, with emphasis being placed on methodological accuracy and the use of this model in a new environment and location rather than on the accuracy of results, although results will be explored and will dictate future research opportunities. This study will use results gathered from samples analyzed in previous dietary research (Dupras, 1999; Williams, 2008) and extrapolate it using FRUITS to visualize the percentages of specific foods in an individual's diet. The large amount of data available from this location makes it an ideal site for FRUITS testing. Isotopic values from hair keratin of 216 individuals from the Kellis 2 cemetery (Dupras, 1999: Williams, 2008) were specifically chosen as the sample pool for analysis using FRUITS program software. Historical accounts taken from The Kellis Agricultural Account Book (KAB) (Bagnall, 1997) and a menu of food items (Dupras (1999) generated from this historical record were utilized to choose food source information as the basis for FRUITS analysis. The research questions directly addressed in this study are:

1. What were the common dietary choices and preferences of this population?
2. Do food choice contributions derived from FRUITS analysis agree with previously accepted interpretations of dietary differences between adult sex and age groups?
3. What was the preferred diet fed to infants and weaning children, and is this preference reflected in the diet choices of reproductive-age women as well as the fetal age group?
4. Do individuals with discernably different diet choices provide us with a greater level of information about health, aging and general social structures of the time period?

The value of this research is threefold. First, original data derived from isotopic analyses and FRUITS are developed and examined together for the first time in this population. These data are useful as a framework in addressing residual questions concerning dietary choices and preferences for the majority of those interred within the Kellis 2 cemetery. Second, results of this study will include the probable percentages of types of foods being consumed (plants and proteins) as well as any FRUITS output values of food source contributions that may be indicative of health concerns and local practices. This information is essential to understanding the impact of dietary contributions during this time of transition in the Kellis community, and therefore, should provide a more complete picture of food choices/availability during this time period. Third, the method used in this research emphasizes the need for refining information derived from isotopic analyses in conjunction with biological and demographic data when evaluating similarities and differences in diet among population groups.

CHAPTER TWO: LITERATURE REVIEW

This chapter provides a brief overview of stable isotope analysis and its value when reconstructing diet and evaluating nutritional stress. Additionally, a brief historical background of the FRUITS statistical method used in this study is included. Following this is a summary of the physical properties of hair and its use as a tissue in isotopic studies pertaining to diet. Some pertinent limitations of isotopic analyses from archaeological populations concludes this chapter.

Definition and Function

The nucleus of an atom contains positively charged protons and neutrons, which are neutral, and negatively charged electrons. The atomic number of an element is derived from the number of protons it contains and this number is how an element is typically identified. In an electrically neutral atom, there will be an equal number of protons to electrons. Neutrons, while electrically neutral, have the same mass as protons, thereby affecting the mass of the atom without affecting the charge. Should an atom differ in the number of neutrons to protons, an elemental isotope is created (Pollard et al., 2007). Stable isotopes do not decay over time but rather remain constant within the organism. The stable isotopes of carbon (C) and nitrogen (N), the elements considered in this study, are listed in Table 1 along with their environmental abundance.

Naturally occurring variations in isotopic mass can result in slightly different physical and chemical properties (Katzenberg, 2008; Pollard et al., 2007; Tykot, 2006). An example of this can be seen in the amounts of ^{12}C and ^{13}C in an organism (e.g. plants, animals) relative to

Table 1. Carbon and nitrogen isotopes with relative terrestrial abundance.

Element	Isotope	Abundance (%)
Carbon	^{12}C	98.89
	^{13}C	1.11
Nitrogen	^{14}N	99.63
	^{15}N	0.37

that of atmospheric carbon dioxide (CO_2). Atmospheric CO_2 supplies both ^{12}C and ^{13}C to terrestrial plants and both forms are used in photosynthesis to produce carbohydrates, proteins, and lipids. The lighter the element form is, the faster the photosynthetic reaction, and this results in an enriched level of ^{12}C known as isotopic fractionation. The plants are then consumed by organisms, which appropriate these compounds into their tissues, resulting in a reverse fractionation where enrichment of the heavier ^{13}C occurs within the consumer's tissue (Tykot, 2006). According to Katzenberg (2008:416) isotopic fractionation "is the basis for stable isotope variation in biological and geochemical systems." Instead of being reported as ratios (e.g., $^{13}C/^{12}C$), isotope abundance is reported relative to international standards using delta (δ) notation because of their slight variation. The resulting isotope values are measured in parts per mil (‰**)**:

$$^{13}C \text{ (‰ or per mil)} = [\{(\text{sample } ^{13}C/^{12}C) / (\text{standard } ^{13}C/^{12}C)\} - 1] \times 1000$$

This same equation is used for reporting nitrogen ($^{14}N/^{15}N$). The agreed upon standards for these elements consist of atmospheric nitrogen (AIR) as well as the Vienna Peedee belemnite (VPDB) raw values calibrated using the National Bureau of Standards (NBS) 19 reference sample. Previously the South Carolina Peedee Formation *Belemnitella americana*, a Cretaceous marine fossil sample, was used as reference standard for carbon, however, the original material is no longer available resulting in use of the VPDB (Lambert, 1997; Pollard et al., 2007; Tykot, 2006).

Application of Carbon and Nitrogen Isotopes

Studies of stable isotopes have been ongoing since carbon variations and radiocarbon dating was discovered in the early 20th century, and by mid-century carbon studies were being used in archaeological contexts to study ancient diet (Katzenberg, 2008; Tykot, 2006). While at this time there was a known difference in the photosynthetic pathways of C_3 and C_4 plants, it was not until 1970 that this difference was known to create variation in carbon ratios. The first skeletal testing of isotopic values representing this variation (van der Merwe and Vogel, 1978) concluded that an Iron Age Khoi skeleton from South Africa had a dietary dependence on C_4 plants (Katzenberg, 2008; Tykot, 2006). Following this, Vogel and van der Merwe (1977) demonstrated the intense impact maize agriculture had on isotope values in human tissues, leading to a better understanding of how agriculture affected diet in North America (Tykot, 2006). Studies by van der Merwe, Roosevelt, and Vogel (1978; 1981; 1982) on the impact of maize in other geographic regions quickly followed, highlighting the importance of having regional baselines for both plants and animals due to variations in environment and climate (Tykot, 2006). Similar studies continued throughout the 1980s and 1990s, identifying regional agricultural patterns of maize, comparing collagen extraction methods, as well as testing a population's reliance on marine resources (e.g., Bender et al., 1981; Buikstra and Milner, 1991; Katzenberg et al., 1995; Larsen et al., 1992; Schurr and Redmond, 1991).

Studies involving nitrogen isotopes added to the understanding of how the environment can impact isotopic values as well as the importance of understanding trophic levels in both a marine and terrestrial ecosystem. Referred to as the trophic-level effect, nitrogen levels reveal through an organism's protein intake the position of the organism in the food-web. Experiments in controlled animal feeding identified this relationship between dietary stable isotope ratios and

consumer tissue, revealing that with each terrestrial trophic level comes a 2-3‰ enrichment in nitrogen isotope ratios while trophic levels in a marine environment may be enriched as much as 9‰. (DeNiro and Epstein, 1981; Schoeninger and DeNiro, 1984). The approach of studying carbon and nitrogen isotopes to understand past dietary habits continues to be an effective tool when working in archaeological contexts.

Carbon Isotopes

Plants obtain carbon directly from atmospheric CO^2 during photosynthesis. This carbon bonds with the carbon already within the plant and isotopically fractionates, but this process varies depending on the plant in question (Lambert, 1997). Table 2 lists the three major categories of plants currently used in stable isotope analyses.

The first category is referred to as C_3 plants due to their conversion of CO^2 to molecules containing three carbon atoms and includes trees, woody shrubs, and most grasses from temperate environments. Their $\delta^{13}C$ signatures range from -33‰ to -22‰, typically averaging

Table 2. Average $\delta^{13}C$ values for C_3 plants, C_4 plants, and consumers.

Photosynthetic Pathway	**Plants in Category**	**Dietary Choices**	**$\delta^{13}C$ in Plant Source**	**$\delta^{13}C$ in Consumer Animal**
C_3	Trees, shrubs, temperate grasses	Wheat, rice, nuts, tubers, beans, most fruits and vegetables	-26‰	-21‰
C_4	Subtropical grasses	Millet, maize, sorghum, sugarcane	-12‰	-7‰
*CAM	Succulents, cacti	N/A	N/A	N/A
Mixed	Any	Any	Intermediate	Intermediate

Derived from DeNiro, 1987 and Lambert, 1997. *Not included in study

-26‰ (DeNiro, 1987; Lambert, 1997). Dietary resources that are considered C_3 plants include wheat, rice, nuts, tubers, beans, and most fruits and vegetables. The second category is referred to as C_4 plants due to their conversion of CO^2 to molecules containing four carbon atoms and includes grasses from sub-tropical climates with higher temperatures and greater sun exposure. Their $\delta^{13}C$ signatures range from -16‰ to -9‰, typically averaging -12‰ (DeNiro, 1987; Lambert, 1997). Dietary resources that are considered C_4 plants include millet, maize, sorghum, and sugarcane. The third category is referred to as Crassulacean acid metabolism (CAM) plants and includes cacti and succulents, but these will not be considered in this study as they rarely contribute to past diet and were not a resource available to the study population.

The three groups are distinguished by their significant differences in the ratios of ^{13}C to ^{12}C they contain, and this pattern continues as trophic levels increase up the food chain. Collagen within animals that consume these plants reflect the $\delta^{13}C$ signatures of said plants with the addition of +5‰, which is due in part to the fractionation effect between consumed diet and collagen production (Lambert, 1997).

Nitrogen Isotopes

Nitrogen found in tissues originates from a variety of dietary and environmental sources, but primarily it is a biomarker of dietary protein. Plants source nitrogen (N_2) directly from the atmosphere as well as from nitrates found in the soil, and it is this consumption of N_2 from multiple sources that explains why most plants have $\delta^{15}N$ values that are more enriched than the atmosphere, which is valued at 0‰ (Katzenberg, 2008; O'Brien, 2015; van Klinken et al. 2000). The majority of plants are found to have $\delta^{15}N$ values between +3‰ and +10‰. However, there are terrestrial nitrate fixating plants (e.g., alfalfa, peas, beans), many of which are found in the

diet, that, due to an absence of fractionation effects, have values close to 0‰, similar to that of the atmosphere. Much like with carbon, an increase in trophic level creates an increase in the δ^{15}N values of an organism. Herbivores have δ^{15}N values around +9‰ to +13‰ and carnivores +13‰ to +16‰. It should be noted that there is a slow yet constant turnover rate for consumers body proteins, such as collagen, which gives rise to this "trophic level effect" (DeNiro and Epstein, 1981; Hedges and Reynard, 2007). Also, water, which has been isotopically enriched from dissolved nitrates, can cause marine plants and consumers to exhibit more positive nitrogen values (Ambrose, 1991; Katzenberg, 2008; Lambert, 1997; O'Brien, 2015; Schoeninger, 1995). Figure 1 displays a summary of average δ^{15}N values for plants and animals.

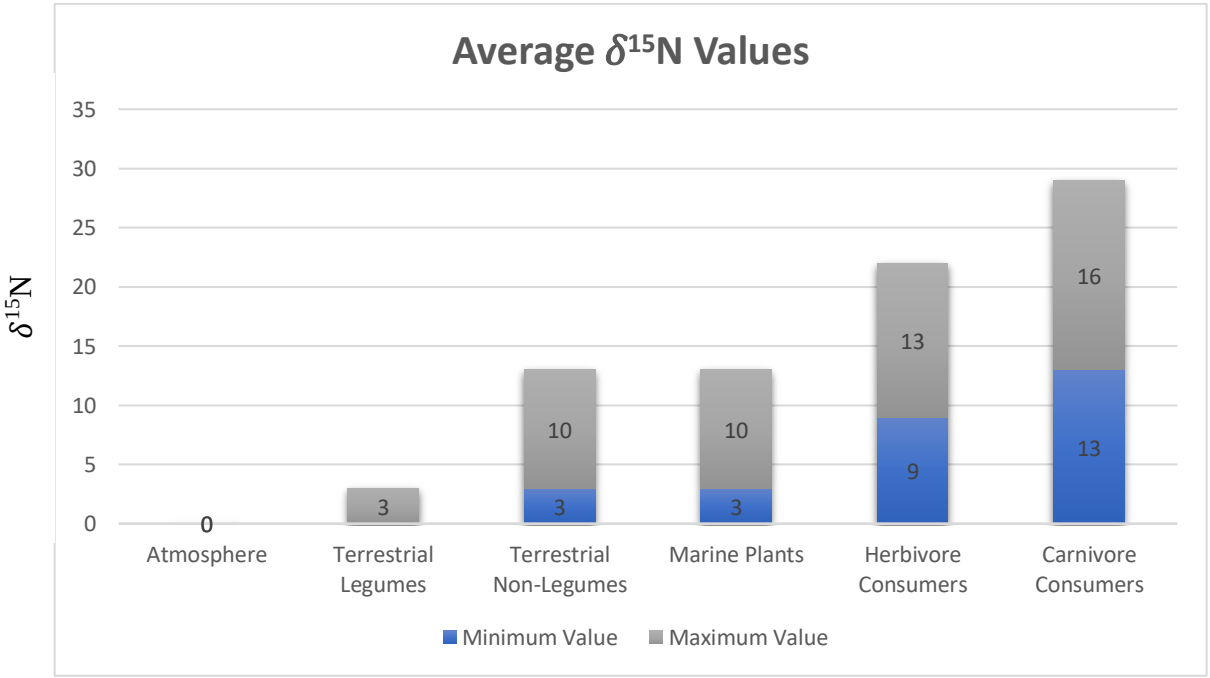


Figure 1. Average N values for plants and consumers show an increase by trophic level, maximum and minimum values present. Marine consumer values not included in this figure due to extensive variation in representative values. Figure derived from Lambert, 1997.

Nitrogen isotopes have been used to examine the variations in marine vs. terrestrial diets (e.g., Schoeninger and DeNiro, 1984; Walker and DeNiro, 1986; Sealy and van der Merwe, 1988); however, nitrogen values can also tell us much about the lifeways of the individual and reflect the location they resided. They can denote environmental or physiological stressors such as climate, water, or protein stress that may increase normal levels (Lambert, 1997; Pollard et al., 2007). Hot and arid environments result in nitrogen levels potentially indicating large variation in elevation. Heaton (1986) researched the relationship δ^{15}N has with rainfall, with values increasing as aridity increases, making dry and desert areas prone to higher values. Aufderheide et al. (1988) further supported this study with sample groups from the Atacama Desert in Chile, where individuals living in more arid climates had higher δ^{15}N values. A more recent study (Schwarcz et al., 1999) identified enriched nitrogen values in plants and also in animal and human bone collagen samples originating from three desert locations including the Dakhleh Oasis in Egypt. The authors suggest higher values at increased soil depths in arid environments may be the cause of this enrichment in nitrogen. These results confirmed earlier studies stating that consumers at all trophic levels are affected, with enriched nitrogen values seen in those experiencing drought effects in extreme aridity over those in more temperate environments with reliable water sources (Ambrose and DeNiro, 1987). Concurrently, physiological water conservation is an adaptation that occurs in such dry environments resulting in excretion of urea that is nitrogen depleted in order to increase osmolality of urine, and as a consequence, body tissues can become ^{15}N enriched (Ambrose and DeNiro, 1986; Dupras and Schwarcz, 2001; Williams, 2011).

Nitrogen Response to Pathological Conditions and Nutritional Stress

Alternative explanations for nitrogen level variances have been assessed in studies utilizing stable isotope analysis, offering ways to assess health in past populations. For example, nutritional stress related to the human condition comes in multiple forms (e.g. pregnancy and morning sickness, eating disorders, pathological conditions), not all of which relate to eating habits.

Nitrogen levels are highly variable and answers to questions pertaining to the relationship between δ^{15}N enrichment and protein intake are of particular interest. There are two current perspectives: high protein intake resulting in δ^{15}N enrichment (Pearson et al., 2003; Sponheimer et al., 2003) and protein deprivation resulting in nitrogen enrichment (Robbins et al., 2005). Both of these scenarios are due to ^{15}N depleted nitrogen being excreted in urea as a by-product of protein metabolism. This depletion results in higher ^{15}N values in remaining tissue. According to Hedges and Reynard (2007:1241), "the disagreement arises as to whether increased protein in the diet results in more or less protein metabolism and urea production, thus changing the ^{15}N enrichment." The results from these studies come from controlled animal feeding experimentation, demonstrating that animal studies are one major avenue of research in understanding nitrogen variability.

Katzenberg and Lovell (1999) discuss the three conditions of nitrogen balance that are important when understanding the body's cyclical response to nitrogen intake and excretion. Positive nitrogen balance occurs when new tissue is forming, more nitrogen is being ingested than excreted and trophic enrichment due to diet is expected. When nitrogen equilibrium is experienced in healthy adults and protein is being maintained, the ingestion amount reflects the excretion amount and any additional dietary protein would be noticeable. During negative

nitrogen balance the body is undergoing stress and tissue loss, with less nitrogen being ingested than excreted, resulting in the bodily catabolism of the amino group. The lighter ^{14}N is excreted leaving behind ^{15}N-enriched tissues compared to those values reflected during tissue maintenance.

Nitrogen studies focusing on nutritional or physical stressors of humans fall into multiple categories: protein deprivation found in mental disorders exhibiting acute starvation (Mekota et al., 2006), pregnancy, morning sickness and infant weaning (e.g. Fuller et al., 2004, 2005), and pathology exhibiting new tissue formation (e.g. Katzenberg and Lovell, 1999; Olsen et al., 2014). Studies involving these categories investigate the relationship $\delta^{15}N$ has with protein metabolism and look at sources of variation beyond that of diet and/or environment.

Severe protein malnourishment results in the fluctuation of nitrogen values. A seminal study by Mekota et al. (2006) used stable isotope analysis of hair keratin from six anorexia nervosa patients throughout their medical treatment from starvation to recovery to monitor nitrogen and carbon levels over a 17-week period. They determined $\delta^{15}N$ levels are inversely related to body mass index (BMI) with levels decreasing as BMI increases. This inverse reaction is in part due to gluconeogenesis, or the "synthesis of glucose from non-carbohydrate sources, the most important of which are pyruvate, lactate, and alanine" (Mekota et al., 2006:1607). Results showed high $\delta^{15}N$ during the initial starvation phase when body proteins were being recycled through catabolism and a trophic level effect was occurring within the patient's body. Positive nitrogen balance is occurring with less nitrogen being excreted as the body becomes anabolic. Further studies by Holder et al. (2013; 2017) exhibit the effects starvation and nutritional stress had on members of Napoleon's Great Army who perished during the Russian

campaign of 1812. These soldiers exhibited fluctuating δ^{15}N levels, likely indicative of multi-ethnic and ranking dietary differences as well as the physiological effects of malnourishment.

Pregnancy and infant weaning patterns can also play a role in fluctuating nitrogen values. Fuller et al. (2005) explain that during pregnancy a female body becomes anabolic and enters positive nitrogen balance causing a decrease in the nitrogen excretion along with an increase in protein synthesis. The authors also concluded that episodes of morning sickness, which the body identifies as nutritional stress, creates a catabolic state resulting in an increase of δ^{15}N values. In 1989, Fogel and colleagues released a study indicating infants being breastfed will have δ^{15}N values at higher enrichment levels than their mothers', reflective of a trophic level increase with the child being the consumer of the mother's tissues. White and Schwarcz (1993) found an increase of 3‰ δ^{15}N in collagen extracted from infant skeletal samples over the adults in their study of Sudanese Nubian mummies. Further examples of studies supporting trophic level increases with infant feeding patterns can be seen in Katzenberg et al. (1993) and more recently Dupras et al. (2001), among others. This enrichment pattern continues until weaning begins at which time the δ^{15}N levels begin to decrease as consumption of other food begins to increase, and within three to five months of completion the levels plateau similar to that of their mother. It should be noted that in the case of collagen analysis the protein source is reflected to a higher degree than supplementary foods containing little to no protein (Ambrose and Knorr, 1993; Katzenberg et al., 1996).

Researchers using isotopic analyses often look to diet to assist in understanding variations in carbon and nitrogen values; however, physiology must also be considered when interpreting results. Katzenberg and Lovell's (1999) findings on the effects of bone pathology on stable isotope values was further researched by Olsen et al. (2014) by focusing on specific osseous-

affecting pathologies. Their results indicate that specific biological processes in tissue remodeling, specifically new bone formation from trauma or lesion activity, can cause distinct variation in δ^{15}N enrichment. Because of this variation, the avoidance skeletal elements displaying healed trauma or lesion-activity is recommended when selecting samples for analysis.

Fruits Use in Dietary Reconstruction

FRUITS, or *Food Reconstruction Using Isotopic Transferred Signals* (Fernandes et al., 2012; Fernandes et al., 2014; Fernandes et al., 2015), is a Bayesian mixing-model used to quantify the contributions various food groups make to a diet. Isotopic values have long been used to identify the presence of specific dietary choices; however, using this model renders the researcher capable of identifying what fraction of the diet is composed of those items. The FRUITS software allows for the input of stable isotope values for specific food group choices (e.g., plants, animals, marine resources), as well as values for the fractionation that occurs diet-to-tissue during digestion. There are many Bayesian mixing-models that can, and have, been used for stable isotope dietary reconstruction, however FRUITS is a recent addition. It was designed in 2009 and has been used in several archaeological studies beginning in 2012 to reconstruct paleodiet in multiple geographic locations (Fernandes et al., 2012; Andrade et al., 2015; Fernandes et al., 2015; Meadows et al., 2015; Pickard et al., 2016; Zavodny, 2017). Phillips et al. (2014) provides a list of best practices when choosing a mixing model best suited for any well-designed research:

- Strength of the model is determined by the strength of the data
- Studies should recognize limitations and use the model which is appropriate for the questions being asked
- Be careful of output interpretations and recall the uncertainty distributions
- Use common sense (e.g., graph data before analysis)

Fernandes et al. (2015) focused on the diet of a Neolithic population from Ostorf, Germany, where varying dietary hypotheses have been considered in the past. The groups studied were late hunter-gatherers and early Neolithic farmers, and the use of the FRUITS method was instrumental in refining results of previously reported dietary isotopic data with the aim of supporting an earlier proposed hypothesis. In this study, estimates generated by FRUITS included calorie contribution and protein contribution from various food groups. The results provided supporting evidence that late hunter-gatherers had adopted cultural elements utilized by Neolithic farmers, including a high-caloric intake of plants as well as marine sources.

Meadows and colleagues (2015) utilized FRUITS to determine the percentages of marine resources consumed by individuals located in the Prehistoric Latvian settlement of Zvejnieki. Due to the freshwater reservoir effect (FRE) there had been anomalies regarding a 300-year spread of radiocarbon dates on five contemporaneous burials. FRUITS allowed for each individual's marine consumption to be assessed, enabling researchers to accurately calculate and account for the FRE and confirm the age of these burials.

Pickard et al. (2016) found information related to Chalcolithic settlements in Anatolia lacking in comparison to those dating to the Neolithic resulting in a lack of societal and economic understanding. In response to this, the authors used the FRUITS method on data from the farming site of Çamlıbel Tarlası to "assess the relative importance of plant vs. animal foods in diet" and reconstruct the community economy through diet (2016: 297). The results indicated that animal proteins were less significant to the diet than believed, which in turn suggested a more complex economic structure than initially assumed.

Zavodny and coauthors (2017) analyzed Neolithic risk-management strategies related to crop diversification and the importance of millet in the Lika region of Croatia. FRUITS was used

to determine dietary percentages of millet that, while typically sequestered as a low-cost famine food due to its abundance and resilient nature, was eaten in Lika in large amounts, indicative of it being a staple item. Results from this study suggested the construction of new ideas concerning crop diversification strategies in response to perceived risks.

Tissue and Isotopic Analysis

While any tissue protein could be used for analysis, typically only skeletal collagen, tooth dentin and hair keratin survive long enough to be advantageous in isotopic analysis. Hair, however, contains roughly 95% keratin, while bone is only roughly 20% collagen and requires extended chemical purification and processing prior to analysis (Roy et al., 2005). Keratin has the ability to preserve isotopic data for millennia, becoming metabolically inert once the protein structures are complete. A time capsule of dietary patterns can then be accessed through stable isotope analysis using human tissues (Petzke et al., 2010; Roy et al., 2005; Williams et al., 2011). Human hair, growing at about 1 cm per month, provides its own sequential timeline within a normal hair cycle, lasting approximately three to five years. Hair is also a quite durable tissue as it is encased in a cuticle, which is highly resistant to both chemicals and microbes (Roy et al., 2005; Williams, 2011). Modern and preserved hair from archaeological contexts has been studied for decades to understand many aspects of past life, such as diet, health, migration patterns, food-stress, and fertility (e.g., Dupras, 1999; Macko et al., 1999; Nakamura et al., 1982; O'Connell et al., 1999; Roy et al., 2005; Webb et al., 1980; White, 1993; Williams, 2008; Williams et al., 2011).

Hair follicles, which extend into the dermis from the skin's surface, are large cavities or sacs from which human hair grows. Human hair is a keratin-containing tissue that once fully

formed, may contain up to four different structures which are the cuticle, cortex, medulla, and cell membrane complex (Robbins, 2012). A representation of the structure of a follicle can be seen in Figure 2. There are roughly six to eight layers of cuticle, which contains keratin protein and lipids, surrounding the cortex. The cortex contains both type I and type II keratin proteins. If hair is course in texture, there will most likely be one or more medullae, or loosely packed porous regions, present near the center of the fiber. The cell membrane complex is considered the interstitial glue that binds the cells together (Robbins, 2012).

Hair growth is a three-stage cycle beginning with the growth stage of anagen, followed up by the transitional phase of catagen, and finally ending with the rest stage of telogen. This growth cycle typically lasts two to six years (Robbins, 2012). Further detailed information on each growth stage can be found in Table 3. During fetal growth, early hair fibers referred to as laguno begin in the follicle and are quite fine and non-medullated. These fibers will be shed prior

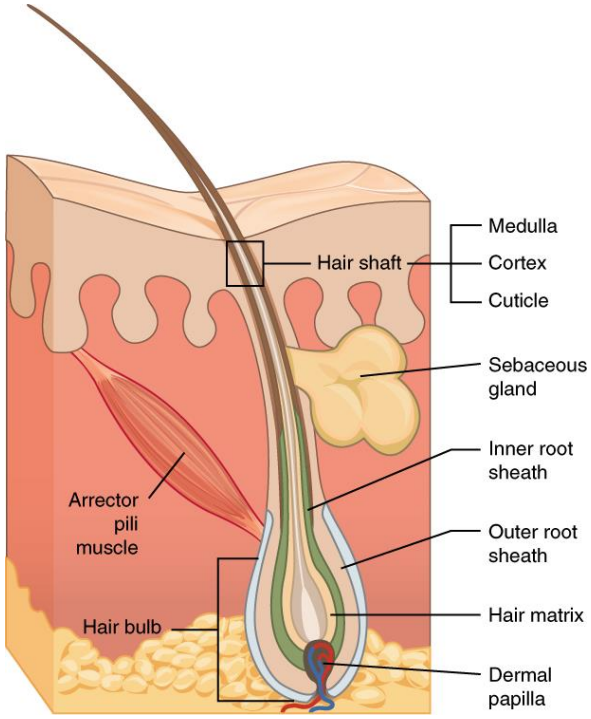


Figure 2. Cross section of a hair follicle. (Photo: CC by 3.0)

to full-term gestation. Following this, the hair follicles will begin a growth cycle of vellus hair which is short, fine, and non-medullated and will be shed a few months after birth (Pecoraro et al., 1964). Postnatal hair also includes terminal hairs that are typically thick, long, and medullated. These medullated hairs completely replace the vellus hairs during early childhood (Pecoraro et al., 1964). At any given time, the amount of actively growing hairs is about 85-90% with 10-15% of hair being inactive (Robbins, 2012), creating approximately a 10% delay in the isotopic signal representing diet (Williams, 2008; Williams et al., 2011).

Table 3. The stages of human hair growth.

Stage	**Phase**	**Descriptor**
Anagen	Growth	• 2-6 years in length • Increased metabolic activity within hair bulb • Hair length determined by stage length
Catagen	Transition	• 2-4 weeks in length • Metabolic activity slows • Bulb base moves upward toward epithelial surface • Molecular regulators responsible for start and finish of this stage
Telogen	Rest	• 4-8 weeks in length • Growth stops completely • Bulb base atrophies • New hair begins beneath follicle leading to the shedding of old fibers effectively ceasing telogen phase with start of anagen

Derived from Robbins, 2012.

Limitations of Isotope Studies in Archaeology

Although the usage of isotopic analyses in archaeological contexts has been successful in the reconstruction of past life experiences, it is not without limitations. Non-dietary variations in elemental values can be attributed to uncertainties over time and location. Temporal and

climactic events altered and continue to alter the amounts of certain elements in the atmosphere including both carbon and nitrogen (Keeling et al., 1979; Heaton et al., 1986, Ambrose, 1991; Schoeninger, 1992; O'Leary, 1995).

Degradation and diagenesis are a concern with ancient samples as organic matter breaks down and alters in chemical composition over time (Chisholm et al., 1982; Hedges, 2002; Lee-Thorp, 2008). The samples used must go through a quality assessment to assure they are in proper testing condition. This can include options such as checking collagen yield, percentages of C and N recovered, and the C:N ratio.

There are considerable dietary factors that can affect values used in data analysis, such as the direct cause of nitrogen variation. As discussed earlier, metabolic processes can be a challenge and a limitation due to an often poor and contested understanding of their true effects. This, however, this can be circumvented with a clear understanding of the environment and culture from which samples have originated. For example, the samples used in this study were recovered in Dakhleh Oasis, Egypt, so extreme seasonal aridity would be a factor.

The FRUITS method, while successful in previous applications (e.g., Andrade et al., 2015; Fernandes et al., 2012; Fernandes et al., 2014; Fernandes et al., 2015; Meadows et al., 2015; Pickard et al., 2016; Zavodny, 2017), has yet to be used on samples outside of Eurasia. There is a clear climactic and environmental difference with the geographic origin for the ancient samples used in this study, and the effectiveness of this model in this region remains unknown at this time. One limitation that should be mentioned about the FRUITS method is that while it can offer percentages that certain food items bring to the overall diet of an individual, it cannot decipher if the input food items were actually consumed, thereby giving the potential for a false-positive. To clarify, if a food source consumed has similar chemical and nutrient properties to

another food source, FRUITS cannot decipher one source from another and therefore it can be mis-identified. Whichever food source is input into FRUITS will result in data, this possibility is offset by enforcing a documented historical perspective derived from account books and census information (e.g., KAB; Bagnall, 1993) and choosing previously identified common menu elements (Dupras, 1999). Phillips and colleagues (2014) list a few best practices to keep in mind while using mixing-models, to assist in keeping accuracy in food sources, they recommend combining food sources with similar chemical values. This may include combining wheat and barley under the title C_3 grains and using the mean isotopic and macronutrient values of both of these plants as the input information, or similarly, combining cow and goat values for an overall herbivore mean. There are a multitude of ways FRUITS can utilize dietary information which are unique to the intended purposes of each study.

CHAPTER THREE: MATERIALS & METHODS

This chapter provides the site background and context for the materials analyzed and an overview of the methods of analysis used in this study. First is a summary of the archaeological site and a brief overview of prior research concerning the food resources and demography of the population from which this study is based. Following this is an overview of how FRUITS Bayesian mixed-modeling methods of analysis were applied to the data.

Site Background

The Dakhleh Oasis Project (DOP) began in 1978 under the direction of Anthony Mills to understand the relationships between humans and Saharan Oasis environments from the Neolithic to present day. Dakhleh was a continuously occupied oasis region in Egypt from Paleolithic through Pharaonic times and since the Old Kingdom period residents led a predominately agrarian lifestyle (Hope, 2001; Bowen, 2007). The ancient city of Kellis, now known as Ismant el-Kharab, is located within the Dakhleh Oasis of Egypt approximately 800 km south-south-west of Cairo and 300 km west of the Nile River (Figure 3). The ancient city of Kellis was a Roman-era village occupied from the end of the Ptolemaic Period (c. 305-30 B.C.E.) until its eventual abandonment around 400 C.E. with no further reoccupation, creating a snapshot of a specific time in history in which to study the diet of this population, as well as the effects of both biological and cultural transition via dietary selection from available food resources (Bowen et al., 2005; Bowen, 2007; Molto et al., 2017).

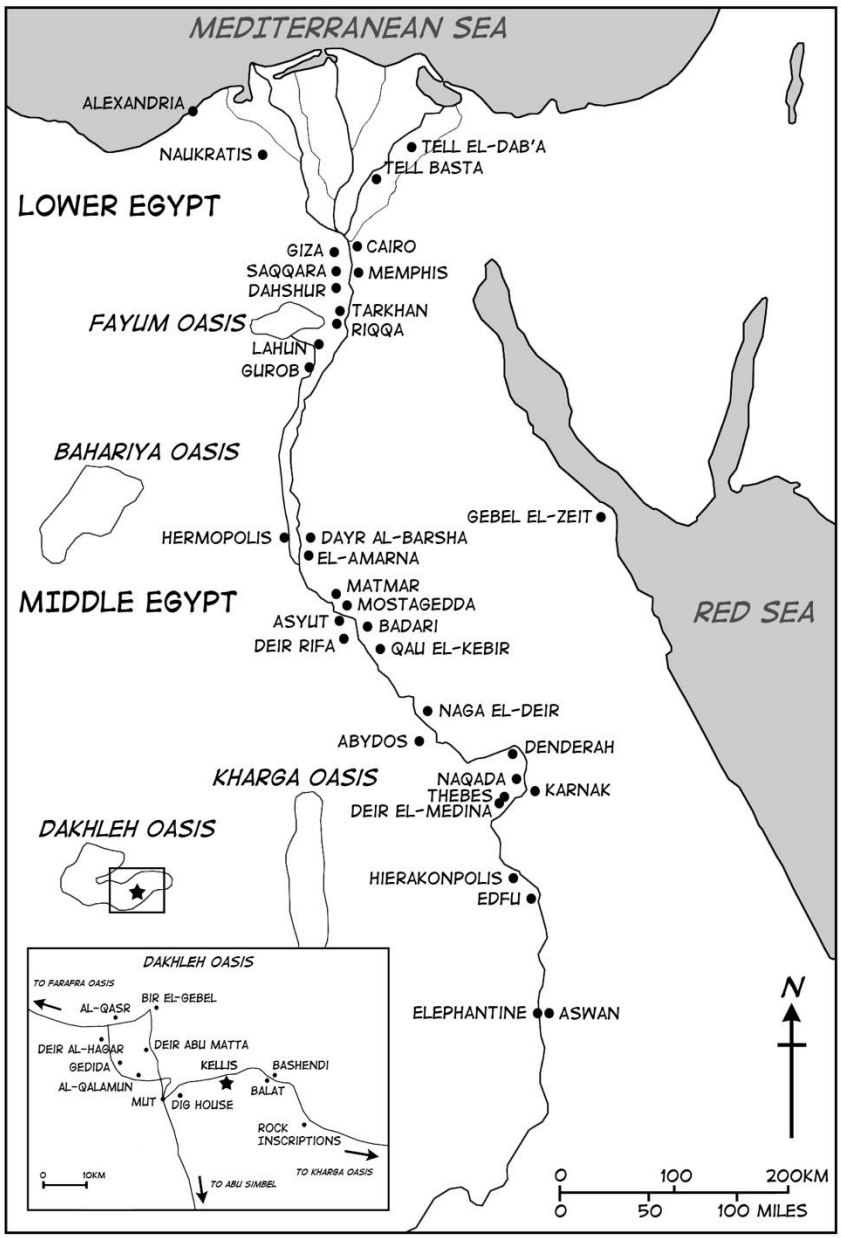


Figure 3. Map of the Dakhleh Oasis from Williams, 2008.

The DOP has been conducting excavations at Kellis since 1986 with its bioarchaeological and cemetery research focusing on the biological and cultural adaptations that have taken place within this region of the world. This research has consisted of pathology, histology, genome sequencing, juvenile life history, paleoepidemiology, migration patterns, mortuary techniques, and nutritional stresses among others (e.g., Dupras, 1999; Dupras et al., 2001; Williams, 2008;

Molto et al., 2017). Stable isotope analysis has been used to reconstruct diet and food practices, as well as migration, health status, and seasonality of life and death (e.g., Dupras, 1999; Dupras et al., 2001; Groff, 2015; Wheeler, 2012; Williams, 2008).

Currently, there are two known cemeteries utilized by the village of Kellis. Kellis 1 cemetery is located west of the village, dating from the 1st through the 3rd centuries C.E., and contains a large number of burials with traditional pagan grave goods (Hope and Mills, 1999; Bowen et al., 2005). Kellis 2, located to the northeast of the townsite, is an early Romano-Christian cemetery that was confirmed in use from 50-450 C.E. with accelerated mass spectrometry radiocarbon dating (Stewart et al., 2003; Molto et al., 2006). This cemetery appears to contain mostly Christian burials based on the evident mortuary style and practice and lack of discernible grave goods (Dupras, 1999; Stewart et al., 2 003; Bowen et al., 2005; Molto et al., 2006; Dupras and Tocheri, 2007). All isotopic data used in this study were derived from individuals excavated from the Kellis 2 cemetery.

The Kellis 2 cemetery is composed of a large number of Nubian red clay pit burials with single burials; it has been estimated to hold 3,000 to 4,000 individuals, with 770 individuals excavated to date (Dupras, 1999; Dupras et al., 2001; Williams, 2008, Wheeler, 2012; Molto et al., 2017). Analyses of these individuals have revealed a high percentage of well-preserved juveniles (64%), which provides an excellent resource for addressing questions pertaining to Roman-era weaning practices, infant mortality, and the effects of dietary choice and changes on the young (Williams, 2008; Wheeler, 2012; East, 2015). Assessed age-at-death ranges from 16 weeks' gestation to approximately 72 years, with more adults categorized as biological females (59%) than males (41%) (Dupras, 1999; Williams, 2008).

While this cemetery was in use, the village of Kellis was transforming from a heavily pagan society to a more Christian community. Despite this transition, Greek, Manichean, and Coptic influences could still be found, making it a time of great cultural flux (Gardner and Lieu, 1996; Peacock, 2000; Molto et al., 2017). Egypt was an area prized for its agriculture, textiles, and minerals, and came under Roman rule by Emperor Augustus in 30 B.C.E. (Peacock, 2000; Wheeler, 2012). Rome enhanced Egyptian agricultural systems in the Oasis that resulted in a lengthening of the growing season and a greater variety of crops grown (Bagnall, 1993; Wheeler, 2012). A change in rule brought a shift in agricultural focus and a change in religious ideology that resulted in a differing mortuary landscape. Christianity was widespread by the 3rd century and its teachings dictated that proper burial rites were important for eternal life (Bowen et al, 2005; Bowen, 2007). Christian burial practices included all individuals regardless of age, which may explain the high percentage of juvenile burials within Kellis 2. Researchers seem to agree that there was likely a water scarcity or soil salination issue, possibly even effects of the encroaching desert on the village, which could serve as a potential explanation for the site's abandonment (Knudstad and Frey, 1999; Wheeler, 2012).

Prior bioarchaeological research at this site, in tandem with the discovery of the Kellis Agricultural Account (KAB), offers a clear listing of the foods that those living in Kellis were raising, growing, and consuming (Bagnall, 1993; Dupras, 1999; Williams, 2008; Wheeler, 2012; Molto et al., 2017). This offers the unique advantage of identifying the specific foods used and selected by the Kellis community in order to enhance the use of isotopic data when making interpretations of social, dietary, and health effects at Kellis during this time (Dupras, 1999; Dupras et al., 2001; Dupras and Tocheri, 2007; Williams, 2008). The intent of this study is to provide the added scope of a refined cross-sectional analysis of dietary choices made in Kellis,

represented by individuals from the Kellis 2 cemetery. FRUITS software is used primarily to reconstruct the diet of the individual, offering the opportunity for outlier representation, it also can identify population patterns, making it the ideal modeling option for this research.

Kellis 2 Cemetery Hair Samples

Of the combined 332 individuals previously analyzed by Dupras (1999) and Williams (2008), 216 individuals with preserved hair were selected for FRUITS analysis. The 216 individuals were separated by age categories (Table 4) previously developed and used by Wheeler (2009) and Williams (2008). Sample preservation was evaluated using the suggested atomic C/N ratio range of 3.0 – 3.8 for each hair keratin sample (O'Connell and Hedges, 1999; O'Connell et al., 2001). Within each age group, any sample with an atomic C/N ratio falling outside of this range was removed from the study. Of the 216 samples selected, 151 were found to be sufficiently preserved for use in this study. Individuals chosen had varying lengths of hair, with most having multiple segments available with isotopic results, the mean of all segments was used for each individuals sample. While this offers an overall view of the individual's dietary choices, up to and including, the weeks before death, it also results in a limitation for those who only had one or two hair segments available. The dietary choices for this individual would only reflect a few months before death.

Figure 4 shows the age-at-death distribution for the original 216 samples compared with the remaining 151 well-preserved samples used in this study. The adult samples were further separated into male and female categories so dietary differences could be distinguished between age groups as well as biological sex. Figure 5 provides the adult sex demographic in each age group for the remaining 151 well-preserved samples used in this study. The well-preserved

samples selected and used in this study mirrors the overall Kellis 2 sample in both a larger percentage of juveniles as well as adult females (Wheeler, 2009; Williams, 2008).

Table 4. Age categories with the number of hair samples represented (n) as well as total sample pool (N).

Age Category	Age Cohort	Samples from Williams (2008)	Samples in Current Study
Juveniles			
F	21 – 36 wks. gestation	*n* = 10	*n=5*
P	37 – 40 wks. gestation	*n* = 23	*n = 21*
N	41 wks. gestation – 1 year	*n* = 40	*n = 35*
C1	13 months – 4 years	*n* = 29	*n = 27*
C2	5 – 10 years	*n* = 14	*n = 0*
C3	11 – 15 years	*n* = 10	*n = 0*
Adults			
A1	16 – 21 years	*n* = 10	*n = 10*
A2	22 – 35 years	*n* = 38	*n = 38*
A3	36 – 50 years	*n* = 27	*n = 0*
A4	51-59 years	*n* = 8	*n = 8*
A5	60+ years	*n* = 7	*n = 7*
TOTAL SAMPLE		***N = 216***	***N = 151***

Age categories derived from Wheeler (2009) and Williams (2008).

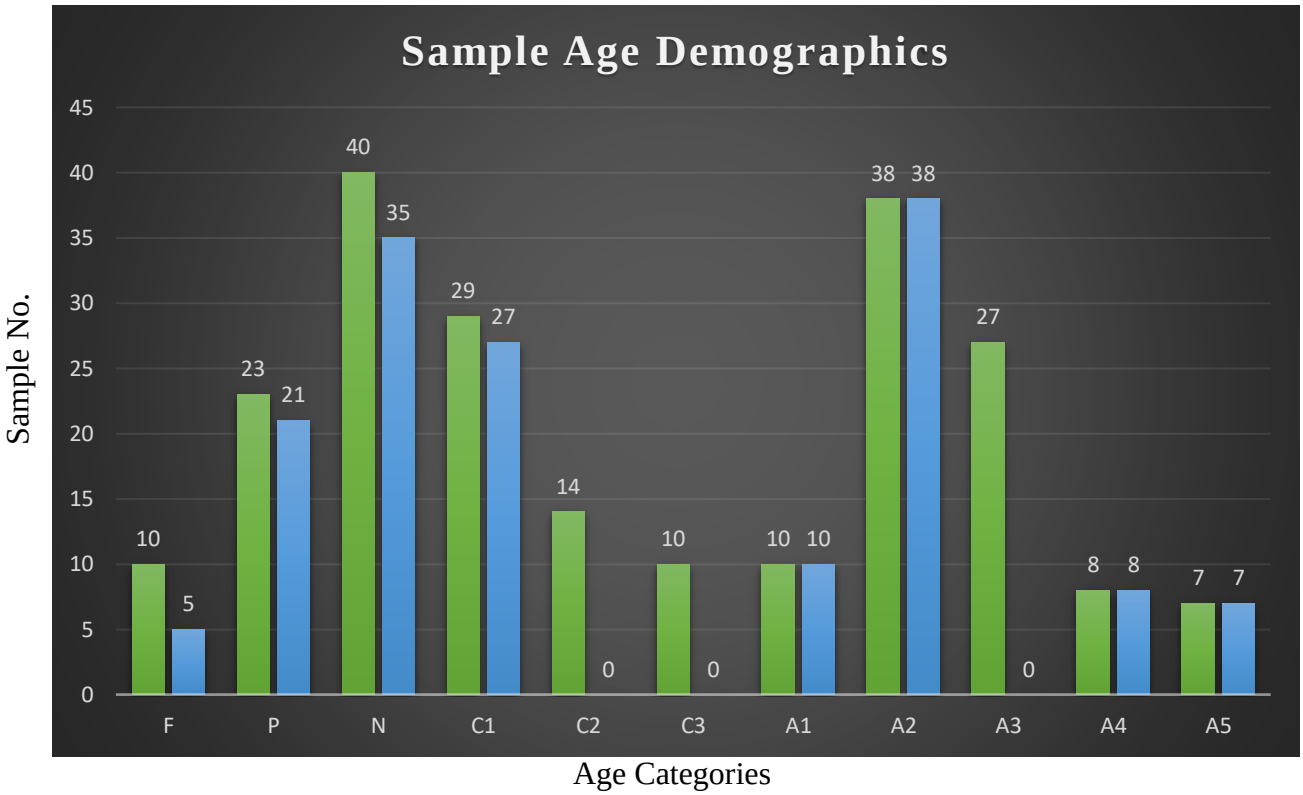


Figure 4. Total sample number by age category in green (N=). Actual sample number used in study by age category in blue (N=) Chart contains information derived from Williams, 2008.

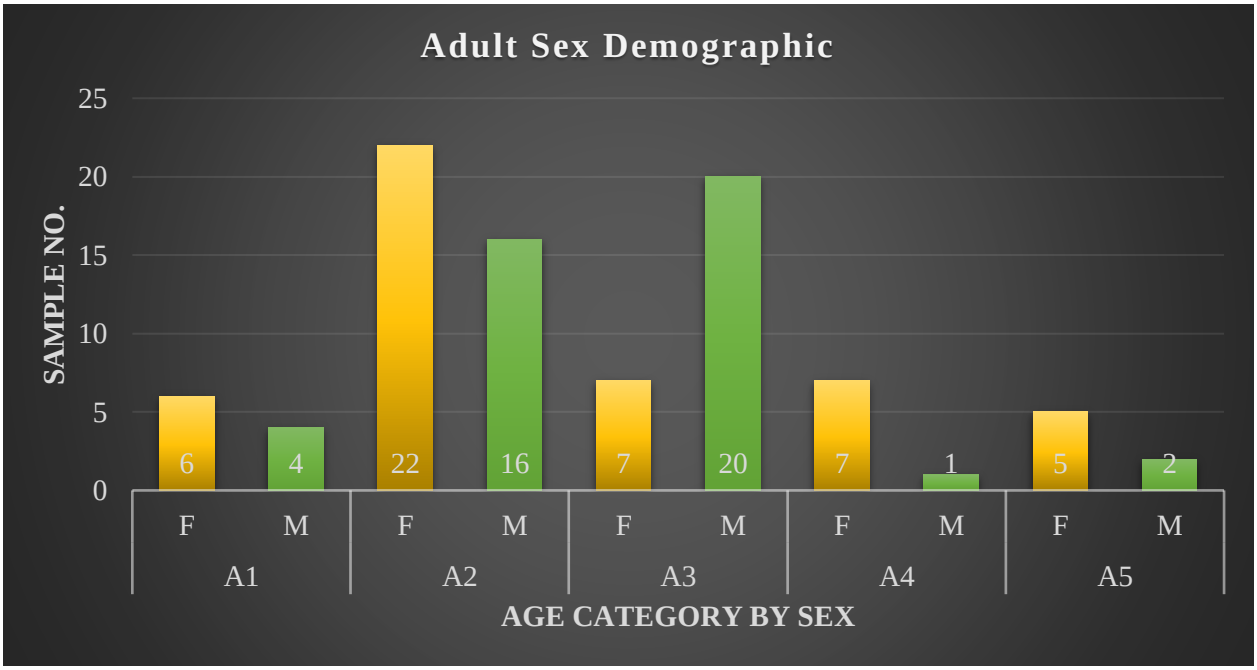


Figure 5. Adult sample pool (N=) listed by determined sex (M or F). Category A3 was not utilized for this study. Chart contains information derived from Williams, 2008.

Method of Analysis

A Bayesian mixing-model, FRUITS (*Food Reconstruction Using Isotopic Transfer Signals*, v. 2.1.1; Fernandes et al., 2014, 2015) was employed to quantify specific food contribution by chosen categories in the human diet (e.g., plants, proteins). FRUITS allows for the input of *a priori* information, including stable isotope values for specific food groups and diet-tissue offsets, which is necessary for accuracy in results (Fernandes et al., 2014).

The diet of Kellis during this time period was broad, as shown in the Kellis Agricultural Account Book (KAB) dated to 350 C.E. The menu in the Dakhleh Oasis during the Ptolemaic and Roman periods can be found in Table 5. While there are many options for dietary analyses, the main components of the everyday diet regardless of age cohort consisted of staple items such as wheat, millet, and animal proteins, therefore these were the items chosen for FRUITS modeling to assist in creating a baseline menu. A FRUITS specific limitation involving menu items states that once a value for any dietary item chosen is entered into the software, FRUITS will give you the resulting output values, regardless of whether the item was truly a part of that individual's diet. This is a secondary reason for using main staple items in this initial FRUITS analyses of the Kellis 2 population, thereby limiting the chance of a false-positive. Six different scenarios were created using FRUITS in an effort to view multiple outputs, while analysis of these outputs assists in choosing the most likely scenario. As both C_3 and C_4 plants and terrestrial herbivores were heavily relied upon (Dupras, 1999; Williams, 2008) (Figure 6), these food groups chosen for representation in the model. Due to the distance of the Dakhleh Oasis to the Nile River, it is likely that marine resources were not common with the possible exception of dried riverine resource options; however, due to lack of physical evidence for marine resources in Kellis food groups, marine consumption was not considered in this study.

Table 5. List of available dietary items by category, during the Roman era in Kellis.

ANIMALS	FIELD CROPS	GARDEN PLANTS	FRUITS & NUTS	OTHER
Cows	Wheat	Turnips	Dates	Honey
Pigs	Barley	Garlic	Palm Nuts	Coriander
Goats	Millet	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	

Table derived from Dupras, 1999 and Bagnall's (1997) Kellis Agricultural Account Book.

Best practices suggest that less than six food sources is ideal for use in a FRUITS model, however there are limitations to not incorporating the entire diet of an individual. This is a problematic combination that while impossible to remove, can be countered (Phillips et al., 2014). Due to the extensive research previously conducted with the Kellis 2 population and the historical documentation provided through the KAB, the main contributors to the population diet and the animal diet were well-known. This detailed record and archaeological context assisted in grouping and limiting the food sources to three scenarios. Additionally, because this study implements a Bayesian mixing model, there are numerous locations within the software to account for diet-tissue discrimination factors as well as uncertainty values for each source making FRUITS a good choice (Phillips et al., 2014).

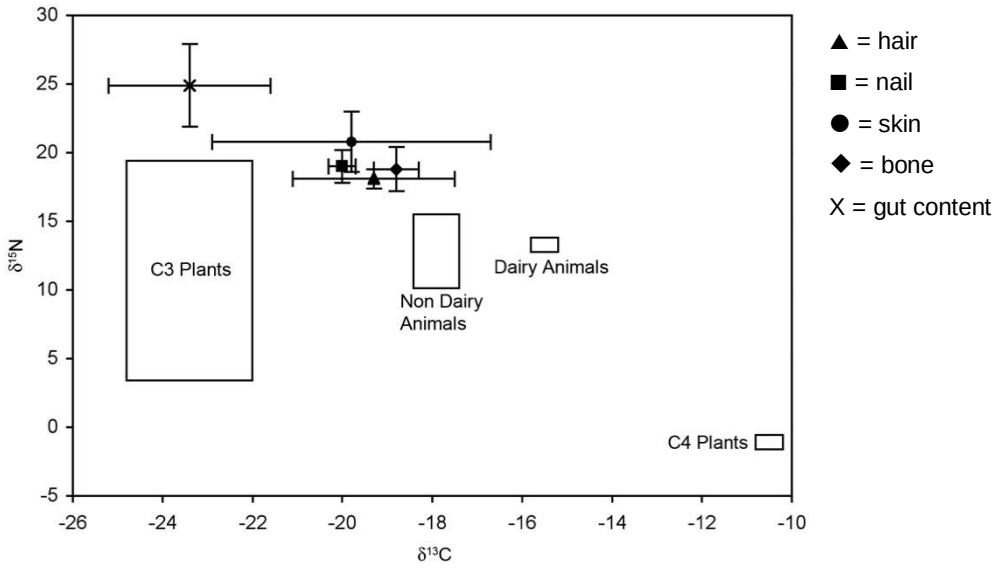


Figure 6. $\delta^{13}C$ & $\delta^{15}N$ data from Kellis 2 tissue samples compared with the overall range of values for foods consumed. Closed symbols are mean values with standard deviation of ± 1σ. Chart taken from Williams, 2008.

While FRUITS is capable of modeling multiple macro- and micronutrient inputs, only the contributions of dietary protein to tissue was considered to limit variables. Offsets for $\Delta^{13}C_{diet\text{-}keratin}$ and $\Delta^{15}N_{diet\text{-}keratin}$ were 4 ± 2.3‰ and 4.5 ± 0.5‰ respectively, with 1‰ being subtracted from the offset of $\Delta^{13}C_{diet\text{-}collagen}$ and $\Delta^{15}N_{diet\text{-}collagen}$, as recommended by Fernandes et al., (2015) and aligning with previous feeding experiments as well as studies implementing the FRUITS model (Minagawa et al., 1986; Yoshinaga et al., 1996; O'Connell et al., 2012; Zavodny, 2017). Stable isotope mean and standard error values for primary data used in this study were taken from Dupras (1999) (APPENDIX A) and Williams (2008) (APPENDIX B) and are represented in Figure 6. Faunal isotopic values from Kellis show non-dairy herbivores having a mean $\delta^{13}C$ value of -18 ± 0.42‰ and a mean $\delta^{15}N$ of 14 ± 1.47‰ and dairy herbivores having a mean $\delta^{13}C$ value of -15.4 ± 0.42‰ and a mean $\delta^{15}N$ of 13.3 ± 0.21‰ (Dupras, 1999; Dupras et al., 2001; Williams, 2008). Specific values indicative of cows and/or goats are used in scenarios where indicated. Isotopic analysis of botanical materials found at Kellis indicate C_3 plants having a

mean $\delta^{13}C$ value of -23.2 ± 1.4‰ and C_4 plants having a mean $\delta^{13}C$ value of -9.9‰ (Dupras, 1999; Dupras et al., 2001; Williams, 2008). Specific values indicative of wheat and/or millet are used in scenarios where indicated.

FRUITS allows users to choose between generic terminology and that of a dietary reconstruction (Table 5), this option is available on the main interface screen (Figure 7) along with the options for model parameters, referred to as Model Options (Figure 8), which are unique and essential to the accuracy of the study. These model options may be saved so that they may be easily re-loaded at any point.

Table 6. Terminology utilized by FRUITS with examples, Fernandes et al., 2014.

GENERIC TERM		FOOD TERM		E.g.
Target	⟺	Consumer	=	Individual, Population
Source	⟺	Food Group	=	C_3, C_4, Terrestrial Mammal
Proxies	⟺	Dietary Proxies	=	13C, 15N
Fractions	⟺	Food Fractions	=	Lipids, Protein, Carbohydrates

Once these parameters are chosen, data entry begins. This involves following the entry options in a straight line and never leaving the original main interface (Figure 9). There are options for the number of sample consumers, food groups, food fractions, and dietary proxies, as well as an entry location for all relevant information on those topics including offsets (Figure 10), which are necessary for consideration of uncertainties.

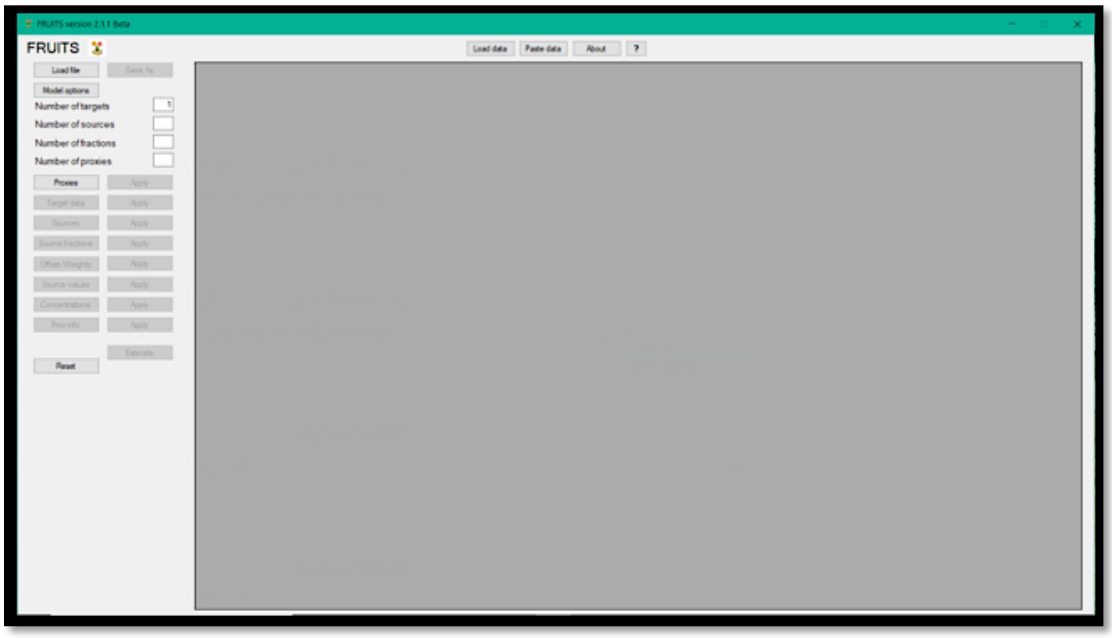


Figure 7. FRUITS main interface (Fernandes et al., 2014).

Figure 8. FRUITS main interface showing Model Options (Fernandes et al., 2014).

Finally, after all pertinent information has been entered, the last step is to choose ‘estimate’ which will generate the model analysis, statistics, and graphical outputs (Figure 11). Box and whisker charts are included in the output, these will be visible in Chapter 4 (e.g., Figure 14). The boxes represent a 68% confidence interval in results while the whiskers represent a 95% confidence interval. These are important when looking at accuracy of results. Along with this data there will be convergence diagnostics if chosen in model options, this was chosen in this study as it is a best practice’s test for Markov chains, a statistical method FRUITS utilizes, to ensure for probabilistically consistent data (Figure 12) (Fernandes et al., 2014; Phillips et al., 2014).

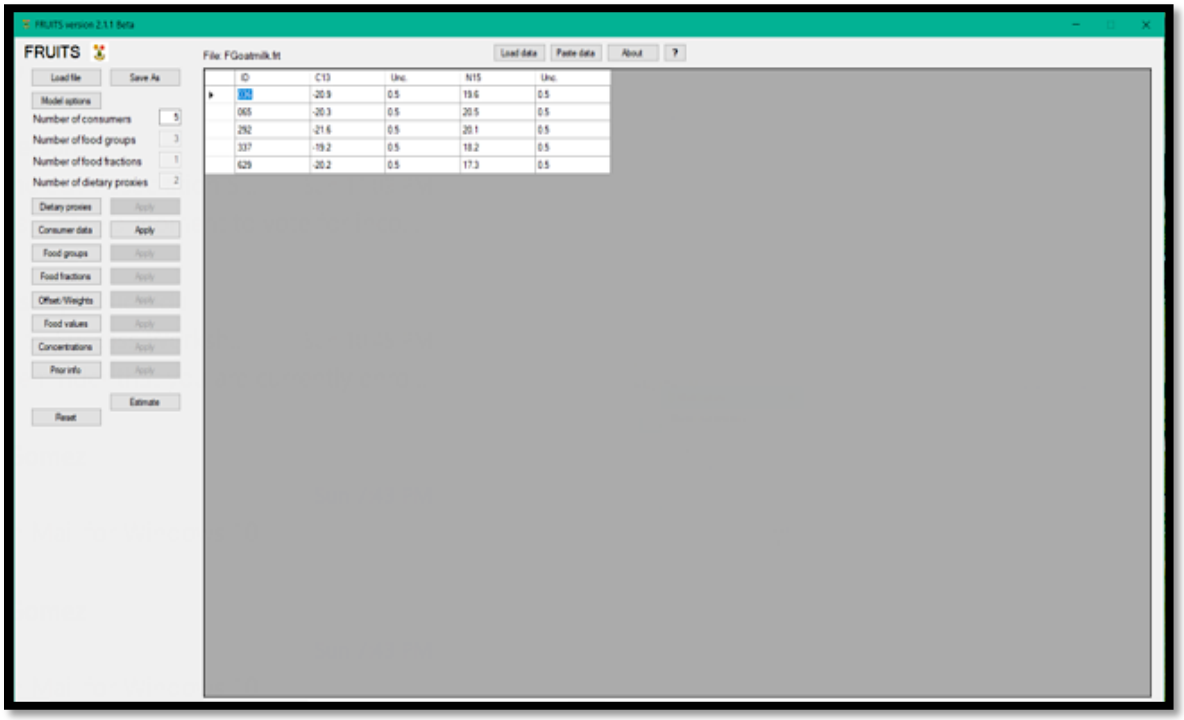


Figure 9. FRUITS interface for sample values (Fernandes et al., 2014).

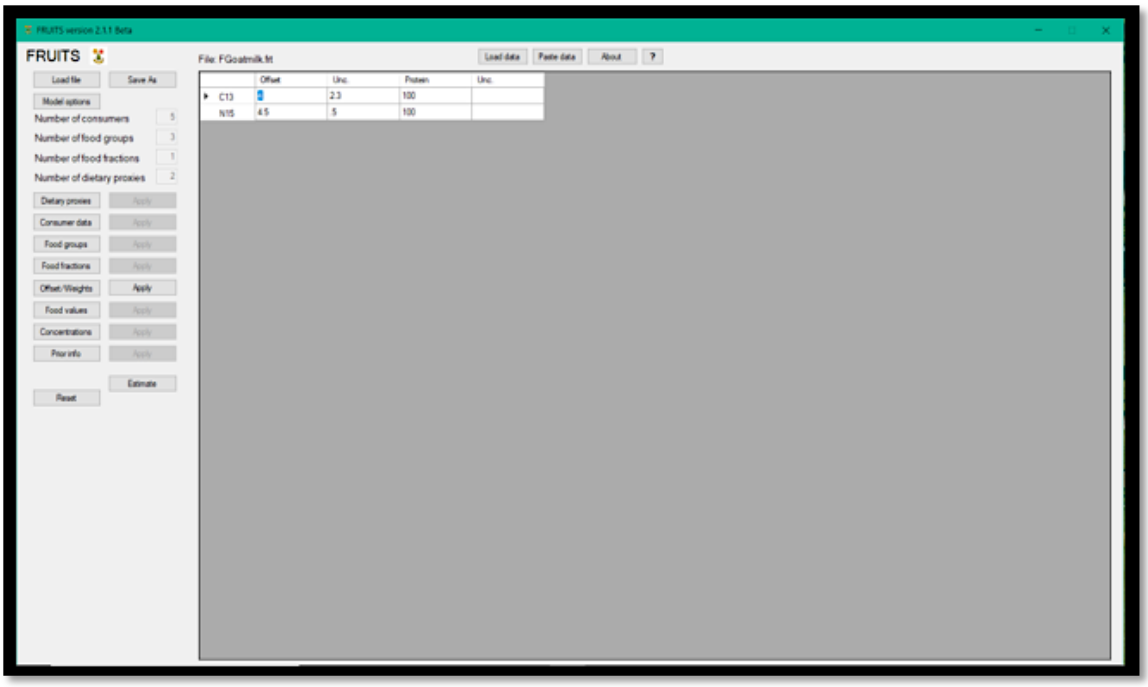


Figure 10. FRUITS interface for offset values (Fernandes et al., 2014).

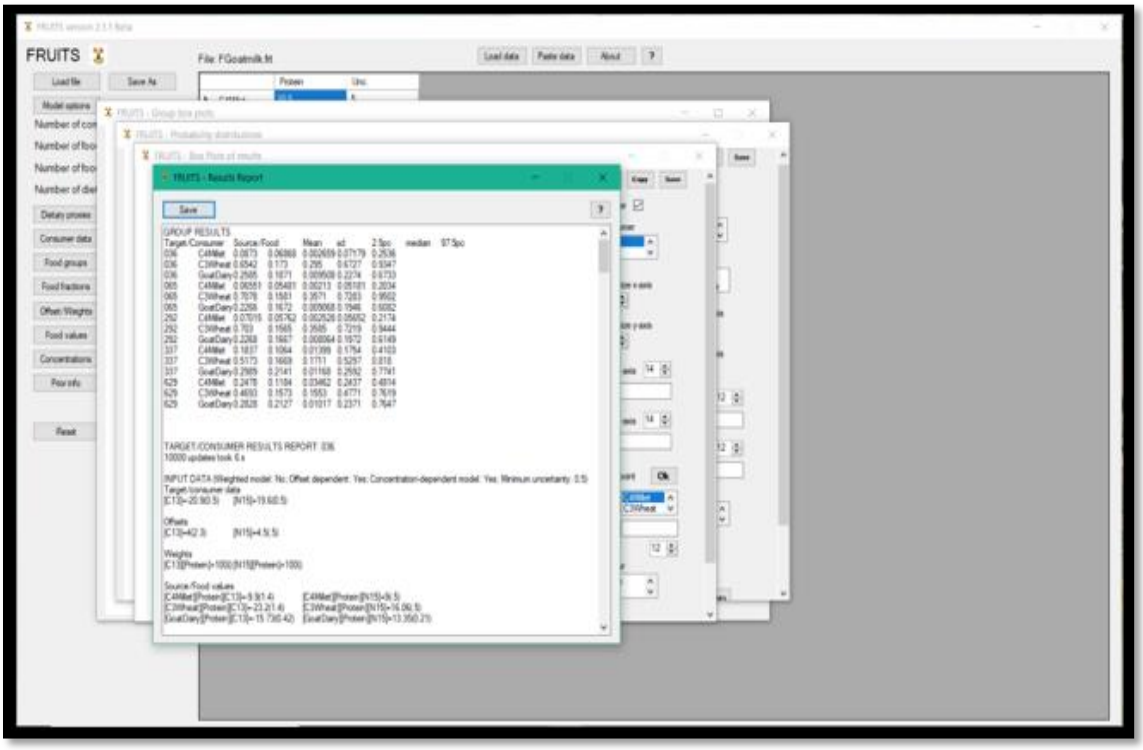


Figure 11. FRUITS statistical and graphical analysis output (Fernandes et al., 2014).

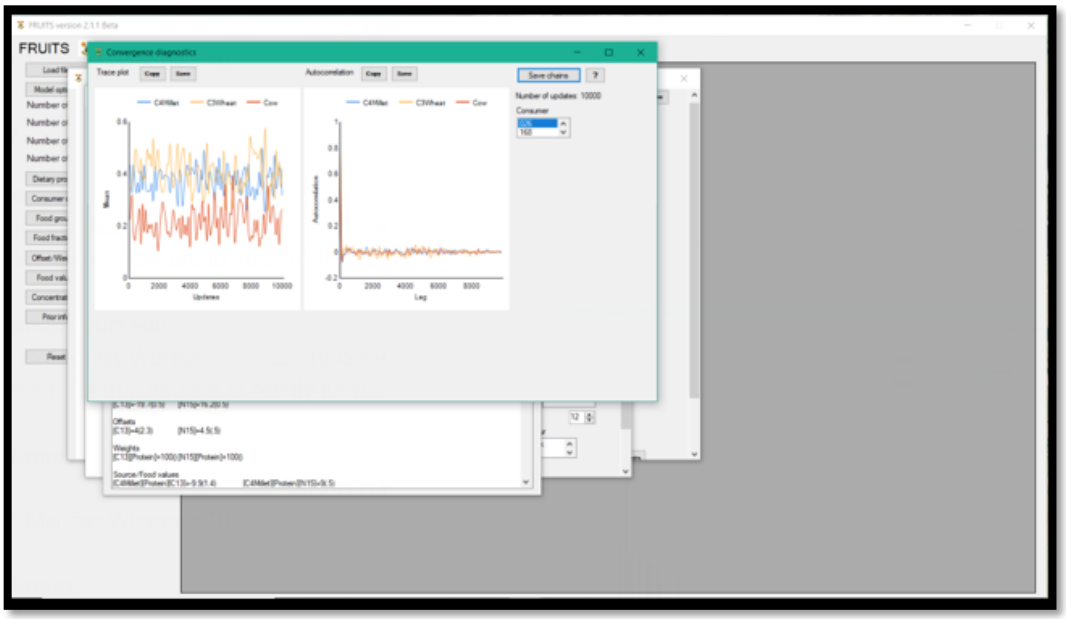


Figure 12. FRUITS convergence diagnostics (Fernandes et al., 2014).

Figure 13 shows a visual interpretation of what occurs during FRUITS modeling. The purpose is to estimate the contributions from multiple food sources towards a specific consumer or mean population sample. Both the sources and the consumer are made of quantitative signals referred to as fractions and proxies respectively. For category examples refer back to Table 6. FRUITS gives the option to use a single food fraction within the mixing problem making it non-weighted as is chosen here. Since only dietary protein is being quantified, this is accounted for in the $\Delta^{13}C_{diet\text{-}keratin}$ being $4 \pm 2.3‰$, typically $\pm 0.5‰$ would be satisfactory if multiple food fractions were being considered in the study narrowing the margin of error (Fernandes et al., 2014, Zavodny, 2017).

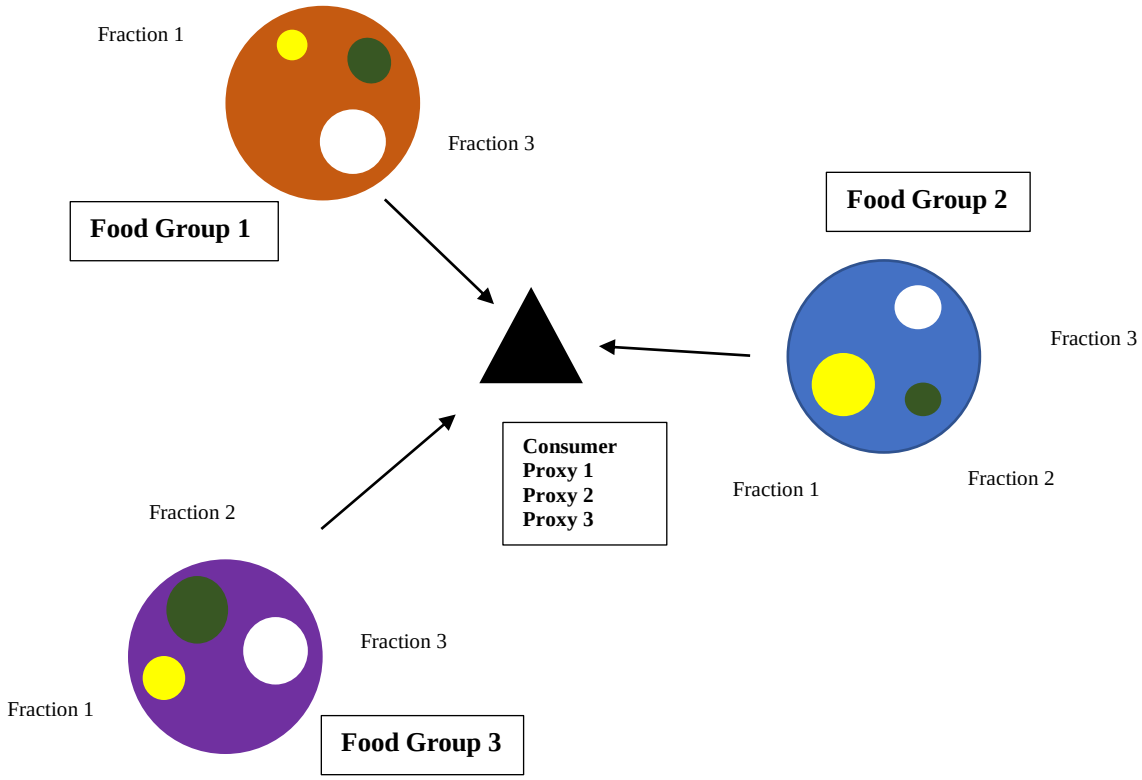


Figure 13. Model depicting concept of FRUITS using dietary-reconstruction modeling variables. Figure derived from FRUITS Manual 2nd Edition Model, (Fernandes, 2014).

CHAPTER FOUR: RESULTS OF FRUITS ANALYSIS

FRUITS modeling begins when particular dietary choices and consumers are chosen for representation in a scenario. These scenarios are constructed using a combination of selected food sources, the concentration of fractions within those sources. their isotopic values, and also their weight contributions. In addition to this information, diet-to-tissue offsets are utilized if applicable. Any resulting analysis and interpretation of results must be viewed within the specific constructed dietary parameters chosen. The information provided in Table 7 was adopted from the *FRUITS Manual 2nd Edition* by Fernandes et al. (2014) and is useful when interpreting results from analyses. These three parameter terms are the framework from which all FRUITS modeling scenarios are built.

Table 7. Descriptions for initial parameter options when using FRUITS for dietary reconstruction modeling.

PARAMETER	**DEPENDENT**	**INDEPENDENT**
CONCENTRATION	The concentrations of the food fractions within the mixing problem are included	The concentrations of food fractions within the mixing problem are ignored
WEIGHT	If more than one food group fraction contributes to a target dietary proxy signal, then the model is weighted	If the target dietary proxy signal is only determined by one food group fraction, then the model is non-weighted
OFFSET	There is an offset in the signal (e.g. isotopic fractionation) between the food group and the dietary proxy	There is no offset in the signal between the food group and the dietary proxy

The primary stable isotope data listed in Appendix A (Kellis food resources) and Appendix B (Kellis 2 individuals) were used for dietary reconstruction using FRUITS. Estimates generated by FRUITS modeling are dependent on the parameters set during *a priori* data entry, and parameter options may often extend well beyond those described in Table 7; therefore, six specific scenarios were constructed for comparative analysis using only these parameters.

Parameters, food groups, dietary proxies and consumers (see Table 6 for examples of FRUITS generic and food terminology if needed) were selected in each scenario based on the probability of refining broad interpretations made previous research studies due to limitations in stable isotope studies where interpretations can confirm or deny broad food source categories but cannot offer information on, or quantification of, specific dietary choices.

Results

The following scenarios summarize FRUITS dietary data for the selected age groups from the Kellis 2 cemetery. Complete FRUITS dietary data for each individual included in this study is provided in Appendix C.

Scenario 1

Parameters for Scenario 1 were constructed and applied to the primary data in an effort to discern preference in herbivore dairy protein (e.g., cow or goat) in the earliest age groups to clarify practices of supplementing and/or substituting for human breastmilk when necessary during early growth and weaning. Scenario 1 (Table 8) is weight independent and offset and concentration dependent, meaning that:

- the consumer signal is only determined by one food fraction;
- an offset in the signal between food groups and consumer is present; and,
- concentrations of the food fractions within the mixing problem are included.

The food fraction macronutrient chosen for modeling is dietary protein and food groups chosen are C_3 plants, C_4 plants, and cow milk. Juvenile age groups were chosen to represent the consumer (N = 88) were F (n = 5), P (n = 21), N (n = 35), and C1 (n = 27) (see Table 5 for age

group descriptions if needed). The dietary proxies being tested in Scenario 1 were C^{13} and N^{15}, and a summary of results from this scenario are provided in Table 9. Figures 14, 15 and 16 provide box plot, mean and median value comparisons among age groups for millet, wheat and cow dairy consumption, respectively.

Table 8. The parameters and sample groups chosen for Scenario 1.

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	COW-MILK	F, P, N, C1

Table 9. Estimates generated by FRUITS for average isotope values of the Kellis II juvenile population for dietary Scenario 1.

	MILLET	**WHEAT**	**COW DAIRY**
FOOD (%)			
Group F (n=5)	11 ± 9	51 ± 27	18 ± 13
Group P (n=21)	16 ± 8	52 ± 15	26 ± 9
Group N (n=38)	13 ± 9	59 ± 15	24 ± 7
Group C1 (n=27)	17 ± 12	51 ± 19	26 ± 6
FRACTION (%)			
Protein	100 ± 0	100 ± 0	100 ± 0

Food (%) reports the estimate of calorie dietary contribution from each food group. Fraction (%) reports the estimate of calorie contribution from each food fraction.

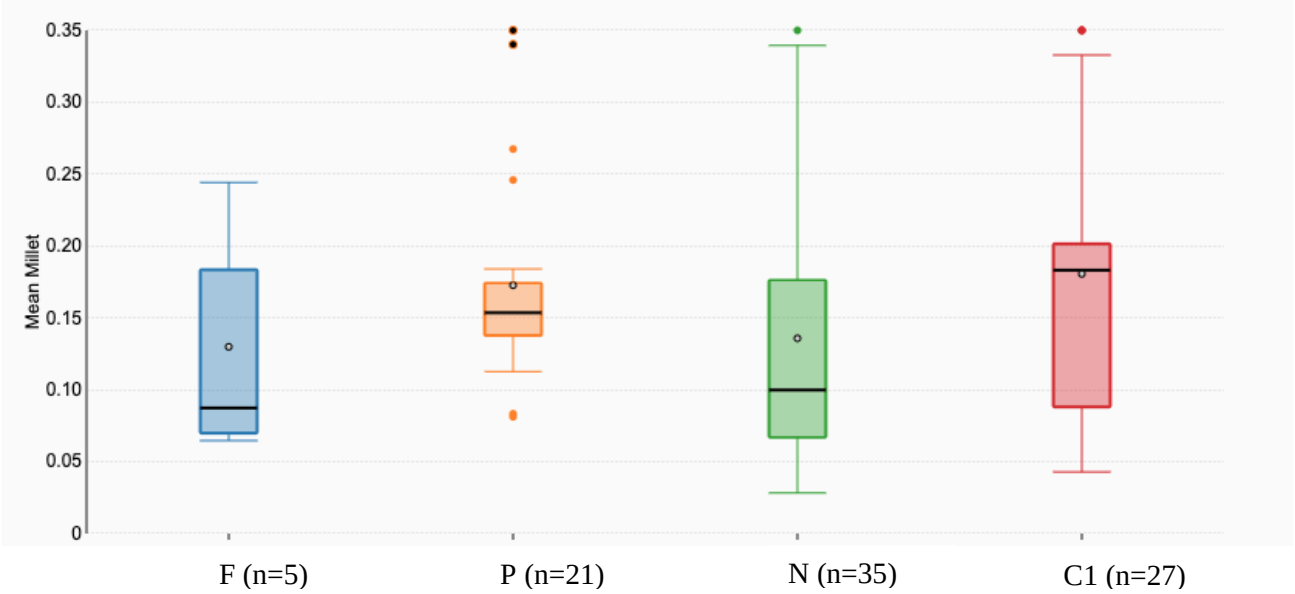


Figure 14. Scenario 1 millet consumption intervals by group F, P, N, C1. Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval. The horizontal line represents the estimated mean while the open circle represents the estimated median.

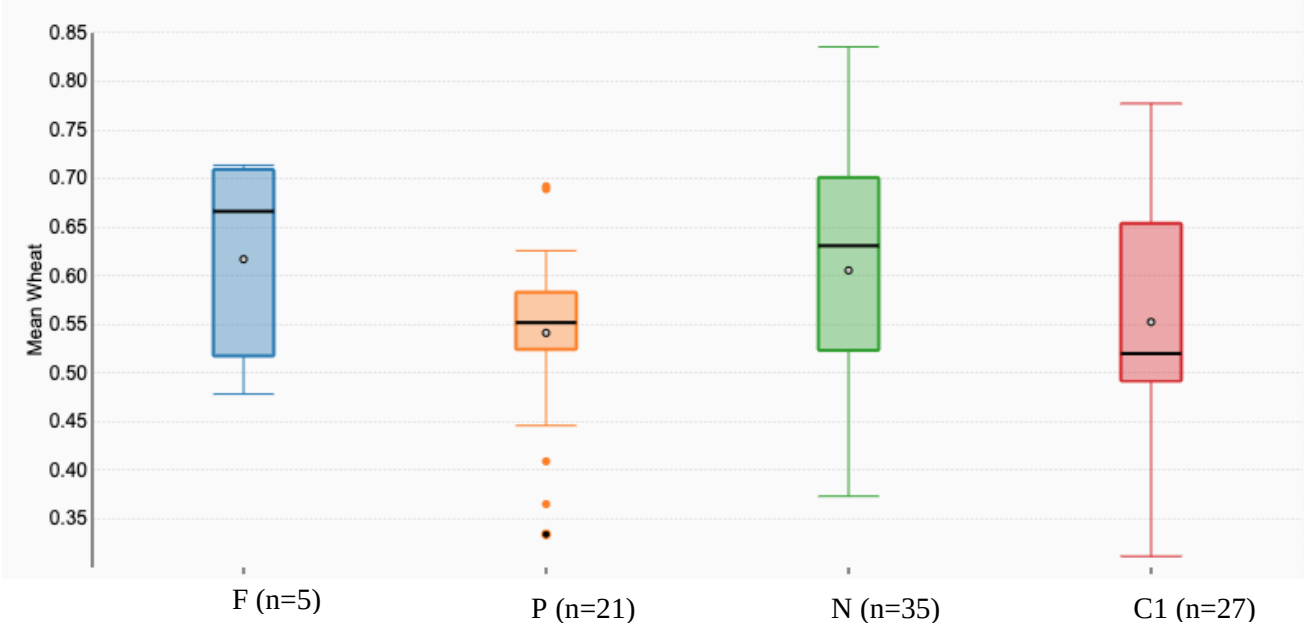


Figure 15. Scenario 1 wheat consumption intervals by group F, P, N, C1. Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval. The horizontal line represents the estimated mean while the open circle represents the estimated median.

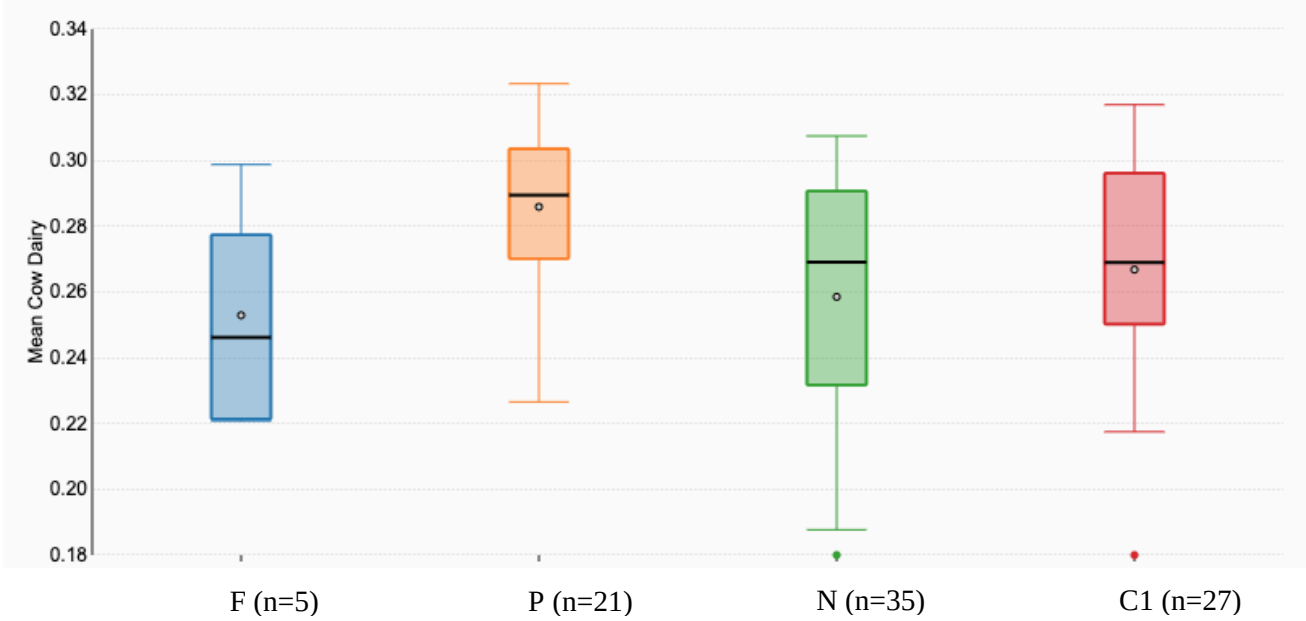
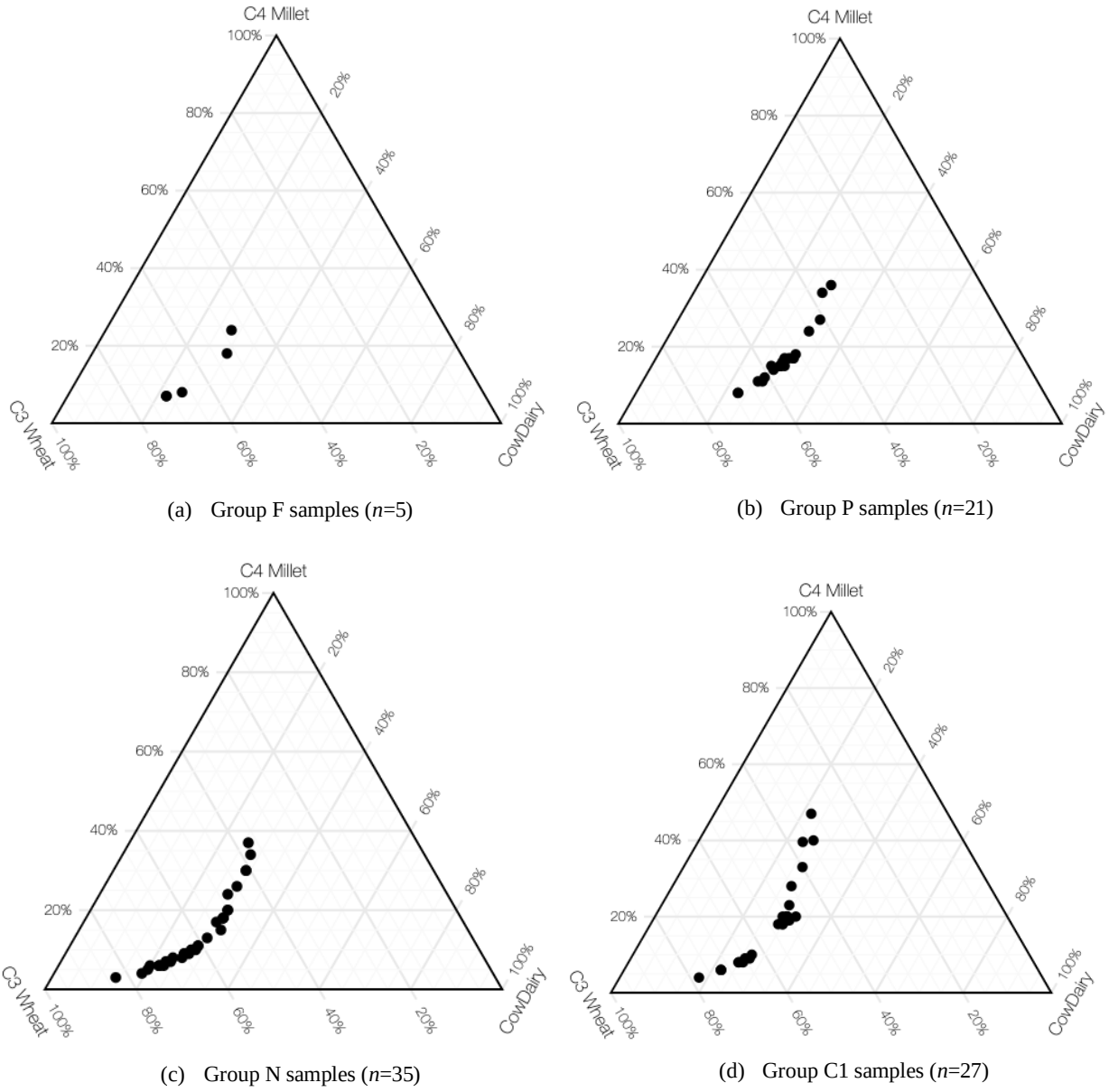


Figure 16. Scenario 1 cow dairy consumption intervals by group F, P, N, C1 Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval. The horizontal line represents the estimated mean while the open circle represents the estimated median.

Scenario 1 contains individual outliers in sample groups P (123, 318B, 484, 599, 608, 616), N (571, 582), and C1(490, 519, 619, 624). These outliers can be seen in Figures 14, 15, and 16, all of which have a direct effect on the mean consumption of each sample group and, therefore, on the overall population. These individuals will be discussed in further detail in Chapter 5.

Visual reconstructions of the food group estimates generated for each individual can be graphed within a ternary plot. Ternary plots show a relationship between three sets of data and are used when the combined data equals 100%, in this case 100% of an individual's diet. Figure 17 shows the ternary plot representations of results for individual diets in relation to each other for the juvenile age groups F, P, N, and C1 in Scenario 1.



(a) Group F samples (*n*=5)

(b) Group P samples (*n*=21)

(c) Group N samples (*n*=35)

(d) Group C1 samples (*n*=27)

Figure 17 (a-d). Ternary plots of juvenile age categories (F, P, N, C1) using food percentage estimates provided in Table 9.

Scenario 2

Parameters for Scenario 2 were also constructed and applied to the primary data in an effort to discern preference in herbivore dairy protein (e.g., cow or goat) in the earliest age groups to better understand practices of supplementing and/or substituting for human breastmilk

when necessary during early growth and weaning. However, Scenario 2 (Table 10) is weight independent and offset and concentration dependent, meaning that:

- more than one food fraction contributes to a consumer signal;
- an offset in the signal between the food groups and the consumer is present; and
- concentrations of the food fractions within the mixing problem are included.

The food fraction macronutrient chosen for modeling is dietary protein and food groups chosen are C_3 plants, C_4 plants, and goat milk. Age groups chosen to represent the consumer (N = 88) were F (n = 5), P (n = 21), N (n = 35), and C1 (n = 27). The dietary proxies being tested in Scenario 2 were C^{13} and N^{15}, and a summary of results for Scenario 2 are provided in Table 11. Figures 18, 19 and 20 provide box plot, mean and median value comparisons among age groups for millet, wheat and goat dairy consumption, respectively.

Table 10. The parameters and sample groups chosen for Scenario 2.

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	GOAT-MILK	F, P, N, C1

Table 11. Estimates generated by FRUITS for average isotope values of the Kellis II juvenile population for dietary Scenario 2.

	MILLET	**WHEAT**	**GOAT DAIRY**
FOOD (%)			
Group F (n=5)	13 ± 8	61 ± 11	26 ± 3
Group P (n=21)	18 ± 8	53 ± 8	28 ± 2
Group N (n=38)	14 ± 9	60 ± 12	27 ± 4
Group C1 (n=27)	18 ± 11	55 ± 12	27 ± 3
FRACTION (%)			
Protein	100 ± 0	100 ± 0	100 ± 0

Food (%) reports the estimate of calorie dietary contribution from each food group. Fraction (%) reports the estimate of calorie contribution from each food fraction.

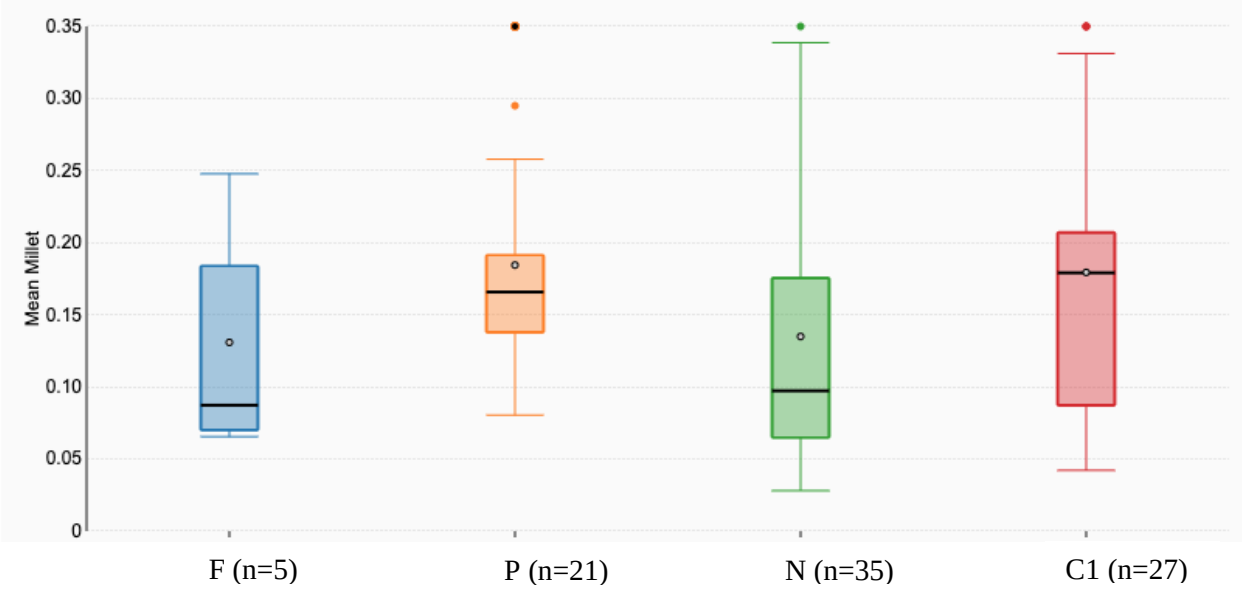


Figure 18. Scenario 2 millet consumption intervals by group F, P, N, C1. Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval. The horizontal line represents the estimated mean while the open circle represents the estimated median.

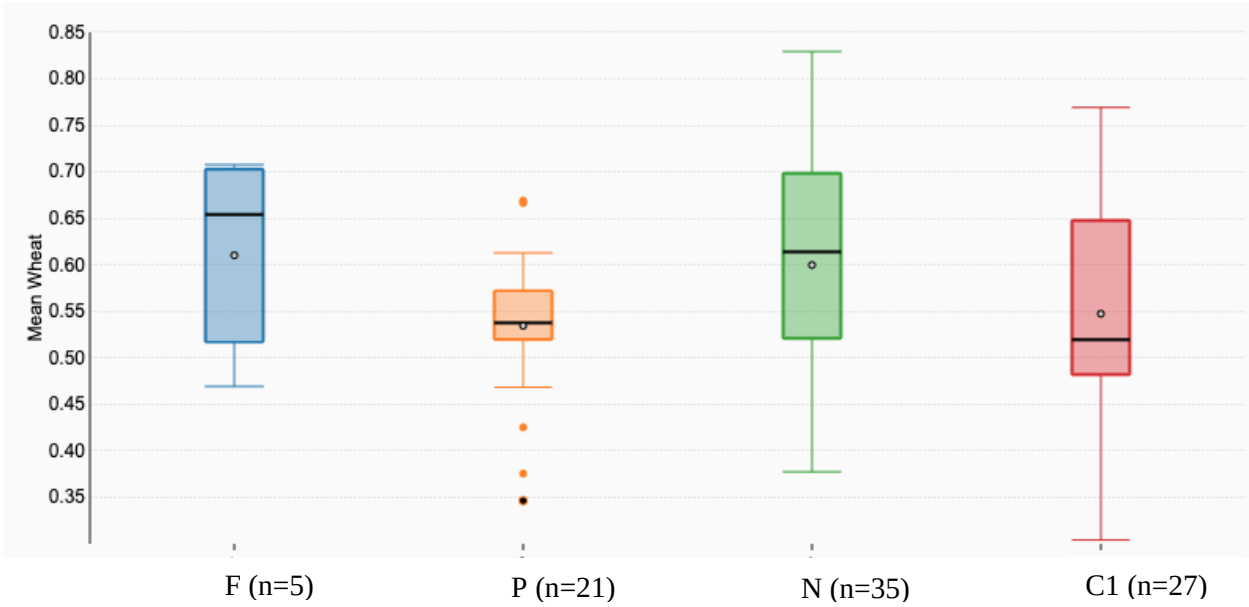


Figure 19. Scenario 2 wheat consumption intervals by group F, P, N, C1 Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval. The horizontal line represents the estimated mean while the open circle represents the estimated median.

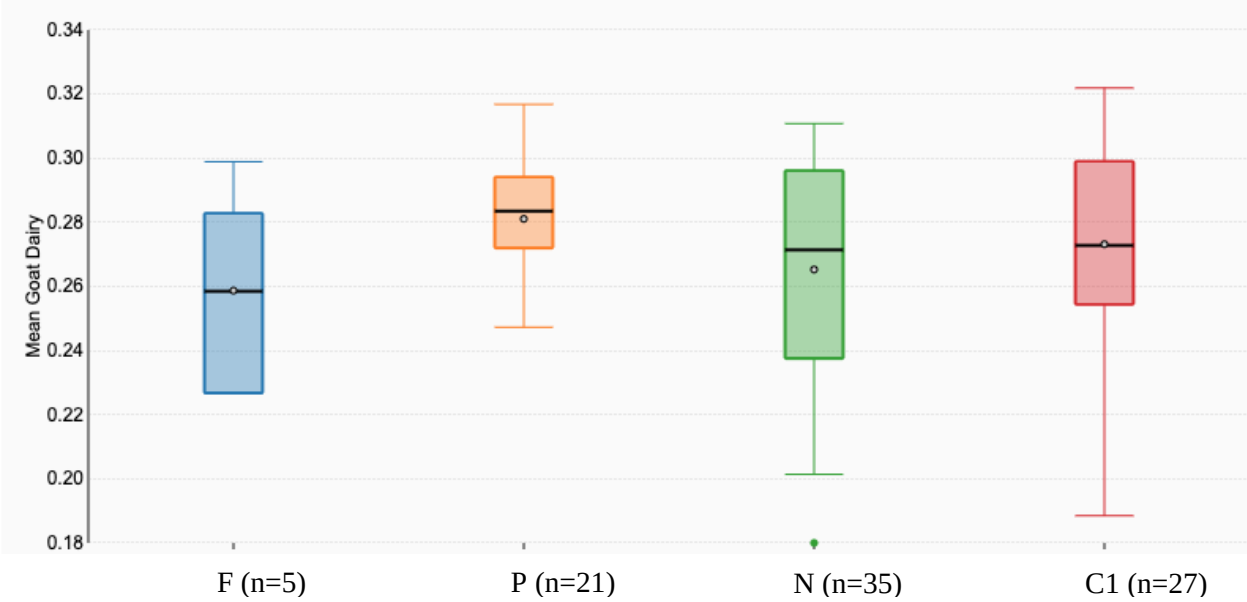
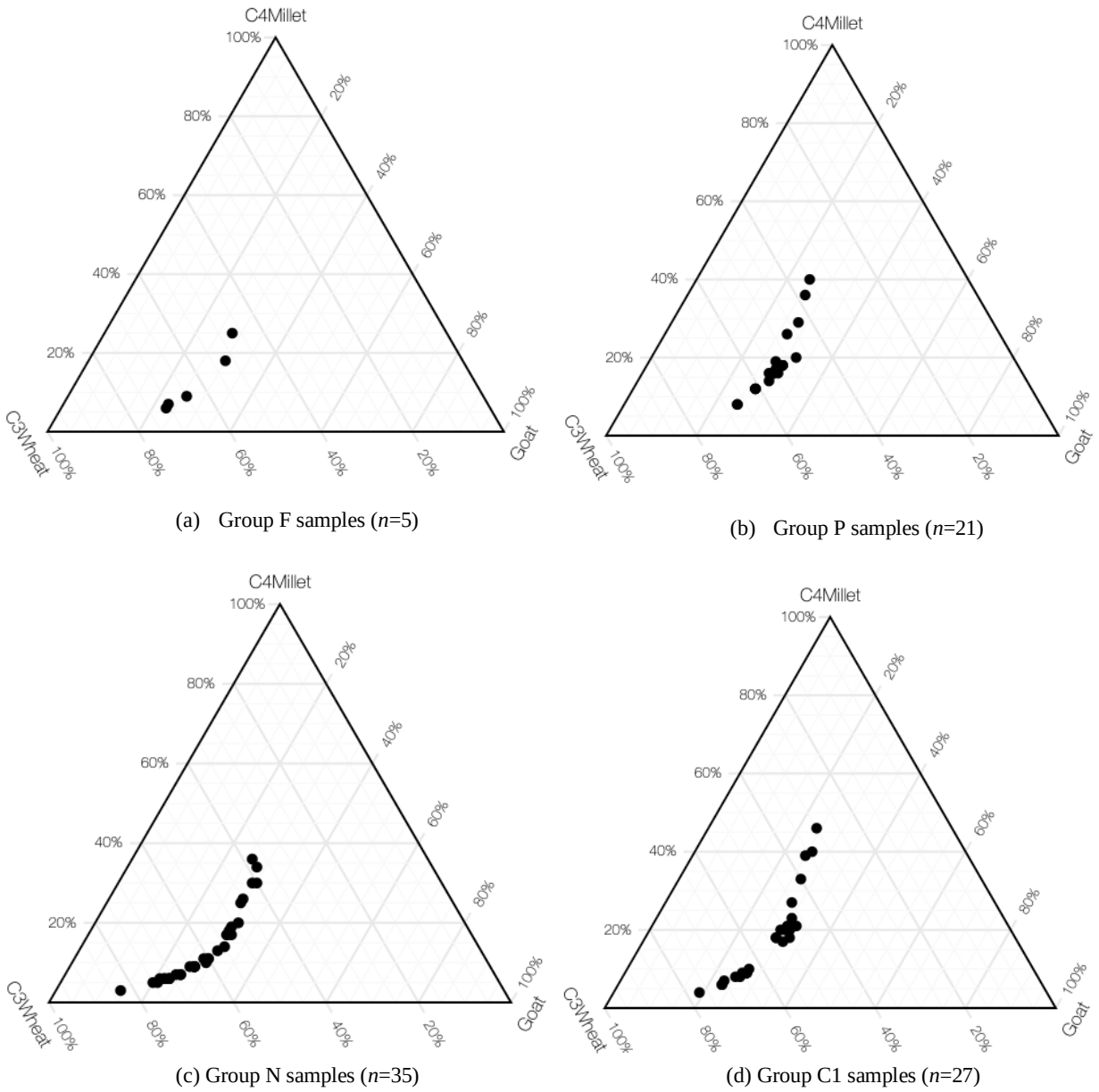


Figure 20. Scenario 2 goat dairy consumption intervals by group F, P, N, C1 Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval. The horizontal line represents the estimated mean while the open circle represents the estimated median.

Scenario 2 contains individual outliers in sample groups P (123, 318B, 484, 599, 616), N (104, 571, 582), and C1(490, 519, 619). These outliers can be seen in Figures 18, 19, and 20, all of which have a direct effect on the mean consumption of each sample group, and, therefore, on the overall population. These individuals will be discussed in further detail in Chapter 5.

Visual reconstructions of the food group estimates generated for each individual were graphed within a ternary plot. Figure 21 shows the ternary plot representations of individual diets in relation to each other for the juvenile age groups F, P, N, and C1 in Scenario 2.



(a) Group F samples (*n*=5)

(b) Group P samples (*n*=21)

(c) Group N samples (*n*=35)

(d) Group C1 samples (*n*=27)

Figure 21. (a-d). Ternary plots of juvenile age categories (F, P, N, C1) using food percentage estimates provided in Table 11.

Scenario 3

Parameters for Scenario 3 were constructed and applied to the primary data in an effort to discern preference in herbivore meat protein (e.g., cow or goat) in adult groups to better understand dietary preferences. In this case younger adult females and adult males are compared

with juvenile and older adult diets. Scenario 3 (Table 12) is weight independent and offset and concentration dependent, meaning that:

- the consumer signal is only determined by one food fraction;
- an offset in the signal between food groups and consumer is present; and,
- concentrations of the food fractions within the mixing problem are included.

The food fraction macronutrient chosen for modeling is dietary protein and food groups chosen are C_3 plants, C_4 plants, and cow meat. Adult age groups chosen to represent the consumer (N = 48; males, n = *20*, females, n = 28) are as follows: Ages (16-21 years) were A1 (n = 10; males, n = 4, females, n = 6) and ages (22-35) were A2 (n = 38; males, n = 16, females, n = 22) (see Table 5 for age group descriptions if needed). The dietary proxies being tested in Scenario 3 were C^{13} and N^{15}, and a summary of results for Scenario 3 are provided in Table 13. Figures 22, 23 and 24 provide box plot, mean and median value comparisons among age groups for millet, wheat and cow meat consumption, respectively.

Table 12. The parameters and sample groups chosen for Scenario 3.

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	COW-MEAT	A1, A2

Table 13. Estimates generated by FRUITS for average isotope values of the Kellis II reproductive-age adult population for dietary Scenario 3.

	MILLET	WHEAT	COW
FOOD (%)			
Group A1-F (n=6)	32±22	49±18	18±5
Group A1-M (n=21)	23±15	57±18	20±5
Group A2-F (n=22)	21±9	59±11	20±3
Group A2-M (n=16)	25±18	56±17	19±5
FRACTION (%)			
Protein	100 ± 0	100 ± 0	100 ± 0

Food (%) reports the estimate of calorie dietary contribution from each food group. Fraction (%) reports the estimate of calorie contribution from each food fraction.

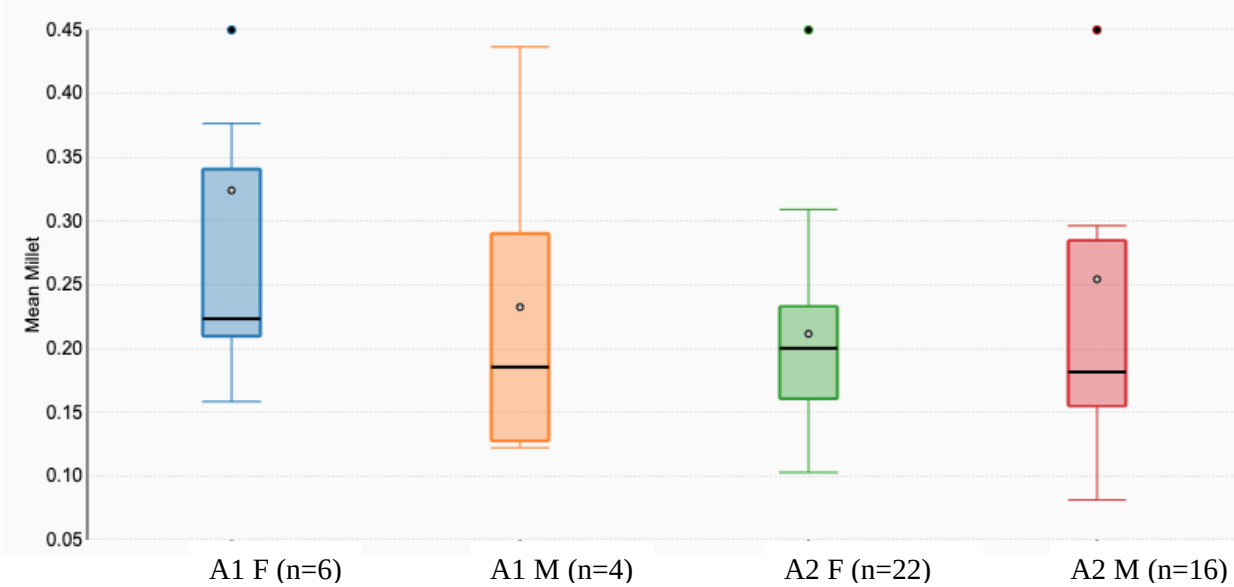


Figure 22. Scenario 3 millet consumption intervals by group A1 and A2 which are further divided into females (F) and males (M), see Figure 5 for details. Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval, the horizontal line represents the estimated mean while the open circle represents the estimated median.

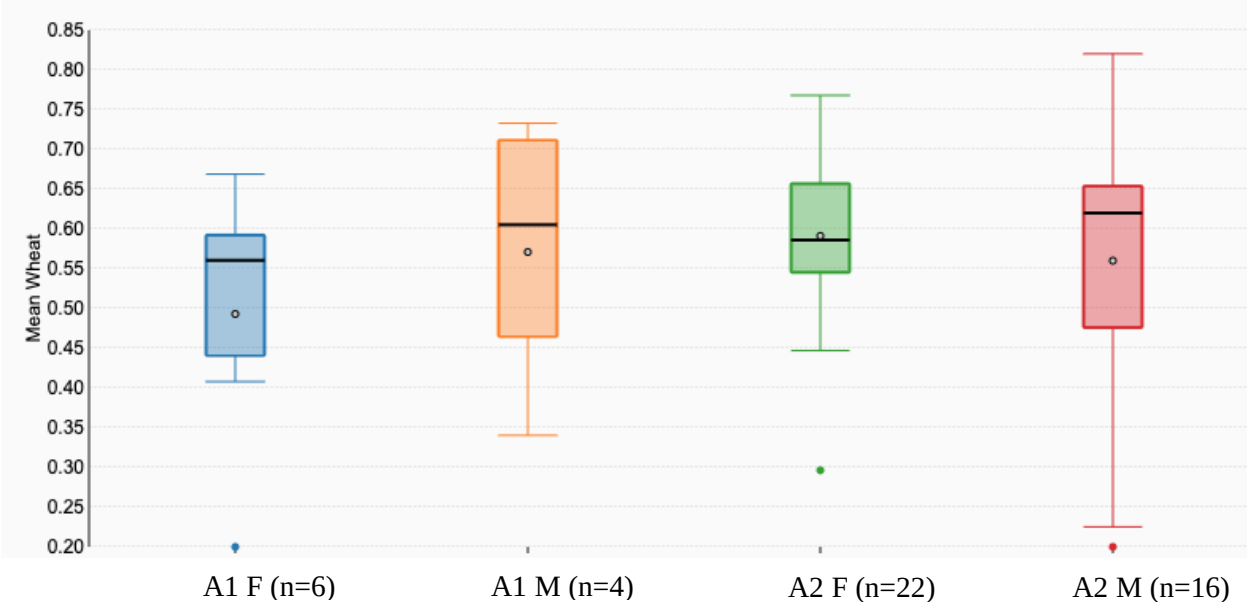


Figure 23. Scenario 3 wheat consumption intervals by group A1 and A2 which are further divided into females (F) and males (M), see Figure 5 for details. Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval. The horizontal line represents the estimated mean while the open circle represents the estimated median.

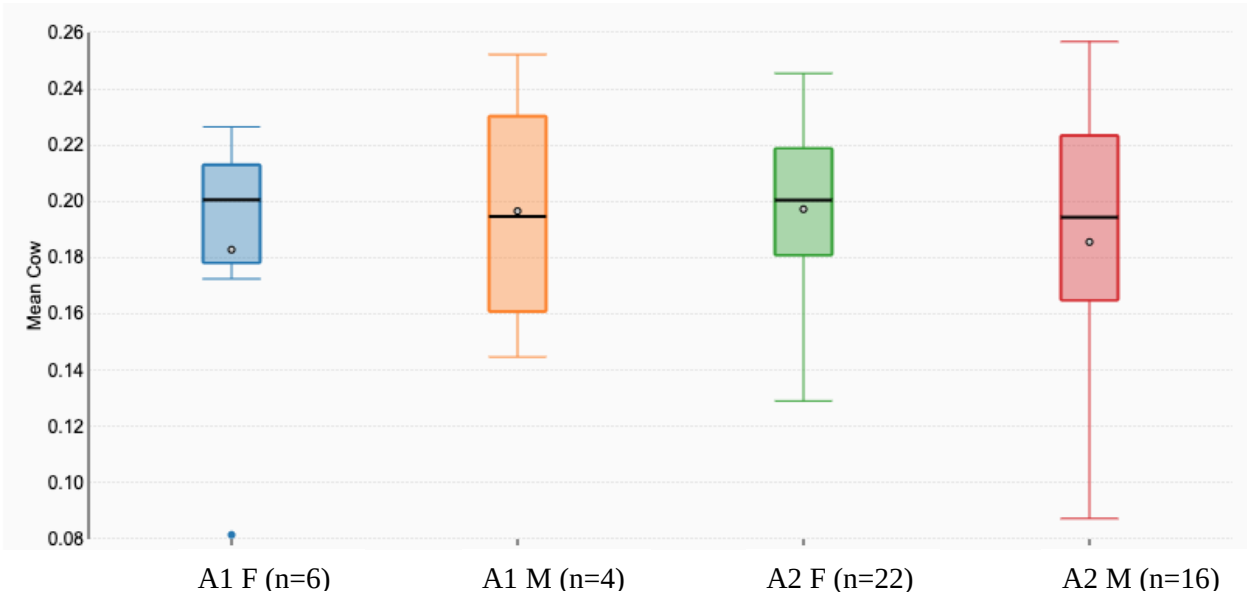
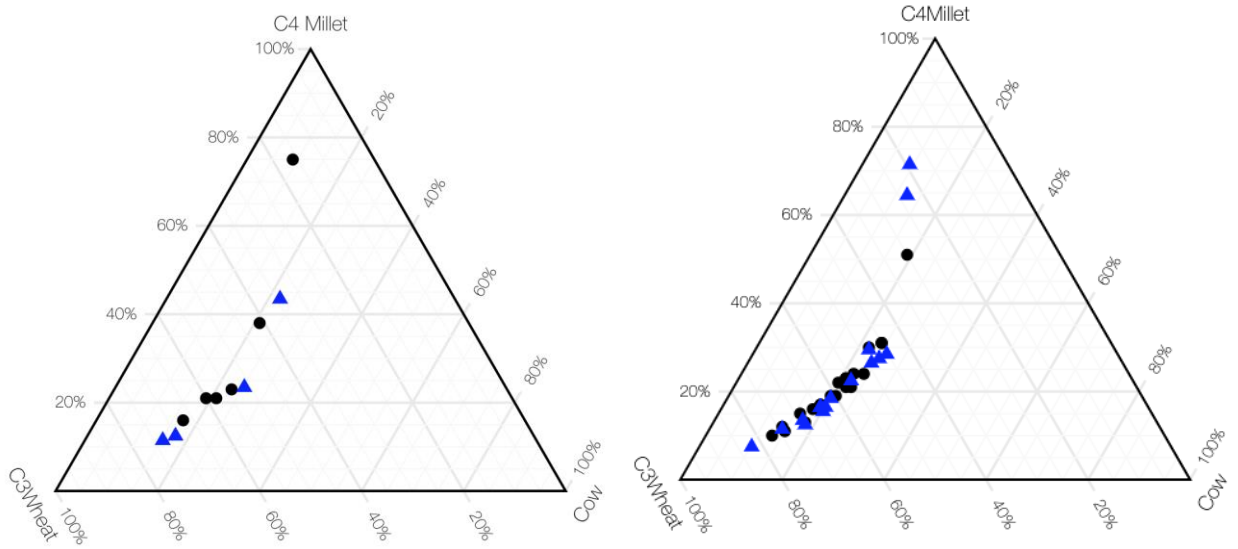


Figure 24. Scenario 3 cow-meat consumption intervals by group A1 and A2 which are further divided into females (F) and males (M), see Figure 5 for details. Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval. The horizontal line represents the estimated mean while the open circle represents the estimated median.

Scenario 3 contains individual outliers in sample groups A1 (485) and A2 (093, 402, 410). These outliers can be seen in Figures 22, 23, and 24, all of which have a direct effect on the mean consumption of each sample group, and, therefore, on the overall population. These individuals will be discussed in further detail in Chapter 5.

Visual reconstructions of the food group estimates generated for each individual were graphed within a ternary plot. Figure 25 shows the ternary plot representations of individual diets in relation to each other for the younger adult male and female age groups A1 and A2 in Scenario 3.



(b) Group A1 samples (*n*=10)

(a) Group A2 samples (*n*=38)

Figure 25. Ternary plots of adult age categories A1(a) and A2 (b) using food percentage estimates provided in Table 13. Black circles represent females and blue triangles represent males.

Scenario 4

Parameters for Scenario 4 were also constructed and applied to the primary data in an effort to discern preference in herbivore meat protein (e.g., cow or goat) in adult groups to better understand dietary preferences. In this case younger adult females and adult males and how they

relate to juvenile and older adult diets. Scenario 4 (Table 14) is also weight independent and offset and concentration dependent, meaning that:

- the consumer signal is only determined by one food fraction;
- an offset in the signal between food groups and consumer is present; and,
- concentrations of the food fractions within the mixing problem are included.

The food fraction macronutrient chosen for modeling is also dietary protein, however, food groups chosen are C_3 plants, C_4 plants, and goat meat. Adult age groups chosen to represent the consumer (N = 48; males, n = *20,* females, n = 28) are as follows: Ages (16-21 years) were A1 (n = 10; males, n = 4, females, n = 6) and ages (22-35) were A2 (n = 38; males, n = 16, females, n = 22) (see Table 5 for age group descriptions if needed). The dietary proxies being tested in Scenario 4 were C^{13} and N^{15}, and a summary of results for Scenario 4 are provided in Table 15. Figures 26, 27 and 28 provide box plot, mean and median value comparisons among age groups for millet, wheat and goat meat consumption, respectively.

Table 14. The parameters and sample groups chosen for Scenario 4.

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	GOAT-MEAT	A1, A2

Table 15. Estimates generated by FRUITS for average isotope values of the Kellis II reproductive age adult population for dietary Scenario 4.

	MILLET	WHEAT	GOAT
FOOD (%)			
Group A1-F (n=6)	32±22	48±18	20±6
Group A1-M (n=21)	23±15	56±18	21±5
Group A2-F (n=22)	21±9	58±11	22±3
Group A2-M (n=16)	25±18	54±17	20±5
FRACTION (%)			
Protein	100 ± 0	100 ± 0	100 ± 0

Food (%) reports the estimate of calorie dietary contribution from each food group. Fraction (%) reports the estimate of calorie contribution from each food fraction.

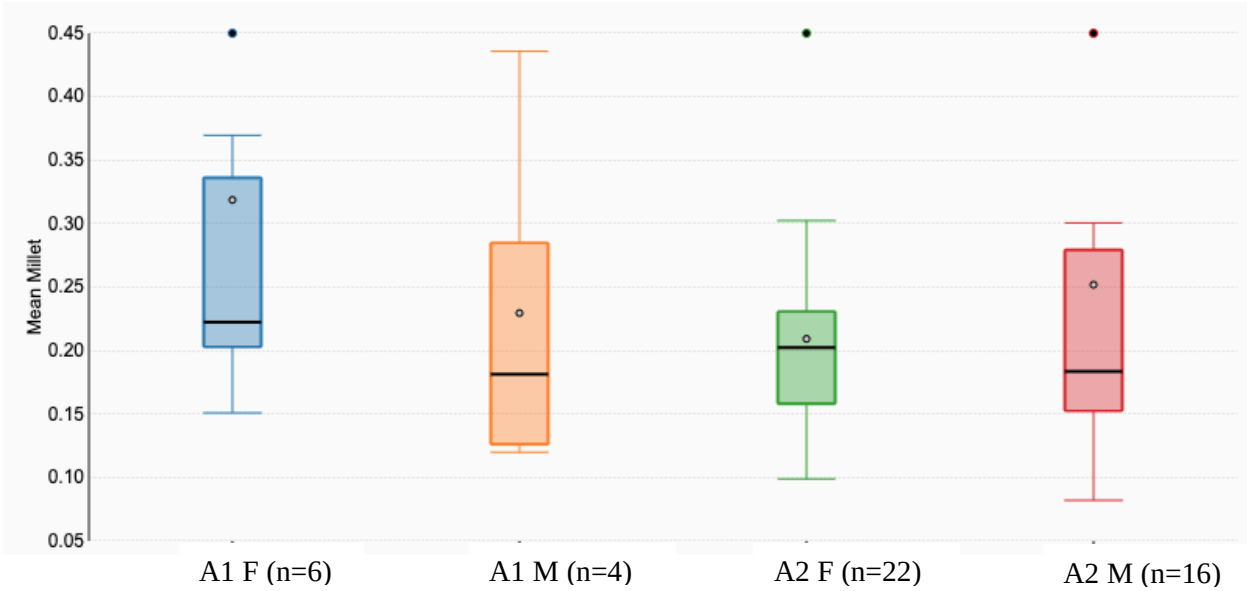


Figure 26. Scenario 4 millet consumption intervals by group A1and A2 which are further divided into females (F) and males (M), see Figure 5 for details. Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval. The horizontal line represents the estimated mean while the open circle represents the estimated median.

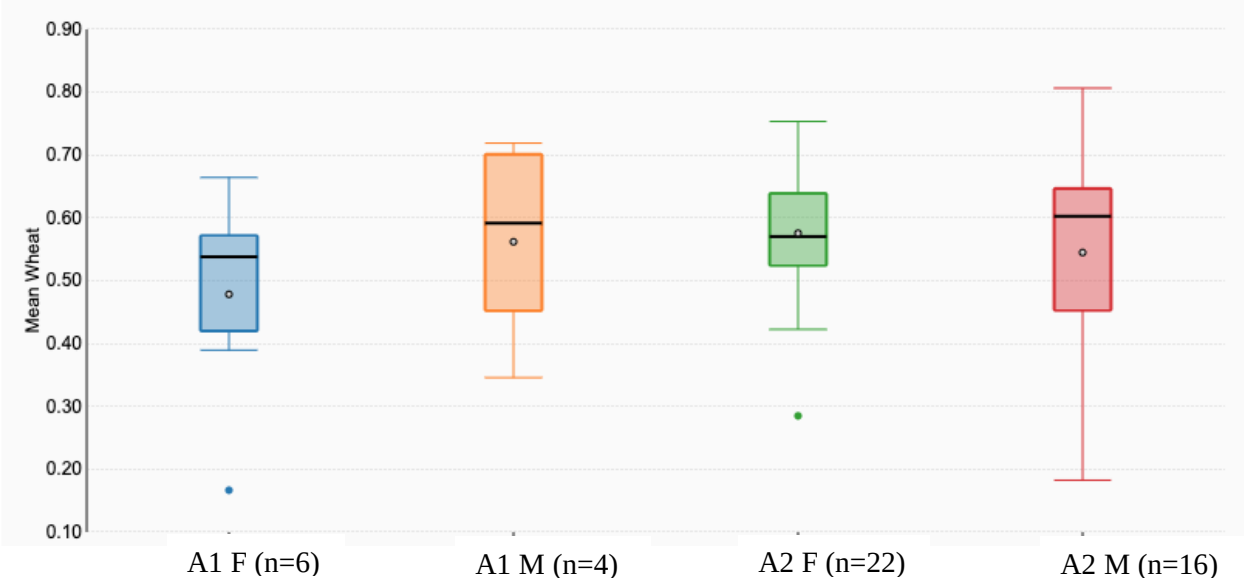


Figure 27. Scenario 4 wheat consumption intervals by group A1 and A2 which are further divided into females (F) and males (M), see Figure 5 for details. Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval. The horizontal line represents the estimated mean while the open circle represents the estimated median.

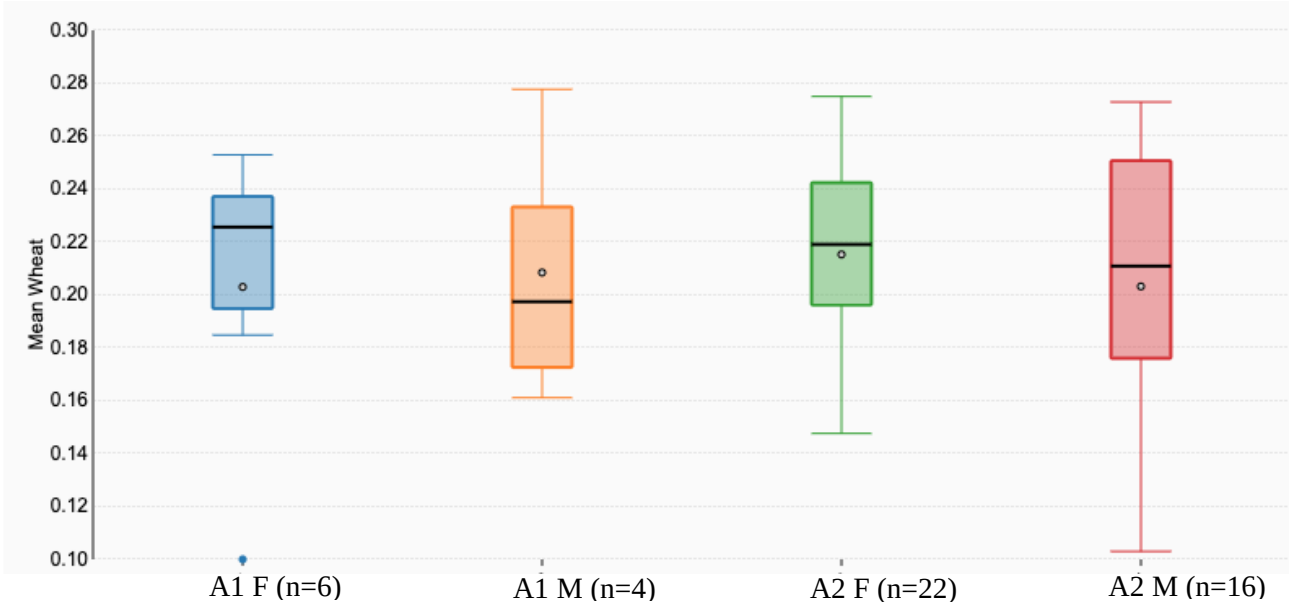
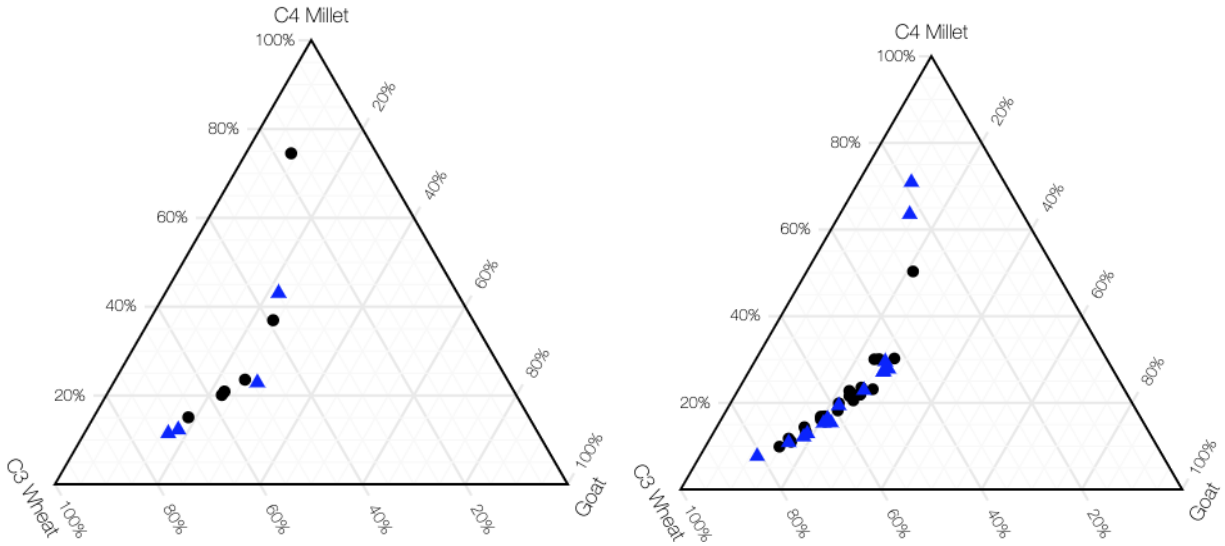


Figure 28. Scenario 4 goat-meat consumption intervals by group A1 and A2 which are further divided into females (F) and males (M), see Figure 5 for details. Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval. The horizontal line represents the estimated mean while the open circle represents the estimated median.

Scenario 4 contains individual outliers in sample groups A1 (485) and A2 (093, 402, 410). These outliers can be seen in Figures 26, 27, and 28, all of which have a direct effect on the

mean consumption of each sample group, and, therefore, on the overall population. These individuals will be discussed in further detail in Chapter 5.

Visual reconstructions of the estimates generated for each individual were graphed within a ternary plot. Figure 29 shows the ternary plot representations of individual diets in relation to each other for the younger adult male and female age groups A1 and A2 in Scenario 4.



(a) Group A1 samples (*n*=10) (b) Group A2 samples (*n*=38)

Figure 29. Ternary plots of adult age categories A1(a) and A2 (b) using food percentage estimates in Table 15. Black circles represent females and blue triangles represent males.

Scenario 5

Parameters for Scenario 5 were constructed and applied to the primary data in an effort to discern preference in herbivore protein sources (e.g., goat meat or dairy) in the adult groups to better understand dietary preferences of elderly adults and how they relate to juvenile and younger adult diets. Goat meat and goat dairy were selected over cow meat and cow dairy in this scenario because results from all associated FRUITS scenarios identify goat as the preferred

herbivore protein source over cow for the Kellis population during this time. Scenario 5 (Table 16) is weight independent and offset and concentration dependent, meaning that:

- the consumer signal is only determined by one food fraction;
- an offset in the signal between food groups and consumer is present; and,
- concentrations of the food fractions within the mixing problem are included.

The food fraction macronutrient chosen for modeling is dietary protein and food groups chosen are C_3 plants, C_4 plants, and goat meat. Age groups chosen to represent the consumer (N = 15) were A4 (n = 8) and A5 (n = 7) (see Table 5 for age group descriptions). Due to the small sample size in each age group, sex differences were not evaluated in this scenario. The dietary proxies being tested in Scenario 5 were C^{13} and N^{15}, and a summary of results for Scenario 5 are provided in Table 17. Figures 30 and 31 provide box plot, mean and median value comparisons among age groups for millet, wheat and goat meat consumption, respectively.

Table 16. The parameters and sample groups chosen for Scenario 5.

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	GOAT-MEAT	A4, A5

Table 17. Estimates generated by FRUITS for average isotope values of the Kellis II elder adult population for dietary Scenario 5.

	MILLET	**WHEAT**	**GOAT**
FOOD (%)			
Group A4 (n=8)	28±6	45±6	27±1
Group A5 (n=7)	21±6	53±6	25±1
FRACTION (%)			
Protein	100 ± 0	100 ± 0	100 ± 0

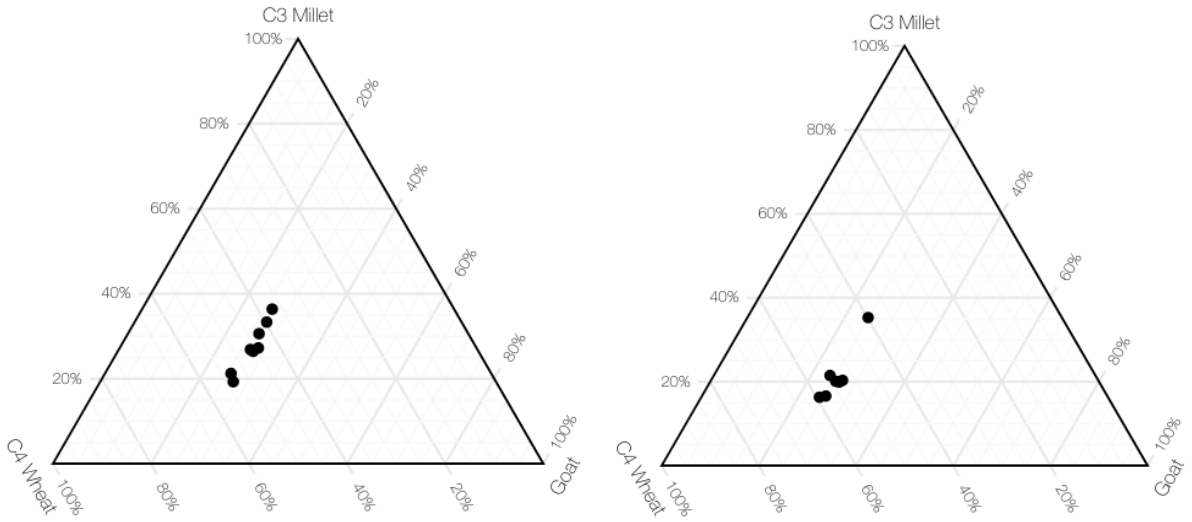
Food (%) reports the estimate of calorie dietary contribution from each food group. Fraction (%) reports the estimate of calorie contribution from each food fraction.

Figure 30. Scenario 5 millet (blue), wheat (orange) and goat meat (green) consumption intervals by group A4 (n=8), see Figure 5 for details. Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval. The horizontal line represents the estimated mean while the open circle represents the estimated median.

Figure 31. Scenario 5 millet (blue), wheat (orange) and goat meat (green) consumption intervals by group A5 (n=7), see Figure 5 for details. Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval. The horizontal line represents the estimated mean while the open circle represents the estimated median.

Scenario 5 contains individual outliers in sample groups A4 (476, 528) and A5 (044, 261). These outliers can be seen in Figures 30 and 31, all of which have a direct effect on the mean consumption of each sample group, and, therefore, on the overall population. These individuals will be discussed in further detail in Chapter 5.

Visual reconstructions of the food group estimates generated for each individual were graphed within a ternary plot. Figure 32 shows the ternary plot representations of individual diets in relation to each other for the elderly adult groups A4 and A5.



(a) Group A4 samples (*n*=8)

(b) Group A5 samples (*n*=7)

Figure 32.. Ternary plots of elder adult age categories A4 (a) and A5 (b) using food percentage estimates in Table 17.

Scenario 6

Parameters for Scenario 6 were also constructed and applied to the primary data in an effort to discern preference in herbivore protein sources (e.g., goat meat or dairy) in the adult groups to better understand dietary preferences of elderly adults and how they relate to juvenile

and younger adult diets. Like Scenario 5, goat meat and goat dairy were selected over cow meat and cow dairy as all associated FRUITS scenarios indicate goat as the preferred herbivore protein source over cow for the Kellis population during this time. Scenario 6 (Table 18) is also weight independent and offset and concentration dependent, meaning that:

- the consumer signal is only determined by one food fraction;
- an offset in the signal between food groups and consumer is present; and,
- concentrations of the food fractions within the mixing problem are included.

The food fraction macronutrient chosen for modeling is dietary protein, however, the food sources chosen are C_3 plants, C_4 plants, and goat dairy. Age groups chosen to represent the consumer (N = 15) were A4 (n = 8) and A5 (n = 7). Due to the small sample size in each age group, sex differences were not evaluated in this scenario. The dietary proxies being tested in Scenario 6 were C^{13} and N^{15}, and a summary of results for Scenario 6 can be seen in Table 19. Figure 32 provides box plot, mean and median value comparisons among age groups for millet, wheat and goat dairy consumption, respectively.

Table 18. The parameters and sample groups chosen for Scenario 6.

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	GOAT-MILK	A4, A5

Table 19. Estimates generated by FRUITS for average isotope values of the Kellis II elder adult population for dietary Scenario 6.

	MILLET	WHEAT	GOAT DAIRY
FOOD (%)			
Group A4 (n=8)	28±5	43±4	29±1
Group A5 (n=7)	21±6	49±5	29±1
FRACTION (%)			
Protein	100 ± 0	100 ± 0	100 ± 0

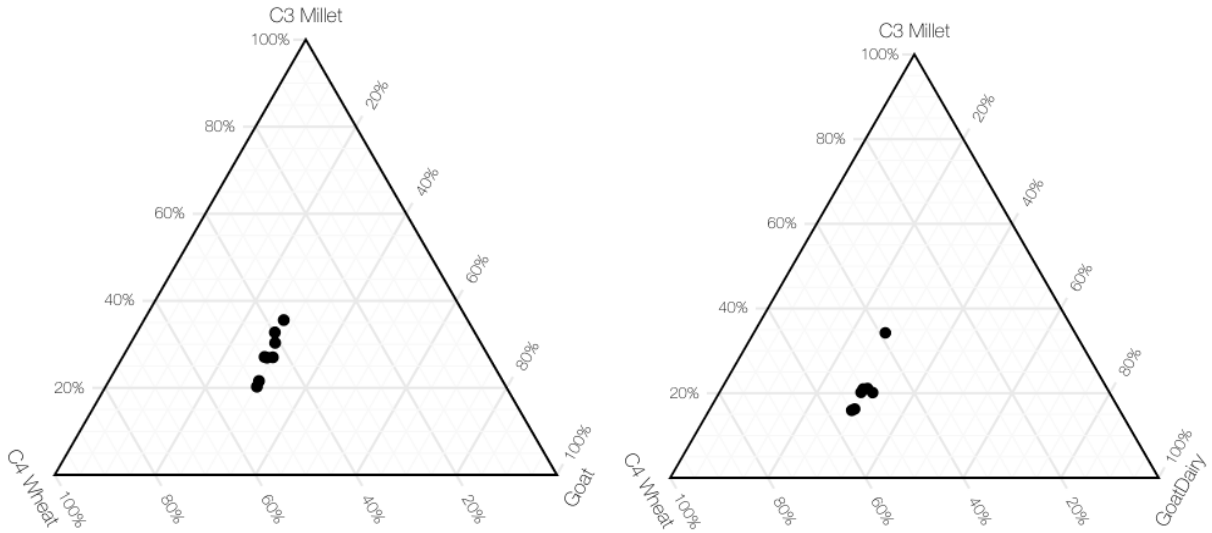
Food (%) reports the estimate of calorie dietary contribution from each food group. Fraction (%) reports the estimate of calorie contribution from each food fraction.

Figure 33. Scenario 6 millet (blue), wheat (orange) and goat dairy (green) consumption intervals by group A4 (n=8), see Figure 5 for details. Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval. The horizontal line represents the estimated mean while the open circle represents the estimated median.

Figure 34. Scenario 6 millet (blue), wheat (orange) and goat dairy (green) consumption intervals by group A5 (n=7), see Figure 5 for details. Boxes represent 68% credible confidence interval while the whiskers represent a 95% credible confidence interval. The horizontal line represents the estimated mean while the open circle represents the estimated median.

Scenario 6 contains individual outliers in sample groups A4 (079, 091) and A5 (044, 072, 281). These outliers can be seen in Figures 33 and 34, all of which have a direct effect on the mean consumption of each sample group, and, therefore, on the overall population. These individuals will be discussed in further detail in Chapter 5.

Visual reconstructions of the food group estimates generated for each individual can be graphed within a ternary plot. Figure 35 shows the ternary plot representations of individual diets in relation to each other for the elderly adult groups A4 and A5.



(a) Group A4 samples (*n*=8)

(b) Group A5 samples (*n*=7)

Figure 35. Ternary plots of elder adult age categories A4 (a) and A5 (b) using food percentage estimates in Table 19.

CHAPTER FIVE: DISCUSSION

Overall Trends in Grain, Meat, and Dairy Resource Consumption

This study was designed to provide more depth in understanding of food selection in diet among the Kellis 2 cemetery population. Previous isotopic analyses indicated a greater selection of and dependence on C_3 plants, but with a clear presence of C_4 resources in the diet, as well as the consumption of herbivore animal proteins (Dupras, 1999; Williams, 2008). Results from the scenarios applied in this study support this interpretation for all age groups sampled, with mean wheat consumption being as high as 61% (±11) in the F (21-36 weeks' gestation) juvenile age group in Scenario 2, and as low as 48% (±18) in the adult A1 female (16-21 years) age group in Scenario 4. Conversely, millet, the only primary C_4 food source known and recognized from archaeological and documentary evidence for Kellis, was present in the A1 female group with the highest mean quantity of 32% (±12) which will be discussed in greater detail in the following section. Goat meat and milk were chosen, or were possibly more accessible, than cow meat and milk in all age groups sampled. The highest mean consumption of both meat and dairy were the elderly adult age groups of A4 (51-59 years) males and females and A5 (60+ years) males and females in Scenario 5 and 6, which will also be discussed in greater detail.

Results from Scenarios 1 and 2 indicate juveniles were fed a diet high in C_3 plants such as wheat and barley. Both grains were considered in previous studies and were available as food resources at Kellis. In this study wheat was the preferred choice considered as wheat has been described as the preferred food choice in Roman Egypt (Bagnall, 1996). The highest mean wheat consumption of 61% (±11) is seen in the fetal (21-36 weeks' gestation) age group, closely followed by the N (41 weeks' gestation -1 year) age group with 60% (±12) as shown in Figure

21. However, the fetal (F) group would be more representative of maternal diet as individuals in this group never reached full term gestation and most likely do not yet exhibit evidence of breastfeeding in their hair tissues. The highest mean millet consumption of 18% (±8) can be seen in the P (37-40 wks. gestation) age group followed closely by the C1 (13 months-4 years) age group at 18% (±11). The highest mean juvenile dairy consumption of 28% (±2) is found in the P (37-40 wks. gestation) age group when goat milk is used as a food source in Scenario 2. Goat milk was a suggested supplemental food item for weaning babies, and it is possible this was also the case for infants who could not or would not breastfeed (Dupras et al., 2001; Dupras and Tocheri, 2007). It is also suggested that millet paps are possible high-fiber supplementary foods that are easier to digest than wheat paps (Dupras et al., 2001; Talib et al., 2017). This is discussed in greater context in the sections below on millet and weaning practices.

Groups consisting of the younger adults, A1 (16-21 years) and A2 (22-35 years) were divided by sex for comparison of food selection. When goat meat was used as a food fraction protein source in Scenario 4, the dietary fraction for A1 males (21% (±5)) and females (20% (±6)) and A2 males (20% (±5)) and females (22% (±3)) did not differ greatly with age or sex. This was also the case when cow meat was used as a food fraction protein source in Scenario 3, with dietary fraction for A1 males (20% (±5) and females (18% (±5)) and A2 males (19% (±5)) and females (20% (±3)) showing little to no difference between age or sex. The highest meat consumption of 22% (±3) is found in the A2 (22-35 years) female group with goat meat as a food fraction protein source, although this category margin when compared with A2 males (20% (±5) was quite narrow and with standard deviation shows no difference between sexes. Therefore, unlike previous isotopic studies (Dupras 1999; Williams 2008) where a meat-preference in the adult male diet was inferred, results from this study suggest the meat fraction of diet is more

equivalent between adult males and females. Any margin of difference may be attributed to availability of meat resources or specialized inclusion into the diet at specific times. For example, Groff (2015) suggested that males within the Kellis community at this time were frequently moving between the Nile Valley and Dakhleh Oasis, possibly indicating that they were limited in the amount of fresh meat protein being consumed during travel (dried meats). In addition, it has been well noted in the literature that increases in protein intake during pregnancy (Inst. Of Medicine, 1990; NRC, 1989) is common. This kind of increase in protein intake during pregnancy might be reflected in the highest meat consumption of 22% (±3) found in the A2 female group.

The elderly adult age groups, A4 (51-59 years) and A5 (60+ years), with goat meat as a food fraction protein source, ate a diet consisting mainly of C_3 plants with mean wheat consumption ranging from 45% (±6) to 53% (±6). This was consistent with all other age groups evaluated in this study. Mean millet consumption was highest in the A4 age group, at 28% (± 6) when compared with other groups evaluated, and goat meat consumption was high in comparison to other age groups in both A4 and A5 age groups at 27% (±1) and 25% (±1) respectively. Much like instances of pregnancy, it is also well documented that increased protein intake is beneficial during the recovery from traumatic injury and critical illness (Dickerson, 2012; Frankenfield, 2006; Larsson et al., 1990). The high goat meat consumption seen in the A4 and A5 age groups may be related to the presence of pathological conditions, such a hip fracture and osteoporosis, common to these age groups and present within the Kellis 2 population (Dupras et al., 2020). When goat milk was used as a food fraction protein source, both A4 and A5 age groups had a mean consumption of 29% (±1) goat dairy, which is the highest mean of all age groups. Millet consumption remained the same at or around 28%, while mean wheat

consumption dropped below 50% in both age groups. Results from Scenario 5, with goat meat as a food fraction protein source, and Scenario 6, with goat milk as a food fraction protein source, are compared visually using ternary plots in Figures 32 and 35. This may represent a transition in diet where individuals were reverting to dietary choices more similar to juveniles than the younger-aged adults, a possibility discussed in more detail in a later section of this chapter.

Outliers in these overall trends exist for a number of reasons – some of which may be attributed to errors in statistical analysis, while others represent actual population anomalies. The individuals identified as outliers in Chapter 4 will be addressed in the following discussion sections where more detailed descriptions of their individual dietary consumption and generated food group estimates are pertinent.

Importance of Millet

FRUITS modeling in this study assumes the population of Kellis exploited certain primary agricultural resources, including millet, wheat, and the meat and dairy of herbivores. Previous research by Dupras (1999) and Williams (2008) has shown that the addition of pearl millet (*Pennisetum americanum)* came during the Romano-Christian period, creating a significant change in the $\delta^{13}C$ values of the population. Prior to as evidenced by results from isotopic research from earlier cemeteries of Kellis 1 (Ptolemaic Period ca. 200 BCE) and ‘ein Tirghi (Third Intermediate ca. 800 BCE) (Dupras, 1999). Individuals from Kellis 1 and ‘ein Trighi do not exhibit the same level of $\delta^{13}C$ enrichment as found in Kellis 2 individuals, indicating a clear delineation between the diet of pre-Roman Egypt and that under Roman rule. While the Kellis Agricultural Book (KAB) does not mention the addition of millet in the agricultural cycle, historical data combined with isotopic analyses of individuals from the

community provide a more integrative and complete picture of available grain resources for consumption.

The results of this study indicate that regardless of the food fraction protein source modeled, the mean millet consumption did not change, as demonstrated in Scenarios 3, 4, 5, and 6 (Tables 13, 15, 17, 19). Updates in software for FRUITS modeling have now allowed for greater clarity and refinement when analyzing and interpreting these data. For example, in a scenario not included among those presented in Chapter 4, results (see Appendix D) indicate a substantial change in millet consumption with an associated food fraction protein source in the F (21-36 wks. gestation) age group. The food fraction protein sources being modeled in the scenario were cow and goat meat, which were used as a proxy for food group estimates in younger reproductive-age females from group A1 (16-21 years). This change resulted in the millet consumption shifting from 13% (±7) with goat meat, a conservative result, to 20% (±12) with cow meat, a result higher than any other juvenile age group regardless of food fraction protein sources used. A similar effect occurred with wheat consumption for the F group, creating a mean of 72% (±14) when goat meat was the food fraction protein source. This is the single highest mean of any age group for wheat consumption. It has previously discussed that millet was used as animal feed with other grains during the Roman era at Kellis, as it was a cheaper grain, easy to grow in arid conditions, and had quick turnover allowing for greater quantities than other grains (Dupras et al., 2001). Although these data were not used in any resulting Scenarios (1-6) in this study, this age group anomaly strongly supports the conclusion and may lead to future information about animal feeding practices.

The highest millet mean consumption of 32% (±22) is seen in the A1(16-21 years) females age group, shown in the ternary plots in Figure 25. As mentioned earlier, the majority of

Kellis 2 individuals, regardless of age category, consumed less than 50% millet in their respective diets. Possible reasons why millet consumption was found in higher amounts among certain age groups may be due to the ease of digestibility (Talib et al., 2017). The A1 age group females are of reproductive age, and millet has been suggested as a morning sickness food for younger higher-risk pregnancies (Shobbit et al., 2020). It is also possible that wheat was being used predominantly in bread, which would be more convenient for consumption by those travelling as previously discussed, or used for beer, or simply that access to wheat was not possible during this time, as it was also used as a food allocation for labor and general economic and taxable payment measure for many villages and townships at this time (Bagnall, 1996; Bagnall and Frier, 206: Scheidel and Freisen, 2009).

When analyzing millet usage in Bronze and Iron Age Croatia, Zavodny and colleagues (2017) saw an increase in millet consumption over time. This trend coordinated with a decrease in herbivore protein suggesting that environmental uncertainties led to a need for crop diversification, with millet becoming a consistent staple food crop. Millet grows well in arid environments with variable rainfall, this is a possible reason it also became a staple in the Dakhleh Oasis. However, unlike Kellis 2, no differences in consumption of millet by age or sex was noted (Zavodny et al., 2017), and it is likely that individual households stored it for times of uncertainty. Over time consumption went from 20% of the diet during the Bronze age and up to 40% of the population's diet well into the Iron Age (Zavodny et al., 2017). Kellis was a city with an uncertain and hostile environment, it is known that the city was abandoned during the late 4th to early 5th-century C.E, and it is believed to be the result of crop desertification with the Sahara taking over the land inhabited by the population (Hope, 2001, 2002, 2003). The adoption of

millet by the Kellis population may have been an effort to stave off crop loss that would affect the diet of both the human and animal populations.

An analysis of the pathological conditions exhibited by the individuals who were outliers in this study may offer further explanation for higher millet consumption. In the adult age groups, outliers of note include Individual 485, a 16-year old female, exhibiting the single highest consumption of millet among all age groups, at 75% (±10). Williams (2008) describes this individual as having extensive carious molars. Dental conditions such as this make eating certain foods difficult, perhaps causing a need for accessible, easier-to-consume foods such as millet cereals. There are health conditions that may be accompanied by dental disease (e.g., diabetes), again leading to the possibility of millet being consumed during illness. In fact, pearl millet has a low glycemic index and may help in dealing with the effects of non-insulin dependent diabetes mellitus (Nambiar et al. 2011). There is also the potentiality for pregnancy in this individual, which at any age carries risk, but at the age of 16 it would have been considered especially high-risk (Dupras et al., 2015). If this was the case, millet may have been consumed following episodes of morning sickness or other illness associated with pregnancy.

Individual 402, is a 29-year old male with a millet consumption of 71% (±11). Williams (2008) describes this individual as having an excess of calculus on their teeth, a possible result of large amounts of sticky starch foods, such as millet. This individual may have suffered from chronic illness making millet a desirable food choice or possibly that millet was the only accessible food.

Individual 093 is a 23-year-old male with a 64% (±13) millet consumption. This individual suffered from spina bifida occulta as well as extreme dental caries (Williams, 2008). It is possible that chronic illness was once again a factor in millet being a dietary choice. Dental

caries could have been a causative agent behind this food choice, as is possible with Individual 485, or it may have been a result of long-term millet consumption.

Finally, Individual 410 is a 27-year-old female with a millet consumption of 50% (±16). She suffered from a chronic illness visible in the extensive new bone formation on the left femur, tibia, and fibula (Williams, 2008). New bone formation is indicative of progressive, chronic, disease which in this individual remains undiagnosed (Ortner, 2003). Millet once again was possibly being used as an illness food for the afflicted individual.

The individual outliers discussed within this section all suffered from a variety of health conditions and all consumed a higher amount of millet than the mean population of the Kellis 2 community. However, there are a number of individuals sampled within the population that suffered from illness and injury (Williams, 2008), but did not consume such large amounts of millet prior to death. Further research into the diet fractions of these individuals, such as analysis of tooth calculus or caries inclusions, and a more comprehensive paleopathological analysis of their skeletal remains, would need to be considered to make any definitive statements on the use of millet as an illness food; however, the results of this study strongly support this argument.

Weaning Practices

During the Roman era in Egypt, infants were breastfed exclusively until about 6 months of age at which point other foods were gradually introduced to their diet, and typical supplementary foods included cow and goat's milk, honey, eggs, cereals, and bread (Dupras et al., 2001). Breastfeeding continued until approximately 3 years of age by which time children would eat the same foods as their household (Dupras, 1999; Dupras et al., 2001; Williams, 2008; Wheeler et al., 2011). Previous isotopic studies show an enrichment in both $\delta^{13}C$ and $\delta^{15}N$

between birth and 6 months of age, while the latter is typical and indicative of the start of weaning practices, the $\delta^{13}C$ enrichment is atypical as breastmilk depletes ^{13}C, and, therefore, enrichment is not an expected result (Wright and Schwartz, 1998; 1999; Dupras 1999; Dupras et al., 2001). Dupras and colleagues (2001) suggest that infants began weaning through introduced ^{13}C enriched foods prior to the age of 6 months, with pearl millet (*Pennisetum americanum*) being the only available C_4 food source capable of producing the resulting ^{13}C enrichment. Cows and goats were fed millet as approximately 20% of their diet which makes them the only other source of ^{13}C enrichment (Dupras et al., 2001). Scenario 1 and Scenario 2 in this study used protein values representative of cow milk (3.2) and goat milk (3.0) respectively to discern a pattern showing one as preferred over the other. Goat milk had a consistent juvenile mean consumption of 26-27% across all age groups, while cow milk results indicate a larger margin of 18-26% for the same groups. FRUITS results in this study, while indicative of a preference for goat milk, are too similar to discern a preference for either as accessibility to certain dairy may have been unavailable at times or seasonally variable in its protein content (Iloeje et al., 1980). What can be ascertained by the results, though, is that cow or goat dairy was a consistent dietary staple as was previously found.

Mean values (μ =) of consumed dietary choices for each age group population in Scenario 1 and 2 are found in in Tables 9 and 11. These values include all individuals per category regardless of individual standard deviation being situated outside of this reported range. Values for agriculture products are consistent with protein choice consumed with all groups consuming a higher percentage of goat products in relation to cow. Although not included in any scenario as previously mentioned, age group F (21-36 wks. gestation) was also tested with values indicative of cow meat and goat meat to represent the diet of the mother (Appendix D). This

change altered the millet value from 13% to 20% when using cow meat protein values, possibly representative of the C_4 diet of the cow being consumed. When goat meat protein values were used, the millet value remained at 13%, bringing into question whether there is a difference in the agriculturally-sourced feed of these animals. However, another explanation is that the mother may have been consuming millet paps directly, due to morning sickness or other chronic issues related to pregnancy, maternal health, or pre-term birthing (e.g., heartburn, preeclampsia, nursing fevers, gestational diabetes, anemia). As mentioned earlier, A1 females exhibit the highest millet consumption at 32% (±22), while males in this category consumed 23% (±15). These results once again provide support for the suggestion of millet being used as a Hyperemesis Gravidarum (a.k.a. morning sickness) food.

There is an increase in C_3 consumption from P (37-40 wks. gestation) age group at 53% (±8) to N (41weeks-1year) age group at 60% (±12), providing support for the interpretation of supplementary C_3 weaning foods being introduced at or around 6 months of age. Following this is an increase in C_4 from N age group at 14% (±9) to C1 (1-4 years) age group consumption at 18% (±11), which could indicate an addition of millet cereals or animal products to the diet. This provides further support for the interpretation that millet is a likely weaning food as well.

As with the adult age groups there are distinct outliers in the juvenile categories. In Figures 14 through 21, most of the outliers are situated in the P (37-40 wks. gestation) age group with higher values for the consumption of millet than the mean (18% (±8)) for the group as a whole when goat milk is the food fraction protein source. For example, Individual 318B in this group, aged at 37 weeks' gestation, has a millet consumption value of 41% (±13), which would be reflecting maternal diet during pregnancy or during early breastfeeding after pre-term birth. This very young individual is described as having bilateral temporal defects, specifically the

petrous and squama (Williams, 2008), although whether this affected the individual's health or was related to their death is not known. Individual 599, aged at 40 weeks' gestation, and Individual 616, aged at 5 months, both exhibit high millet consumption at 37% (±14) and 30% (±13) respectively, but did not exhibit any osteological pathologies; however, this does not rule out the presence of an acute illness or one that affected the bone. All three cases point to millet once again being a primary food resource for mothers and the youngest of juveniles during periods of breastfeeding and weaning.

Individual 571, ages approximately 6 months, has the single highest value for wheat consumption for any age category at 83% (±12). This individual presents with active cribra orbitalia and abnormal cranial porosity (Williams, 2008), indicating a chronic illness. However, the individual consumed less than 3% (±3) millet, therefore it is possible a higher quality wheat-based supplementary food was fed to the child at a critical time of initiating the weaning process. This child was not receiving supplemental dairy, as their consumption was 14% (±12), which is far below the mean goat dairy consumption of 27% (±4) for age group N, suggesting that their diet was missing a key milk protein resource possibly as a trade-off for increased wheat consumption, a lack of access to milk, or inability to digest dairy products.

Individual 519, aged from 2-3years, and is identified as a probable victim of child abuse (Wheeler et al, 2013). There is evidence of bilateral fractures of the humeri, as well as multiple fractures in various stages of healing around the thoracic and pelvic region, excess new bone formation, active cribra orbitalia, and enamel hypoplasia indicative of poor diet and/or malnutrition. This individual consumed 40% (±14) millet, a larger amount than the mean C1 millet consumption of 17% (±12) with cow dairy and 18% (±11) with goat dairy as a protein

source. It is unknown whether millet was the only food choice, however it is clear that this individual was dependent on millet for the majority of their dietary intake.

Elderly Diet Transition

There is a scarcity of information available on the diet and lifeways of the elderly population in Roman-era Egypt. Available information suggests that the elderly population ate less meat, dairy, and millet compared to other age groups, and more wheat, or other C_3 plants, which accounts for their depleted carbon and enriched nitrogen levels, however, disease and illness could also cause enrichment in nitrogen levels (Williams et al., 2011; East, 2015). Paleopathological analyses indicate a high prevalence of osteoporosis and related fractures in elderly females, as well as the presence of osteoarthritis, tuberculosis, leprosy, extensive dental wear, tooth loss, and excess calculus in males and females in the A4 (51-59 years) and A5 (60+ years) age groups, making infectious and non-infectious disease a credible factor in elevated nitrogen levels along with diet (Williams, 2008; Graham, 2016; Dupras et al, 2020).

FRUITS results from this study indicate that when goat meat is used as a food group in Scenario 5, individuals in the A4 (50-59 years) age group had a distinct increase in the consumption of millet. Millet consumption in the A4 age group is 28% (±6), while the mean millet consumption of the A2 (22-35 years) age group is between 21% (±9) and 25% (±18) (see Tables 15 and 17 for comparison). Conversely, the mean of wheat consumption decreases with age, as the A2 age group is between 54% (±17) and 58% (±11), while the A4 age group mean consumption is 45% (±6). Goat meat consumption in the A4 age group is the single highest of all age groups tested, at 27% (±1), and with a very narrow margin visible in Figure 30, however, when goat dairy was used as a food group protein source, the results indicate consumption of

dairy remained the same throughout adulthood regardless of age group (see Appendix C for individual values in all age groups). These results suggest that individuals in the A4 age group did eat millet and goat meat in high amounts, and their decrease in wheat consumption marks a dietary transition at this life stage.

FRUITS results from this study also indicate that when goat meat is used as a food group, individuals in the A5 (60+ years) age group ate 21% (±6) millet, which is less than what the A4 (50-59 years) age group consumed on average (28% ±6). Conversely, mean wheat consumption increased to 53% (±6) in the A5 age group, making it comparable to the level of wheat consumption seen in the A1 and A2 age groups in Scenarios 4 and 5, but not as high as the mean for juvenile age groups (>60%) (Table 11). Meat consumption in the A5 age group decreased to 25% (±1) from the 28% (±1) consumption seen in the A4 age group, but it still remains higher than the A1 and A2 age groups or any juvenile age group. When goat dairy is used as a food group protein source, the results indicate consumption of dairy also remained the same throughout adulthood regardless of age group (Appendix C). These results suggest that individuals in the A5 age group, the most elderly of individuals included in this study, consumed roughly half their diet in C_3 grains like wheat, while also consuming meat and millet in moderate amounts.

A clear increase in the amount of millet and meat consumed by the A4 (50-59 years) age group, as well as a decrease in the amount of wheat consumed when compared to that of younger age groups, suggests a dietary transition taking place over the age of 50. Millet consumption in the A4 age group is 28% (±6), the highest amount after A1 age group females and relatively higher than the A2 age group millet consumption ranging from 21% (±9) to 25% (±18) dependent on sex. As with other groups, the increase in millet for individuals in the A4 age

group could be a result of illness. As mentioned earlier, there were significant pathological conditions noted among the A4 age group. Millet is as high in protein as meat, has a higher fat content than wheat, and is easier to digest than wheat, providing added bioavailability and making it a good choice for strength and weight-gain during and after illness (Talib et. Al, 2017; Dupras et al., 2020). This would have left the more valued wheat for bread and beermaking and consumption by individuals who may have had better access or may have been traveling and/or laboring. When boiled or soaked, millet is a soft food that can be easily eaten as a porridge or pap. Foods such as this would have been useful for weaning children and also beneficial to elderly adults as well, especially those with extensive dental disease and tooth loss, of which a considerable number have been identified in the A4 age group (Dupras et al., 2020). Another consideration in the A4 age group transitional diet is that elderly women in this age group were most likely assisting with child-care and weaning of children in a grand mothering capacity, and therefore ingesting some of the same foods as the children and raising their own consumption level in the process.

Age group A5 (60+ years) has a millet consumption of 21% (±6), which is lower than the A4 age group. Conversely, wheat consumption increases to 53% (±6) from the 45% (±6) consumption level seen in the A4 age group, which may be a result of shifting to more valued food options if available. The treatment of the elderly in this community is unknown, and mortuary treatments do not suggest any change in status (Bowen, 2007). However, in this case, it is suggested that, through these results on food preference, age had its privileges. The high level of meat consumption for the A4 and A5 age groups was an unexpected result, with both groups having the highest consumption of goat meat of any age group tested (28% (±1) and 25% (±1) respectively). It is suggested that the elderly and the infirm were given the best possible options

for protein consumption, in this case goat meat. In addition, it is recognized that they may have perceived meat as a necessity for strength and / or as a social access marker of seniority. Increasing goat meat consumption would also increase millet consumption due to the animal's diet being partially made up of millet, providing another possible explanation for a millet consumption increase in the A4 age group.

Within the elderly age groups, there are a few individuals of note. For example, Individual 275 is a 55-year old female with millet consumption of 36% (±14), which is higher than the group mean consumption of 28% (±6). While pathological analysis does not show any evidence of progressive disease or acute trauma (Williams, 2008), this does not rule out the presence of illness not indicated by skeletal markers and being treated with a high millet-content diet. This individual may also have eaten millet out of necessity if that is what was accessible economically or through possible assistance with childcare.

Individual 044 is a 63-year old female with millet consumption of 35% (±14), which is also higher than the group mean consumption of 21% (±6). Pathological analysis lists a number of ailments that this individual suffered from including severe osteoporosis, vertebral collapse of the L5, a healed fracture of the radius, considerable antemortem tooth loss, and biomechanical markers of repeated motion on the tali, tibiae, and patellae, possibly from work-related labor (Williams, 2008). The reasoning for the increased millet consumption seen in this individual would be similar to those provided above for Individual 275, however this female exhibits various pathological conditions where a high millet-content diet would have been beneficial to her health and comfort in eating softer foods.

CHAPTER SIX: CONCLUSION

Results from FRUITS analysis of primary data obtained in stable isotope studies of those interred at Kellis 2 indicate that common dietary choices and preferences did exist in this population. While the population relied heavily on C_3 plant grain agriculture, there were age groups within the population that directly consumed C_4 plants in varying amounts and indirectly through trophic level enrichment. Animal protein in the form of goat dairy was consumed consistently regardless of age group, with consumption ranging from 26-29% (±2) reflected as early as 21 weeks fetal gestation and evident up through 60+ years of age. Animal protein in the form of meat from cow and goat resources was more variable among ages groups. Most individuals consumed a generalized diet of these food sources, although proportionally there were outliers in all four food group categories and in most age groups with the exception of the F (21-36 weeks' gestation) age group.

Results from this study can also be used in supporting as well as arguing against previously accepted dietary differences between adult sexes and age groups. Unlike previous studies (Dupras, 1999: Williams, 2008), no notable differences in the diets of adult males and females of the population were identified, suggesting that both males and females ate the same general diet with the possible exceptions of pregnant women and the infirm. There is, however, dietary diversity between juvenile and adult groups with juveniles consuming the highest percentage of wheat and the elderly adult age groups consuming the highest percentage of animal protein. There is also a marked difference in the N (41 weeks–1 year) and C1 (13 months-4 years) age groups that would be affected by weaning. These juvenile age groups show an increase in millet consumption that supports earlier evidence of millet being used as a

supplemental weaning food (Dupras et al., 2001). This increase in millet consumption is reflected in the younger A1 (16-21 years) age group of reproductive-age women who contain the highest percentage of millet consumption of any age category, also supporting the previously suggested use of millet as a morning sickness food (Dupras et al., 2001; Williams, 2008). The elderly adult A4 (50-59 years) age group also shows an increase in millet consumption, and outliers within this group and the A5 (60+ years) age group indicate a possible link between increase millet consumption and various pathological conditions, as millet is known to be used as an illness food due to its ease of digestibility and high protein and fat content (Talib et al., 2017). Both the A4 and A5 age groups consumed a significantly large amount of animal protein, more than any other age group. This is the first time that this has been reported for this population and suggests that meat consumption was either a privilege of age and / or consumed for anticipated health benefits.

Limitations of this study include the number of individuals with quality primary data in each age group as well as the size of the sample diet tested. While primary data sets for age groups F, A4, and A5 suffered from diagenetic loss prior to and during stable isotope analysis, age groups C2, C3, and A3 were not tested using FRUITS due to time limitations in processing this exceptionally large data set for Kellis 2 cemetery. The addition of these primary data sets might add even more clarity to age-related transitions in diet and reveal new patterns that further help our understanding of preference for specific food resources in relation to health, aging, and community social structures. The sample diet chosen for testing was minimal, using only three food sources. For results from FRUITS to be of highest accuracy, the entire individual's diet should be input. As this study was the initial use of this software and testing of the primary data from this site, the sample diet was kept as simple as possible while still remaining effective

based on general practice recommendations (Fernandes et al., 2014, 2015; Phillips et al., 2014). The addition of a more complete listing of food sources to be included in the diet would increase value accuracy.

Further research of FRUITS abilities is necessary to gain the most knowledge about the diet of Kellis 2. Ideally, in future research, the entire primary data set including all age groups will be input through FRUITS along with a more complete dietary picture with twice as many dietary food sources to clarify accuracy in consumer chosen items. New isotopic data from samples waiting on analysis would be prioritized for specific age groups such as the elderly to expand the current interpretations about aging in Romano-Christian Egypt. Furthermore, this could be extrapolated to include individuals recovered from older cemeteries and township of Kellis to determine whether the same dietary patterns existed regarding age, sex, and social status, and, more importantly, what food choices and preferences were in place prior to the wide availability of millet. Further research on this topic would also include utilizing the last segment of hair sampled for each individual to account for the dietary choices of the last few months of life, I feel this would act as an equalizer for the entire sample population as all individuals have at least this segment available. The removal of outliers is also an option, allowing for values to reflect the population majority rather than be affected by extreme values. Future research will also include statistical probability analysis to ensure confidence in the results found. This being the pilot study my concerns lay with methodological accuracy and not in results analyses, although the results of this study shall dictate my future directives.

This study has shown that using FRUITS as a mixing-model can provide greater detail about diet, health, aging and general social structures in the Kellis community during Roman rule in Egypt. It was revealed that there was more variation between age groups than between sexes,

and that the elderly experienced a previously unknown dietary transition, shining a new light on the possible privilege of aging in Romano-Christian Egypt. Results of this study also point to the important relationship that Kellis 2 had with pearl millet as a food resource, where it served as a probable supplemental weaning food, possible morning sickness food, as well as a possible general illness food. In addition, millet may have been the most ecologically resilient form of grain available at a time when the community was in decline prior to complete abandonment of the town.

The addition of FRUITS modeling to the interpretation of isotopic dietary analyses has provided more detail on what the population of Kellis were consuming. While it has been shown that the Kellis 2 population were consuming both C_3 and C_4 plants as well as animal protein in a variety of sources, the applied FRUITS models have allowed for the testing of particular food sources so that interpretations on the cultural or social significance of those food sources can be refined.

APPENDIX A: FOOD SOURCE DATA

Table 20. Food source values used in FRUITS Scenarios.

FOOD SOURCE	*CARBON*	*NITROGEN*	*PROTEIN*
COW	-15.4	13.3	26
COW MILK	-15.4	13.3	3.0
GOAT	-15.73	13.35	23
GOAT MILK	-15.73	13.35	3.2
WHEAT	-23.2	16.06	12.8
MILLET	-9.9	9	10.5

Values for carbon and nitrogen taken from Dupras (1999) and Williams (2008).

APPENDIX B: STABLE ISOTOPE VALUE

Table 21. Isotopic data with C:N ratios for hair samples used in this study and analyzed by Williams, 2008 (APPENDIX M).

Burial ID	**Age Cat.**[a]		Hair Sample (increments in cm)														
Juveniles (n = 126)			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
015	N	$\delta^{13}C$[b]	-19.7														
		$\delta^{15}N$[b]	20.8														
		C/N ratio[c]	3.8														
023	C1	$\delta^{13}C$	-21.2	-19.8													
		$\delta^{15}N$	16.8	16.9													
		C/N ratio	3.6	3.6													
024	C2	$\delta^{13}C$	-19.6	-19.5	-19.6												
		$\delta^{15}N$	18.2	18.4	18.1												
		C/N ratio	3.6	3.6	3.6												
036	F	$\delta^{13}C$	-20.9														
		$\delta^{15}N$	19.6														
		C/N ratio	3.6														
049	C2	$\delta^{13}C$	-19.5	-19.6	-19.7	-19.8	-19.9	-19.8	-20.0	-20.0	-20.0	-19.7					
		$\delta^{15}N$	15.3	15.9	15.5	15.8	15.6	15.6	15.8	15.7	16.0	16.5					
		C/N ratio	3.6	3.6	3.7	3.7	3.7	3.6	3.7	3.7	3.7	3.6					
051	N	$\delta^{13}C$	-19.1	-19.2	-19.4												
		$\delta^{15}N$	18.8	18.4	18.0												
		C/N ratio	3.5	3.5	3.5												

054	P	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.4 18.7 3.6														
056	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-20.4 19.1 3.8	-18.8 18.9 3.7	-19.1 18.3 3.8	-19.4 17.7 ***3.9***[d]	-19.7 17.6 3.8	-19.6 18.0 3.8									
057	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.8 17.6 3.8	-19.5 17.9 ***3.9***	-19.9 18.0 ***3.9***												
063	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.9 21.6 3.5	-18.8 21.8 3.5													

Burial ID	**Age Cat.**		Hair Sample (increments in cm)														
Juveniles *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
064	C2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.7 19.1 3.6	-19.6 17.5 3.6													
065	F	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-20.3 20.5 3.8														
070	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.8 20.9 3.6	-18.6 21.0 3.6													
071	C1	$\delta^{13}C$ $\delta^{15}N$	-18.3 18.3 3.6	-18.1 18.5 3.5	-17.9 18.3 3.5	-18.2 18.5 3.6	-18.9 17.4 3.6	-19.0 17.2 3.6									

		C/N ratio														
086	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.8 18.1 3.7	-19.7 17.7 3.6												
094	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.8 21.0 3.5													
095	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.0 21.9 3.8	-19.5 21.3 ***4.0***												
096	P	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.1 18.2 3.7													
097	C2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.6 16.7 3.7	-19.6 17.3 3.7	-19.3 18.7 3.8	-19.0 19.4 3.8	-19.3 18.0 3.7	-19.1 17.8 3.7								
103	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-20.1 17.3 3.7													

Burial ID	**Age Cat.**		Hair Sample (increments in cm)													
Juveniles *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
104	N	$\delta^{13}C$ $\delta^{15}N$	-18.9 16.2 3.8	-19.1 16.7 3.8												

		C/N ratio					
108	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.2 18.0 3.6				
113	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.2 19.0 3.5	-19.0 18.6 3.5	-19.0 18.1 3.5	-19.5 17.1 3.5	-19.9 16.9 3.6
115	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.8 17.2 3.6				
123	P	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.9 20.1 3.7				
125	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.8 20.9 3.6				
130	F	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-21.7 17.2 ***4.5***				
133	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.8 20.0 3.8				
147	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.0 20.4 3.6	-19.3 19.5 3.6	-19.3 20.2 3.6		

149	C3	$\delta^{13}C$	-20.1	-20.2	-20.0	-19.8
		$\delta^{15}N$	16.4	16.6	16.8	17.5
		C/N ratio	3.6	3.6	3.6	3.5

Appendix M *continued*

Burial ID	**Age Cat.**		Hair Sample (increments in cm)														
Juveniles *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
163	C2	$\delta^{13}C$	-20.2														
		$\delta^{15}N$	20.5														
		C/N ratio	3.6														
164	N	$\delta^{13}C$	-19.6														
		$\delta^{15}N$	18.3														
		C/N ratio	3.6														
173	C3	$\delta^{13}C$	-19.7														
		$\delta^{15}N$	16.6														
		C/N ratio	3.8														
180	F	$\delta^{13}C$	-20.6														
		$\delta^{15}N$	19.6														
		C/N ratio	***4.4***														
197	P	$\delta^{13}C$	-19.4	-19.3													
		$\delta^{15}N$	18.5	18.2													
		C/N ratio	3.5	3.5													
206	N	$\delta^{13}C$	-20.8														
		$\delta^{15}N$	20.8														
		C/N ratio	3.6														

209	P	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.6 19.3 3.7														
237	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.1 20.8 3.6														
239	C3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.8 18.7 3.7	-19.3 18.6 3.7	-19.1 19.0 3.8	-19.2 19.1 3.8											
243	C3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.2 18.1 3.6	-19.3 18.2 3.6	-19.5 18.0 3.5	-19.6 16.9 3.5											

Burial ID	**Age Cat.**		Hair Sample (increments in cm)														
Juveniles *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
258	C2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.7 18.7 3.7														
260	C3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-21.1 19.0 3.3	-20.4 18.8 3.6	-20.1 17.6 3.5												
263	C3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.5 16.8 3.5														
276	P	$\delta^{13}C$ $\delta^{15}N$	-19.2 18.4 3.7	-19.2 18.4 3.6													

		C/N ratio														
278	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.1 18.6 3.7	-19.2 18.1 3.6	-20.4 18.3 3.6	-18.9 17.9 3.6										
288	C3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.6 17.4 3.5	-19.4 18.0 3.6	-19.7 17.8 3.5	-20.1 17.4 3.6	-24.3 16.7 3.6	-20.0 16.7 3.6	-19.9 17.2 3.6	-19.9 17.4 3.7	-19.7 17.2 3.7	-19.7 17.6 3.7	-19.4 17.9 3.7	-19.4 17.2 3.1	-19.7 17.2 3.6	
292	F	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-21.6 20.1 3.8													
295	C3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.5 17.5 3.7	-19.3 17.4 3.6	-19.3 17.4 3.6	-19.3 17.6 3.6	-19.4 17.5 3.6	-19.5 17.2 3.6	-19.7 17.0 3.6	-19.7 16.8 3.7						
299	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.2 19.3 3.5	-19.0 19.4 3.5	-18.7 19.9 3.5	-18.5 20.3 3.6	-18.4 20.4 3.5	-18.6 19.9 3.5	-18.7 19.8 3.5	-18.9 19.5 3.6	-19.3 19.3 3.6					
302	C3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.7 18.6 3.6	-19.8 18.5 3.6	-19.6 17.6 3.6											

Burial ID	**Age Cat.**		Hair Sample (increments in cm)														
Juveniles *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
316	F	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-21.3 17.5 ***4.4***														

318B	P	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-20.3 16.1 3.2							
323	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.5 20.0 3.6							
328	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.8 20.3 3.7	-18.9 19.7 3.6	-19.2 19.3 3.7	-19.9 19.0 3.6	-20.3 19.1 3.4	-18.9 20.3 3.7	-19.2 19.8 3.8	-19.3 19.5 3.7	-19.0 20.2 3.7
330	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-17.9 18.4 3.7	-18.6 17.3 3.6	-19.4 17.6 3.5	-19.6 18.1 3.5	-19.8 18.9 3.8				
331	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.7 20.2 3.5								
334	F	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.1 16.1 ***3.9***	-19.4 16.6 3.8							
335	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.0 18.9 3.5	-18.8 18.7 3.6							
336	C2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.9 16.8 3.6	-19.9 16.5 3.5	-20.1 16.8 3.5						
337	F	$\delta^{13}C$ $\delta^{15}N$	-19.2 18.2 3.7								

		C/N ratio															

Burial ID	**Age Cat.**		Hair Sample (increments in cm)														
Juveniles *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
338	P	$\delta^{13}C$	-19.5														
		$\delta^{15}N$	17.7														
		C/N ratio	***3.9***														
342	N	$\delta^{13}C$	-19.5														
		$\delta^{15}N$	17.9														
		C/N ratio	3.8														
347	N	$\delta^{13}C$	-18.3	-18.2													
		$\delta^{15}N$	19.6	19.6													
		C/N ratio	3.7	3.6													
349	C1	$\delta^{13}C$	-19.4														
		$\delta^{15}N$	17.9														
		C/N ratio	3.6														
351	C1	$\delta^{13}C$	-19.7														
		$\delta^{15}N$	16.5														
		C/N ratio	3.6														
356	N	$\delta^{13}C$	-19.2	-19.1													
		$\delta^{15}N$	19.2	19.9													
		C/N ratio	3.7	3.8													
357	C1	$\delta^{13}C$	-18.9														
		$\delta^{15}N$	20.9														
		C/N ratio	3.7														

358	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.4 18.3 3.5	-19.6 17.8 3.6	-19.9 18.1 3.6											
360	C2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.6 16.5 3.7	-19.2 16.1 3.6	-19.1 16.2 3.5	-19.3 16.1 3.6										
362	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.8 17.4 3.5	-19.6 17.6 3.5												

Burial ID	**Age Cat.**		Hair Sample (increments in cm)													
Juveniles *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
370	C2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.8 17.5 3.7													
374	C2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.2 17.2 3.8	-19.1 17.6 3.7	-19.0 17.4 3.7	-18.9 17.2 3.7	-19.6 16.8 3.7	-19.6 16.7 3.8	-19.8 16.8 3.8	-20.0 16.7 3.8							
378	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.2 19.2 3.5													
386	P	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.4 18.6 3.7													

396	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.0 17.6 3.8	-19.3 17.3 3.8	-19.5 16.6 3.7	-19.7 17.2 3.7	-19.5 17.6 3.6	-18.9 19.1 3.7	-18.4 20.0 3.7							
428	F	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-21.0 21.8 ***4.2***													
436	P	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.8 18.7 3.6													
468	C3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.8 17.1 3.7	-19.7 17.9 3.6	-19.7 17.5 3.7	-19.7 17.1 3.6	-19.6 18.1 3.6	-19.6 18.2 3.6	-19.6 18.0 3.6	-19.4 18.1 3.6	-19.9 18.5 3.6	-19.9 18.3 3.6				
472	P	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-20.2 18.2 3.7													
476	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.6 19.7 3.7													

Burial ID	**Age Cat.**		Hair Sample (increments in cm)														
Juveniles *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
483	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.5 19.9 3.7														
484	P	$\delta^{13}C$ $\delta^{15}N$	-19.3 20.2 3.7														

		C/N ratio								
487	C1	$\delta^{13}C$	-17.7	-18.1	-18.9	-19.4	-19.1			
		$\delta^{15}N$	19.0	18.5	17.9	17.7	18.3			
		C/N ratio	3.5	3.5	3.5	3.6	3.7			
490	C1	$\delta^{13}C$	-19.2	-20.0						
		$\delta^{15}N$	16.2	15.3						
		C/N ratio	3.5	3.4						
495	P	$\delta^{13}C$	-19.7							
		$\delta^{15}N$	19.2							
		C/N ratio	3.7							
508	N	$\delta^{13}C$	-19.7							
		$\delta^{15}N$	18.2							
		C/N ratio	3.6							
513B	P	$\delta^{13}C$	-19.4							
		$\delta^{15}N$	18.7							
		C/N ratio	3.7							
519	C1	$\delta^{13}C$	-19.7	-20.5	-21.2					
		$\delta^{15}N$	15.2	15.8	16.3					
		C/N ratio	3.7	3.6	3.8					
520	C2	$\delta^{13}C$	-20.2	-20.2	-20.4					
		$\delta^{15}N$	16.6	16.4	16.7					
		C/N ratio	3.6	3.6	3.6					
534	C1	$\delta^{13}C$	-18.9	-19.2	-19.0	-19.0	-18.9	-18.9	-18.8	-19.0
		$\delta^{15}N$	17.9	18.5	19.6	19.7	20.5	21.3	21.0	20.6
		C/N ratio	3.5	3.6	3.5	3.6	3.5	3.7	3.6	3.6

Burial ID	Age Cat.		Hair Sample (increments in cm)														
Juveniles *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
538	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.0 20.5 3.7	-18.0 20.7 3.7	-18.6 20.6 3.7	-18.2 20.8 3.7											
542	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.7 19.5 3.7														
551	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.9 19.5 3.8														
560	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.0 20.8 3.6														
562	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-20.3 17.9 ***3.9***	-20.0 18.0 3.8													
568	P	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.0 18.5 3.5														
571	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.5 23.6 3.7	-18.5 23.4 3.6													
577	P	$\delta^{13}C$ $\delta^{15}N$	-18.9 18.8 3.7	-19.0 18.6 3.7	-18.4 17.7 3.7	-18.7 19.0 3.8	-18.8 19.3 3.7										

		C/N ratio														
579	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.6 18.8 3.8	-19.1 20.0 3.6	-18.9 19.8 3.6	-18.9 20.3 3.6	-18.7 20.4 3.6	-18.9 20.1 3.6								
580	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.0 16.9 3.6													

Burial ID	**Age Cat.**		Hair Sample (increments in cm)													
Juveniles *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
582	C2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.7 16.2 3.6													
583A	C2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.7 18.0 3.6	-19.6 18.2 3.6												
583B	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.8 20.1 3.8	-19.3 19.9 3.6	-19.2 20.0 3.6	-19.4 20.2 3.6	-19.5 20.3 3.6	-19.6 20.3 3.7	-19.4 20.1 3.6							
584	C2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-20.0 16.6 3.6	-20.4 17.3 3.8	-20.2 16.3 3.6	-20.4 16.1 ***3.9***										
587	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.8 21.1 ***3.9***													

593A	C1	$\delta^{13}C$	-19.0	-19.1	-20.4	-19.1
		$\delta^{15}N$	18.8	17.6	17.9	18.5
		C/N ratio	3.7	3.6	3.6	3.6
596	N	$\delta^{13}C$	-22.7			
		$\delta^{15}N$	20.1			
		C/N ratio	***6.9***			
599	P	$\delta^{13}C$	-20.1	-20.5		
		$\delta^{15}N$	16.4	16.4		
		C/N ratio	3.7	3.8		
600	N	$\delta^{13}C$	-19.3			
		$\delta^{15}N$	20.6			
		C/N ratio	3.7			
602	N	$\delta^{13}C$	-18.7			
		$\delta^{15}N$	21.4			
		C/N ratio	3.6			

Burial ID	**Age Cat.**		Hair Sample (increments in cm)														
Juveniles *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
603	N	$\delta^{13}C$	-19.2														
		$\delta^{15}N$	16.8														
		C/N ratio	3.8														
605	P	$\delta^{13}C$	-19.1	-19.0	-19.0												
		$\delta^{15}N$	18.8	18.9	19.2												
		C/N ratio	3.6	3.6	3.6												
606	C2	$\delta^{13}C$	-19.7	-19.6	-19.5												
		$\delta^{15}N$	17.9	17.8	18.1												
			3.6	3.7	3.7												

		C/N ratio	
608	P	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-20.2 17.4 3.7
609	P	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.7 18.4 3.6
610	P	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-21.2 19.0 ***7.1***
614	P	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.4 19.4 3.6
616	P	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.4 17.2 3.6
618	N	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.0 19.8 3.8
619	C1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-20.9 15.1 3.4

Burial ID	**Age Cat.**		Hair Sample (increments in cm)

Juveniles *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
620	C1	$\delta^{13}C$	-19.4	-20.4	-19.9	-20.7											
		$\delta^{15}N$	20.4	20.2	20.1	19.7											
		C/N ratio	3.8	3.8	3.8	3.6											
621	N	$\delta^{13}C$	-19.2	-19.1													
		$\delta^{15}N$	20.4	20.5													
		C/N ratio	3.6	3.6													
624	C1	$\delta^{13}C$	-19.4	-19.4	-19.6	-19.6											
		$\delta^{15}N$	21.9	21.9	21.8	21.8											
		C/N ratio	3.7	3.6	3.7	3.6											
626	N	$\delta^{13}C$	-19.2	-19.2													
		$\delta^{15}N$	22.1	22.0													
		C/N ratio	3.8	***3.9***													
628	C1	$\delta^{13}C$	-19.5														
		$\delta^{15}N$	20.1														
		C/N ratio	***3.9***														
629	F	$\delta^{13}C$	-20.2														
		$\delta^{15}N$	17.3														
		C/N ratio	3.8														

Adult Females (n = 47)			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
019	A3	$\delta^{13}C$	-17.7	-17.9													
		$\delta^{15}N$	19.4	19.2													
		C/N ratio	3.5	3.5													
021	A3	$\delta^{13}C$	-19.5	-19.0													
		$\delta^{15}N$	17.1	17.6													
		C/N ratio	3.5	3.4													

022	A2	$\delta^{13}C$	-19.4	-19.5	-19.6	-19.5	-19.6	-19.8	-19.7	-19.6	-19.8
		$\delta^{15}N$	17.3	16.8	16.8	17.6	17.8	17.5	17.5	18.0	17.8
		C/N ratio	3.8	3.8	3.8	3.8	3.7	3.8	3.8	3.8	3.7

Burial ID	**Age Cat.**		Hair Sample (increments in cm)														
Adult Females *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
026	A1	δ13C	-19.5	-19.6	-19.7	-19.8	-19.8	-19.9									
		δ15N	15.7	16.0	15.9	16.1	16.5	16.8									
		C/N ratio	3.6	3.6	3.6	3.6	3.6	3.6									
044	A5	$\delta^{13}C$	-20.0	-20.0													
		$\delta^{15}N$	16.0	16.6													
		C/N ratio	3.7	3.6													
072	A5	$\delta^{13}C$	-19.3														
		$\delta^{15}N$	17.9														
		C/N ratio	3.4														
073	A3	$\delta^{13}C$	-19.4	-19.4	-19.4	-19.4											
		$\delta^{15}N$	17.4	17.5	17.6	17.5											
		C/N ratio	3.6	3.6	3.6	3.6											
080	A3	$\delta^{13}C$	-19.6														
		$\delta^{15}N$	19.3														
		C/N ratio	3.7														
091	A4	$\delta^{13}C$	-19.5	-19.4	-19.5	-19.3											
		$\delta^{15}N$	18.3	17.9	17.9	17.7											
		C/N ratio	3.4	3.5	3.4	3.4											

131	A2	$\delta^{13}C$	-20.2	-20.0	-20.1	-20.0	-20.0	-19.8	-19.6	-19.5	-19.6	-19.7	-19.7	-19.9	-19.9	-19.9	-19.9
		$\delta^{15}N$	16.6	16.4	16.4	16.2	16.7	17.0	17.1	17.3	17.3	17.0	16.8	16.6	16.6	16.9	17.1
		C/N ratio	3.5	3.6	3.5	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
168	A1	$\delta^{13}C$	-19.5	-19.8	-19.8	-19.7	-19.7	-19.7	-19.8	-19.9	-20.0						
		$\delta^{15}N$	17.5	17.8	18.0	18.5	18.4	18.0	17.5	17.0	16.4						
		C/N ratio	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8						
170	A2	$\delta^{13}C$	-20.5	-20.3	-20.0	-20.0											
		$\delta^{15}N$	18.8	18.9	18.6	18.6											
		C/N ratio	3.7	3.7	3.7	3.7											
177	A4	$\delta^{13}C$	-20.0	-19.9													
		$\delta^{15}N$	17.0	17.2													
		C/N ratio	3.7	3.6													

Burial ID	**Age Cat.**		Hair Sample (increments in cm)													
Adult Females *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
190	A1	$\delta^{13}C$	-19.8	-19.8	-19.9	-20.4	-20.1	-20.0	-20.2								
		$\delta^{15}N$	18.1	18.1	18.4	18.6	18.7	18.6	18.9								
		C/N ratio	3.6	3.6	3.5	3.6	3.6	3.5	3.5								
204	A2	$\delta^{13}C$	-19.3	-19.4	-19.6	-20.2	-20.3	-20.3	-20.2	-20.4							
		$\delta^{15}N$	18.1	17.8	17.7	17.5	17.2	17.3	17.4	17.9							
		C/N ratio	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7							
261	A5	$\delta^{13}C$	-20.2	-20.7	-20.1	-20.1	-20.1	-20.3									
		$\delta^{15}N$	17.7	18.0	17.6	17.7	17.8	17.6									
		C/N ratio	3.7	3.8	3.6	3.6	3.6	3.6									

269	A4	$\delta^{13}C$	-19.0	-19.4	-19.0	-19.4	-19.8	-20.4
		$\delta^{15}N$	16.9	16.5	16.3	17.6	17.8	17.6
		C/N ratio	3.5	3.5	3.6	3.4	3.5	3.4
271	A2	$\delta^{13}C$	-19.4	-19.4	-19.5			
		$\delta^{15}N$	16.9	16.6	16.8			
		C/N ratio	3.6	3.6	3.6			
275	A4	$\delta^{13}C$	-18.7	-18.6	-18.7	-19.1		
		$\delta^{15}N$	16.5	16.1	16.2	16.3		
		C/N ratio	3.6	3.5	3.4	3.6		
279	A2	$\delta^{13}C$	-19.3	-19.7	-19.7	-19.7	-19.9	
		$\delta^{15}N$	18.7	17.4	17.1	17.5	17.5	
		C/N ratio	3.5	3.6	3.6	3.6	3.5	
280	A5	$\delta^{13}C$	-19.8	-19.7	-19.8			
		$\delta^{15}N$	18.1	17.7	18.0			
		C/N ratio	3.7	3.6	3.6			
282	A2	$\delta^{13}C$	-19.4	-18.9	-18.7	-18.8	-19.3	-19.8
		$\delta^{15}N$	17.9	18.1	17.8	17.8	18.2	17.8
		C/N ratio	3.6	3.6	3.6	3.6	3.5	3.5
284	A2	$\delta^{13}C$	-19.7	-19.8	-20.1			
		$\delta^{15}N$	18.5	17.5	17.7			
		C/N ratio	3.5	3.5	3.7			

Burial ID	**Age Cat.**	Hair Sample (increments in cm)													
Adult Females *continued*		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**

289	A2	$\delta^{13}C$	-19.3	-19.1	-19.3											
		$\delta^{15}N$	17.8	17.5	17.7											
		C/N ratio	3.6	3.6	3.6											
291	A3	$\delta^{13}C$	-19.3	-19.2	-19.2	-19.2	-19.1	-19.1								
		$\delta^{15}N$	16.6	16.6	16.8	16.3	16.4	16.4								
		C/N ratio	3.5	3.5	3.5	3.5	3.5	3.5								
306	A5	$\delta^{13}C$	-20.0	-20.1	-20.0	-20.0	-19.9									
		$\delta^{15}N$	18.4	18.4	18.3	18.2	18.4									
		C/N ratio	3.5	3.6	3.5	3.6	3.6									
307	A2	$\delta^{13}C$	-19.6	-19.5	-19.6	-19.9	-19.7	-19.8	-19.4	-19.2	-19.0	-19.4	-19.8	-19.9	-20.0	-19.7	-19.5
		$\delta^{15}N$	19.5	19.3	19.3	19.4	18.8	18.5	17.8	17.4	16.8	16.5	16.8	17.7	18.0	19.1	19.3
		C/N ratio	3.6	3.6	3.6	3.6	3.6	3.6	3.4	3.6	3.6	3.6	3.7	3.7	3.7	3.7	3.7
314	A4	$\delta^{13}C$	-19.2	-19.2	-19.5											
		$\delta^{15}N$	17.5	16.8	16.1											
		C/N ratio	3.5	3.5	3.5											
318A	A2	$\delta^{13}C$	-19.2	-19.1	-19.2	-19.4	-19.3	-20.4	-19.2							
		$\delta^{15}N$	17.2	16.8	17.2	18.2	18.1	18.5	18.0							
		C/N ratio	3.8	3.8	3.8	3.8	3.6	3.8	3.8							
327	A1	$\delta^{13}C$	-19.7	-19.8	-19.6											
		$\delta^{15}N$	19.1	17.0	17.2											
		C/N ratio	3.5	3.5	3.5											
410	A2	$\delta^{13}C$	-19.3	-19.1	-18.9	-18.9	-19.1	-18.9								
		$\delta^{15}N$	15.5	15.2	15.3	15.3	15.0	15.4								
		C/N ratio	3.8	3.7	3.7	3.7	3.7	3.8								
426	A2	$\delta^{13}C$	-19.7	-19.9	-19.9	-19.8	-19.9									
		$\delta^{15}N$	17.9	18.2	18.4	18.3	18.5									
			3.7	3.7	3.7	3.7	3.8									

		C/N ratio														
430	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.6 13.5 3.6													

Burial ID	**Age Cat.**		Hair Sample (increments in cm)													
Adult Females *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
431	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.4 17.0 3.5	-19.2 16.9 3.5	-19.4 16.7 3.5	-19.9 16.5 3.4	-20.0 16.8 3.5										
434	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.5 18.8 3.5	-19.5 19.4 3.5	-19.2 19.8 3.6												
456	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.7 17.6 3.7														
460	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.6 18.7 3.8	-19.6 18.2 3.8	-19.9 18.2 3.8	-19.7 18.3 3.7											
463	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.3 18.3 3.6	-19.5 18.2 3.6	-19.6 18.2 3.6	-19.2 18.5 3.7	-19.2 18.7 3.7	-19.2 18.8 3.7	-19.3 18.6 3.7	-19.2 18.5 3.6	-19.1 18.6 3.6	-18.7 19.2 3.6					
467	A4	$\delta^{13}C$ $\delta^{15}N$	-20.1 17.9 3.6	-20.1 17.4 3.6													

		C/N ratio														
475	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.2 19.0 3.8													
485	A1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.6 13.6 3.6													
494	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.5 16.2 3.5													
506	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.9 18.9 3.7	-18.7 19.2 3.7	-18.1 19.8 3.6	-18.2 20.2 3.6	-18.7 19.8 3.6									

Burial ID	**Age Cat.**		Hair Sample (increments in cm)													
Adult Females *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
511	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.2 18.3 3.6	-19.4 18.8 3.7	-19.7 20.8 3.6	-19.7 20.6 3.7	-19.5 20.4 3.7	-19.3 20.1 3.7	-19.0 19.0 3.7	-19.1 18.9 3.7	-19.0 19.4 3.7						
513A	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.2 17.9 3.7	-19.1 18.5 3.7	-19.1 18.2 3.7	-18.9 18.0 3.7	-18.8 18.0 3.7	-18.5 18.1 3.7	-18.2 18.4 3.7								
523	A1	$\delta^{13}C$ $\delta^{15}N$	-19.4 17.5 3.6														

		C/N ratio															
528	A4	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.2 17.1 3.5	-19.1 16.6 3.5	-18.8 18.0 3.5												
Adult Males (n = 43)			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Beard**
042	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.2 19.7 3.8														-18.8 19.0 3.6
059	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.4 12.8 3.7	-19.4 12.5 3.7	-19.1 12.7 3.7												
069	A2	δ13C δ15N C/N ratio	-19.4 19.9 3.7	-19.6 20.4 3.6	-19.5 20.7 3.6												
079	A4	δ13C δ15N C/N ratio	-18.8 16.2 3.6	-19.3 17.0 3.5													
081	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.4 18.3 3.5	-19.5 18.4 3.5	-19.5 18.0 3.5												-19.8 18.5 3.7

Burial ID	**Age Cat.**	Hair Sample (increments in cm)														
Adult Males *continued*		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Beard**

089	A5	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.7 18.4 3.5	-19.7 18.6 3.6										
093	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.3 14.4 3.6											
107	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.4 18.6 3.7	-19.5 17.6 3.6	-19.3 18.7 3.5	-19.2 18.8 3.5	-19.3 18.7 3.5							
111	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.4 17.7 3.7											
132	A1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.5 15.8 3.6	-19.8 15.6 3.6										
138	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-20.0 16.9 3.8											
143	A1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-20.4 17.9 3.6	-19.7 18.2 3.7	-19.7 18.6 3.7	-19.5 19.3 3.8	-19.4 20.1 3.8	-19.4 20.3 3.7	-19.3 20.0 3.7	-19.1 19.6 3.7	-19.1 19.2 3.7	-19.2 18.9 3.7	-19.4 19.0 3.7	-19.6 19.0 3.8	-19.8 18.9 3.7
159	A1	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.4 18.6 3.8	-19.5 18.8 3.8	-19.4 19.2 3.8	-19.3 18.8 3.8	-19.5 19.7 3.8							
211	A3	$\delta^{13}C$ $\delta^{15}N$	-19.3 16.6 3.6											

		C/N ratio															
222	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.9 19.3 3.7	-18.8 19.2 3.7	-18.9 19.6 3.7	-18.9 19.7 3.7	-18.7 18.5 3.7	-18.8 19.0 3.7	-18.5 18.7 3.7								

Burial ID	**Age Cat.**		Hair Sample (increments in cm)														
Adult Males *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Beard**
228	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.2 17.0 3.6	-19.1 17.1 3.5													
240	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.3 17.8 3.7	-19.3 18.0 3.5													
242	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.9 17.9 3.7														
249	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.8 18.9 3.7	-19.0 18.9 3.7	-19.1 19.1 3.7												
250	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.2 18.3 3.6														
262	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.1 17.1 3.5														

264	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.0 18.5 3.6													
265	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.2 16.5 3.6	-19.1 15.3 3.6	-18.6 15.3 3.5											
281	A5	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.4 17.9 3.6	-19.7 17.7 3.5												
293	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.5 18.7 3.6	-19.7 18.5 3.7	-19.6 18.1 3.6	-19.6 18.1 3.6	-19.7 18.1 3.6									

Burial ID	**Age Cat.**		Hair Sample (increments in cm)													
Adult Males *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Beard**
303	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.8 16.8 3.7													
305	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.7 19.3 3.7	-19.5 19.3 3.7												
309	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.8 16.7 3.6	-18.7 17.0 3.6	-18.5 17.2 3.6											
310	A1	$\delta^{13}C$ $\delta^{15}N$	-19.4 16.8 3.6	-18.9 17.6 3.6	-18.7 17.7 3.6	-18.1 18.0 3.7										

		C/N ratio														
321	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.3 14.3 3.6	-19.0 14.5 3.5	-18.9 14.5 3.4											
388	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.3 21.5 3.6	-19.2 20.8 3.6	-19.2 20.8 3.5	-19.2 20.8 3.5	-19.4 20.9 3.5	-19.4 20.8 3.5								
393	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.6 18.5 3.5	-19.8 18.2 3.5	-19.6 18.1 3.5	-19.3 17.9 3.5										
402	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.3 15.7 3.8	-19.4 14.7 3.7	-19.7 13.8 3.8	-20.0 13.0 3.8	-20.0 13.0 3.8	-20.0 13.3 3.8	-20.1 13.5 3.8	-20.3 13.4 3.8						
412	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-19.7 17.3 3.5	-19.6 17.2 3.5												-19.9 17.5 3.5
437	A3	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-18.9 16.0 3.5	-18.7 16.3 3.6												

Burial ID	**Age Cat.**		Hair Sample (increments in cm)													
Adult Males *continued*			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Beard**
457	A2	$\delta^{13}C$ $\delta^{15}N$ C/N ratio	-20.0 18.1 3.8	-19.5 17.9 ***3.9***	-19.3 17.2 3.7	-19.7 17.3 3.8	-19.6 17.2 3.8	-19.8 17.3 3.7	-19.9 17.5 3.8	-19.7 17.8 3.8	-19.7 17.6 3.8	-19.7 17.2 3.8					

461	A3	$\delta^{13}C$	-19.6	-19.9	-20.0	-20.4			
		$\delta^{15}N$	17.0	16.7	16.5	16.6			
		C/N ratio	3.6	3.6	3.5	3.5			
466	A2	$\delta^{13}C$	-19.0	-19.2	-19.4				
		$\delta^{15}N$	18.9	18.7	18.0				
		C/N ratio	3.6	3.6	3.6				
469	A3	$\delta^{13}C$	-19.6	-19.7					
		$\delta^{15}N$	14.7	13.9					
		C/N ratio	3.6	3.6					
488	A3	$\delta^{13}C$	-19.2	-20.1					
		$\delta^{15}N$	16.1	16.3					
		C/N ratio	3.7	3.8					
512	A3	$\delta^{13}C$	-19.5	-19.4					-19.5
		$\delta^{15}N$	20.6	19.5					19.9
		C/N ratio	3.7	***3.9***					3.6
539	A3	$\delta^{13}C$	-20.4						
		$\delta^{15}N$	18.1						
		C/N ratio	***4.0***						
543	A2	$\delta^{13}C$	-19.6	-19.5	-19.5	-18.8			
		$\delta^{15}N$	18.6	18.5	18.4	18.0			
		C/N ratio	3.8	3.8	3.8	3.3			

[a] Age categories are divided as follows: F (21-36 weeks' gestation), P (37-40 weeks' gestation), N (41 weeks' gestation-12 months), C1 (13 months-4 years), C2 (5-10 years), C3 (11-15 years), A1 (16-21 years), A2 (22-35 years), A3 (36-50 years), A4 (51-59 years), A5 (60+ years).

[b] All $\delta^{13}C$ and $\delta^{15}N$ values are expressed in per mil (‰).

[c] All C/N ratios represent atomic ratios.

[d] Bold italic indicates C/N ratio is outside the generally accepted range of 3.0–3.8 for keratin and may indicate postmortem contamination (O'Connell *et al*., 2001).

APPENDIX C: FRUITS DATA

Table 22. Individual FRUITS results for Scenarios 1-6.

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	COW-MILK	F, P, N, C1

GROUP F Sample #	μ MILLET %	μ WHEAT %	μ COW MILK %
036	0.08737	0.6664	0.2462
065	0.06468	0.7139	0.2214
292	0.06986	0.7094	0.2208
337	0.1835	0.5176	0.2988
629	0.2442	0.4784	0.2774

GROUP P Sample #	μ MILLET %	μ WHEAT %	μ COW MILK %
054	0.1468	0.5653	0.2879
096	0.1841	0.5055	0.3104
123	0.08333	0.6892	0.2274
197	0.1468	0.5653	0.2879
209	0.1142	0.6179	0.2679
276	0.1704	0.5246	0.305
318B	0.3626	0.3341	0.3033
386	0.1586	0.5519	0.2895
436	0.1466	0.5832	0.2702
472	0.1741	0.5356	0.2903
484	0.08121	0.6922	0.2266
495	0.1215	0.6119	0.2666
513B	0.1468	0.5653	0.2879
568	0.1664	0.5244	0.3092
577	0.1536	0.5482	0.2982
599	0.3402	0.3652	0.2946
605	0.1378	0.5775	0.2847
608	0.2459	0.446	0.3081
609	0.1662	0.5302	0.3036
614	0.1127	0.6259	0.2614
616	0.2674	0.4092	0.3234

GROUP N Sample #	μ MILLET %	μ WHEAT %	μ COW MILK %
015	0.06008	0.7227	0.2173
051	0.166	0.5406	0.2934
056	0.1765	0.5216	0.3019
063	0.04572	0.7666	0.1877
094	0.05912	0.7193	0.2216
103	0.2444	0.4781	0.2775
104	0.3395	0.3821	0.2785
113	0.2012	0.4964	0.3024
115	0.2581	0.4528	0.2891
125	0.06295	0.7172	0.2198
133	0.08834	0.6483	0.2633
147	0.08541	0.6541	0.2604

164	0.1752	0.5251	0.2997
206	0.05796	0.7401	0.202
237	0.06263	0.7098	0.2276
331	0.07531	0.6832	0.2415
335	0.1466	0.5458	0.3075
342	0.2006	0.5006	0.2988
347	0.1074	0.6074	0.2852
356	0.09987	0.631	0.2691
378	0.1266	0.5811	0.2923
476	0.09276	0.6507	0.2565
483	0.08509	0.657	0.2579
508	0.1757	0.5254	0.2989
538	0.06761	0.7014	0.231
542	0.1074	0.6127	0.2799
551	0.1053	0.6166	0.2781
571	0.02826	0.8356	0.1362
580	0.302	0.4052	0.2928
582	0.3691	0.3733	0.2575
600	0.06653	0.701	0.2325
602	0.04956	0.7496	0.2009
603	0.3039	0.4111	0.285
618	0.08937	0.6408	0.2698
621	0.07039	0.6938	0.2358

GROUP C1 Sample#	μ MILLET %	μ WHEAT %	μ COW MILK %
023	0.2767	0.4542	0.269
070	0.05945	0.723	0.2175
071	0.2012	0.4817	0.317
086	0.2002	0.506	0.2939
108	0.1976	0.5059	0.2966
278	0.1832	0.5201	0.2967
299	0.09493	0.6367	0.2683
323	0.08327	0.6671	0.2496
328	0.09546	0.6344	0.2702
330	0.1887	0.51	0.3013
349	0.2019	0.5024	0.2957
351	0.3328	0.3949	0.2723
357	0.0604	0.7178	0.2218
358	0.1811	0.5254	0.2934
362	0.2339	0.4795	0.2867
396	0.1976	0.5059	0.2966
487	0.1839	0.5026	0.3135
490	0.4047	0.3382	0.2571
519	0.3967	0.3663	0.237
534	0.09297	0.6449	0.2621
560	0.06024	0.7158	0.224
579	0.09297	0.6449	0.2621
583B	0.0809	0.6682	0.2509
593A	0.1832	0.5201	0.2967

619	0.4698	0.3115	0.2187
620	0.08088	0.6632	0.2559
624	0.04293	0.7774	0.1796

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	GOAT-MILK	F, P, N, C1

GROUP F Sample #	μ MILLET %	μ WHEAT %	μ GOAT MILK %
036	0.0873	0.6542	0.2585
065	0.06551	0.7078	0.2266
292	.07015	0.703	0.2268
337	0.1837	0.5173	0.2989
629	0.2478	0.4693	0.2828

GROUP P Sample #	μ MILLET %	μ WHEAT %	μ GOAT MILK %
054	0.1589	0.5525	0.2886
096	0.2017	0.4815	0.3168
123	0.08326	0.6666	0.2501
197	0.1589	0.5525	0.2886
209	0.115	0.613	0.272
276	0.1823	0.5236	0.2941
318B	0.4063	0.3464	0.2473
386	0.1658	0.5375	0.2968
436	0.1572	0.5631	0.2797
472	0.1912	0.5253	0.2835
484	0.08049	0.6691	0.2504
495	0.1213	0.6107	0.268
513B	0.1589	0.5525	0.2886
568	0.1759	0.5198	0.3044
577	0.1673	0.5377	0.295
599	0.3647	0.3756	0.2598
605	0.1379	0.5719	0.2903
608	0.2579	0.4684	0.2738
609	0.1787	0.5208	0.3006
614	0.1152	0.6106	0.2743
616	0.295	0.4253	0.2797

GROUP N Sample #	μ MILLET %	μ WHEAT %	μ GOAT MILK %
015	0.0602	0.7191	0.2207
051	0.1717	0.5245	0.3037
056	0.174	0.5208	0.3053
063	0.04531	0.7533	0.2014
094	0.05969	0.7164	0.2239
103	0.2502	0.4576	0.2922
104	0.3387	0.3781	0.2832
113	0.1879	0.5082	0.3038

115	0.261	0.4487	0.2903
125	0.06061	0.7109	0.2285
133	0.08947	0.643	0.2675
147	0.08459	0.644	0.2714
164	0.1678	0.5354	0.2968
206	0.05584	0.7332	0.211
237	0.06201	0.7049	0.2331
331	0.07271	0.6781	0.2492
335	0.143	0.5518	0.3052
342	0.2025	0.4867	0.3108
347	0.1055	0.6049	0.2896
356	0.09728	0.614	0.2887
378	0.1313	0.5674	0.3013
476	0.09304	0.6365	0.2704
483	0.08588	0.6542	0.2599
508	0.1769	0.5213	0.3018
538	0.06596	0.692	0.242
542	0.1072	0.6069	0.2859
551	0.1107	0.5981	0.2912
571	0.02807	0.8295	0.1424
580	0.2971	0.4073	0.2956
582	0.3585	0.3775	0.264
600	0.06405	0.7058	0.2302
602	0.04945	0.7388	0.2117
603	0.3041	0.3994	0.2966
618	0.09169	0.6405	0.2678
621	0.06949	0.6831	0.2474

GROUP C1 Sample#	μ MILLET %	μ WHEAT %	μ GOAT MILK %
023	0.2731	0.4455	0.2814
070	0.06008	0.7126	0.2273
071	0.2079	0.4702	0.3219
086	0.2019	0.5083	0.2898
108	0.1962	0.4946	0.3092
278	0.1791	0.5285	0.2924
299	0.09386	0.635	0.2711
323	0.08431	0.6536	0.2621
328	0.09504	0.6307	0.2743
330	0.1952	0.5039	0.3009
349	0.2062	0.4936	0.3002
351	0.3312	0.396	0.2728
357	0.06137	0.7047	0.234
358	0.1727	0.5195	0.3078
362	0.2318	0.4705	0.2977
396	0.1962	0.4946	0.3092
487	0.1822	0.502	0.3158
490	0.4007	0.3365	0.2628
519	0.3895	0.3585	0.252

534	0.09022	0.6419	0.2679
560	0.06385	0.7038	0.2323
579	0.09022	0.6419	0.2679
583B	0.07872	0.665	0.2563
593A	0.1791	0.5285	0.2924
619	0.461	0.3041	0.2349
620	0.08055	0.6669	0.2526
624	0.04217	0.7693	0.1885

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	COW-MEAT	A1, A2

SAMPLE A1-F	μ MILLET %	μ WHEAT %	μ COW MEAT %
026	0.3766	0.4079	0.2155
168	0.2133	0.5811	0.2056
190	0.1585	0.6689	0.1725
327	0.2086	0.5959	0.1955
485	0.7543	0.1641	0.08153
523	0.2336	0.5399	0.2265

SAMPLE A1-M	μ MILLET %	μ WHEAT %	μ COW MEAT %
132	0.4367	0.3403	0.223
143	0.1223	0.733	0.1447
159	0.1296	0.7041	0.1663
310	0.2415	0.5063	0.2522

SAMPLE A2-F	μ MILLET %	μ WHEAT %	μ COW MEAT %
022	0.2385	0.5421	0.2194
131	0.3032	0.48	0.2168
170	0.1463	0.6939	0.1598
204	0.2223	0.575	0.2027
271	0.3076	0.4469	0.2455
279	0.2255	0.5597	0.2147
282	0.2051	0.5741	0.2209
284	0.1955	0.6063	0.1982
289	0.2144	0.5552	0.2304
307	0.1667	0.6438	0.1896
318A	0.2256	0.5642	0.2102
410	0.5134	0.2963	0.1903
426	0.1715	0.6381	0.1904
431	0.3092	0.4518	0.2391
434	0.1168	0.7427	0.1404
456	0.2354	0.5245	0.2401
460	0.1628	0.6586	0.1786
463	0.1601	0.6518	0.1881
475	0.132	0.6938	0.1742
506	0.1113	0.7423	0.1464
511	0.1029	0.768	0.1291

513A	0.1881	0.597	0.2149

SAMPLE A2-M	μ MILLET %	μ WHEAT %	μ COW MEAT %
069	0.08131	0.8203	0.09844
093	0.6547	0.2252	0.12
107	0.1655	0.6422	0.1923
222	0.1307	0.6883	0.181
228	0.2836	0.4721	0.2444
242	0.1955	0.6063	0.1982
249	0.1349	0.6923	0.1728
262	0.2743	0.4877	0.2381
264	0.1647	0.6336	0.2017
303	0.2964	0.4772	0.2264
305	0.116	0.7426	0.1414
309	0.288	0.4552	0.2568
402	0.7258	0.1869	0.08731
457	0.2293	0.5483	0.2224
466	0.162	0.6417	0.1964
543	0.1679	0.6402	0.1919

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	GOAT-MEAT	A1, A2

SAMPLE A1-F	μ MILLET %	μ WHEAT %	μ GOAT MEAT %
026	0.3696	0.3896	0.2408
168	0.209	0.5648	0.2262
190	0.1509	0.6643	0.1848
327	0.2011	0.5739	0.225
485	0.7454	0.1666	0.08807
523	0.2357	0.5114	0.2529

SAMPLE A1-M	μ MILLET %	μ WHEAT %	μ GOAT MEAT %
132	0.4358	0.3458	0.2184
143	0.1199	0.719	0.1611
159	0.1283	0.6953	0.1764
310	0.2343	0.488	0.2777

SAMPLE A2-F	μ MILLET %	μ WHEAT %	μ GOAT MEAT %
022	0.2354	0.522	0.2427
131	0.3006	0.4634	0.236
170	0.1438	0.6813	0.1749
204	0.2277	0.5498	0.2225
271	0.3024	0.4226	0.275
279	0.2156	0.5556	0.2288
282	0.2056	0.5529	0.2415

284	0.199	0.585	0.2159
289	0.219	0.532	0.2489
307	0.1688	0.6285	0.2027
318A	0.2192	0.5371	0.2437
410	0.5033	0.2849	0.2118
426	0.1683	0.6363	0.1953
431	0.301	0.4537	0.2453
434	0.1176	0.7258	0.1566
456	0.2315	0.5011	0.2674
460	0.1615	0.6397	0.1988
463	0.157	0.6336	0.2094
475	0.1332	0.6837	0.1831
506	0.1102	0.7245	0.1653
511	0.09889	0.7535	0.1476
513A	0.1824	0.5955	0.2222

SAMPLE A2-M	μ MILLET %	μ WHEAT %	μ GOAT MEAT %
069	0.08198	0.8065	0.1116
093	0.6406	0.2229	0.1365
107	0.1588	0.6357	0.2055
222	0.1268	0.6914	0.1818
228	0.2779	0.4562	0.2659
242	0.199	0.585	0.2159
249	0.1345	0.68	0.1855
262	0.2762	0.4582	0.2656
264	0.1595	0.6202	0.2203
303	0.3006	0.4416	0.2578
305	0.1137	0.7277	0.1586
309	0.2834	0.4437	0.2729
402	0.7144	0.1826	0.103
457	0.2343	0.5173	0.2483
466	0.1603	0.6269	0.2128
543	0.1681	0.6231	0.2089

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	GOAT-MEAT	A4, A5

SAMPLE A4	μ MILLET %	μ WHEAT %	μ GOAT MEAT %
091	0.193	0.5357	0.2713
177	0.2688	0.4628	0.2684
269	0.2645	0.4594	0.2761
275	0.3639	0.3708	0.2653
314	0.3061	0.4266	0.2673
467	0.2125	0.5305	0.257
528	0.2726	0.4448	0.2826
079	0.3333	0.3974	0.2693

SAMPLE A5	μ MILLET %	μ WHEAT %	μ GOAT MEAT %
044	0.3528	0.3987	0.2485
072	0.2033	0.5261	0.2707
261	0.2149	0.546	0.239
280	0.1991	0.5353	0.2656
306	0.1659	0.5792	0.2549
089	0.163	0.5939	0.2432
281	0.201	0.5412	0.2578

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	GOAT-DAIRY	A4, A5

SAMPLE A4	μ MILLET %	μ WHEAT %	μ GOAT DAIRY %
091	0.2027	0.4959	0.3013
177	0.2693	0.4426	0.2881
269	0.2711	0.4465	0.2824
275	0.3558	0.366	0.2782
314	0.3034	0.4093	0.2873
467	0.2158	0.4853	0.2989
528	0.2702	0.4305	0.2993
079	0.3275	0.3978	0.2747

SAMPLE A5	μ MILLET %	μ WHEAT %	μ GOAT DAIRY %
044	0.3425	0.3881	0.2693
072	0.2014	0.4848	0.3139
261	0.2099	0.50	0.2901
280	0.2019	0.5083	0.2898
306	0.1627	0.5409	0.2964
089	0.1594	0.5487	0.2919
281	0.2111	0.4904	0.2985

Table 23. Mean consumption values for all tested age groups. Values in black are from Scenarios 1-5, values in red represent tests for Scenarios not listed in Results.

	F (μ =)	*P (μ =)*	*N (μ =)*	*C1 (μ =)*	*A1 (μ =)*	*A2 (μ =)*	*A5 (μ =)*
Millet	11±9	16±8	13±9	17±12	N/A	N/A	N/A
Wheat	51±27	52±15	59±15	51±19	N/A	N/A	N/A
Dairy-Cow	18±13	26±9	24±7	26±6	N/A	N/A	N/A

	F (μ =)	*P (μ =)*	*N (μ =)*	*C1 (μ =)*	*A1 (μ =)*	*A2 (μ =)*	*A4(μ =)*	*A5 (μ =)*
Millet	13±8	18±8	14±9	18±11	F 30±18 M 22±14	F 21±8 M 24±15	28±5	21±6
Wheat	61±11	53±8	60±12	55±12	F 42±14 M 49±13	F 50±8 M 48±13	43±4	49±5
Dairy-Goat	26±3	28±2	27±4	27±3	F 28±4 M 29±1	F 29±14 M 28±3	29±1	29±1

	F (μ =)	*P (μ =)*	*N (μ =)*	*C1 (μ =)*	*A1 (μ =)*	*A2 (μ =)*	*A5 (μ =)*
Millet	20±12	N/A	N/A	N/A	F 32±22 M 23±15	F 21±9 M 25±18	N/A
Wheat	71±10	N/A	N/A	N/A	F 49±18 M 57±18	F 59±11 M 56±17	N/A
Meat- Beef	10±3	N/A	N/A	N/A	F 18±5 M 20±5	F 20±3 M 19±5	N/A

	F (μ =)	*P (μ =)*	*N (μ =)*	*C1 (μ =)*	*A1 (μ =)*	*A2 (μ =)*	*A4(μ =)*	*A5 (μ =)*
Millet	13±7	N/A	14±9	18±12	F 32±22 M 23±15	F 21±9 M 25±18	28±6	21±6
Wheat	72±14	N/A	66±14	60±15	F 48±18 M56±18	F 58±11 M 54±17	45±6	53±6
Meat-Goat	15±7	N/A	20±6	22±5	F 20±6 M 21±5	F 22±3 M 20±5	27±1	25±1

APPENDIX D: ADDITIONAL SCENARIO DATA

Table 24. FRUITS results for unused Scenarios.

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	COW-MEAT	F

GROUP F Sample #	μ MILLET %	μ WHEAT %	μ COW MEAT %
036	0.1291	0.7683	0.1025
065	0.1022	0.7642	0.1336
292	0.1023	0.8037	0.09402
337	0.2896	0.6174	0.09306
629	0.3671	0.5757	0.05728

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	GOAT-MEAT	F

GROUP F Sample #	μ MILLET %	μ WHEAT %	μ GOAT MEAT %
036	0.09605	0.7864	0.1175
065	0.07122	0.8391	0.08972
292	0.07547	0.8316	0.09292
337	0.183	0.5998	0.2172
629	0.2386	0.5312	0.2302

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	GOAT-MEAT	N, C1

GROUP N Sample #	μ MILLET %	μ WHEAT %	μ GOAT MEAT %
015	0.06509	0.7912	0.1437
051	0.1646	0.5778	0.2575
056	0.1736	0.5734	0.253
063	0.04804	0.8378	0.1141
094	0.06168	0.7921	0.1462
103	0.2499	0.4944	0.2556
104	0.3422	0.3927	0.2651
113	0.1898	0.5425	0.2677
115	0.2586	0.4733	0.268
125	0.06266	0.7916	0.1458
133	0.08934	0.7128	0.1979
147	0.08958	0.7266	0.1838
164	0.1767	0.5743	0.2491
206	0.06223	0.8065	0.1313
237	0.0658	0.7867	0.1475
331	0.07636	0.7622	0.1614
335	0.1429	0.6056	0.2515
342	0.1976	0.5255	0.2769
347	0.1069	0.6801	0.2131
356	0.1001	0.7024	0.1974

378	0.125	0.6325	0.2425
476	0.09787	0.7095	0.1926
483	0.09222	0.7217	0.1861
508	0.1775	0.5701	0.2524
538	0.06887	0.7653	0.1659
542	0.6718	0.2197	0.1099
551	0.6678	0.2223	0.03124
571	0.03124	0.9027	0.06611
580	0.3008	0.4194	0.2798
582	0.3778	0.3767	0.2455
600	0.07051	0.7731	0.1564
602	0.05618	0.8161	0.1277
603	0.3085	0.4213	0.2702
618	0.09662	0.7075	0.1958
621	0.07292	0.7644	0.1626

GROUP C1 Sample#	μ MILLET %	μ WHEAT %	μ GOAT MEAT %
023	0.2828	0.464	0.2532
070	0.06369	0.793	0.1433
071	0.2011	0.5199	0.279
086	0.1991	0.5353	0.2656
108	0.2006	0.5342	0.2652
278	0.1781	0.5678	0.2541
299	0.0934	0.7119	0.1947
323	0.08971	0.7312	0.1791
328	0.09669	0.7151	0.1882
330	0.1871	0.5393	0.2735
349	0.1994	0.529	0.2716
351	0.339	0.4042	0.2568
357	0.064	0.7879	0.1481
358	0.177	0.5647	.2583
362	0.2359	0.499	0.2651
396	0.2006	0.5342	0.2652
487	0.1778	0.5392	0.283
490	0.415	0.3443	0.2408
519	0.4169	0.3733	0.2097
534	0.09166	0.7121	0.1962
560	0.06543	0.7886	0.1459
579	0.09166	0.7121	0.1962
583B	0.08153	0.7453	0.1731
593A	0.1781	0.5678	0.2541
619	0.5015	0.3116	0.1869
620	.08458	0.7365	0.179
624	0.04508	0.8517	0.1032

CONCENTRATION	**WEIGHT**	**OFFSET**	**PROTEIN**	**SAMPLE GROUPS**
INDEPENDENT	INDEPENDENT	DEPENDENT	GOAT-MILK	A1, A2

SAMPLE A1-F	μ MILLET %	μ WHEAT %	μ GOAT DAIRY %
026	0.3585	0.3775	0.264
168	0.2068	0.4924	0.3008
190	0.1491	0.5568	0.2941
327	0.2079	0.4982	0.2939
485	0.64	0.1523	0.2077
523	0.238	0.4552	0.3068

SAMPLE A1-M	μ MILLET %	μ WHEAT %	μ GOAT DAIRY %
132	0.4066	0.3237	0.2697
143	0.1167	0.6074	0.2759
159	0.1263	0.5861	0.2876
310	0.2411	0.4408	0.3181

SAMPLE A2-F	μ MILLET %	μ WHEAT %	μ GOAT DAIRY %
022	0.2311	0.4672	0.3017
131	0.2976	0.4253	0.2771
170	0.1392	0.5813	0.2794
204	0.2228	0.4832	0.2939
271	0.2991	0.418	0.283
279	0.2209	0.4751	0.3039
282	0.2028	0.4834	0.3138
284	0.1916	0.5064	0.302
289	0.2207	0.473	0.3063
307	0.1678	0.5354	0.2968
318A	0.223	0.4818	0.2952
410	0.4603	0.2752	0.2645
426	0.1647	0.5331	0.3022
431	0.2959	0.4183	0.2858
434	0.114	0.5975	0.2885
456	0.2362	0.4535	0.3103
460	0.1567	0.5397	0.3035
463	0.1532	0.5472	0.2996
475	0.132	0.5768	0.2912
506	0.1048	0.601	0.2942
511	0.09685	0.6343	0.2689
513A	0.1809	0.501	0.3181

SAMPLE A2-M	μ MILLET %	μ WHEAT %	μ GOAT DAIRY %
069	0.07253	0.6754	0.2521
093	0.5497	0.2127	0.2377
107	0.1615	0.5305	.308
222	0.1217	0.5842	0.294
228	0.274	0.4274	0.2985
242	0.1916	0.5064	0.302
249	0.1278	0.5765	0.2957
262	0.2746	0.4329	0.2925
264	0.1661	0.5321	0.3018
303	0.299	0.4177	0.2833

305	0.1071	0.6237	0.2692
309	0.2922	0.4053	0.3025
402	0.6039	0.1763	0.2198
457	0.2318	0.4705	0.2977
466	0.1583	0.5446	0.2971
543	0.1668	0.5275	0.3057

REFERENCES

Ambrose, S.H., 1991. Effects of diet, climate, and physiology on nitrogen isotope abundances in terrestrial food webs. *J Archaeol Sci* 18:293-317.

Ambrose, S.H. & DeNiro, M.J. 1987. Bone nitrogen isotope composition and climate. *Nature* 325:201-201.

Ambrose, S.H. & Norr L. 1993. Experimental evidence for the relationship of carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: Lambert JB, Grupe G, editors. *Prehistoric human bone archaeology at the molecular level*. Berlin: Springer-Verlag, pp. 1–37.

Aufderheide, A. C., Tieszen, L. L., Allison, M. J., Wallgren, J. & Rapp, G. 1988. Chemical reconstruction of components in complex diets: a pilot study. In (B. V. Kennedy & G. M. LeMoine, Eds) *Diet and Subsistence: Current Archaeological Perspectives*. Calgary: The University of Calgary, Archaeological Association.

Bagnall, R.S. 1993. *Egypt in Late Antiquity.* Princeton: Princeton University Press.

Bagnall, R. S. 1996. *Egypt in late antiquity*. Princeton University Press.

Bagnall, R.S. 1997. *Kellis agricultural account book (P. Kell. IV Gr. 96).* Oxbow Books: Oxford.

Bagnall, R. S., & Frier, B. W. 2006. *The Demography of Roman Egypt* (Vol. 23). Cambridge University Press.

Bender, M.M., Baerreis, D.A., & Steventon, R.L. 1981. Further light on carbon isotopes and Hopewell agriculture. *Am Antiquity* 46:346-353.

Birrell, M. 1999. Excavations in the cemeteries of Ismant el-Kharab. In (Hope, C., Mills, A., eds.) *Dakhleh Oasis project: Preliminary reports on the 1992-1993 to 1993-1994 field seasons.* Oxford: Oxbow Books, pp. 29-41.

Bowen, G.E. 2007. Ismant el-Kharab, ancient Kellis, in the Dakhleh Oasis. *Numismatic Chronicle* 167:260-263.

Bowen, G.E., Chandler, T., & Martin, D. 2005. Reconstructing Ancient Kellis. *Buried History* 41:51-64.

Buikstra, J.E. & Milner, G.R. 1991. Isotopic and archaeological interpretations of diet in the central Mississippi valley. *J Archaeol Sci* 18:319-329.

Chisholm, B.S., Nelson, D.E., & Schwarcz, H.P. 1982. Stable-carbon isotope ratios as a measure of marine versus terrestrial protein in ancient diets. *Science* 216(4550):1131-1132.

DeNiro, M.J. & Epstein, S. 1978. Influence of diet on the distribution of carbon isotopes in animals. *Geochim Cosmochim Acta* 42:495-506.

DeNiro, M.J. & Epstein, S. 1981. Influence of diet on the distribution of nitrogen isotopes in animals. *Geochim Cosmochim Acta* 45:341-351.

Dickerson R.N., Pitts S.L., Maish G.O. 3rd, Schroeppel, T.J., Magnotti, L.J., Croce, M.A., Minard, G., & Brown, R.O. 2012. A reappraisal of nitrogen requirements for patients with critical illness and trauma. *J Trauma Acute Care Surg* 73(3):549-557.

Dupras, T.L. 1999. *Dining in the Dakhleh Oasis, Egypt: Determination of diet using documents and stable isotope analysis.* D. Phil. Thesis. McMaster University, Canada.

Dupras, T.L. & Schwarcz, H.P. 2001. Strangers in a strange land: Stable isotope evidence for human migration in the Dakhleh Oasis, Egypt. *J Archaeol Sci* 28:1199-1208.

Dupras, T.L., Schwarcz, H.P., & Fairgrieve, S.I. 2001. Infant feeding and weaning practices in Roman Egypt. *Am J Phys Anthropol* 115:201-212.

Dupras, T.L. & Tocheri, M.W. 2007. Reconstructing infant weaning histories at Roman period Kellis, Egypt using stable isotope analysis of dentition. *Am J Phys Anthropol* 134:63-74.

Dupras, T. L., Sheldrick, P. G., Williams, L. J., & Wheeler, S. M. 2020. Bones of the Ancestors: 40 Years of Bioarchaeology in the Dakhleh Oasis, Egypt. In *Proceedings of the Ninth International Dakhleh Oasis Project Conference: Papers presented in honour of Anthony J. Mills* (p. 109). Oxbow Books.

Dupras, T.L., Wheeler, S.M., Williams, L.J., & Sheldrick, P.G. 2015. Birth in Ancient Egypt: Timing, trauma, and triumph, evidence from the Dakhleh Oasis. In, S. Ikram, J. Kaiser and R. Walker (eds.): *Egyptian Bioarchaeology: Humans, Animals, and the Environment*. Sidestone Press, Cairo. Pp. 53-66.

East, K. 2015. *Exploring social identity through stable isotope analysis in the Kellis 2 cemetery.* MA Thesis. University of Central Florida, United States.

Fernandes, R. 2015. A simple(R) model to predict the source of dietary carbon in individual consumers. *Archaeol* 58(3):500-512.

Fernandes, R., Grootes, P., Nadeau, M.J., & Nehlich, O. 2015. Quantitative diet reconstruction of a Neolithic population using a Bayesian mixing-model (FRUITS): The case study of Ostorf (Germany). *Am J Phys Anthropol* 158:325-340.

Fernandes, R., Millard, A.R., Brabec M., Nadeau M.J. & Grootes, P. 2014. Food Reconstruction Using Isotopic Transferred Signals (FRUITS): A Bayesian Model for Diet Reconstruction. PLoS ONE 9(2): e87436

Fernandes, R., Rinne, C., Nadeau, M.J., & Grootes, P.M. 2012. Revisiting the chronology of northern German monumentality sites: preliminary results. In Frühe Monumentalität und soziale Differenzierung. Hinz, M., Muller, J., Lüth,F. (eds.). Band 2, verlag Dr. Rudolf Habelt GmbH.

Fogel, M.L., Tuross, N., & Oswley, D.W. 1989. Nitrogen isotope tracers of human lactation in modern and archaeological populations. *Carnegie Inst Yr Bk* 88:111-117.

Frankenfield D. 2006. Energy expenditure and protein requirements after traumatic injury. *Nutr Clin Pract* 21(5):430-437.

Gardner, I.M.F. & Lieu, S.N.C. 1996. From Narmouthis (Medinet Madi) to Kellis (Ismant el-Kharab): Manichean documents from Roman Egypt. *J Rom Stud* 86:146-149.

Graham, I.A. 2016. Paleoepidemiological Analysis of Trauma in a Roman Period Population from Kellis, Egypt, Circa 50-450 AD. *Electronic Thesis and Dissertation Repository*. 4200.

Groff, A.T. 2015. *Evaluating migratory aspects of adults from Kellis 2 cemetery, Dakhleh Oasis, Egypt through oxygen isotope analysis to address social organization and disease stigma.* D. Phil. Thesis. University of Central Florida, United States.

Heaton, T.H.E., Vogel, J.C., von la Chevallerie. G. & Collet, G. 1986. Climatic influence on the isotopic composition of bone nitrogen. *Nature* 322:822-823.

Hedges, R.E. 2002. Bone diagenesis: an overview of processes. *Archaeometry* 44(3):319-328.

Hedges, R.E.M. & Reynard, L.M. 2007. Nitrogen isotopes and the trophic level of humans in archaeology. *J Archaeol Sci* 34:1240-1251.

Holder, S. 2013. Tracking diet and starvation in Napoleon's grand army using stable isotope analysis. Master's Thesis. University of Central Florida, United States.

Holder, S., Dupras, T.L., Jankauskas, R., Williams, L., & Schultz., J. 2017. Reconstructing diet in Napoleon's grand army using stable carbon and nitrogen isotope analysis. *Am J Phys Anthropol* 63:53-63.

Hope, C.A. 2001. Observations on the dating of the occupation at Ismant el-Kharab. In (Marlow, M. ed.) *The oasis papers I: Proceedings of the first international symposium of the Dakhleh Oasis project.* Oxbow Books: Oxford pp.43-59.

Hope, C.A. 2002. Excavations in the settlement of Ismant el-Kharab in 1995-1999. In (Hope, C.A. & Bowen, G.E., eds.) *Dakhleh Oasis project: Preliminary reports on the 1994-1995 to 1998-1999 field seasons.* Oxbow Books: Oxford pp.167-208.

Hope, C.A. 2003. The excavations at Ismant el-Kharab from 2000-2002. In (Hope, C.A. & Bowen, G.E., eds.) *The oasis papers 3: The proceedings of the third international conference of the Dakhleh Oasis project.* Oxbow Books: Oxford pp. 207-289.

Iloeje, M. U., Rounsaville, T. R., McDowell, R. E., Wiggans, G. R., & Van Vleck, L. D. 1980. Age-season adjustment factors for Alpine, LaMancha, Nubian, Saanen, and Toggenburg dairy goats. *Journal of Dairy Science*, 63(8)1309-1316.

Institute of Medicine (US) Committee on Nutritional Status During Pregnancy and Lactation. Nutrition During Pregnancy: Part I Weight Gain: Part II Nutrient Supplements. Washington (DC): National Academies Press (US); 1990. https://www.ncbi.nlm.nih.gov/books/NBK235228/ doi: 10.17226/1451

Katzenberg, M. 2008. Stable isotope analysis: a tool for studying past diet, demography, and life history. In: Katzenberg MA, Saunders SR, editors. *Biological anthropology of the human skeleton*. New York: Wiley-Liss, pp. 413-441.

Katzenberg, M. A., Herring, D. A. & Saunders, S. R. 1996. Weaning and infant mortality: evaluating the skeletal evidence. *Yearb Phys Anthropol* 39:177–200.

Katzenberg, M. A. & Lovell, N.C. 1999. Stable isotope variation in pathological bone. *Int J Osteoarchaeol* 9:316-324.

Katzenberg, M.A., Saunders, S.R., & Fitzgerald, W.R. 1993. Age differences in stable carbon and nitrogen isotope ratios in a population of prehistoric maize horticulturists. *Am J Phys Anthropol* 90:267–281.

Katzenberg, M.A., Schwarcz, H.P., Knyf, M., & Melbye, F.J. 1995. Stable isotope evidence for maize horticulture and paleodiet in southern Ontario, Canada. *Am Antiq* 60(2):335-350.

Keeling, C.D., Mook, W.G. & Tans, P.P. 1979. Recent trends in the C/ C ratio of atmospheric carbon dioxide. *Nature* 277:121-123.

Knudstad, J.E. & Frey, R.A. 1999. Kellis, the architectural survey of the Romano-Byzantine town at Ismant el-Kharab. In (Churcher, C.S. & Mills, A.J., eds.) *Reports from the survey of Dakhleh Oasis, Western Desert of Egypt, 1977-1987: Dakhleh Oasis project monograph 2.* Oxford:Oxbow Monograph 99:189-214.

Lambert, J.B. 1997. *Traces of the past: unraveling the secrets of archaeology through chemistry*. Cambridge: Perseus Publishing.

Larsen, C.S., Schoeninger, M.J., van der Merwe, N.J., Moore, K.M., & Lee-Thorp, J.A. 1992. Carbon and nitrogen stable isotopic signatures of human dietary change in the Georgia Bight. *Am J Phys Anthropol* 89:197-214.

Larsson, J., Lennmarken, C., Martensson, J., Sandstedt, S., & Vinnars, E. 1990. Nitrogen requirements in severely injured patients. *Br J Surg* 77:413-416.

Lee-Thorp, J.A. 2008. On isotopes and old bones. *Archaeometry* 50(6):925-950.

Minagawa, M., Wada, E. 1984. Stepwise enrichment of ^{15}N along food chains: Further evidence and relation between $\delta^{15}N$ and animal age. *Geochim cosmochim acta* 48:1135-1140.

Molto, J.E., Loreille, O., Mallot, E.K., Malhi, R.S., Fast, S., Daniels-Higginbotham, J., & Marshall, C., Parr, R. 2017. Complete mitochondrial genome sequencing of a burial from a Romano-Christian cemetery in the Dakhleh Oasis, Egypt: Preliminary indications. *Genes* 8:262

Molto J.E., Stewart J.D., Reimer P.J., & Williams L.J. 2006. The dating of the Kellis 2 cemetery: an ongoing conundrum. Paper presented at the Fifth International Conference of the Dakhleh Oasis Project. Cairo.

Nambiar, V.S., Dhaduk, J.J., Sareen, N., Shahu, T., & Desai, R. 2011. Potential functional implications of pearl millet (*Pennisetum glaucum*) in health and disease. *J Appl Pharm Sci*, 1(10):62

O'Connell, T.C., Hedges, R.E.M., Healey, M.A., & Simpson, A.H.R.W. 2001. Isotopic comparison of hair, nail, and bone: Modern analysis. *J Archaeol Sci* 28:1247-1255.

O'Connell, T.C., Kneale, C.J., Tasevska, N., & Kuhnle, G.G.C. 2012. The diet-body offset in human nitrogen isotopic values: A controlled dietary study. *Am J Phys Anthropol* 149:426-434.

O'Leary, M.H. 1995. Environmental effects on carbon isotope fractionation in plants. In (E. Wada, T. Yoneyama, M. Minigawa, T. Andao, & B.D. Fry, Eds.) *Stable Isotopes in the Biosphere.* Kyoto: Kyoto University Press, pp. 78-91.

Olsen, K.C., White, C.D., Longstaffe, F.J., von Heyking, K., McGlynn, G., Grupe, G., & Rühli, F.J. 2014. Intraskeletal isotopic compositions of bone collagen: Nonpathological and pathological variation. *Am J Phys Anthropol* 153:598-604.

Ortner, D.J. 2003. *Identification of pathological conditions in human skeletal remains.* Academic Press: USA

Peacock, D. 2000. The Roman Period (30 BC-AD 395). In: (Shaw, I. ed.), *The Oxford History of Ancient Egypt.* Oxford: Oxford University Press, pp. 422-445.

Pecoraro, V., Astore, I., & Barman, J.M. 1964. Cycle of the scalp hair of the new-born child. *J Invest Dermatol* 43:145-147.

Phillips, D.L., Inger, R., Bearhop, S., Jackson, A.L., Moore, J.W., Parnell, A.C., Semmens, B.X., & Ward, E.J. 2014. Best practices for use of stable isotope mixing-models in food-web studies. *Can J Zool* 92:823-835.

NRC (National Research Council). 1989. Recommended Dietary Allowances, 10th ed. Report of the Subcommittee on the Tenth Edition of the RDAs, Food and Nutrition Board, Commission on Life Sciences. National Academy Press, Washington, D.C. pp. 284.

Reitsema, L.J. 2013. Beyond diet reconstruction: stable isotope applications to human physiology, health, and nutrition. *Am J Hum Bio, 25*(4):445-456.

Robbins, C.T., Felicetti, L.A., & Sponheimer, M. 2005. The effect of dietary protein quality on nitrogen isotope discrimination in mammals and birds. *Oecologia*
DOI 10.1007/s00442-005-0021-8

Robbins, C.R. 2012. *Chemical and physical behavior of human hair.* Berlin: Springer-Verlag.

Schoeninger, M.J. 1995. Stable isotope studies in human evolution. *Evol Anthropol* 4:83-98.

Schoeninger, M.J. & DeNiro, M.J. 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochim Cosmochim Acta* 48:625-639.

Schoeninger, M.J. & Moore, K. 1992. Bone Stable Isotope Studies in Archaeology. *J World Prehist* 6(2):247-296.

Schurr, M.R. & Redmond, B.G. 1991. Stable isotope analysis of incipient maize horticulturists from Gard Island 2 Site. *MidCont J Archaeol* 16:69-84.

Sealy, J.C. & van der Merwe, N.J. 1988. Social, spatial and chronological patterning in marine food use as determined by 13C measurements of Holocene human skeletons for the southwestern Cape, South Africa. *World Archaeol* 20:87-102.

Scheidel, W. & Friesen, S. J. 2009. The Size of the Economy and the Distribution of Income in the Roman Empire. *The Journal of Roman Studies*, 99:61-91.

Shobhit, P.K., Ambawat,S., & Singh, S. 2020. 8 Biofortification and Medicinal Value of Pearl Millet Flour. In Punia, S., Siroha, A.K., Sandhu, K.S., Gahlawat, S.K., Kaur, M. (eds.) *Pearl Millet: Properties, Functionality and its Applications*. CRC Press: Florida

Stewart, J.D., Molto, J.E., & Reimer, P.J. 2003. The chronology of Kellis 2: The interpretive significance of radiocarbon dating of human remains. In (Bowen, G.E., Hope, C.A., eds.) *The Oasis papers 3: Proceedings from the third international conference of the Dakhleh Oasis project.* Oxford: Oxbow Books, pp. 373-382.

Talib, M.I., Burse, A.T., & Parate, V.R. 2017. Development of weaning food from pearl millet malt. *IJCRT* DOI: http://doi.one/10.1727/IJCRT.17174
Tykot, R.H. 2006. Isotope analyses and the histories of maize. In: Staller J, Tykot R, Benz B, editors. *Histories of maize: Multidisciplinary approaches to the prehistory, linguistics, biogeography, domestication, and evolution of maize*. Amsterdam: Elsevier, pp. 131-142

van der Merwe, N.J. 1982. Carbon isotopes, photosynthesis and archaeology: different pathways of photosynthesis cause characteristic changes in carbon isotope ratios that make possible the study of prehistoric human diets. *Am Scient* 70(6):596-606.

van der Merwe, N.J. & Vogel, J.C. 1978. ^{13}C content of human collagen as a measure of prehistoric diet in Woodland North America. *Nature* 276:815-816.

van der Merwe, N.J., Roosevelt, A.C., & Vogel, J.C. 1981. Isotopic evidence for prehistoric subsistence change at Parmana, Venezuela. *Nature* 292:536-538.

Vogel, J.C. & van der Merwe, N.J. 1977. Isotopic evidence for early maize cultivation in New York State. *Am Antiq* 42:238-242.

Walker, P.W. & DeNiro, M.J. 1986. Stable nitrogen and carbon isotope ratios in bone collagen as indicators of prehistoric dietary dependence on marine and terrestrial resources in southern California. *Am J Phys Anthropol* 71:51-61.

Wheeler, S.M. 2012. Nutritional and disease stress of juveniles from the Dakhleh Oasis, Egypt. *Int J Osteoarchaeol* 22(2):219-234.

Wheeler, S.M., Williams, L., Beauchesne, P., & Dupras, T.L. 2013. Shattered lives and broken childhoods: Evidence of physical child abuse in ancient Egypt. *Int J Paleopathol*, 3(2):71-82.

Wheeler, S.M., Williams, L., Dupras, T.L., Tocheri, M., & Molto, J.E. 2011. Childhood in Roman, Egypt: Bioarchaeology of the Kellis 2 cemetery, Dakhleh Oasis, Egypt. In: Lally, M., Moore, A., editors. *(Re)Thinking the little ancestor: New perspectives on the archaeology of infancy and childhood.* Archaeopress: England, pp. 110-121.

White, C.D., & Schwarcz, H.P. 1994. Temporal trends in stable isotopes for Nubian mummy tissues. Am *J. Phys Anthropol* 93:165-187.

Williams, L. 2008. *Investigating seasonality of death at Kellis 2 cemetery using solar alignment and isotopic analysis of mummified tissues.* D. Phil. Thesis. The University of Western Ontario, Canada.

Williams, L. J., White, C. D., & Longstaffe, F. J. 2011. Improving stable isotopic interpretations made from human hair through reduction of growth cycle error. *Am J of Phys Anthropol*, 145(1):125-136.

Yoshinaga, J., Minagawa, M., Suzuki, T., Ohtsuka, R., Kawabe, T., Inaoka, T. & Akimichi, T. 1996. Stable carbon and nitrogen isotopic composition of diet and hair of Gidran-speaking Papuans. *Am J Phys Anthropol* 100:23–34.