A STABLE ISOTOPE INVESTIGATION OF DIET AT VAGNARI

A STABLE ISOTOPE INVESTIGATION OF DIET AT VAGNARI

BY LISA SEMCHUK, B.A.

A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree Master of Arts

MASTER OF ARTS (2016) McMaster University
(Anthropology) Hamilton, Ontario

TITLE: A Stable Isotope Investigation of Diet in the Vagnari Cemetery

AUTHOR: Lisa Semchuk, B.A., Hon. (University of Manitoba)

SUPERVISOR: Dr. Tracy Prowse

NUMBER OF PAGES: xii, 166

Abstract

This thesis applies stable isotope analysis to the study of diet from a rural Roman estate, Vagnari (1^{st} – 4^{th} centuries AD), in southern Italy. The major objectives of this research are to identify the types of food eaten in the Vagnari skeletal sample from stable isotope ratios, as well as to explore individual variation in diet in the sample. Isotopic composition of collagen and carbonate indicate a diet heavy in C_3 plants with the incorporation of some animal-based proteins. Isotopes of carbon from collagen ($\delta^{13}C_{col}$) were relatively consistent across the sample, with some variation according to burial type. Nitrogen ($\delta^{15}N$) values varied with age-at-death and the number of grave goods buried with an individual, suggesting possible status-based variation in diet. Carbon isotopes from carbonate ($\delta^{13}C_{ap}$) suggested variation in total diet with increased age-at-death. Isotope ratios from Vagnari were also compared with other Imperial Italian sites to situate the diet within a broader Roman context. Isotopically, diets at Vagnari were most similar to other inland and rural sites, and distinct from coastal urban diets based on marine fish. These results indicate the diversity in foods eaten in the Roman Empire, both at a local site level and between different settlements. Studying diet from Vagnari provides another window into the lives of people who lived and worked on industrial estates, and bolsters knowledge of the diets of rural residents, which are underrepresented in the literature.

Acknowledgements

This thesis would not have been possible without the support of many individuals. First and foremost, my supervisor Dr. Tracy Prowse was invaluable in guiding me through stable isotope procedures, interpretations of results, and the process of writing the thesis. I would also like to thanks to my committee members Dr. Megan Brickley and Dr. Henry Schwarcz, whose insights have helped make this thesis the best it can be. My appreciation also extends to all the helpful individuals at various laboratory facilities I utilized, including Paul Middlestead and Wendy Abdi from the G.G. Hatch - Stable Isotope Laboratory at the University of Ottawa and Dr. Steve Kornic from the Combustion Analysis and Optical Spectroscopy facility at McMaster University.

My thanks also goes out to my family, including my mother Nancy, father Alan, sister Claire and brother Adam for their support and understanding from afar. The anthropology graduate cohort at McMaster also gave me plenty of guidance and support while writing, particularly my Thesis Jail Co-Warden Laura Lockau and office mate Becca Burns. A special shout out to my friends in the swing dancing communities of Hamilton and beyond for providing me with opportunities for much needed creative outlets while writing my thesis.

Table of Contents

List of Tables

List of Figures

List of Equations

List of Abbreviations

Abbrev.	Full Name
AD	*Anno Domini*
AIR	Ambient Inhalable Reservoir
AMTL	Antemortem tooth loss
BC	Before Christ
C:N	Carbon to nitrogen ratio
CAOS	Combustion Analysis and Optical Spectroscopy facility
CI	Crystallinity index
EAE	External auditory exostoses
FTIR	Fourier transform infrared spectroscopy
HCl	Hydrochloric acid
IRMS	Isotope ratio mass spectrometer
MNA	Minimum number of artifacts
NaOCl	Sodium hypochlorite, or bleach
NaOH	Sodium hydroxide
SES	Socioeconomic status
VPDB	Vienna Peedee belemnite carbonate

1 Introduction

1.1 Research Objectives, Methods, and Significance

This thesis is a study of diet from a human skeletal sample using stable isotope analysis. The sample comes from the cemetery at Vagnari (1^{st} – 4^{th} centuries AD), a rural industrial estate from Roman Italy. Most knowledge of Roman diet is based on historical sources, and these records primarily represent experiences of the urban elite. The lives of rural residents and the foods they ate are largely neglected in these accounts of the past. Studying diet at Vagnari will contribute to a growing body of knowledge on rural inhabitants of the Roman Empire and life on an Imperial estate.

The main objective of this research is to use stable isotope analysis to study the diet of people living and working at Vagnari. This thesis will seek to test the hypothesis that if differences in diet are present at Vagnari, they may be linked to broader social variation in identity and power. Isotope ratios from skeletal materials provide indication of the types of foods eaten by an individual, such as C_3 or C_4 plants, and the proportion of marine versus terrestrial food sources. Stable isotope methods have been widely applied in bioarchaeological research (see reviews by Katzenberg, 2008; Lee-Thorp, 2008), with studies of past diet conducted on samples from throughout the Roman Empire. Most isotopic studies of Roman diet in Italy have focused on urban or peri-urban settlements (e.g., Craig et al., 2009; Craig et al., 2013; Killgrove & Tykot, 2013; Prowse et al., 2004; Rutgers et al., 2009), leaving rural residents underrepresented in the literature.

Additional objectives of this project are to understand variation in diet within the Vagnari sample, and between diets from Vagnari and other Roman sites from Italy. Dietary habits are culturally acquired, and can be a signifier of preferences or identities for an individual or group (Schutkowski, 2008). Social differences in diet can be investigated at Vagnari by comparing stable isotope ratios with individual variation in age-at-death, sex, and burial treatment. Comparisons with other sites can situate the diet at Vagnari within a broader Roman context, and allow for analysis of urban and rural variation. These comparisons are not an extensive representation of Roman diet, but a study of what a sample of people ate from specific Roman sites.

To date there have been no other isotopic studies of diet in Roman Italy that have solely focused on a rural site. Some studies have incorporated small rural cemeteries for comparison, or researched diet on the outskirts of Rome (e.g., Killgrove & Tykot, 2013; Prowse et al., 2004). Studying Vagnari presents an opportunity learn more about rural diet, and adds a point of comparison for other urban sites. Diet at Vagnari, especially when compared with other sites, can illustrate the diversity of foods eaten by Romans from different areas of the Empire.

Diet is based both on biological need and cultural preference. It is a behavioural category of the food and drink selected from options available for consumption (Schutkowski, 2008). Diet is the food choices made by an individual or community. Food choices may represent social relations, power dynamics, cultural ideas of edibility, or understandings of the human body and health within a particular society (Caplan, 1997).

These dimensions can be explored when studying diet at Vagnari to learn more about the lives of rural residents of the Roman Empire.

1.2 Organization of the Thesis

Chapter 2 begins with a review of Roman diet, including dietary staples and factors that influenced food choices in a Roman context. This chapter integrates information from Roman classical literature, historical evidence, and bioarchaeological research on Roman diet. The urban-rural dynamic of the Roman Empire and the estate system of production are also discussed. An overview of the research conducted on the Vagnari cemetery is also presented to form testable hypotheses for stable isotope research on the skeletal sample from this site.

Chapter 3 is a review of stable isotope analysis in bioarchaeological research. Basic concepts are introduced, including the isotopes of interest, bone components from which isotopes are extracted, and applications of stable isotope analysis in the study of past diet. A brief literature review of stable isotope studies of diet in Imperial Roman Italy is also presented.

Chapter 4 details the cemetery sample studied from Vagnari, and a brief history of its excavation. Stable isotope methods, including the preparation of bone collagen and apatite carbonate for mass spectrometry, are described. Chapter 5 presents the results from the stable isotope analysis of bone collagen and carbonate. Results from statistical tests applied to explore variation in diet at Vagnari are also presented.

Chapter 6 discusses the results in more detail. Information from Chapter 2 about Roman diet is integrated to interpret stable isotope ratios and variation in diet at Vagnari. Published isotope data from other Roman sites are compared with Vagnari to explore variation in diet across the Roman Empire. Conclusions of this study and future avenues of research are presented in Chapter 7.

2 Roman Diet and Culture

2.1 Introduction

To interpret diet from isotopes of human bone, the social, cultural, and historical context in which the people of Vagnari lived must be understood. Food fulfills a biological need for energy and nutrition, and food choices are influenced by cultural factors such as an individual's role or place in society. Diet varies between individuals due numerous factors, in part due to social aspects of identity, including age or gender. Variation in diet due to social distinctions will be examined for Vagnari, an Imperial Roman estate. Differences in foods eaten at the site may indicate differences in identity or power among the people living and working at the estate. This chapter discusses diet within a Roman cultural context and the conditions of rural estates such as Vagnari during the Imperial period (1^{st} – 4^{th} centuries AD) in Italy.

2.2 Roman Diet

Knowledge of Roman diet comes from a wide range of sources, including historical sources (e.g., cookbooks, medical treatises, or other literary works), analyses of these historical sources, and evidence from the archaeological record. Historical sources provide valuable information about Roman diet, but require a nuanced interpretation. Roman historical sources are not entirely representative of all the people who were living and eating food in the Roman Empire. Writers of the Roman age were mainly middle-to-upper class men, who represented their own interests and ideas in

their works. When documents refer to "*populus Romanus*" or the "Roman people," they may have only been writing with the official citizens of Rome, adult men of certain social categories, in mind when using this term. These writings may not have included lower classes, women, workers, slaves, or rural inhabitants (Purcell, 2003).

2.2.1 Literary evidence

Prominent writings about food in Roman society, such as medical treatises or cookbooks, give insight into the foods available to Roman people but may not represent day-to-day dietary preferences. Medical treatises may indicate dietary ideals rather than what was actually practised, or may have also been recorded to further an agenda. For example, the Greek physician Galen (129-204 AD) displays a wealth of knowledge about different foods in his writings (e.g., *On Food and Diet*), but this was for the purpose of establishing himself as both a philosopher and physician in Roman society (Grimm, 2006). The cookbook by Apicius (4th to 5th century AD) presents some luxury recipes (e.g. *ofellae* [little pieces of meat], snails, roasted meats and the accompanying sauces), and also contains recipes that could have been accessible to Romans of differing classes, such as *patina* (a mixture of meat, fish, or vegetables set in a large dish with eggs), minced meat, vegetables and pulses (Apicius, trans. 2006). Cookbooks such as the one written by Apicius have a broader view of Roman food because they were written to be used in the kitchen by cooks; these people were not the elites of society, but could have served the upper class (Grocock & Grainger, 2006). Cookbooks present the variety of the Roman menu, and medical writings (e.g., Galen's *On Food and Diet*) reveal perceptions

about the role of food in health, giving voice to different food knowledge that was present during the Roman Empire.

Roman literary sources often indirectly mention food within the context of other topics, and this reveals important perceptions about social positions, health, and power (Grimm, 2006). Meals often served as a backdrop for Roman literary settings. Roman upper class meals consisted of the *gustatio*, an appetizer of roots, vegetables, fish, or eggs; *cena,* the main course of sacrificial meat; and *secunda mensa*, desserts such as fruits, nuts, or pastries (Gowers, 1993). The number of courses in a meal varied, but would be lengthier for wealthier Romans. Rich, lengthy banquets are featured in both Greek and Roman literature, such as *The Deipnosophists* by Athenaeus (3rd century AD) and *The Satyricon* by Petronius (1st century AD). In these cases, the narrative is less focused on the food that is served, but the conversations and theatrics that surround each dish. Various foods are listed, described, or discussed in these works, such as hors d'oeuvres, fish with *garum* sauce, suckling pig, peahen eggs, boar, pastries, cakes, and wine, among others (Athenaeus, trans. 2006; Petronius, trans. 2009). The many different foods presented in *The Deipnosophists* and the *Satyricon* demonstrate the array of dishes that the Roman elite had access to.

The meals in *The Deipnosophists* and the *Satyricon* serve as a backdrop for social commentary. Trimalchio's extravagant banquet in the *Satyricon* has repulsing imagery of oozing foods and bodies bursting at their limits, which draws attention to Roman insecurities about consumption and the body (König, 2012; Petronius, trans. 2009). In

The Deipnosophists, food is often discussed in the context of health and etiquette (Athenaeus, trans. 2006; König, 2012). A repeated theme in the work of Athenaeus is that of the contrast between luxury and moderation, likely for the purpose of providing a moral lesson (König, 2012). The *Satyricon* and *The Deipnosophists* are social commentaries on the topic of consumption, particularly gross overconsumption, for reasons of both moral and physical wellness. These works provide information about the variety of a Roman menu, how meals were structured, and the perceptions about health and etiquette held in relation to food. However, this information could preferentially represent ideas about food held by the elites of society.

Many Romans lived at a subsistence level, and the banquets described by Athenaeus or Petronius would not have been accessible to them. Works that discuss food in a more ordinary Roman context include the *Epigrams* by Martial (84-85 AD) and *De re rustica* by Lucius Junius Moderatus Columella (1st century AD). In *Book XIII: The Xenia* Martial writes several poems about food items that could be given as gifts to houseguests during Saturnalia, the Roman winter solstice festival held in December (Martial, trans. 2001). In addition to some delicacies (e.g. peacocks and dormice), common fare such as beans, lentils, barley, radishes, and olives are poeticized (Martial, trans. 2001). The inclusion of these commonplace foods as possible gifts shows what foods may have been regular household items for Romans living at the subsistence level. Columella's *De re rustica* serves as an instructional piece, focusing on the production of food, rather than its consumption. *De re rustica* discusses topics such as tilling soils,

viticulture, growing fruits and olives, and raising domesticated animals, which give insight into both what was produced for food and how (Columella, trans. 1941). Columella's writings present more practical aspects of food production, but they still represent an elite male perspective, as he wrote about farming at the estates he owned in the Roman countryside.

Popular literature in the Roman world is informative for the foods available and perceptions that factored into food choices, but these ideas could be held predominantly by the literate middle and upper classes. Viewpoints and lived experiences of the lower class labourers of the Roman world are still missing.

2.2.2 Archaeological and historical evidence

Types of Food

Historical and archaeological research gives evidence for different types of foods eaten by Romans. The core of the Roman diet is typically characterized in historical research as a Mediterranean triad of olives, wine, and cereals, though this triad was not equally available to all areas of the Roman Empire. Both olive and vine growing were restricted geographically by climate, but the demand for olive oil and wine was widespread across the Empire (Garnsey, 1999). Olives and wine grapes could only be grown in the temperate climate of the Mediterranean basin as they do not tolerate frost, and were imported as oils or wines into northern climates on a limited basis (Garnsey, 1999; Stirling, 2006). Olives and wine were important crops both for Roman consumption and the economy, but they do not represent the extent of Roman cuisine.

Cereals and their products were staples of Roman diet to the extent that they were associated with civility and acted as a community identifier (Purcell, 2003). Although the exact percentage of the Roman diet that was composed of cereals is unknown, it is clear that they were frequently eaten. Cereals were so central to Roman diet that the consumption of other foods, such as beans, nuts, or other non-cereal complements could socially distinguish an individual from the dominant cereal-eating group (Purcell, 2003). Romans mainly relied on *far*, or emmer wheat, which was both eaten and used in ritual sacrifice (Garnsey, 1999). According to contemporary writers of the Augustan period, Roman people subsisted on *far* for 300 years (Purcell, 2003). *Far* was mainly eaten as porridge, and later declined in popularity with the introduction of naked wheats, which were used to make breads. Breads were also a common way for Romans to eat cereals.

Archaeological lines of evidence also demonstrate the use of cereals in Roman diet. Frequencies of dental caries and dental calculus reflect the regular consumption of cereals and soft, sticky foods by Roman people. Frequencies of both dental caries (71.6% of individuals) and calculus (83.6% of individuals) indicated consumption of carbohydrates in an analysis of adult teeth from the Roman site Quadrella (1^{st} – 4^{th} centuries AD) (Bonfiglioli, Brasili, & Belcastro, 2003). Similar trends of moderate to high frequencies of dental caries and calculus are seen in adults from other Imperial Roman sites in Italy, such as Isola Sacra (mean Caries Rate 7.8 for males and 6.6 for females; calculus prevalence in 90% of individuals) and Lucus Feroniae (caries prevalence 52.0%

of individuals; calculus prevalence 66.7% of individuals) (Manzi, Salvadei, Vienna, & Passarello, 1999; Prowse, 2011). The moderate to high frequencies of caries and calculus suggest a reliance on cereals at different Roman sites, though some of these values may be high due to the reporting of data by individual, rather than the number of observable teeth.

Caries are formed when plaque bacteria ferment dietary carbohydrates, producing acids that demineralize tooth enamel, and calculus is formed by the mineralization of plaque around the teeth (Hillson, 2008). The prevalence of both caries and calculus are utilized in studies of diet, though calculus to a lesser extent as its formation process is not as clearly understood. In combination with low frequencies of dental wear, high frequencies of caries indicate regular consumption of soft, carbohydrate–rich foods (Bonfiglioli et al., 2003). High frequencies of dental calculus also indicate the consumption of carbohydrates, but calculus does not specifically form in response to carbohydrates. Dental calculus can also speak to poor dental hygiene practices or diets high in fat or protein (Lieverse, 1999).

Romans made use of other food sources outside of the Mediterranean triad. One such source was legumes, although they were considered the “poor man’s meat” (Garnsey, 1999:15). The most common varieties of legumes eaten were broad beans, chickpeas, lentils, fava beans, and peas (Erdkamp, 2012). Both the rich and the poor ate legumes; the difference was that the poor needed them for survival, whereas the rich could choose from other foods to eat (Garnsey, 1999). Legumes were cultivated and

consumed by Roman people despite a lack of associated prestige, as varieties such as lentils provided nutrients that cereals did not have (Garnsey, 1999). Plants indigenous to and foreign to the Mediterranean region were grown and eaten, including different fruits, vegetables, nuts, or spices. Walnuts, grapes, and celery, as well as spices like coriander and dill were introduced into Roman cuisine and grown locally for consumption (Halstead, 2012). These foods were valued for being exotic and incorporated into Roman diet through trade, but would likely be more common for the elites of society to eat.

Meat was less of a staple in Roman diet as compared to components of the Mediterranean triad. Meat was still eaten, but it was not always the central focus of a meal. Geographic and climatic limitations, such as a short growing season, small amounts of grass and fodder, and the tendency for pastures to dry out in the spring limited the supply of meat for Romans (Garnsey, 1999). That is not to say that a meat economy did not exist in the Imperial Roman era, but rather that it was not a top priority. The energy for raising livestock was more often invested in secondary products or other economic functions of the animals (Garnsey, 1999). Cattle were principally reared as plough animals and sheep were kept for wool and cheeses, though both beef and mutton were eaten on occasion (Garnsey, 1999; Halstead, 2012). Chickens were abundant in the Roman period, and while favoured in some sacrificial contexts, could be raised and consumed by poorer households (Halstead, 2012). Of the meats available to eat, pork was the most commonly consumed by Romans since pigs have large litters and

yield no secondary products (Garnsey, 1999; Halstead, 2012). Romans did incorporate meat into their diet, but not on a scale where it could be considered a dietary staple according to historical evidence.

Fish were even more of a rarity in the Roman diet than meat for reasons of limited access and availability. Most people living in Roman territories were land-based agriculturalists, and the smaller numbers of fishermen with limited catch sizes restricted the presence of fish as a dietary staple (Garnsey, 1999). Additionally, the main way to get fish was through markets (Broekaert & Zuiderhoek, 2012; Garnsey, 1999), which would have catered mainly to coastal urban dwellers and their purchasing power. Acquiring fish through market sales would have been more difficult and costly for rural inland populations. Fish by-products such as sauces were more common than the fish themselves because they lasted longer, and could be prepared in high quantities to be shipped out to trade centres (Garnsey, 1999). The expansion of the Roman Empire and Mediterranean cuisine throughout the ancient world also spread the taste for fish sauce, or *garum* (Broekaert & Zuiderhoek, 2012). Isotopically, regular consumption of *garum* would look similar to regular consumption of the fish from which it is made of; the isotopic signatures of *garum* would vary based on the fish's position in the aquatic food chain (see discussion in Section 3.2.2).

Food preferences and perceptions

Romans associated differing levels of status and prestige with different foods. Primary prestige foods for the Romans were imported foods and spices (Garnsey, 1999).

Though cereals and wine were common aspects of Mediterranean Roman diets, the type or quality set them apart for consumption by upper or lower classes. Social distinctions in cereals came from the type of grains and the way they were prepared. For example, unlike their Greek neighbours, Romans considered barley to be a low-status crop best reserved for animal fodder (Garnsey, 1999). Free-threshing wheats made up the prized white bread eaten by high-class Romans, whereas cereals such as barley or emmer wheat were eaten by the poor as groats, gruel, flatbread or rusks (Halstead, 2012). Wine was also available to both the rich and poor, but in different qualities. Wine that was available to poorer Romans would not have been much better than vinegar, whereas upper class Romans could purchase their choice of high-quality local or imported wines (Broekaert & Zuiderhoek, 2012; Garnsey, 1999). Wines could also vary in quality based on different treatments, such as the ingredients added for flavour, or the amount of water added. The quality and status of different types of foods can be distinguished in literary sources from antiquity, but it is difficult to determine differences in food quality with stable isotope analysis.

The consumption of meat was more common for the rich than the poor, as they could afford to raise livestock or purchase meat at the market. Commoners consumed meat in the form of sausages or cheap cuts, whereas higher-grade red meats were more available to upper classes (Garnsey, 1999). Meat had an important social role in Roman public sacrifices and feasts, and often the meat from sacrificed animals was distributed amongst the participants of the ritual (Broekaert & Zuiderhoek, 2012). Most of the

participants in these festivities were elites, but any excess meat, usually of lesser quality, would be sold in the market (Garnsey, 1999). Though meat could be considered a prestige food for the Romans, its social distinction comes from its type, quality, preparation, and the context in which it was consumed, not merely its presence in the diet.

Few foods were forbidden in the Roman diet; upper class writers scorned some foods as being unfit for consumption, but they were in a position where they could afford to do so (Garnsey, 1999). Many factors could restrict one's diet, including perceptions about health, gender, and moral or religious obligations. Moral or religious-based food perceptions indicate shared ideas of what Romans considered appropriate to eat and how it should be eaten. Some philosophers, priests, and sages practiced vegetarianism for the sake of intellectual enlightenment or from moral oppositions to eating animals (Garnsey, 1999). While few things were forbidden from being eaten, Romans still considered there to be appropriate social contexts for the consumption of certain items. Animal feed and wild plants would not regularly be considered appropriate food for people, but this meaning could change in times of food shortages (Garnsey, 1999). Rules of etiquette were held for the consumption of foods such as meat. Meat could not be eaten raw, on its own, in excess, or without a display of manners – to break these rules would be considered barbaric (Garnsey, 1999). Though few foods were seen as taboo, Romans did have shared cultural rules about how food should be eaten.

Roman diet is thus more nuanced than the Mediterranean triad. Though the triad does represent common dietary staples, it is not exhaustive of all foods that were relied on or considered important by Romans in the Mediterranean region. Roman diet too cannot be blanketed over an entire empire of people, each with their own unique living conditions. Individual variation in diet must also be considered.

2.3 Diet and Identity in Roman Society

Behaviours surrounding food reflect hierarchies and power in social relationships (Garnsey, 1999). The food that is accessible, distributed, or allocated to an individual speaks to their identity and power within a society. Biases in the distribution of food can play out at different levels of social organization, such as regional or even household levels of power. Different aspects of identity, such as gender, age, and status intersect to influence the foods an individual will eat. The way in which identity affects one's diet operates differently for each culture. The relationship between diet and identity will be explored within Roman society, while taking insight from modern patterns of dietary variability.

2.3.1 Gendered differences in Roman diet

Gender relates to the ideology, role, and identity of people (Sofaer, 2006). The study of gender in archaeology focuses on the performance of gender roles for personhood (Fuglestvedt, 2014). In archaeological research biological sex may inform gender, but this is not always true. Gender is based on behaviour, as is diet. Perceptions and attitudes about food shared by a group of people will influence food choices,

particularly ideas of gender-appropriate foods. Gender has an influence over the foods a person will eat, or is permitted to eat, as this is a way of performing masculinity or femininity in a society.

Gendered differences in relation to food may include the selection, collection, preparation, or processing of foods to be eaten. Among Western societies the household preparation and dispensing of food is work largely undertaken by women (Caplan, 1997). Gender also reveals different entitlements to food. These entitlements may differ both in the type and quantity of food eaten (O'Doherty Jensen & Holm, 1999). Biologically, men and women have different caloric and nutritional needs, but certain foods and their portions may be associated with cultural ideas of masculinity or femininity. In Western culture the consumption of red meat is linked with masculinity, as meat is associated with strength, power, and virility (O'Doherty Jensen & Holm, 1999). Men are thought to need more meat, especially red meat. Men in Western culture are also entitled to greater quantities of food, and women are expected to practice maternal altruism, denying themselves food if there is not enough to go around to their children or male partners (Caplan, 1997). Though these gendered patterns in food consumption are observed in modern societies, they have long-established historical precedents and similarly reflect attitudes about food and gender in the past.

Historical sources indicate regimens of control and supervision for Roman women, which extended into their diet (Garnsey, 1999). Medical writings suggested exercising control over the diet of women for physiological and moral purposes;

women's diets were initially overseen by their fathers, then later by their husbands (Gardner, 1993; Parker, 1998). Roman medical practices were based on the theory of the four humours, and dietetics was seen as one way to keep these humours balanced and maintain health in antiquity. With humoural theory, it was believed that a woman's body was colder and wetter than that of a man, so cold or wet foods (e.g. fish or seafood) were to be avoided to keep the humours balanced (Garnsey, 1999). Hot and dry foods were recommended, meaning women were advised to eat a diet consisting more of grains and land-based, non-fatty proteins (Garnsey, 1999; Prowse, 2011).

These dietary restrictions not only limited the types of foods that women could eat, but their quantity as well. In patriarchal societies such as the Roman Empire, women were given less food resources than men (Garnsey, 1999). Additionally, many of these medical treatises linked dietary restrictions with chastity; controlling the body and its desires was a way to ensure a woman's virginity prior to marriage (Alberici & Harlow, 2007). Diet was a way to control women's sexuality throughout marriage as well (Harlow & Laurence, 2002; Parker, 1998). Women were perceived to be incapable of controlling their gluttony or sexual desires, and depriving them of that autonomy was a way for men to preserve the food stores and honour of the household (Harlow & Laurence, 2002; Parker, 1998).

The allocation of food in the Roman household was favoured towards men as a result of ideas held about needs, status, and power (Garnsey, 1999). Men were seen as active producers of the household, whereas women's roles were primarily domestic

duties (Knapp, 2011; Scheidel, 1996). Because such importance was placed on the male producer, men were thought to have greater food needs and they had greater access to food resources. Though social sanctions legitimized greater access to food resources for men, the food that men ate differed based on their position in society. Poor or ordinary Roman men ate mainly cereal porridge, olive oil, legumes, pulses and cheap wine (Broekaert & Zuiderhoek, 2012), whereas other food items were considered luxuries. In comparison, the Roman military diet had both more variety in foods and nutrients than the common Roman diet (Knapp, 2011). Soldiers mainly ate unground wheat, vegetables, pulses, fruits and cheese. Fish and meat were occasionally eaten, with meat coming from both domesticated and wild animals while on military campaigns (Knapp, 2011). Wine was a staple drink for soldiers, and their food was often salted to keep it preserved. Literary and historical sources indicate gendered differences in diet between Roman men and women, but additional factors also shaped the foods that each gender ate.

2.3.2 Diet over the Roman life course

As age is a dynamic process over an individual's life course, so too are the foods that are eaten. A life course perspective considers connections between events in the lifetime of individuals, within the lived social and historical context (Giele & Elder, 1998). Diet varies throughout the life course due to both biological and cultural factors, as basic nutritional needs also change with age. Diet may change throughout one's lifetime due to cultural customs, beliefs about food and health, or personal preferences. During

childhood, parental influence on diet is strong, and personal preferences do not factor into diet as strongly until later in life (Mikkilä, Räsänen, Raitakari, Pietinen, & Viikari, 2004). Behaviours surrounding diet are learned early in life, and may persist into adulthood or change with age and experience.

Bioarchaeological research into age draws upon a tripartite model of physiological age, chronological age, and social age. Physiological age is the physical aging of the body, as an individual matures, grows, and develops (Sofaer, 2011). Chronological age is the amount of time that has passed since the birth of an individual, and is typically measured in years or months (Sofaer, 2011). Bioarchaeology uses physiological age from growth, development, or degenerative changes to the skeleton to estimate the chronological age of an individual, as physical changes to the skeleton happen at relatively consistent years of age. Translating physiological age into chronological age facilitates the sorting of individuals into age groups for comparison.

Social age refers to the age-appropriate attitudes and behaviours that are constructed by and particular to a culture (Sofaer, 2011). Romans recognized several life stages associated with expected behaviours or biological changes. Infancy (*infantia*) ranged from birth to seven years of age, during which the transitional feeding and weaning of infants took place (Prowse, 2011). Childhood (*pueritia*) began with the start of formal education, or biologically with the loss of deciduous dentition (Dixon, 1988; Rawson, 2003). Adolescence (*adulescentia*) was a transitional stage when an individual was still not considered fully adult, though both men and women could get married and

have children; this lasted from approximately 14 to 30 years of age (Harlow & Laurence, 2002). Adulthood was divided into three stages; youth (*juventus*), lasting approximately from age 30 to 45 years; adulthood (*seniores*) from 45-60 years; and lastly old age (*senectus*) from 60 years and beyond (Harlow & Laurence, 2002). These transitions were based on Roman ideas of the male life course, involving education, military training, public life, and roles in the senate. The life course for Roman females was defined by reproductive status, such as menarche, marriage, motherhood, and declining fertility with age and menopause.

Diet varied for Romans throughout their life course. During infancy, Roman newborns were fed breast milk and then weaned onto solid foods. Upper class women would have had wet nurses to feed their babies for them, whereas lower class women may not have had this luxury (Dixon, 1988; Harlow & Laurence, 2002). Historical, skeletal, and archaeological data suggest weaning occurred around one year of age with the introduction of cereal-based foods (Prowse, 2011). During weaning transitions in infancy, most of the diet was composed of semi-liquid cereals as recommended by medical writers such as Soranus and Galen (Garnsey, 1999; Harlow & Laurence, 2002). Roman weaning foods included bread softened with milk, honey, or wine, as well as porridge, eggs, or even vegetables and meat for wealthier families (Garnsey, 1999).

Following weaning, children took on a similar diet to that of women. Children were perceived to be weak and with similar humours to women, therefore their diets were similar as well (Prowse, 2011). Between the ages of 5 and 7 years Roman children

began to assume new roles, relationships, and chores that were often differentiated based on sex (Rawson, 2003). Social distinctions between children at this age could also extend to their diet; as children take on new roles, they could also take on new eating behaviours. There is some discussion over the extent of gender-based preferential treatment among Roman children; it is possible that male children could have received preferential food allocations, though female children were still valued in Roman society (Rawson, 2003). Skeletal evidence unfortunately can do little to alleviate this question, as sex-specific skeletal markers often do not emerge until puberty.

Aging was considered by Roman physicians to be caused by the cooling and drying of the body (Cokayne, 2003). Dietetics, in accordance with humoural theory, recommended various approaches towards food in old age. First was a moderation in eating and drinking to keep healthy; in old age one could eat frequently, but sparingly (Cokayne, 2003). Moist and warm foods were also recommended for the elderly to balance their humours (Cokayne, 2003). In addition, the food had to be easy to digest, as old age was associated with weakness and fragility. Foods to avoid for older men included starches, cheese, hard-boiled eggs, snails, onions, beans or pork (Cokayne, 2003). Fowl was a preferred meat over venison, goat, or beef for older men as it was easier to digest; wine was also recommended in old age because it was thought to have warming abilities (Cokayne, 2003). There is little in the medical literature from antiquity about older women, though their diets may have changed based on health regimens for aging and with different social roles (Prowse, 2011).

2.3.3 Status and diet in Roman Society

Gender and age do not independently affect diet, but intersect to influence the availability or choices of food for an individual. The same can be said of status, particularly in a stratified society like the Roman Empire. Socioeconomic status classifies individuals into groups with the same status, prestige, power, knowledge and resources (Galobardes, Morabia, & Bernstein, 2001). Using a model of status based on wealth or material gain, higher social status may result in greater access to foods, more nutritious foods, or higher quality foods. Status differences in food are not only about quantity and quality, but also taste and variety.

Status in the Roman Empire is a complicated part of identity. People had differing levels of power based on their gender, age, wealth, occupation and the prestige associated with particular roles in society. As previously discussed, men had greater status in Roman society, but an adult man would have more status than an adolescent man. In Roman society, status was also recognized through legal distinctions of freeborn, freedman, and slave. A freeborn Roman could be anyone from elite nobles, poor beggars, and the ordinary citizens falling in between. An individual could become a slave through birth, judicial punishment, voluntary enslavement, or by being sold into slavery (Knapp, 2011). The living and working conditions of slaves depended on their owners, but slaves were often denied equal shares in food and drink. Similar to women, slaves they were considered to be gluttonous and libidinous and therefore kept in submissive roles and fed restricted diets (Parker, 1998).

Slavery was not necessarily a permanent status, as there were possible ways in which people could be freed. Freedmen became so through manumission by their owners or by proving improper enslavement before a magistrate (Knapp, 2011). Though freedmen could then accumulate their own wealth, they were generally looked down upon and treated with hostility by freeborn elites (Knapp, 2011). A freedman's lifestyle could mirror that of a freeborn Roman, with the only distinction being legal status. Similarities between a freeborn and a freedman's life could also exist for their diets. Depending on the wealth of the freedman, his or her diet could reflect that of ordinary or elite citizens; the difference would be in the prestige associated with status.

These distinctions in social and legal status are difficult to observe based solely on the archaeological record. Burial treatments including burial structures or grave goods can indicate wealth or an individual's access to resources (Robb, Bigazzi, Lazzarini, Scarsini, & Sonego, 2001), but status in the Roman Empire was based on more than material wealth. In addition, it is the mourners and not the deceased who deposited grave goods or built grave structures. How the survivors chose to represent an individual is what is preserved in the archaeological record, which may not be the same as how that individual was viewed in life. Though status differences were very much a part of Roman life, detecting differences in status from archaeological samples is challenging.

Diet is influenced by aspects of one's identity such as age, sex, and status. When endeavouring to study these factors archaeologically, complications arise as these pieces of information may not be observable in an archaeological context. Gender is culturally

constructed and personally identified, which is difficult to identify solely from archaeological materials and may require additional information from ethnographic or historic sources (Hollimon, 2006). Sex can be observed from markers on the skeleton, but must be done so knowing that it is not a direct proxy for gender. Age can also be estimated from biological changes of growth, development, and degeneration of the skeleton, but needs to be understood within the social ages of a particular culture (Sofaer, 2011). Archaeological observations of status are based on funerary representations of an individual, which may not overlap with their status when alive. Despite methodological limitations of assessing identity from the archaeological record, investigations into past dietary variability can provide meaningful information when read within the cultural context of the time.

2.4 Vagnari During the Imperial Roman Period

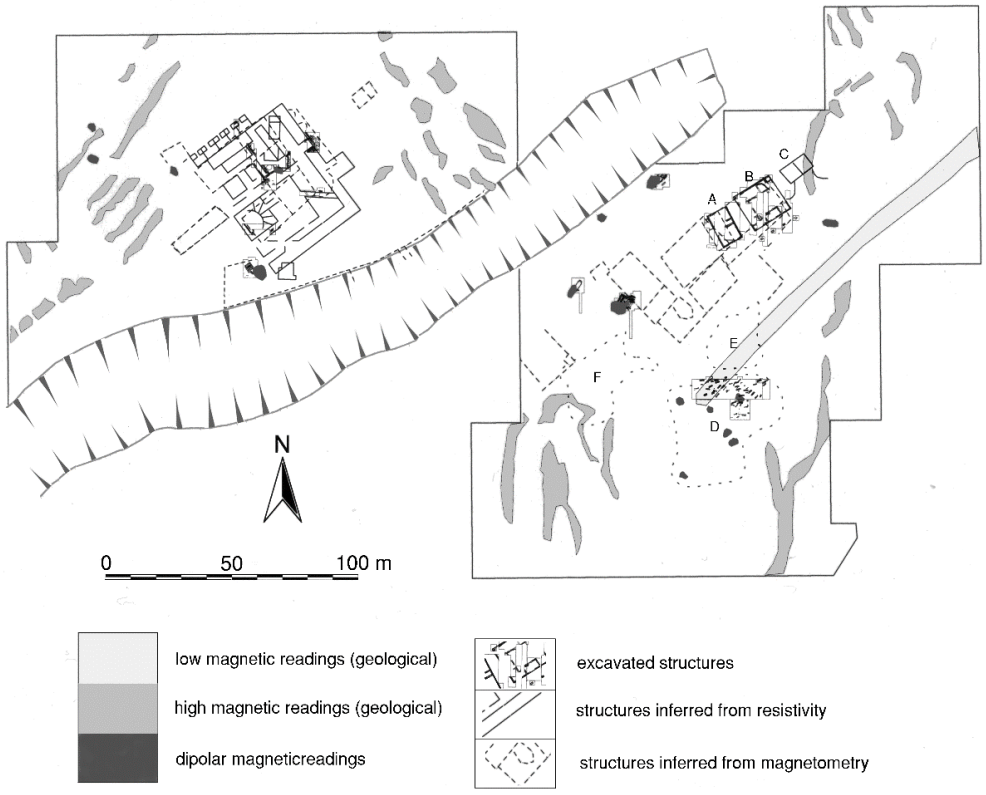
2.4.1 Research at the Vagnari estate

Vagnari was an Imperial Roman estate that lies between the Roman regions of *Apulia et Calabria* to the East, and *Lucania et Bruttii* to the West (Figure 2.1) (Small, 2007). Located 12 km west of the modern city Gravina in Puglia, the site of Vagnari stretches across 3.5 hectares and is divided in two sections by a ravine (Prowse & Small, 2009) (Figure 2.2). The site was situated along a past communications route, the Via Appia, allowing for trade and the movement of people and products from the capital in Rome to the Mediterranean coasts (Small, 2007).

Figure 2.1 - Map of Italy Showing the Location of Vagnari. Originally published in Small (2007:124), with permission to reprint from Alastair Small.

Archaeological excavation has uncovered a village (*vicus*) and a cemetery at the site. Presumably, these features are places where the workforce of Vagnari lived, worked, and were buried. Occupation at Vagnari was from the 4th century BC to the 6th century AD, with the earliest buildings located on the North side of the ravine and newer buildings on the South side of the ravine (Prowse & Small, 2009). The main phase of occupation of the site is from the 1st century to the 4th century AD.

Figure 2.2 - Site layout at Vagnari. The cemetery is located between areas D and E. Originally published in Strutt, Hunt, and Small (2011:83)*, with permission to reprint from Alastair Small.*



The urban and rural dynamic of the Roman Empire was much of cities as centres of consumption, with hinterlands and rural labour efforts supplying the demand of urban dwellers (Kehoe, 2006). Approximately 10% of the population of the Mediterranean basin lived in cities during antiquity, and this percentage is likely much greater for Italy (Garnsey, 1999). Most people living in cities did not have any direct access to land; only wealthy landowners did. Concentrations of people and demands for resources in cities created a system of agricultural production that went beyond subsistence farming for the rural peasant. Estates were widespread across the Roman

Empire, including Italy and the provinces, and were a means for maintaining the wealth of both the state and local elite. These estates produced cash crops, namely wine or olives, for supply to urban centres using a labour force mainly composed of slaves (Kehoe, 2006). Agriculture was the main investment of the wealthy, and was seen as a relatively stable, long term source of income that brought prestige (Kehoe, 2006).

During the 1st and 2nd centuries AD, a prevailing pattern was the decline of rural sites, particularly in areas along the Roman coast with links to the city of Rome (Patterson, 2006). Perhaps as a result of geographic, population, and economic factors, the villa system of agriculture transformed in the 1st and 2nd centuries AD to fewer rural sites with larger estates cultivated less intensively (Kehoe, 2006; Patterson, 2006). At Vagnari, the settlement grew in size during the 1st century AD (C. Small, 2011). Pottery sherds at the site indicate that a new population was brought in to expand the settlement during the early Principate, and that occupation continued through the 2nd to late 5th centuries AD (C. Small, 2011). The building patterns at the site also reflect expansion and growth. During the 1st century AD, one large dwelling was present on the northern side of the ravine, and new buildings were constructed on the South side of the ravine during the 2nd to 3rd centuries AD (C. Small, 2011). Vagnari was not a luxury site, although a few marble fragments were found, indicating that some elegant rooms or features were built (C. Small, 2011). Vagnari was mainly an industrial site with a fairly dense population of workers, presumably of lower status, though it may have been inhabited by wealthier Romans as well (C. Small, 2011).

The land and space at Vagnari were used for many different purposes. The plateaus around the site were used for cereal cultivation since the soil could be easily ploughed (Small, 2007). Charred plant material found around hearths at the *vicus* of Vagnari indicates that durum wheat, a drought-resistant plant, was grown at the estate (Carroll, 2013). Much of the land around the site was probably forest and grazing patches (Small, 2007). The *traturri* (drove roads) that led into Vagnari allowed for sheep and goats to be driven into different seasonal pastures, meaning large numbers of animals could be raised near the site (A. M. Small, 2011). Herding and shearing sheep, as well as making cheese were part of the rural, animal-based economic activities at Vagnari (A. M. Small, 2011). Goats and cattle were kept at the site mainly for their secondary products, whereas pigs were raised mainly as a food source and deer from the nearby forest were occasionally hunted for their meat (A. Small, 2011). These trends indicate that C_3 plants and terrestrial protein contributed significantly to the diet at Vagnari, which can be verified with isotopic analysis.

Additional activities at the site included metalworking of iron, bronze, and lead. Lead pieces at the site were also recycled and reworked into new objects (Carroll, 2013). The presence of iron and glass slag suggests both metalworking and glass manufacturing took place at Vagnari (Carroll, 2013). Tile making is evident at Vagnari due to the recovery of stamped tiles and multiple tile kilns (3-4) at the site (Small, 2007). Multiple industries, such as agriculture, animal husbandry, metal-working, and tile making were carried out by the people at Vagnari.

2.4.2 Research at the Vagnari cemetery

The cemetery of Vagnari, located on the South side of the ravine, has undergone excavations since 2002. Presently, 108 burials have been excavated. The burials at Vagnari date from the 1st to 3rd centuries AD, with a few burials extending into the 4th century AD (Prowse, 2013). Detailed descriptions of the burial types and chronology of the cemetery are presented in Section 4.1.2.

Investigations of the burial types and grave goods of the people interred at Vagnari give some insight into what their lives were like. In the absence of epitaphs at Vagnari, grave goods provide information about individual variation in burial treatment, which could have links to variation in diet (Brent & Prowse, 2014). Almost all of the burials at Vagnari (approximately 91%) contained grave goods, and a variety of items were included in the burials, such as; ceramic vessels, lamps, coins, or items of personal dress (Brent & Prowse, 2014). Brent and Prowse (2014) note that individuals who were buried with a greater number of grave goods tended also to have higher quality items (e.g. luxury goods), while those who were buried with fewer grave goods had lesser quality items.

Gendered differences are apparent in grave good assemblages, with adult males buried with more items, luxury items (e.g. bronze rings and bronze vessels), and objects that could be indicative of occupation, such as agricultural tools and spear heads (Brent & Prowse, 2014). In comparison, the lower number of grave goods buried with adult females indicate a sex-based hierarchy with regards to burial practices, and perhaps in

life (Brent, 2012). There also appears to be an age-related pattern to the type and quantity of grave goods found in the burials. Generally, the average number of grave goods buried with an individual increased with age, and infants and children tended to be buried with items of personal adornment, such as bracelets or earrings, more often than adults (Brent & Prowse, 2014). These patterns indicate that both age and sex factored into the items that were buried with an individual.

Grave good assemblages at Vagnari overlap with Roman patriarchal ideas of social hierarchy (Brent & Prowse, 2014). These age and sex-based patterns of grave good assemblages discussed by Brent and Prowse (2014) may also be present with regards to diet at Vagnari. Adult males were buried with larger grave good assemblages and with more luxury items, so they may have had greater access to a variety of foods, including luxury foods. Adult females may have comparatively lesser access to different foods or luxury foods, as their grave good assemblages tended to have fewer items and fewer luxury goods than adult males. Grave goods tended to increase with the age of the individual, so it is possible that the people who lived at Vagnari had access to different foods as they grew older. Roman status such as freeborn, freedman, and slave cannot be distinguished from grave goods, but different burial treatments can be used to understand relative social distinctions within the cemetery sample at Vagnari.

Research conducted on the skeletal sample at Vagnari has included dental pathology, childhood stress, and trauma to understand lifestyles of the individuals buried at the site (Prowse, Nause, & Ledger, 2014). Dental pathology at Vagnari

indicates age and sex-based variation, suggesting differences in diet or behaviour between these groups. Caries and antemortem tooth loss (AMTL) were more common in young adult and older adult males than females from the same age groups, suggesting sex-based differences in adult diet at Vagnari (Prowse et al., 2014). Adult males were consuming more cariogenic foods than adult women at Vagnari, which could translate to isotopic differences in diet.

In comparison with other skeletal samples from Roman Italy, the oral health of Vagnari is similar to urban Romans at Isola Sacra and Pompeii (Prowse et al., 2014). With the economic dynamic of Roman rural areas as centres of production, and urban areas as centres of consumption, one might anticipate to see differences in diet and subsequently oral health between these locales. The results of this oral health comparison between Vagnari and urban locales could indicate a few possibilities; 1) that the diets at these locations were very similar in composition, or 2) that the diets had the same cariogenic properties, despite being composed of foods that were socially distinct. Isotopic analysis of diet at Vagnari will help to clarify the types of food eaten at the site, and further explore the degree of dietary variability between urban and rural settlements of the Roman Empire.

Linear enamel hypoplasia (LEH) is an indicator of childhood stress, and can provide detail about the conditions of the early years of life at Vagnari. Prowse and colleagues (2014) found no sex-based differences in prevalence of LEH, meaning men and women were equally exposed to stress as children. Both the percent of teeth

affected by LEH and the average defects per tooth varied significantly by age category, with younger individuals stressed repeatedly or chronically based on the average number of defects per tooth and the fact that they died at a young age (Prowse et al., 2014). In comparison, older individuals had lower percentages of teeth affected by LEH and lower numbers of defects per tooth, which suggests that individuals who experienced fewer stresses during childhood survived to an older age (Prowse et al., 2014). Childhood was thus a stressful period that could end in fatality, but people were able to survive stressful times into adulthood.

Traumatic injuries to the skeleton at Vagnari reveal some information about the living conditions of the estate workforce. A preliminary study on trauma at the site found that sixty-nine percent (69%) of the individuals studied exhibited one or more injuries, the most common being fractures and Schmorl's nodes, along with other non-descriptive irregular bone formations (Prowse et al., 2014). The location of skeletal injuries varied by sex, with fractures concentrated in the lower limbs for males and thorax region and upper limbs for females (Prowse et al., 2014). The different locations of fractures for males and females suggest gendered division of labour at Vagnari. Roman literary sources also discuss the division of subsistence and economic activities between men and women (Knapp, 2011; Scheidel, 1996). Physical evidence of gendered division of labour further supports differences in the ways men and women were treated in life, which may translate to differences in diet.

The prevalence of traumatic injuries and their location in the skeleton is in accordance with heavy agricultural labour at Vagnari. Archaeological evidence supports that agricultural and manufacturing activities took place at the site. Fractures did not vary with age at death, which Prowse and colleagues (2014) suggested could indicate similar work burdens for different age groups. The work conducted by people living at the site could be similar across age, but differences in age could result in differential access to food resources.

2.4.3 Political-economic context during occupation at Vagnari

Industrial properties such as Vagnari were often owned by the state and subjected to both social and political changes in the empire. The Roman state had the biggest landholdings across the Empire, and could come into possession of new property by donations from senators, defaulting of land when the owners died without an heir, or seizure of property for capital crimes or tax arrears (Kehoe, 2006). Elite Romans also owned their own land and estates. The early Empire saw the cessation of Rome's growth as a consumer centre, spurring classes of elite landowners to move outwards to the western and eastern Italian provinces (Kehoe, 2006). The predominant system of agriculture changed in the late 1st and 2nd centuries AD, potentially causing a crisis for elite landowners, but the extent of these financial crises is debated (Kehoe, 2006).

The later empire is often considered a period of instability. With the 3rd century AD and onwards, taxation rose, trade and agriculture were reduced, lands were abandoned, and overall the Roman state weakened (Garnsey, 1999). These patterns are

reflected at Vagnari, with the gradual decline of activity at the site and its eventual abandonment in the 6th century AD. Many changes were occurring throughout the Roman Empire during the main phase of occupation at Vagnari, which could indicate changes in diet at the site over time.

2.5 Conclusion

Historical and archaeological records both lend valuable information to the understanding of Roman diet. Historical records shed light on the culturally shared ideas and attitudes about food held by people, but the biases and perspectives present in these accounts of the past need to be recognized. Historical sources speak about the foods available to be eaten, and to how food played a role in society as related to power, health, and sexuality. Food also relates to Roman identity, as what was eaten varied based on one's gender, age, and status in society. Archaeological traces of diet, such as in human bones and teeth, allow for the identification of the types of foods that were eaten by individuals.

Industrial estates were adapted as main part of the agricultural economy in Italy during the 1st to 2nd centuries AD. Vagnari, one such estate, had evidence of industries such as agriculture, tile making, and metallurgy at the site, and was likely a fully independent functioning village. Research conducted thus far on the cemetery of Vagnari has shown variability in grave goods possibly suggesting social distinctions during life, gendered division of labour based on skeletal evidence, stressful events in childhood contributing to mortality or survivorship, and dietary variation in relation to

age and sex based on dental evidence. These patterns suggest possible isotopic variation in diet based on sex, age, and status as based on grave good assemblages. The historical period during which Vagnari was occupied was one of change and transformation. These effects are likely to play out on diet at the local site level, both in dietary variability and food accessibility.

Much of what is known of Vagnari aligns with information from Roman history about rural estates, power relationships, and labour. Grave good assemblages indicate differences burial treatments at the site (which could be related to individual variation in life), and dental pathology indicates dietary variability between the workers. The diet of the people at Vagnari will now be further explored using stable isotope techniques.

3 Stable Isotope Analysis

3.1 Introduction: Basic Concepts of Stable Isotopes

Isotopic analyses of human bone can be utilized in the study of diet in the past. Stable isotopes are atoms of the same element with the same number of protons, but differing numbers of neutrons and different atomic masses. The number of heavier or lighter isotopes per element varies, and some isotopes are more abundant in nature than others. Stable isotopes also do not decay into other elements like unstable radioactive isotopes. For example, the stable isotopes of carbon are the lighter, more common isotope ^{12}C (6 protons and 6 neutrons) and the rarer, heavier isotope ^{13}C (6 protons and 7 neutrons), whereas the radioactive isotope of carbon is ^{14}C (6 protons and 8 neutrons).

Heavier and lighter isotopes will subsequently have different physical and chemical properties related to their different masses. These different properties may impact chemical reactions and alter physical phenomena, in what is called an 'isotope effect' (Katzenberg, 2008). Heavier isotopes react more slowly than the lighter isotopes of an element, which leads to the separation, or fractionation, of isotopes during physical or biochemical processes (Lee-Thorp, 2008). Fractionation allows for the pathways of isotopes to be traced through a series of reactions, such as the changes from isotopic ratios at the environmental baseline to their incorporation into the tissues of organisms.

As food is consumed it is broken down by the body into its constituent elements, absorbed by the body, and eventually incorporated into human tissues such as bones and teeth. The stable isotope values preserved in bone reflect long term diet, and can be used to indicate the types of food eaten by an individual over a period of years, depending on the bone turnover rate. Stable isotope analysis is often implemented in bioarchaeological research to understand diet of people in the past. This chapter will explore the utility of stable isotope analysis in bioarchaeological research endeavours, namely in studies of Roman diet during the Imperial period (1st – 4th centuries AD).

3.2 Applications of Carbon and Nitrogen Isotopes in the Study of Diet

Chemical reactions and isotope effects of nitrogen and carbon are of interest to diet due to their natural abundance in food webs (Lee-Thorp, 2008). Carbon and nitrogen are important biochemical components of organisms that eat and are eaten. Additionally, the global cycles of carbon and nitrogen in the environment are scientifically well understood, allowing fractionation to be traced. When discussing stable isotope values, they are represented using the delta notation, $\delta^{13}C$ and $\delta^{15}N$. Stable isotope ratios are presented as delta values using Equation 3.1 and Equation 3.2 (DeNiro & Epstein, 1981).

Equation 3.1 – Formula for delta notation of carbon isotopes.

$$\delta\,^{13}C = \left[\frac{\frac{^{13}C}{^{12}C}\ sample}{\frac{^{13}C}{^{12}C}\ standard} - 1 \right] * \ 1000‰$$

Equation 3.2 - Formula for delta notation of nitrogen isotopes.

$$\delta\,^{15}N = \left[\frac{\frac{^{15}N}{^{14}N}\,sample}{\frac{^{15}N}{^{14}N}\,standard} - 1 \right] * \; 1000‰$$

Ratios of the heavier stable isotopes of nitrogen and carbon are compared with the lighter isotope and referenced to international standards used by all laboratories conducting stable isotope analyses. The standard for $\delta^{13}C$ measurements is Vienna Peedee belemnite carbonate (VPDB), and the standard for $\delta^{15}N$ measurements is Ambient Inhalable Reservoir (AIR).

3.2.1 Carbon

Carbon is abundant in living things, especially the human body and the foods relied on by humans for energy. Its stable isotopes, ^{13}C and ^{12}C, have important implications for understanding past diet. In controlled feeding studies of rodents over a 6-week period, DeNiro and Epstein (1978) demonstrated that the isotopic composition of an animal's diet could be estimated from the $\delta^{13}C$ values of its tissues, with the consideration of fractionation from the incorporation of dietary carbon into the animal. Knowledge of the relationship between an organism's tissues and their stable isotope ratios was later adopted to research diet in archaeological contexts.

Some of the first major applications of carbon isotopes to archaeological investigations of diet were studies of the spread of maize agriculture in North America (e.g., van der Merwe & Vogel, 1978; Vogel & van der Merwe, 1977). Terrestrial plants

vary isotopically due to different photosynthetic pathways, which result in differences in the number of carbon atoms fixed by the plants from atmospheric CO_2 (Vogel & van der Merwe, 1977). The two pathways are the Calvin (or C_3) and the Hatch-Slack (or C_4) pathways, which fix three and four carbon atoms respectively from the atmosphere. Most native plants that grow in temperate zones are typically C_3 plants, whereas C_4 plants thrive in hot, arid environments. The $\delta^{13}C$ values of C_3 plants range between -22‰ to -38‰, but average around -26‰ (Katzenberg et al., 1995; Vogel & van der Merwe, 1977). Examples of C_3 plants include; wheat, barley, oats, rice and root starches such as potato, manioc, and yam. The $\delta^{13}C$ values of C_4 plants range from -9‰ to -16‰, and average around -12.5‰ (Vogel & van der Merwe, 1977). Types of C_4 plants include; maize, millet, sorghum and cane sugar.

Isotopes of carbon can also be used to indicate the proportion of marine and terrestrial food sources in the diet. Marine primary producers draw their carbon from dissolved bicarbonate in the ocean, resulting in ^{13}C-enriched tissues over terrestrial C_3 plants and average $\delta^{13}C$ values of -20‰ (Chisholm et al., 1982; Katzenberg, 2008; Lee-Thorp, 2008). Dissolved bicarbonate has a $\delta^{13}C$ value of 0‰, and atmospheric CO_2 has a $\delta^{13}C$ value of -7‰. The average 7‰ difference in $\delta^{13}C$ values is reflected in mammals, including humans (Chisholm et al., 1982). The isotopic variation of $\delta^{13}C$ from marine to terrestrial producers allows for the consumption of land and water-based foods to be detected.

3.2.2 Nitrogen

Most of the nitrogen found in the environment exists in the atmosphere and in the earth's oceans. Atmospheric nitrogen has a $\delta^{15}N$ value of 0‰ (Katzenberg, 2008). Certain plants such as legumes have a symbiotic relationship with nitrogen-fixing bacteria and have lower $\delta^{15}N$ values as they are closer in value to atmospheric nitrogen. Plants that do not have nitrogen-fixing bacteria rely on decomposed organic matter as a source of nitrogen, and have higher $\delta^{15}N$ values as they are enriched in ^{15}N. Nitrogen ($\delta^{15}N$) isotopes vary based on trophic level, and have been applied to examine the trophic level of foods consumed (Schoeninger & DeNiro, 1984; Schoeninger, 1985).The $\delta^{15}N$ values of an organism are typically 3‰ higher than the $\delta^{15}N$ of their diet, with successive enrichment effects for higher trophic-level organisms (DeNiro & Epstein, 1981). A herbivore will have $\delta^{15}N$ values 3‰ greater than the plants they eat, and a carnivore will have $\delta^{15}N$ values 3‰ greater than the herbivores they eat (Schoeninger, 1985). Humans are best studied relative to other organisms within their environment to determine the trophic level of their diet.

Nitrogen isotopes can also be used to distinguish between freshwater or marine food sources. Marine fish will have higher trophic levels and distinct $\delta^{13}C$ values from terrestrial-based foods (Lee-Thorp, 2008; Schoeninger & DeNiro, 1984), resulting in distinct $\delta^{13}C$ and $\delta^{15}N$ values of marine food consumers when compared to consumers of terrestrial foods. Previous assumptions were that freshwater fish were isotopically similar to terrestrial C_3-eating animals, when in fact freshwater fish exhibit a trophic

level effect; slightly higher $\delta^{15}N$ and $\delta^{13}C$ values are found in carnivorous fish (Katzenberg, 1989, 2008). Freshwater fish also have varying $\delta^{13}C$ values (-14.2‰ to -24.6‰) based on their habitat; shallow water inhabitants have higher $\delta^{13}C$ values, while those in deeper waters have lower $\delta^{13}C$ values (Katzenberg, 1989).

Nitrogen isotopes can indicate breastfeeding and weaning in an organism. Infants are enriched in ^{15}N from consuming breastmilk, and exhibit a trophic level effect (+3‰) over the $\delta^{15}N$ values of their mothers. The first applications of stable isotope analysis to breastfeeding and weaning studies were conducted by Fogel and colleagues (1989). By analyzing fingernails from breastfeeding infants and mothers, Fogel and colleagues demonstrated increased $\delta^{15}N$ values while the infant breastfed, decreased $\delta^{15}N$ infant values with the onset of weaning, and similar infant and mother $\delta^{15}N$ values shortly after the cessation of weaning (1989). Similar patterns in $\delta^{15}N$ values due to breastfeeding and weaning can also be detected in skeletal samples, though the timing is less precise because bone has a longer turnover rate (and therefore longer time to incorporate nitrogen isotopes) than fingernails (Fuller, Richards, & Mays, 2003). Rib samples from infants are typically sampled for isotopic work, as they have a shorter bone turnover rate.

Since the initial application of nitrogen isotopes to assess breastfeeding and weaning transitions, this approach has been utilized in bioarchaeological studies of infant feeding and weaning in the past. Carbon isotopes ($\delta^{13}C$) also demonstrate a slight trophic level effect (1‰) from breastfeeding and have been included in studies of

weaning (Clayton, Sealy, & Pfeiffer, 2006; Fuller, Fuller, Harris, & Hedges, 2006; Fuller et al., 2003; Richards, Mays, & Fuller, 2002; Wright & Schwarcz, 1999). Fuller and colleagues (2006) found infant fingernails to be enriched in ^{13}C by 1‰ when exclusively breastfed, and with the introduction of solid foods to the diet fingernail $\delta^{13}C$ values approached maternal $\delta^{13}C$ values. With the adoption of solid foods, $\delta^{13}C$ values become more negative and approach maternal isotopic values in other tissues such as bones and teeth.

The ratios of $\delta^{15}N$ may also be influenced by water or protein stress. Animal $\delta^{15}N$ values vary with the rainfall of a region, and in dry, arid environments animals are elevated in ^{15}N to a degree where these values cannot be taken as indicators of marine or terrestrial based diets (Sealy, van der Merwe, Lee-Thorp, & Lanham, 1987). Animals living in water-stressed environments retain water but excrete more urea, leaving more ^{15}N in the body (Katzenberg, 2008). Water stress allows for ^{15}N to accumulate in the body and enrich tissues over time. Consumption of water stressed animals also results in higher $\delta^{15}N$ values than would be expected from dietary enrichment, and could be mistaken for the consumption of marine foods (Katzenberg, 2008).

With protein stress, insufficient protein intake results in the breakdown of tissues already rich in ^{15}N. New protein is synthesized from the breakdown and recycling of old protein, ^{14}N from protein is excreted, and ^{15}N is enriched by being kept in these recycled tissues (Katzenberg, 2008). Enrichment in ^{15}N has been observed in humans with new bone deposition from osteomyelitis (Katzenberg & Lovell, 1999) and

osteoporosis (White & Armelagos, 1997). D'Ortenzio and colleagues (2015) demonstrated that physiological stress from chronic illnesses, infections, or bone fractures can elevate ^{15}N values in hair, whereas stress from pregnancy reduces $\delta^{15}N$ values. The effects of stress are important to keep in mind when interpreting elevated $\delta^{15}N$ values, as they may be due to environmental or health-related factors rather than solely the trophic level effect on diet.

3.3 Components of bone used for isotopic analysis

3.3.1 Collagen

Bone samples for stable isotope analysis are processed to extract collagen, a structural protein of bone. Bone is composed of approximately 70% inorganic and 30% organic components. Structurally, the organic matrix of bone is primarily collagen (85-90%), but also includes non-collagenous proteins, proteoglycans and lipids (Katzenberg, 2008). Collagen is a choice tissue for isotopic studies of diet for numerous reasons. First, its structure contains calcium phosphate crystals, which allow it to preserve well in archaeological contexts (Katzenberg, 2008; Lee-Thorp, 2008). Second, it is composed of both essential and nonessential amino acids. Amino acids are synthesized from consumed proteins, or from the breakdown of products in the body (Krueger & Sullivan, 1984), meaning the proteins from foods and their isotopic signatures become incorporated into bone collagen. Collagen is also approximately 35% carbon and 11-16% nitrogen (van Klinken, 1999), which adds to the likelihood of successfully obtaining

isotope ratios from bone. Since collagen is a structural protein, its isotopic values primarily represent the protein content of the diet.

3.3.2 Carbonate

Bone carbonate is the mineral portion of bone, and is another source of carbon isotopes for studies of diet. Bone mineral is composed of apatite crystals, $Ca_{10}(PO_4)_6$, but other ions such as carbonate (CO_3) may substitute for its component phosphate (PO_4) ions. Unlike collagen, bone carbonate reflects the entire diet of an organism (Ambrose & Norr, 1993; Krueger & Sullivan, 1984; Tieszen & Fagre, 1993). Foods consist of carbohydrates, lipids, and proteins, and these dietary constituents are present in dissolved bicarbonate in blood after being eaten (Katzenberg, 2008; Tieszen & Fagre, 1993). Dissolved bicarbonate in blood is used to form bone carbonate, thus the isotopic signatures of carbohydrates, lipids, and proteins (i.e., total diet) are reflected in bone carbonate.

A limitation of using bone carbonate is that it is more susceptible to diagenesis than collagen. Bone carbonate may be altered in its burial environment by an exchange between components of bone mineral and carbonates in the soil (Lee-Thorp, Sealy, & van der Merwe, 1989). Diagenetically altered carbonate may no longer reflect *in vivo* diet, but soil contaminants instead. Preparation methods to remove surface carbonates from bone, described by Krueger and Sullivan (1984) and Lee-Thorp and colleagues (1989), can ensure that the carbonate used for isotopic analysis is endogenous and

reflects *in vivo* dietary values. Researchers have adopted the principle of analyzing both carbonate and collagen for a more complete sense of past diets.

3.3.3 Spacing factors for collagen, carbonate, and total diet

When isotopic ratios are analyzed from both collagen and carbonate in bone, the protein and non-protein components of diet can be discussed. Fractionation from diet to bone collagen or bone carbonate differs for each phase of bone tissue. The fractionation factor of carbon from diet to collagen is approximately +5‰ in large mammals, including humans (van der Merwe, 1982). The offset of bone carbonate relative to diet varies due to body mass and diet physiology, but is suggested to be +12‰ for herbivores, carnivores, and omnivores (Harrison & Katzenberg, 2003; Krueger & Sullivan, 1984; Lee-Thorp et al., 1989).

Differences between the $\delta^{13}C$ ratios of carbonate, collagen, and total diet are represented as $\Delta^{13}C$. Controlled feeding studies of rodents suggested that the offset between diet and carbonate ($\Delta^{13}C_{ap\text{-}diet}$) remained constant, but the offset between diet and collagen ($\Delta^{13}C_{col\text{-}diet}$) varied depending on whether the $\delta^{13}C$ values of dietary protein and energy were the same (Ambrose & Norr, 1993; Tieszen & Fagre, 1993). Ambrose and Norr (1993) also suggested that rodent apatite-collagen spacing ($\Delta^{13}C_{ap\text{-}col}$) will equal 4.4‰ if the $\delta^{13}C$ values of dietary protein and energy are the same, and that $\Delta^{13}C_{ap\text{-}col}$ varies with changes in diet. For diets based on C_4 carbohydrates and C_3 proteins, $\Delta^{13}C_{ap\text{-}col}$ is greater than 4.4‰ (Ambrose et al., 1997). Diets based on C_3 carbohydrates and marine protein will have $\Delta^{13}C_{ap\text{-}col}$ values less than 4.4‰ (Ambrose et al., 1997). These

patterns would be similar among omnivores such as humans, but their $\Delta^{13}C_{ap\text{-}col}$ values would be closer to 7‰ (Krueger & Sullivan, 1984; Lee-Thorp et al., 1989). The differences in spacing between $\Delta^{13}C_{ap\text{-}col}$ can therefore be used to determine whether the protein content is more or less enriched in ^{13}C than the total diet.

3.4 Isotopic Studies of Roman Diet

Many isotopic studies have been conducted on diet in the Roman Empire. These applications have included determining the importance of fish in the diet (e.g., Craig et al., 2013; Keenleyside et al., 2009; Prowse et al., 2004; Rutgers et al., 2009), comparisons of diet between different sites (e.g., Craig et al., 2009; Keenleyside et al., 2009; Killgrove & Tykot, 2013; Rutgers et al., 2009), changes in diet over time (e.g., Keenleyside et al., 2009; Müldner, 2013; Redfern, Hamlin, & Athfield, 2010), diet and mobility (e.g., Chenery et al., 2010), and age, sex, occupation, or status-based variation in diet (e.g., Craig et al., 2009; Crowe et al., 2010; Keenleyside et al., 2009; Müldner, 2013; Prowse et al., 2005). Studies of breastfeeding and weaning have also been conducted over the Roman Empire using stable isotope analysis (e.g., Dupras, Schwarcz, & Fairgrieve, 2001; Fuller et al., 2003; Prowse et al., 2008). Isotopic studies of Roman diet have spanned across the geography of the Empire, including Italy, Britain, Egypt, Tunisia, and Croatia. Studies of diet from Roman Italy, as well as other areas with similar isotopic compositions in environment and diet will be discussed in more length.

3.4.1 Roman Italy

Coastal cities and marine diets

A number of coastal sites of Roman Italy have been studied to explore the prominence of marine foods in the diet, such as Portus Romae, Velia, and Herculaneum. Portus Romae was an important coastal trading hub linked to Rome by the Tiber River, and its inhabitants utilized the necropolis Isola Sacra for a burial ground from the 1st to 3rd centuries AD (Prowse et al., 2004). Prowse and colleagues (2004) studied diet from those buried at Isola Sacra and compared their diet to people from the ANAS cemetery, a small inland rural necropolis.

Prowse and colleagues (2004) interpreted Isola Sacra $\delta^{13}C$ (-17.8‰ to -19.7‰), and $\delta^{15}N$ (7.5‰ to 14.4‰) values as evidence of marine fish consumption for the people at Portus Romae. Results from apatite values ($\delta^{13}C_{ap}$) suggested that the main source of carbon in the diet came from terrestrial foods, with some contributions of marine foods (Prowse et al., 2004). The ANAS $\delta^{13}C$ (-20.0‰ to -18.9‰) and $\delta^{15}N$ (6.9% to 11.3‰) values indicated a more heavily terrestrial-based diet (Prowse et al., 2004). The diets of those buried at Isola Sacra and ANAS were set apart by differences in their consumption of fish, though both relied on terrestrial foods as main components of their diets.

Prowse and colleagues (2005) also investigated age and sex-based variation in diet at Isola Sacra using isotopic ratios from bone collagen and carbonate. Small differences were observed between the diets of men and women when values from collagen were considered. With age and sex considered, $\delta^{15}N$ values were higher for

males than females in all age categories, though $\delta^{15}N$ increased with age for females (Prowse et al., 2005). Age more so than sex-based variation was present at Isola Sacra, with increasing meat and fish consumption as individuals grew older. Males had greater consumption of marine fish than females in all age categories, but the isotopic data suggest that females consumed more marine foods at older ages (Prowse et al., 2005).

Craig and colleagues (2009) studied diet at Velia, another coastal city site located approximately 400 km south of Rome. Velia was a port centre South of Naples with some agricultural economy, and a necropolis dating from the 1st to 2nd centuries AD. The similarities between environment and contemporaneous dates of occupation allow for comparisons with the cemetery sample of Isola Sacra. Isotopic results from Velia collagen had a tight range of $\delta^{13}C$ values from -20.0‰ to -18.7‰, but broader $\delta^{15}N$ values ranging from 6.4‰ to 14.1‰ (Craig et al., 2009). Two dietary groups were exhibited at Velia; one consisted of individuals with diets high in cereal and legume consumption (C_3 and C_4 plants), while the second consisted of individuals (mainly males) who ate more marine fish and a mixture of terrestrial-based C_3 carbohydrates (Craig et al., 2009).

Burial type, grave goods, and age-at-death were not significantly correlated with isotope values at Velia, but significant differences were found between males and females (Craig et al., 2009). Sex-based differences in diet at Velia could relate to broader patterns of occupational access to or cultural restrictions on marine foods. Craig and colleagues (2009) observed that values of both $\delta^{13}C$ and $\delta^{15}N$ were lower at Velia than at

Isola Sacra, which indicates lower marine fish consumption at Velia. Differences in isotopic values between Velia and Isola Sacra were hypothesized by Craig and colleagues (2009) to be the result of marine fish consumption being more widespread at Isola Sacra, since mainly males ate fish at Velia.

Differences between Velia and Isola Sacra are also reflected in the varying prevalence of external auditory exostoses. External auditory exostoses (EAE) are a stress marker related to water exposure, thus higher EAE frequencies at Velia indicates more activities involving submersion in cold water at the site (Crowe et al., 2010). The prevalence of EAE at Isola Sacra have been tied to Roman public baths, but continuous cold water exposure from fishing or diving activities may also result in the formation of exostoses (Crowe et al., 2010; Manzi, Sperduti, & Passarello, 1991). Differences in diet and stress markers could indicate differences in status and occupation between these sites; Portus Romae was a much larger trading hub that could receive fish imports, whereas it may have been more important for individuals at Velia to procure their own fish. The exostoses were most common in adult males at Velia, which were also the group to most commonly eat marine foods (Crowe et al., 2010). Using patterns observed from Velia and Isola Sacra by Craig and colleagues (2009) and Crowe and colleagues (2010) as indicators, if marine foods were consumed at Vagnari, they may have been more common among males than females.

Craig and colleagues (2013) also investigated diet through isotopic analyses for victims of the Vesuvius eruption at Herculaneum. Herculaneum was a coastal town in

the Bay of Naples, with the Vesuvius victims dating to 79 AD. The collagen $\delta^{13}C$ values at Herculaneum ranged from -20.2‰ to -18.2%, and $\delta^{15}N$ values ranged from 8.2‰ to 11.7‰ (Craig et al., 2013). Much like in previous examples, these values were indicative of the consumption of marine fish along with terrestrial proteins and C_3 plants. Craig and colleagues (2013) estimated that marine foods accounted for up to 30% (mean: 15%) of the carbon in collagen, and 10-50% (median: 34%) of the nitrogen in collagen assuming a 20% meat diet at Herculaneum (Craig et al., 2013). Though marine foods make up portions of the diet at coastal sites such as Herculaneum, they may not be the largest contributors or food staples. Craig and colleagues (2013) suggested that marine foods contributed more to the diet than terrestrial protein, but plant foods still made up the majority of the diet at Herculaneum. Even at locations where marine food is more accessible, it may make up a significant portion of the diet, but not the majority. At a rural inland site such as Vagnari, marine foods are anticipated to make a minimal contribution the diet when in comparison to coastal sites of Herculaneum, Velia, and Isola Sacra.

Isotopic studies of coastal cities from the Imperial Roman period have been beneficial not only to explore Roman diet, but to evaluate the importance of marine foods. Though marine fish were important in the diet at Portus Romae, Velia, and Herculaneum, the degree to which they were consumed varied at each site. The prevalence of marine foods in the diet at these sites could be the result of advantages from living in a coastal city. Vagnari, a rural inland site, may not have had access to these

resources. Diet at Vagnari is anticipated to be composed of mainly C_3 plants and terrestrial protein, though marine or freshwater fish could have been imported to the site and made a small contribution to the diet. Marine foods, if utilized, may also be more common among certain groups at Vagnari, such as males, older females, or higher status individuals.

Rome

Isotopic studies of diet from Rome have included Christian catacombs and cemeteries from suburbs around the city. Rutgers and colleagues (2009) examined diet from the Liberian Region of St. Callixtus, a large early Christian catacomb of ancient Rome (3^{rd} – 5^{th} centuries AD). The catacomb was situated on the *Via Appia*, and served as a burial place for the Christian poor. Values of $\delta^{13}C$ from collagen ranged from -20.8‰ to -18.9‰, and $\delta^{15}N$ values ranged from 9.7‰ to 11.9‰ (Rutgers et al., 2009). No significant differences in diet were found between individuals based on factors of age, sex, or burial type, indicating a relatively similar diet among the individuals buried in St. Callixtus.

The relatively high $\delta^{15}N$ values in combination with low $\delta^{13}C$ values also indicated the consumption of freshwater fish at St. Callixtus (Rutgers et al., 2009). Early Christian diets were assumed to be similar to that of other Romans, yet fish was not a staple of Roman diet (Garnsey, 1999). Rutgers and colleagues (2009) hypothesized that the greater presence of fish in early Christian diet was due to financial rather than religious reasons; though Christian belief could have motivated the consumption of fish over

meat, during the later Roman Empire the price of freshwater fish was fixed at one half to one third the price of marine fish. The catacomb of St. Callixtus was a burial place for poor Christians, so it is probable that they would have taken advantage of a less costly protein source that fit with dietary recommendations from their faith. If the consumption of fish was motivated mainly by economic necessity rather than religious beliefs, this could be a possibility to explore at Vagnari. Fixed prices on freshwater fish during the later Roman Empire could have provided an affordable source of protein for the labourers or managers of an industrial estate.

Killgrove and Tykot (2013) investigated diet in the urban and suburban areas of Rome during the Imperial period. Human skeletons from two cemeteries, the peri-urban Casal Bertone (2-3rd centuries AD) and the suburban Castellaccio Europarco (1st-3rd centuries AD) were analyzed for the study. The *suburbium* of Rome extended up to 50 km from the city's walls; Casal Bertone was located 1.5 km from the city walls, and Castellaccio Europarco was located 12 km from Rome (Killgrove & Tykot, 2013). Isotope ratios from collagen revealed that diets from individuals buried in the Casal Bertone Necropolis (mean $\delta^{13}C$ = -18.3 ± 0.7‰, mean $\delta^{15}N$ = 10.1 ± 1.4‰), Casal Bertone Mausoleum (mean $\delta^{13}C$ = -18.2 ± 0.5‰, mean $\delta^{15}N$ = 9.9 ± 1.5‰), and at Castellaccio Europarco (mean $\delta^{13}C$ = -18.5 ± 0.6‰, mean $\delta^{15}N$ = 9.8 ± 1.5‰), were similarly based on C_3 plants and terrestrial herbivores, with some contributions of marine fish, freshwater fish, or C_4 plants (Killgrove & Tykot, 2013).

Casal Bertone and Castellaccio Europarco did not differ significantly in diet except for the $\delta^{13}C$ values from bone apatite carbonate (Killgrove & Tykot, 2013). These differences in diet were interpreted by Killgrove and Tykot (2013) to be a result of greater C_4 reliance in the diet at Castellaccio Europarco, meaning the people buried in this cemetery likely ate more millet than those from Casal Bertone. Only one individual from Castellaccio Europarco has $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ values indicative of a diet primarily based on C_4 foods, but it is likely the people at Castellaccio Europarco mixed some C_4 sources into a primarily C_3-based diet. In comparison with Portus Romae and St. Callixtus, Casal Bertone and Castellaccio Europarco had lower $\delta^{15}N$ and higher $\delta^{13}C$ values, indicating consumption of more terrestrial C_3 protein and C_4 foods at these sites (Killgrove & Tykot, 2013).

Millet was considered a sub-standard grain by Romans, used for animal feed, or eaten by the poor or during food shortages (Garnsey, 1999). Differences in millet consumption for these sites could relate to differences in socioeconomic status (SES); the peri-urban Casal Bertone with lower millet consumption could have had higher SES than the more millet-reliant suburban Castellaccio Europarco (Killgrove & Tykot, 2013). Murphy (2016) suggests that millet filled an important dietary niche by being an affordable grain that was easy to grow, providing protection against famine regardless of culturally constructed values. Millet also had medicinal uses in the Roman world, including pain relief, digestive system regulation, or remedies for dysentery and hypochondria (Murphy, 2015). The pattern of increasing millet consumption with more

rural, inland settlements and its relation with status discussed by Killgrove and Tykot (2013) could have important implications for diet at Vagnari. As a rural, inland site predominantly occupied by labourers, one might expect to see higher millet consumption and lower status than at more urbanized locales.

Though dietary studies using stable isotopes have been performed for the Imperial Roman period, few have investigated dietary patterns of rural settlements. Most of the sites considered have been the burial grounds of urban centres, particularly port cities or towns along the western coast of Italy (Craig et al.2013, Craig et al. 2009, Keenleyside et al. 2009, Prowse et al. 2004). The diets at these sites are those of urban residents, and may not be representative of all Romans. Dietary research on the Roman *suburbium*, as discussed by Killgrove and Tykot (2013), gives some idea as to what rural diets could look like in comparison with urban diets. At rural sites there may be less access to marine foods due to greater distances to the coastline, and higher consumption of poor grains such as millet. Lifestyles and resource access differ between urban and rural locations, so it is anticipated that diet should differ as well. The impacts of diet on oral health has been shown to be similar between the urban Isola Sacra and rural Vagnari (Prowse et al., 2014), however the isotopic compositions of these diets could differ. The study of diet at a rural site such as Vagnari can expand knowledge on the variation of Roman diet across Imperial Italy.

3.4.2 Diet Across the Roman Empire

Isotopic analyses have been applied broadly to the study of diet in the Roman Empire, including many areas outside of Roman Italy. The most thoroughly researched region is Roman Britain, but the discussion of this research will be brief as the different environments make isotope ratios not directly comparable between Roman Britain and Roman. Isotopic studies from Roman sites in Tunisia, Egypt, and Croatia will be discussed in more detail as they are closer in geography and climate, and hence more applicable to Roman Italy.

Isotopic studies of diet in Roman Britain often tackle the changes in diet that occurred as a result of Romanization. Adopting Roman food values resulted in dietary shifts, such as more nutritional variety, perceptions of marine resources as a high-status food, and gendered differences in marine food consumption (Müldner, 2013). Sex and status-based differences in diet, often due to the consumption of marine foods, were noted at Romano-British sites such as Queenford Farm (Fuller et al., 2006), and Gloucester (Cheung, Schroeder, & Hedges, 2012). The diet of individuals interred in a mass burial at Roman Gloucester (2nd century AD) was very similar to the rest of Roman Britain, in that it included C_3-based foods, terrestrial animal protein, and consumption of some non-local foods (Chenery et al., 2010). When comparing Late Iron Age and Roman diets from Dorset, Redfern and colleagues (2010) found that Romanization produced less dietary variation than was previously seen in diets during the Iron Age. Though $\delta^{13}C$ values were slightly higher for Roman Dorset, $\delta^{15}N$ values did not increase significantly

(Redfern et al., 2010). Thus, it is likely that diets within Dorset continued from the Late Iron Age into the Roman period to be mainly terrestrial based without much greater adoption of fish. Similar foods such as marine fish were eaten between inhabitants of rural Imperial Italy and Roman Britain, however their isotopic values are not directly comparable due to environmental variation.

Isotopic studies of diet have also been conducted at Leptiminus, a Roman port city with extensive suburbs along the Mediterranean coast of Tunisia. The cemeteries studied by Keenleyside and colleagues (2009) dated to two periods, the 2nd to 3rd centuries AD and the 4th to 5th centuries AD. Stable isotope ratios from collagen ranged from -16.5‰ to -19.2‰ for $\delta^{13}C$, and 8.4‰ to 17.6‰ for $\delta^{15}N$ (Keenleyside et al., 2009). The $\delta^{13}C_{ap}$ values ranged from -7‰ to -14.5‰ (Keenleyside et al., 2009). Based on these values, diet from collagen indicated the consumption of marine resources, while diet from apatite carbonate suggested a reliance on terrestrial plant-based and carbohydrate-rich foods (Keenleyside et al., 2009). Collagen ($\delta^{13}C_{col}$) and apatite carbonate ($\delta^{13}C_{ap}$) values were not significantly correlated, likely due to marked trophic level differences between individuals in the sample (Keenleyside et al., 2009).

No significant dietary differences were found between sexes or among adult (36-50 years) and young adult (18-35 years) age groups at Leptiminus (Keenleyside et al., 2009). Though there were slight variations in $\delta^{15}N$, $\delta^{13}C_{col}$, and $\delta^{13}C_{ap}$ values between burial types (pits, ceramic coffins, cut stone coffins) and grave markers (none, *cupula*, or *mausolea* and *hypogea*), these relationships disappeared when looking at adult burials

only (Keenleyside et al., 2009). This lack of variation suggests that the people at Leptiminus were eating similar foods regardless of social status or burial treatment.

The $\delta^{13}C$ and $\delta^{15}N$ values at Leptiminus were higher than values at Isola Sacra, which indicates a greater reliance on marine foods for Leptiminus than the inhabitants of Portus Romae (Keenleyside et al., 2009). However, the importance of marine foods at Leptiminus changed in the diet with time. Greater amounts of marine foods were consumed by the 5th century AD, perhaps as a result of decreased availability of terrestrial protein or broader social, political and economic changes in the Roman Empire at the time (Keenleyside et al., 2009). The main dates of occupation for the Vagnari cemetery overlap with periods of change and instability in the Roman Empire, so it is possible that food resources could have changed in importance at Vagnari over time.

Dupras (1999) studied diet at the Romano-Christian Period cemetery Kellis 2 (250-450 AD), as part of a larger isotopic study of diet in the Dakhleh Oasis of Egypt. The mean $\delta^{13}C$ value of -18.84‰ ± 0.5‰ suggests a diet based on C_3 and some C_4 plants (Dupras, 1999). The high mean of $\delta^{15}N$ 18.65‰ ± 1.59 ‰ at Kellis 2 was more likely the result of water stress from the arid environment than the consumption of marine foods (Dupras, 1999). Individuals who fell more than one standard deviation below the mean $\delta^{15}N$ value for the Dakhleh Oasis sites may have exhibited lower $\delta^{15}N$ values as result of diet, migration or disease (Dupras, 1999). Dupras (1999) suggested that these individuals were consuming food at a lower trophic level, or could have been migrants from less arid environments such as the Nile Valley or Nubia. Pathological conditions may also

alter $\delta^{15}N$ values in bone, which could be the case for an individual with periostitis and $\delta^{15}N$ values below the Dakhleh Oasis mean (Dupras, 1999; Katzenberg & Lovell, 1999).

Statistically significant sex-based differences in diet at Kellis 2 were observed for $\delta^{13}C$, with adult males being more enriched in ^{13}C than adult females, which Dupras (1999) interpreted to indicate that the male diet at Kellis 2 was composed of more meat, whereas the female diet was composed of more wheat, barley, and millet. Age-related differences in diet were only considerable when subjects were less than two years old; after the transition to weaning, the diets among those buried at Kellis 2 became similar (Dupras, 1999). Spacing between the carbon of bone carbonate and collagen ($\Delta^{13}C_{ap\text{-}col}$ = 6.01‰) approximates the 7‰ spacing factor suggested for omnivores (Dupras, 1999; Krueger & Sullivan, 1984; Lee-Thorp et al., 1989). No significant relationship was found between $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$, and a weak linear relationship was observed between $\Delta^{13}C_{ap\text{-}col}$ and $\delta^{15}N$. This tends to occur in samples with trophic level differences in diet, which at Kellis 2 could stem from differences in meat consumption or disease among adults.

Much like for the Roman *suburbium*, millet was an important resource in adult diet for the people buried at Kellis 2. Patterns discussed by Killgrove and Tykot (2013) regarding rural sites and millet were also exhibited in Roman Egypt. The Dakhleh Oasis is an inland site distanced from the Red and Mediterranean Seas, located approximately 660 km southwest from Cairo, and situated between different trade routes to the Nile Valley (Dupras, 1999). The situation of the Dakhleh Oasis and its reliance on millet for

adult diet may indicate the social status of its inhabitants, and could be similar to the diet at Vagnari.

Lightfoot, Ŝlaus and O'Connell (2012) studied the changes in diet over time in the Ravni Kotari region of the Dalmatian coast in Croatia. The Roman conquest of Dalmatia began in 34 BC and resulted in structural and cultural changes in the region. The isotopic values for the Roman and Late Antique sites in the Ravni Kotari region ranged from -19.6‰ to -17.7‰ for $\delta^{13}C$ and 8.5‰ to 12.9‰ for $\delta^{15}N$ (Lightfoot et al., 2012). Roman-era diets from the Ravni Kotari sites studied were based mainly on C_3 resources with some contributions from C_4 plants and marine foods. Mean isotope values for $\delta^{13}C$ (-18.8‰) and $\delta^{15}N$ (10.1‰) in the Roman period samples differed from the mean values from the Early Medieval samples, and only differed from the Iron Age average $\delta^{13}C$ values (Lightfoot et al., 2012).

The Roman period in Dalmatia was prosperous and peaceful, though political instability characterized the transition into the Late Antiquity and Early Medieval periods. Romanization in the Dalmatian region brought about a greater consumption of marine fish, which was not a major component of the diet during the Iron Age and Early Medieval periods (Lightfoot et al., 2012). This increased consumption of fish was likely due to the adoption of Roman diets, in which seafood was a luxurious and valued food item. The Roman sites studied, Zadar-Relje, Podvršje, and Vis Bandirica were all coastal or island cities; the close proximity to the Adriatic Sea and accessible markets may be over-representing the prevalence of fish in Roman Dalmatian diets, particularly when

compared with sites that are located further inland from the Iron Age and Early Medieval periods. Much like with the coastal cities of Roman Italy, the coastal sites of Roman Croatia relied on marine food sources in addition to C_3 food sources. Coastal cities have advantages from their situation that allows for greater consumptions of marine fish, but these advantages are not present at inland sites such as Vagnari.

Though there are similarities in diet across the Roman Empire, the foods eaten in Roman Italy, Britain, Tunisia, Egypt and Croatia differ based on environmental, economic and cultural conditions. Reliance on C_3 plants was widespread across the Empire, and despite social perceptions of millet as a poor grain, C_4 plants were likely an important dietary resource for adults. Seafood was a luxury food item, and its accessibility from coastal cities could account for the prevalence of marine foods across the Mediterranean. The importance of seafood in the diet varies from place to place, as marine foods are not equally available or accessible in all areas of the Roman Empire.

3.5 Conclusion

Stable isotope analysis is a technique that has successfully been utilized to study the diet of individuals in the past. It has useful applications in the study of Roman diet, particularly to tackle questions of the types of food eaten (i.e. the contribution C_3 foods, C_4 plants, and/or marine foods to the diet), changes in diet over time, or variation in diet between different locations across the Empire. Marine foods made many significant contributions to the diet of inhabitants of coastal Roman sites, such as Isola Sacra, Velia, Herculaneum, Leptiminus, and the Dalmatian region of Croatia. Inland settlements, such

as the city of Rome, the Roman *suburbium*, and the Dakhleh Oasis, relied much more on terrestrial food sources, including C_4 plants (i.e. millet). It is anticipated that the isotopic signals of the people at Vagnari will be similar to other inland cemeteries of the Roman Empire, and as a rural industrial estate it will make for an interesting point of comparison against urban centres or port cities. Isotopic analyses of $\delta^{13}C$ and $\delta^{15}N$ from the individuals buried at Vagnari will help to explore these hypotheses and compare between sites.

4 Materials & Methods

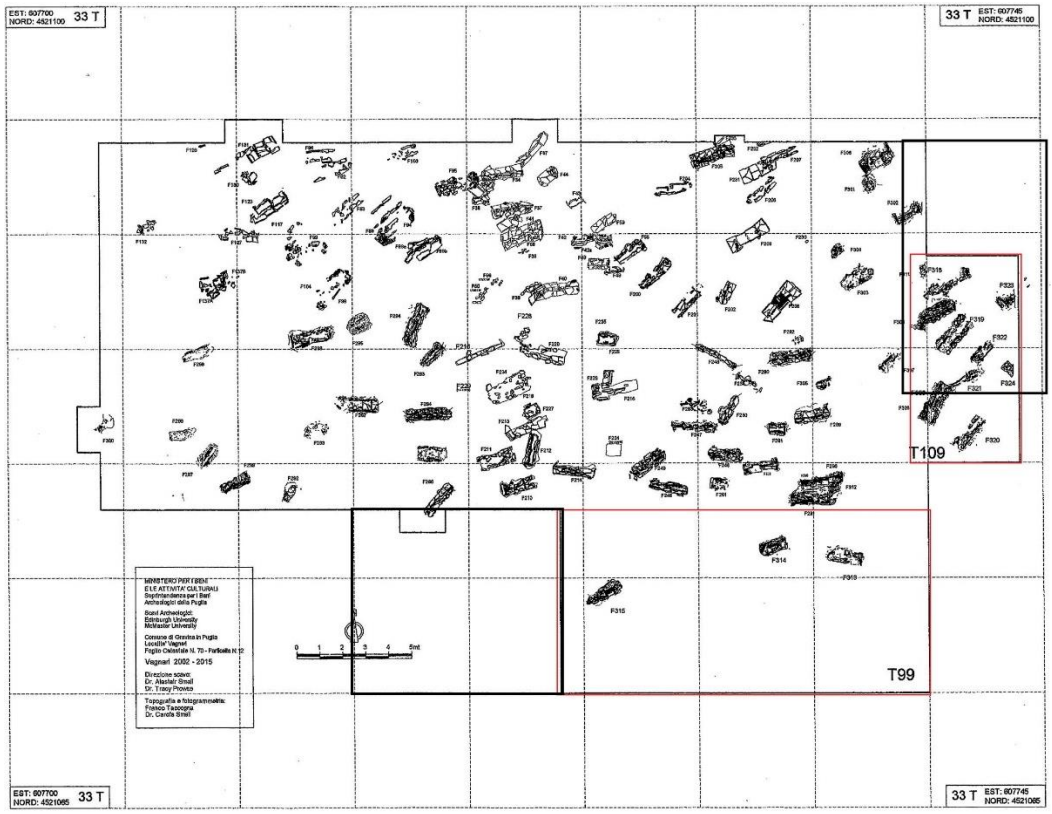
4.1 Site of Study: The Vagnari Cemetery

4.1.1 History of excavation at the Vagnari Cemetery

The site of Vagnari was first discovered by Dr. Alastair Small during a surface survey of the Basentello Valley in the late 1990s. Excavations at Vagnari since 2000 have uncovered a *vicus* where workers and their dependents lived, and a large work area where industrial tasks were carried out (Carroll, 2013; Prowse & Small, 2009; A. Small, 2011). The Vagnari cemetery was found in 2002 on the southern side of the ravine, and excavations have been ongoing under the direction of Dr. Alastair Small in 2002 and Dr. Tracy Prowse from 2003 to present (Figure 4.1). Excavation of trenches in the cemetery revealed that burials were spread in different directions, with no clear pattern in their orientation or distribution (Small, 2007).

From the 2002 to 2014 field seasons, a total of 108 burials have been excavated. Burials were assigned feature numbers in ascending order, which alternated with assigned feature numbers from the village excavations. These feature numbers (e.g. F200) will be used when discussing burials and the individuals interred in them. Materials prepared for stable isotope analysis in this project were a selection of burials from the 2004 to 2014 field seasons, with feature numbers ranging from F55 to F312.

Figure 4.1 - Layout of the Vagnari cemetery prepared by Franco Taccogna. Reproduced with permission from Tracy Prowse.



4.1.2 Burial types at Vagnari

The most common burial types at Vagnari were '*alla cappuccina*' burials, where an individual was interred in a shallow grave with roof tiles (*tegulae*) placed over it in an inverted V-shape (Prowse, 2013) (Figure 4.2). These types of burials were common for ordinary Roman people from the late Republic to the late Empire (Small, 2007). Tile burials were similar to *cappuccina* burials, though the graves were covered with a row of flat *tegulae* instead (Figure 4.3). Libation burials were characterized by an unlined pit covered with flat tiles, with two rounded *imbrex* tiles placed vertically to form a funnel

for receiving offerings (Prowse, 2013; Small, 2007) (Figure 4.4). In a small number of cases, a cappuccina burial would also have a libation tube inserted at the top of the burial.

Figure 4.2 (below) - F205, an 'alla cappuccina' burial. Photo by Tracy Prowse.

Figure 4.3 (below) - F292, a tile burial. Photo by Tracy Prowse.

Libation burials were also used in cemeteries across Roman Italy, and are thought to be from Roman funeral practices of pouring liquid offerings on the tomb of the deceased to honour them (Small, 2007).

Figure 4.4 - F231, a libation burial. Circled area is the funnel for receiving offerings. Photo by Tracy Prowse.

A rare funerary treatment at Vagnari was cremation; only three cremated burials have been excavated thus far. In Roman Italy, cremation began to decrease in favour of inhumation by the late 1st century AD (Small, 2007). Most burials from Vagnari date to the 2nd century AD, which aligns with a smaller instance of cremations. Cremation of the deceased at Vagnari occurred *in situ*, with funeral pyres built over top of the grave (Brent & Prowse, 2014). Two individuals, F201 and F302, were cremated with a *cappuccina* style grave covering it, but were recorded as cremation burials for the purposes of analysis.

Figure 4.5 - F201, a cremation burial with overlying cappuccina cover. Photo by Tracy Prowse.

Individuals were also interred in pit burials, involving a shallow grave with no accompanying structure. Additionally, some burials were classified as disturbed, meaning the grave structure was in a poor state, unidentifiable, or altered from secondary deposition or modern agricultural activity.

4.1.3 Chronology of the cemetery

The Vagnari cemetery is dated from the 1st to 4th centuries AD, with most burials dating to the 2nd century AD. Chronological dating of the Vagnari cemetery was based on the grave goods included in burials. Coins, lamps, and pottery were the items most frequently used to estimate the date of burial, with differences in precision based on the item (Brent, 2012). The most precise date estimates were spans of 1 to 21 years, and the least precise a particular century or span of two centuries. Coins found at Vagnari

pictured busts of Emperors Trajan, Hadrian, Antonius Pius, Faustina I, Faustina II, and Constantine, who collectively reigned from AD 98-335 (Brent, 2012). The period of rule for each individual emperor gives date of burial ranges within 1 to 21 years (Brent, 2012). Lamps found at Vagnari all dated to the 2nd century AD, whereas pottery indicated broad regional styles from the 2nd to 3rd centuries AD (Brent, 2012). Items such as coins or lamps could have been kept much longer than when they were initially made or circulated, and thus represent a lower boundary for date of burial estimates. Date of burial estimates were sorted into groups by century for comparison with stable isotope data at Vagnari.

4.1.4 Grave good assemblages

Grave goods buried with individuals from Vagnari were identified and quantified for analysis. The most common item found in Vagnari graves were pottery or pottery fragments (Brent, 2012). Total grave good counts at Vagnari were estimated from the minimum number of artifacts (MNA) per grave. With MNA, fragments of an artifact are treated as pieces of the same item unless separate items can be identified. Many items were fragmented in Vagnari burials, so this method allowed for more conservative estimates where the number of grave goods in a burial would not be overstated (Brent, 2012). Items of personal dress were included in grave good counts, as were iron nails if they were buried in association with a pot (Brent, 2012). Structural nails from coffins or pyres were counted as one item, even if multiple were present. Items found outside the grave structure were excluded from grave good counts, since they may not have been

intentionally buried with the individual. Estimated numbers of grave goods were recorded and incorporated into analysis of diet at Vagnari.

4.2 Materials Studied from Vagnari

Human and faunal skeletal remains studied from Vagnari were recovered from the cemetery of the site. Bone samples (femora and ribs) from 58 human individuals and 8 animals were prepared for stable isotope analysis, and can be viewed in more detail in Appendix A. The animals analyzed included one omnivorous species, a dog, and seven herbivorous species; a cow, sheep, and pig, along with an equid and three ungulates of unknown species. These animals were studied to create an isotopic baseline for interpretation of the human values. The human subsamples for bone collagen (n = 55) and apatite carbonate (n = 48) differed in number, as in some cases there was not enough bone to prepare for both analyses. In these instances, collagen sampling was prioritized.

4.3 Methods for Assessing Age and Sex

Assessments of age and sex of the individuals buried at Vagnari were conducted by field researchers at Vagnari according to standard methods in human osteology and bioarchaeology from Buikstra and Ubelaker (1994). Age estimations for subadults were based on the development and eruption of dentition, as well as long bone length if these elements were preserved. For adults, age estimations were made based on methods using morphology of the pubic symphysis, morphology of the auricular surface, and cranial suture closure. Sex was determined among adults using features of the cranium

and pelvis. The most recent age and sex assessments up to the 2014 excavations are not yet published, though assessments from earlier excavation years are incorporated in publications on the Vagnari cemetery by Brent and Prowse (2014) and Prowse and colleagues (2014).

For this project, individuals with an age-at-death greater than 16 years old were considered adults, as at this stage the os coxae fused, sexually dimorphic traits become established on the skeleton, and sex of the individual could be assessed. Subadults were individuals with an age-at-death less than 15.9 years old, in which sex cannot confidently be assessed. Broad classifications of 'adult' and 'subadult' at Vagnari were based on physiological age, but age-based dietary variation has an important social dimension.

To capture more specific age-related changes with diet, the sample from Vagnari was split into categories of infancy-early childhood (0-3.9 years), childhood (4-14.9 years), adolescence (15-29.9 years), early adulthood (30-44.5 years) and mid-late adulthood (45+ years). Age categories used for comparison at Vagnari are based on Roman social age groups, combined with aging methods in human osteology and trends in stable isotope analysis of diet.

4.4 Stable Isotope Methodology

4.4.1 Collagen preparation

Bone collagen preparation methods for isotopic analysis were drawn from procedures proposed by Longin (1971) and Chisholm and colleagues (1982). Three to five (3-5) grams of human and faunal femoral or rib segments were taken for analysis,

pulverizing the bone pieces with a mortar and pestle if needed. Bone samples were cleaned using tap water and trabecular bone was ground down using a metal file. After the trabecular bone was removed bone samples were rinsed in an ultrasonic bath with distilled water several times, then left overnight in a drying oven at 60°C. Sample weights were measured once the bones were dried.

After the bones had been cleaned and dried, they were placed in plastic 50 ml centrifuge tubes for bone mineral dissolution. The mineral portion of bone was removed by soaking the samples in 45 ml of 0.25 M HCl (hydrochloric acid). The acid was changed out daily until the bone mineral had dissolved, leaving a pellet composed of organic materials such as collagen.

Bone pellets were washed with distilled water to remove any remaining acid, and then rinsed with 25 ml of 0.1 M NaOH (sodium hydroxide) to remove base-soluble contaminants. Additional bases and humic or fulvic acids were removed by soaking the samples in 45 ml of 0.1 M NaOH for 20 minutes to an hour. Following this, samples were washed repeatedly with distilled water to remove any remaining NaOH from the pellet. In preparation for hot water extraction, bone samples were slightly acidified by adding 45 ml of 0.001 M HCl.

Collagen was then hot water extracted from the organic pellet. Bone pellets were sealed in 50 ml glass test tubes filled with 0.001 M HCl and placed in a heating oven at 90°C to react overnight. Heating the bone pellet caused the collagen within it to become water soluble. The hot water extracted solution was removed from the oven, and its

liquid component was decanted into 50 ml Teflon beakers and placed back in the 90°C oven. While the liquefied collagen dried, the organic pellets went through the hot water extraction process again to ensure as much collagen was extracted as possible.

After the collagen dried, it was dissolved in a small amount of distilled water (< 5 ml) and transferred from Teflon beakers to pre-weighed vials. The pre-weighed vials were placed in the drying oven overnight at 60°C. Once the distilled water had evaporated, the solid collagen was weighed and its percent yields were calculated using Equation 4.1.

Equation 4.1 - Formula to calculate collagen percent yield.

$$\frac{weight\ of\ collagen}{weight\ of\ bone} * 100 = \%\ yield\ of\ collagen$$

A 5% yield or greater is the standard for stable isotope research as it indicates the collagen is well preserved, and that the isotope values in bone are *in vivo* dietary signals (Ambrose, 1990; DeNiro, 1985; Schwarcz & Schoeninger, 1991). Based on the amount of extracted collagen after, 61 out of 63 prepared samples were selected for mass spectrometry. Up to 100 mg of collagen was collected from the glass vials and transferred into labelled 2.0 ml micro tubes for mass spectrometry.

Mass spectrometry of bone collagen was conducted at the G. G. Hatch Stable Isotope Laboratory (Ottawa, Ontario) using a Thermo Finnigan Delta XP. Analytical precision based on internal lab standards is within ± 0.2‰. The Hatch Lab procedures for mass spectrometry of collagen were as follows. First, powdered collagen samples and

laboratory standards were weighed into tin capsules, and these capsules were loaded into an elemental analyser linked to an isotope ratio mass spectrometer (IRMS). Once in the elemental analyser collagen samples and standards were flash combusted at 1800°C. The resulting carbon dioxide (CO_2) and nitrogen (N_2) gas products were carried by helium through columns of oxidizing and reducing chemicals optimised for CO_2 and N_2. A purge and trap adsorption column separated CO_2 and N_2 before they were sent to the IRMS interface and IRMS, and the IRMS generated the isotope ratios from each sample. Isotope ratios were reported in Delta notation relative to international standards, with $\delta^{13}C$ reported as ‰ vs. VPDB and $\delta^{15}N$ reported as ‰ vs. AIR.

Following mass spectrometry, preservation of bone collagen was evaluated using both percent yield and carbon to nitrogen (C:N) ratios of the samples. A C:N ratio between 2.9 to 3.6 signals that the collagen in bone has not been affected by post-mortem processes (DeNiro, 1985). Ratios of carbon to nitrogen were calculated using Equation 4.2.

Equation 4.2 - Formula to calculate the carbon to nitrogen ratio in collagen.

$$C{:}N = \frac{\%C\ of\ sample}{\%N\ of\ sample} * \frac{14}{12}$$

Samples were included in this study if their collagen yields and/or C:N ratios were within the accepted range.

4.4.2 Carbonate preparation

Methods used to prepare bone apatite carbonate for isotopic analysis were drawn from procedures developed by Sullivan and Krueger (1981) and Lee-Thorp and van der Merwe (1987). Human and faunal bone segments of 3-5 grams were cleaned using tap water, trabecular bone was removed, and the samples were washed in an ultrasonic bath using distilled water. Samples were then dried, weighed, and broken into smaller pieces to better facilitate the reaction processes.

Samples were placed in 50 ml plastic centrifuge tubes and 20 ml of 2.5% NaOCl (sodium hypochlorite, or bleach) was added to the bone samples. Samples were soaked in NaOCl for 24 hours to remove organic materials such as collagen and lipids, and then washed 5 times with distilled water. The samples were dried in an overnight at 60°C, and weighed to estimate the organic material removed from bone. Next, 10 ml of 1M $C_2H_4O_2$ (acetic acid buffer solution) was added to remove potentially contaminating surface carbonates. The acid was decanted after 1 hour, and the samples were rinsed with distilled water to remove any remaining acid. After drying in an oven overnight, the samples were weighed to determine the extent of surface carbonates removed by acetic acid. After measuring weight, bone samples were crushed into a finer powder. Between 40 and 100 mg of bone was measured into labelled 2 ml micro tubes for mass spectrometry.

Isotope ratios from bone apatite carbonate were measured on a Thermo Finnigan Delta XP and Gas Bench II at the G. G. Hatch Stable Isotope Laboratory.

Analytical precision is ± 0.1‰. Mass spectrometry procedures for bone apatite carbonate performed by the Hatch Lab are as follows. Carbonate samples were weighed into containers and 0.1 ml of H_3PO_4 (phosphoric acid) was added. Containers were closed and Helium-flushed while horizontal. The carbonate samples reacted for 24 hours at different temperatures depending on the mineral type (25.0°C for calcite, and 50.0°C for dolomite). Sample analysis was conducted by extraction in continuous flow, in which gases were carried by helium to the elemental analyser, IRMS interface, and IRMS. Isotope ratios were reported in Delta notation relative to international standards, with $\delta^{13}C_{ap}$ measured as ‰ vs. VPDB.

Diagenetic alteration of bone carbonate was assessed from 20 individuals of the Vagnari carbonate sample using Fourier transform infrared spectroscopy (FTIR). Approximately 100 mg of bone powder was used for this procedure. FTIR procedures were carried out by Dr. Steve Kornic at the Combustion Analysis and Optical Spectroscopy (CAOS) facility at McMaster University (Hamilton, Ontario) according to methods from Wright and Schwarcz (1996). Bone powder was passed through a #200 mesh sieve to collect the finer powder. For each sample, approximately 2 mg of fine powder was ground together with 200 mg of KBr (potassium bromide). This mixture was compressed at 15,000 psi into 12 mm pellets, and analyzed using a Thermo Nicolet 6700 FTIR spectrometer to read absorbance spectra. Absorbance spectra data were then compiled into graphs for each individual studied.

The bone carbonate samples were then evaluated for diagenesis by calculating the crystallinity index (CI) from FTIR absorbance graphs. The crystallinity index (CI) is calculated using the following equation:

Equation 4.3 - Formula to calculate crystallinity index.

$$CI = \frac{(A_{565} + A_{605})}{A_{595}}$$

where A_x is the absorbance at that wavenumber (Shemesh, 1990). Modern bone typically has a CI of 3.1, while the CI of acetic acid treated bone is usually 3.5 (Wright & Schwarcz, 1996). A CI less than 3.8 signifies that the sample possesses endogenous carbonate (Shemesh, 1990).

4.5 Statistical Methods for Data Analysis

Statistical tests were calculated using SPSS 23 and mathematical functions in Microsoft Excel 2016. Data were also graphed using Excel 2016. The distributions of $\delta^{13}C$, $\delta^{15}N$ and $\delta^{13}C_{ap}$ were examined using the Kolmogorov-Smirnov and Shapiro-Wilk tests of normality. The isotope data were not normally distributed ($p < 0.05$), therefore nonparametric statistical tests, including the Mann-Whitney U test, Kruskal-Wallis test, and Spearman's rank correlation coefficient were used to analyze the isotope data.

5 Results

5.1 Introduction

Data from stable isotope analysis of collagen and apatite from Vagnari are presented below. Prepared isotope data (n = 50) are compared with age, sex, and burial information to explore factors potentially linked to dietary variation at the site. Results from collagen and apatite samples prepared for mass spectrometry are integrated with previously analyzed isotope data (n = 30) from the Vagnari sample for statistical analysis and graphs.

5.2 Results from Stable Isotope Analysis of Faunal Collagen

Before human values could be interpreted, the preservation of faunal collagen was assessed according to methods from Section 4.4.1. The collagen yields and C:N ratios of the faunal sample are presented in Table 5.1. Five of the eight animals had collagen yields over 5% and all C:N ratios were within the range of 2.9 to 3.6, so all faunal samples were included in this study.

The isotope values of these animals largely reflect herbivorous diets based on C_3 plants (see Table 5.1 and Figure 5.1). Some exceptions are the dog, pig, and ungulate 1 whose values overlap with those of humans, indicating these animals ate isotopically similar foods to humans.

Table 5.1 - Stable isotope results from collagen for the Vagnari faunal sample.

Family	Genus	Species	Notes	$\delta^{13}C$ VPDB (‰)	$\delta^{15}N$ AIR (‰)	% yield	C:N ratio
Unknown			Ungulate 1	-21.0	7.8	23.9	3.3
Canidae	*Canis*	*lupus familiarious*	Dog	-19.6	8.3	8.7	3.2
Suidae	*Sus*	*scrofa domesticus*	Pig	-20.1	7.3	2.2	3.2
Bovidae	*Ovis*	*aries*	Sheep	-20.6	4.0	3.9	3.2
Bovidae	*Bos*	*taurus*	Cow	-21.1	4.6	5.3	3.2
Equidae	*Equus*		Equid	-20.7	4.3	4.4	3.2
Unknown			Ungulate 2	-19.6	2.9	5.3	3.3
Unknown			Ungulate 3	-21.8	4.0	5.4	3.2
Mean				**-20.6**	**5.4**		
SD				**0.7**	**2.1**		

5.3 Assessment of Human Bone Collagen Preservation

Preservation of collagen from the human sample (*n* = 53) was also evaluated according to methods in Section 4.4.1. A total of 41 samples had collagen yields greater than 5% (see Table 5.2). Of the remaining 12 samples with low collagen yields, 3 samples (F104, F201, F302) had extremely high C:N ratios, likely because the individuals had been cremated.

Fifty collagen samples had C:N ratios within the range of 2.9-3.6 (see Table 5.2). If collagen yields were low, but the C:N ratios were in the accepted range, the samples were included in this study. The three samples with C:N ratios over 3.6 were from cremated burials (see Table 5.2, highlighted in red). Cremated individuals were consistently beyond the accepted range for both collagen yields and C:N ratios, and have been excluded from statistical comparisons of isotope ratios.

Table 5.2 - Collagen results from the Vagnari human sample. Outliers from cremated burials are highlighted in red.

Sample ID	$\delta^{13}C$ VPDB (‰)	$\delta^{15}N$ AIR (‰)	% yield	C:N
F100	-19.3	9.7	*	3.2
F104	-15.9	7.2	2.8	9.1
F117	-18.5	9.8	*	3.1
F123	-18.3	12.5	*	3.2
F126	-19.5	9.1	*	3.2
F127	-18.4	9.8	*	3.1
F130	-19.3	9.7	*	3.2
F131	-18.6	9.9	*	3.3
F132	-19.1	10.6	*	3.1
F137 A	-19.3	9.0	*	3.1
F137 B	-18.2	9.1	*	3.1
F200	-19.4	9.1	6.8	3.2
F201	-15.8	1.0	3.3	11.2
F204	-19.3	9.1	2.3	3.2
F205	-19.7	8.2	11.6	3.2
F206	-19.4	9.3	3.2	3.2
F207	-19.4	9.1	11.1	3.2
F208	-19.0	9.5	11.0	3.2
F209	-19.1	8.6	10.0	3.2
F210	-19.1	9.9	10.6	3.2
F211	-19.4	9.3	7.4	3.2
F213	-19.5	10.3	6.8	3.2
F214	-19.7	8.5	8.3	3.2
F215	-19.9	9.6	8.8	3.2
F216	-20.2	9.5	8.1	3.3
F218	-19.4	9.5	4.9	3.2
F220	-19.7	9.7	8.4	3.2
F225	-18.1	13.1	7.8	3.2
F226	-19.1	10.0	9.9	3.2
F228	-18.0	13.2	4.2	3.2
F229	-18.8	9.8	13.3	3.2
F231	-19.2	9.1	9.4	3.2
F234	-18.6	9.6	5.1	3.2
F235	-19.6	9.1	11.1	3.2
F245	-19.1	9.7	8.3	3.2
F246	-19.4	8.2	4.8	3.2
F247	-19.3	9.8	7.2	3.2

F248	-19.6	8.5	4.7	3.2
F249	-19.0	9.7	11.1	3.2
F250	-18.9	10.9	8.9	3.2
F252	-19.6	7.6	12.0	3.2
F253	-19.2	10.3	7.7	3.2
F254	-19.3	10.1	10.0	3.2
F284	-19.3	10.3	16.0	3.2
F286A	-19.6	8.1	2.7	3.2
F286B	-19.5	7.7	3.7	3.2
F287	-19.2	9.5	6.4	3.2
F288A	-19.6	10.1	9.3	3.2
F289	-19.5	8.6	7.3	3.2
F290	-19.1	9.4	10.0	3.2
F291	-19.5	9.1	7.2	3.2
F292	-18.6	11.7	10.2	3.2
F293	-19.3	9.0	10.5	3.2
F294	-19.5	8.9	8.6	3.2
F295	-18.1	12.8	5.0	3.2
F296	-19.4	8.2	6.8	3.2
F298	-19.2	9.7	5.0	3.2
F299	-19.8	8.0	7.4	3.2
F302	-18.8	9.5	2.7	5.9
F305	-18.1	13.0	1.1	3.1
F306	-19.1	10.4	7.6	3.2
F312	-19.5	8.3	7.0	3.2
F34	-18.9	9.1	*	3.1
F35	-18.8	10.3	*	3.2
F39	-17.1	12.0	*	3.0
F40	-19.5	8.2	*	3.2
F42	-18.8	8.7	*	3.2
F42A	-18.8	9.3	*	3.1
F43	-18.2	10.0	*	3.1
F48	-18.4	10.7	*	3.2
F49	-18.3	8.5	*	3.1
F55	-19.4	8.9	6.6	3.2
F59	-18.8	9.4	*	3.1
F67	-19.3	9.0	*	3.2
F68	-18.3	9.5	*	3.1
F86	-19.7	6.9	*	3.1
F89	-18.1	6.1	*	3.0

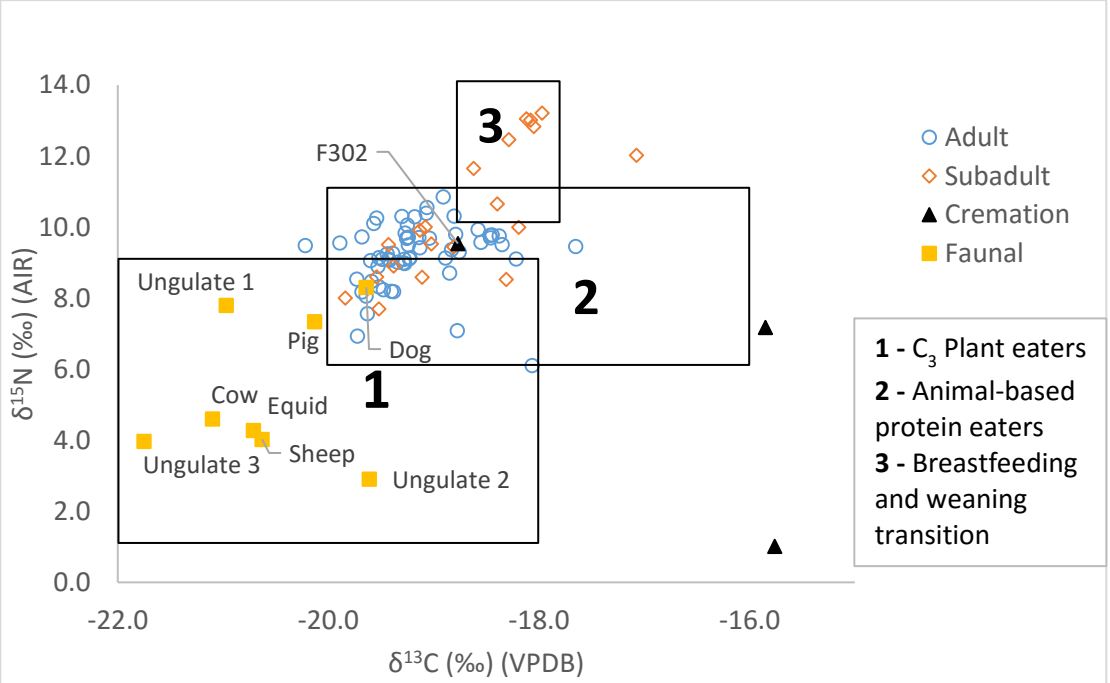
F92	-19.2	9.1	*	3.2
F93	-18.8	9.4	*	3.1
F94	-18.5	9.7	*	3.0
F96A	-18.8	7.1	*	3.1
F96B	-17.7	9.5	*	3.1
F98	-18.4	9.8	*	3.1
Mean	**-19.0**	**9.4**		
S.D.	**0.8**	**1.6**		

** - Yield data unavailable.*

5.4 Results from Isotopic Analyses of Human Collagen

Results of the analysis of $\delta^{13}C$ and $\delta^{15}N$ from bone collagen are discussed below. The sample for analysis includes data from 30 individuals previously studied (but as yet unpublished), and 50 samples prepared for mass spectrometry for this thesis (*N* = 80). The full collagen sample studied from Vagnari, including the age, sex, burial conditions, and isotope ratios of each individual are presented in Appendix B. Adult (age-at-death >16 years) and subadult (age-at-death <15.9 years) results are discussed together. Adult diet based on $\delta^{13}C$ ranges from -17.7‰ to -20.2‰ (mean -19.1 ± 0.5‰), and adult $\delta^{15}N$ ranges from 6.1‰ to 10.9‰ (mean 9.2 ± 0.9‰). These ranges indicate a diet based primarily on C_3 plants and terrestrial protein (see Figure 5.1).

Figure 5.1 - Human and collagen faunal results from Vagnari. Boxes are adapted from Schwarcz, Chisholm and Burchell (2014).



The $\delta^{15}N$ values of a subset of the subadults (11.7‰ to 13.2‰) in Box 3 (Figure 5.1) range much higher than the adult $\delta^{15}N$ range (6.1‰ to 10.9‰). The subadults in Box 3 have $\delta^{15}N$ values that range up to 3‰ greater than adult $\delta^{15}N$ values, which is likely a result of breastfeeding, although prolonged nutritional stress could be another factor. The $\delta^{15}N$ values of older subadults approximate adult $\delta^{15}N$ values, which indicate individuals who had been weaned off of breastmilk (see section 5.4.2).

The three cremated individuals are also depicted in Figure 5.1. Bone samples burned from cremation have $\delta^{13}C$ and $\delta^{15}N$ values that are distinct from the typical adult dietary signals at Vagnari. Two cremated individuals (F104, F201) have $\delta^{13}C$ values of ~16‰, and $\delta^{15}N$ values from ~1 to 7‰. In comparison, F302 has $\delta^{13}C$ and $\delta^{15}N$ values

similar to other adults, but this individual's collagen yield and C:N ratio imply that post-mortem alteration of collagen has taken place.

In order to analyze stable isotope values for patterns of variability, the distributions of stable isotope values had to be tested for normality first. Both the $\delta^{13}C$ and $\delta^{15}N$ data significantly deviated from normal ($p < 0.05$) using the Kolmogorov-Smirnov and Shapiro-Wilk tests of normality. Since the data were not normally distributed, non-parametric tests were applied in statistical analyses of Vagnari collagen isotope ratios.

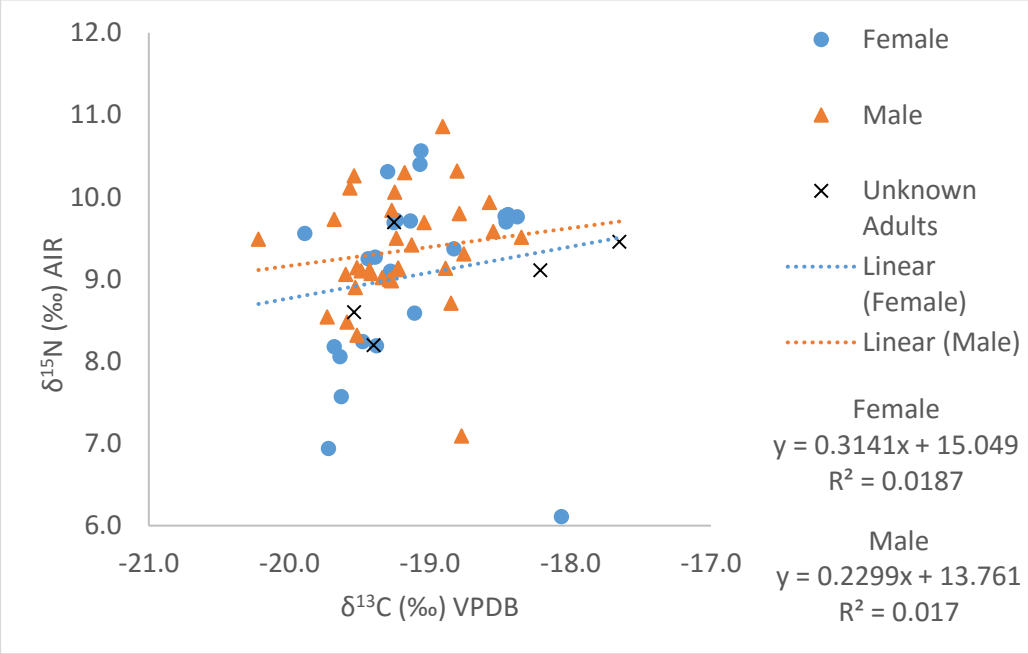
5.4.1 Sex-based variation in bone collagen values

Diet at Vagnari was investigated for sex-based differences in adults. The adult sample analyzed from Vagnari includes 34 males and 23 females. Five individuals of unknown sex were adults, and the remaining 18 individuals of unknown sex were subadults, for which sex cannot be assessed. When adult $\delta^{13}C$ and $\delta^{15}N$ values are compared using the Mann-Whitney U test, no significant differences are found in diet between sexes ($\delta^{13}C$ $U = 374$, $p = 0.782$; $\delta^{15}N$ $U = 362$, $p = 0.637$). Graphed comparisons of male and female isotopic values at Vagnari illustrate that the diets were very similar between sexes, as they have nearly parallel trend lines with similar slopes (see Figure 5.2). There are a number of females with low $\delta^{15}N$ values (< 8‰), indicating that some females relied more heavily on lower trophic level foods.

Table 5.3 – Vagnari collagen sample divided by sex.

	Min.	Max.	Mean	SD
Male (n = 34)				
$\delta^{13}C$ VPDB (‰)	-18.6	-20.2	-19.2	0.4
$\delta^{15}N$ AIR (‰)	7.1	10.9	9.3	0.7
Female (n = 23)				
$\delta^{13}C$ VPDB (‰)	-18.1	-19.9	-19.1	0.5
$\delta^{15}N$ AIR (‰)	6.1	10.6	9.0	1.1
Unknown Adults (n = 5)				
$\delta^{13}C$ VPDB (‰)	-17.7	-19.3	-18.4	0.8
$\delta^{15}N$ AIR (‰)	9.1	9.7	9.4	0.3

Figure 5.2 - Adult male and female variation in $\delta^{13}C$ and $\delta^{15}N$ in the Vagnari sample.



5.4.2 Age-based variation in diet from collagen

The collagen results indicate age-based differences in diet at Vagnari, but this variation should be investigated beyond broad differences between adults and

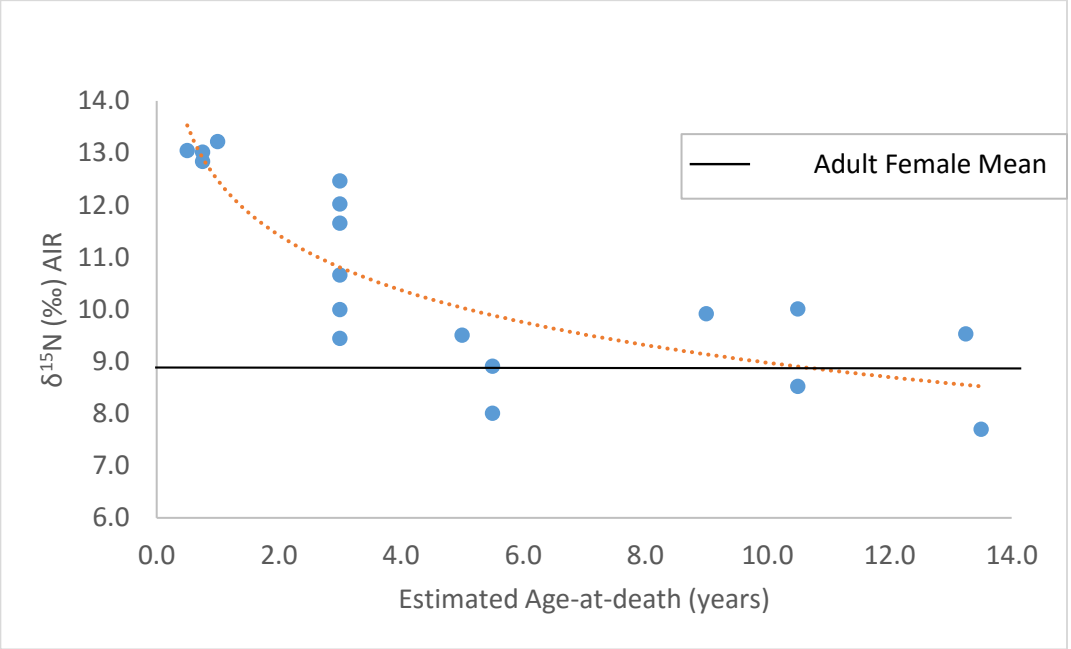
subadults. Distribution of the Vagnari collagen sample across these age categories is presented in Table 5.4. The primary focus of this project is adult diet, but subadult diet is discussed as well.

Table 5.4 - Vagnari collagen data by age categories.

Age Categories		***n***	**Mean $\delta^{13}C$ VPDB (‰)**	**SD**	**Mean $\delta^{15}N$ AIR (‰)**	**SD**
Infancy-Early Childhood	0-3.9 years	7	-18.0	0.5	12.6	0.6
Childhood	4-14.9 years	11	-19.0	0.4	9.3	0.9
Adolescence	15 to 29.9 years	19	-19.3	0.4	8.8	0.6
Early Adulthood	30 to 44.9 years	12	-19.1	0.6	9.8	0.5
Mid-Late Adulthood	45+ years	14	-19.3	0.3	9.6	0.6
Unknown Adults		17	-19.0	0.6	8.9	1.2
Total		**80**				

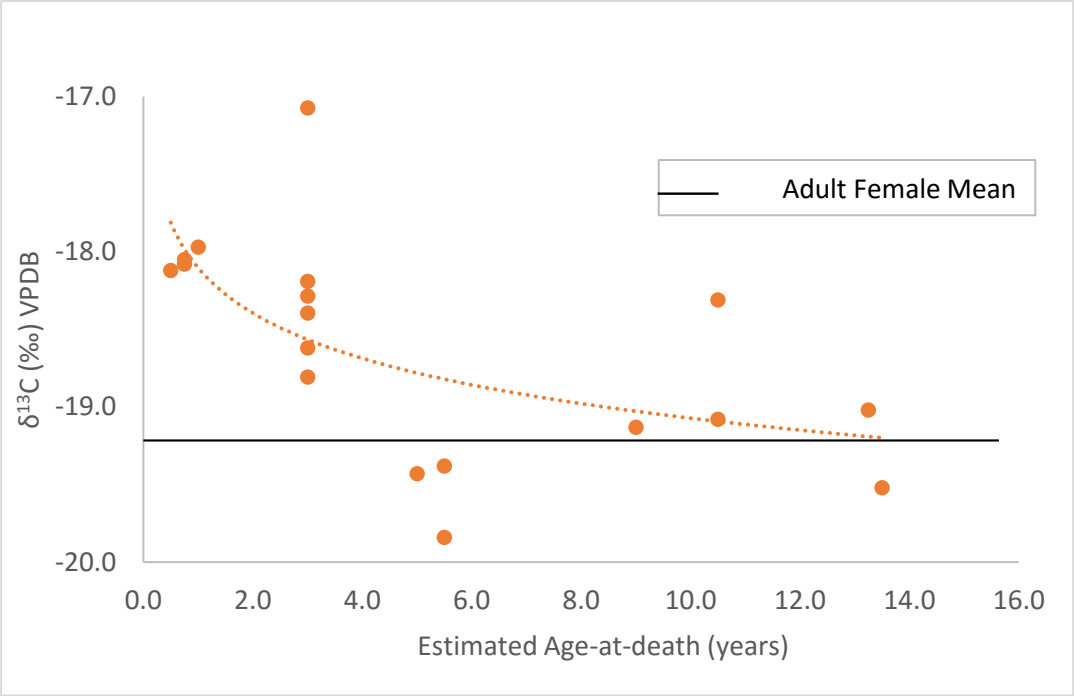
When the age and isotope ratios of individuals from infancy-early childhood and childhood are compared, the graphs exhibit breastfeeding and weaning trends (Figure 5.3 and Figure 5.4). Between birth and 3 years of age, $\delta^{15}N$ values exceed the adult female mean by 3‰ or more. At age 3, $\delta^{15}N$ values are variable, with individuals approximating the adult female mean by age 5. Weaning was in progress for subadults by age 3, with its completion by age 5 at the latest. A precise estimate of when complimentary foods were introduced and individuals were weaned off breast milk cannot be discerned since many subadults between 0-6 years of age did not have precise age estimates. In addition, there are only three individuals with age-at-death around 5 years of age, so these results should be interpreted with caution.

Figure 5.3 – Estimated subadult age-at-death compared with $\delta^{15}N$, demonstrating trends of breastfeeding and weaning.



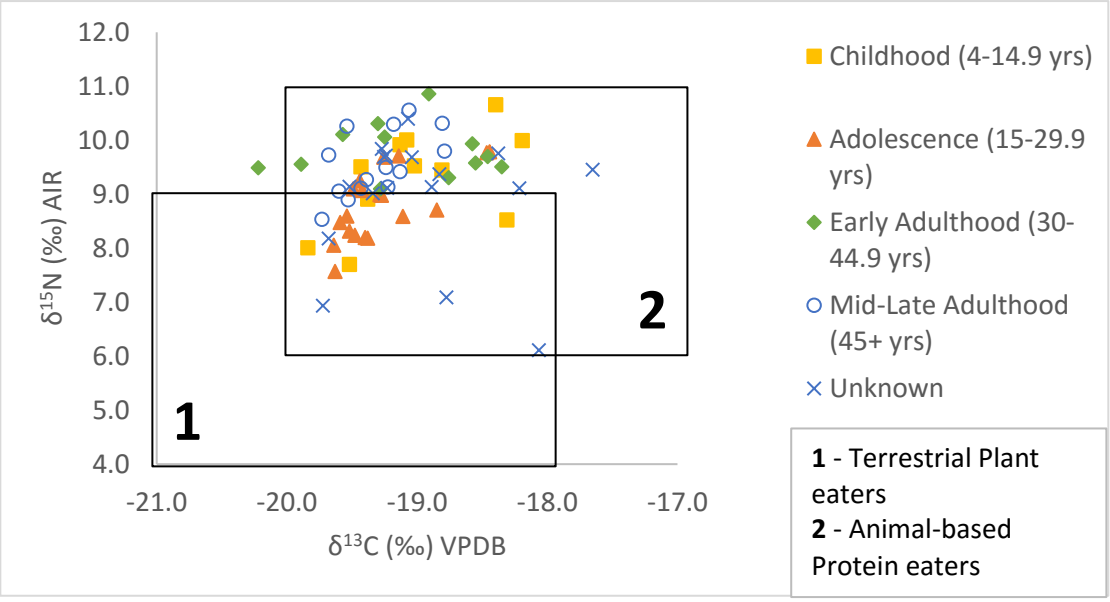
Carbon isotopes from the subadults in this sample also display similar trends (see Figure 5.4). Prior to 3 years of age, $\delta^{13}C$ values are higher than the adult mean, and around 3 years of age $\delta^{13}C$ values are variable. By 5 years of age $\delta^{13}C$ values are even more negative than the adult female mean.

Figure 5.4 - Subadult age-at-death estimates compared with $\delta^{13}C$ values.



Age-related variation in diet was also investigated for individuals age 4 years and older (*N* = 73). Subadults from the infancy-early childhood age category were removed from this analysis, as higher $\delta^{13}C$ and $\delta^{15}N$ levels from breastfeeding could cloud investigations of dietary variation in older individuals. A Kruskal-Wallis H test shows that there are no statistically significant differences in $\delta^{13}C$ values between age categories from Vagnari ($\chi^2(3) = 3.732$, $p = 0.292$). There is, however, a statistically significant correlation between $\delta^{15}N$ values and age categories ($\chi^2(3) = 14.346$, $p = 0.002$). The results of this test indicate that access to higher trophic level foods changed as an individual grew older at Vagnari. After breastfeeding, $\delta^{15}N$ values are lower in childhood and adolescent stages, then higher into early and mid-late adulthood stages.

Figure 5.5 - Variation in diet for individuals ages 4 and older.



Variation in $\delta^{15}N$ values for individuals 4 years of age or older are presented in Figure 5.5. The individuals in early and mid-late adulthood tend to have higher $\delta^{15}N$ values. Individuals from childhood and adolescent stages have $\delta^{15}N$ ranges extending the lowest of the categories studied, not including individuals of unknown age. Adults appear more likely to eat higher trophic level foods than children or adolescents at Vagnari.

5.4.3 Variation in collagen by burial date, burial type, and grave goods

For analyses of diet and burial type, breastfeeding and weaning individuals were removed so that dietary variation by burial treatment would not be obscured by age-related patterns. Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) data were compared with an individual's date of burial to see whether diet changed over time at Vagnari. The dates

of burial for people interred at Vagnari ranged from the 1st to 4th centuries AD, with most burials dating to the 2nd century AD (see Table 5.5). The $\delta^{13}C$ and $\delta^{15}N$ values are not significantly different between different dates of burial (Kruskal-Wallis test $\chi^2(3) = 0.945$, $p = 0.815$; $\chi^2(3) = 1.269$, $p = 0.737$, respectively), though the sample sizes of the 1st, 3rd, and 4th centuries are much smaller than the 2nd century. Results of the Kruskal-Wallis test reveal that the diet of people at Vagnari was isotopically very similar from the 1st to 4th centuries AD, though small sample sizes mean this result should be interpreted with caution.

Variation in isotopic signal was also compared with variation in burial type for individuals over 4 years old. Different burial treatments at Vagnari may indicate different treatment of people when they were alive. Using a Kruskal-Wallis H test, no significantly different distributions of $\delta^{15}N$ between burial type are present, ($\chi^2(4) = 1.421$, $p = 0.841$), but the distribution of $\delta^{13}C$ between different burial types is statistically significant ($\chi^2(4) = 12.533$, $p = 0.014$). These tests illustrate that $\delta^{13}C$ values are different among individuals with different burial treatments.

Table 5.5 - Vagnari collagen sample by date of burial, burial type, and size of grave good assemblage.

	n	**Mean $\delta^{13}C$ VPDB (‰)**	**SD**	**Mean $\delta^{15}N$ AIR (‰)**	**SD**
Date of Burial					
1st c. AD	3	-19.3	0.3	9.3	0.7
2nd c. AD	34	-19.0	0.5	9.3	0.8
3rd c. AD	9	-19.1	0.6	9.5	0.6
4th c. AD	1	-18.8	-**	8.7	-
Unknown	26	-19.3	0.4	9.0	1.0
Total	**73***				
Burial Type					
Cappuccina	56	-19.2	0.5	9.2	0.9
Disturbed	6	-18.6	0.3	9.3	1.2
Libation	5	-18.9	0.3	9.5	0.7
Pit	5	-19.4	0.4	9.2	0.9
Tile	1	-19.3	-	9.0	-
Total	**73**				
# of grave goods					
0-5	47	-19.2	0.5	9.1	1.0
6-10	19	-19.0	0.5	9.4	0.6
11-15	3	-19.0	0.2	9.3	0.9
16-20	1	-19.6	-	10.1	-
21-25	3	-19.4	0.9	9.8	0.4
Total	**73**				

** The total is 73, because individuals between 0-4 years of age are not included (n = 7).*
*** A dash (-) signifies unobservable or inapplicable data.*

Grave good assemblages and diet were also compared. The number of grave goods an individual was buried with is not significantly correlated with $\delta^{13}C$ ($r_s(70) = 0.034$, $p = 0.779$), but a weak positive correlation exists between $\delta^{15}N$ and the number of grave goods an individual was buried with ($r_s(70) = 0.259$, $p = 0.028$). The correlation between nitrogen isotopes and grave goods indicates that individuals with higher $\delta^{15}N$ values tended to be buried with greater numbers of grave goods.

The relationship between $\delta^{15}N$ and number of grave goods is graphed in Figure 5.6. The majority of individuals from the Vagnari sample (65%) were buried with less than 5 grave goods. Individuals with higher $\delta^{15}N$ values and 5 or more grave goods tended to be males from the age group adolescence or older (53%).

Figure 5.6 - Variation in $\delta^{15}N$ values and size of grave good assemblages at Vagnari.

5.5 Assessment of Bone Carbonate Preservation

Bone carbonate is the inorganic component of bone, and is also useful for the study of past diet, but can experience greater alteration in the post-mortem environment than collagen. Bone carbonate samples were evaluated for diagenesis using methods in Section 4.4.2. For the Vagnari sample, 19 out of 20 CI values fall in the

accepted range (3.1-3.8) (see Table 5.6), which suggested that the majority of the bones in the sample do not have diagenetically altered carbonate.

Table 5.6 - Calculated CI results from Vagnari.

ID #	CI	ID #	CI
F206	3.3	*F245*	3.2
F207	3.3	*F248*	3.5
F208	3.3	*F250*	3.1
F210	3.3	*F252*	3.3
F211	3.4	*F253*	3.5
F215	3.5	*F280*	3.9
F226	3.1	*F286B*	3.5
F229	3.4	*F289*	3.2
F234	3.0	*F296*	3.6
F235	3.5	*F55*	3.2
Mean		**3.4**	
SD		**0.2**	

One sample, F280, is beyond the accepted CI range and its carbonate has likely been diagenetically altered. The collagen yields from this individual were also too low to perform mass spectrometry. Since both the preservation of collagen and carbonate from F280 has been altered, it is excluded from further statistical analyses. In addition, one subadult (F210) was indicated by the Hatch Lab as an outlier during their lab procedures, and has also been removed from further statistical analyses.

5.6 Results from Isotopic Analyses of Bone Carbonate

5.6.1 Human and faunal diet from bone carbonate

The total diet of an organism is represented by $\delta^{13}C_{ap}$ from bone carbonate. Collagen results indicate the protein components of the diet, whereas total diet is

represented in bone carbonate. Faunal and human carbon isotopes ($\delta^{13}C_{ap}$) results are presented below.

Eight animals from Vagnari were analyzed for total diet from apatite. Their $\delta^{13}C_{ap}$ results are presented in Table 5.7. Apatite is enriched in ^{13}C over the diet consumed (Δ_{a-d}), where Δ is the offset between apatite and dietary values. Exact values of fractionation from diet are unknown, but are suggested to be ~12‰ by Krueger and Sullivan (1984). This can vary between species due to differences in digestive physiology; methanogenic animals such as cattle have higher apatite-diet spacing (12-14‰), whereas animals producing little methane have apatite-diet spacing of approximately 9‰ (Passey et al., 2005). Using 12‰ for the offset value, the adjusted $\delta^{13}C_{ap}$ values range from -20.8‰ to -24‰ (mean -22.6 ± 1.1‰), indicating a largely terrestrial diet with C_3 plants at its base.

Table 5.7 - Faunal bone carbonate ($\delta^{13}C_{ap}$) results.

Family	Genus	Species	Notes	$\delta^{13}C_{ap}$ VPDB (‰)	$\Delta^{13}C_{ap\text{-}col}$ VPDB (‰)	$\Delta_{ap\text{-}diet}$ VPDB (‰)
Unknown			Ungulate 1	-12.4	8.6	-24.4
Canidae	*Canis*	*lupus familiarious*	Dog	-11.2	8.4	-23.2
Suidae	*Sus*	*scrofa domesticus*	Pig	-8.8	11.3	-20.8
Bovidae	*Ovis*	*aries*	Sheep	-10.8	9.8	-22.8
Bovidae	*Bos*	*taurus*	Cow	-10.0	11.1	-22
Equidae	*Equus*		Equid	-10.7	10.0	-22.7
Unknown			Ungulate 2	-9.8	9.8	-21.8
Unknown			Ungulate 3	-10.9	10.9	-22.9
Mean				**-10.6**	**10.0**	**-22.6**
SD				**1.1**	**1.1**	**1.1**

The human apatite carbonate sample is composed of 48 individuals prepared for mass spectrometry, and 18 previously studied individuals (*N* = 66). Isotope data for the

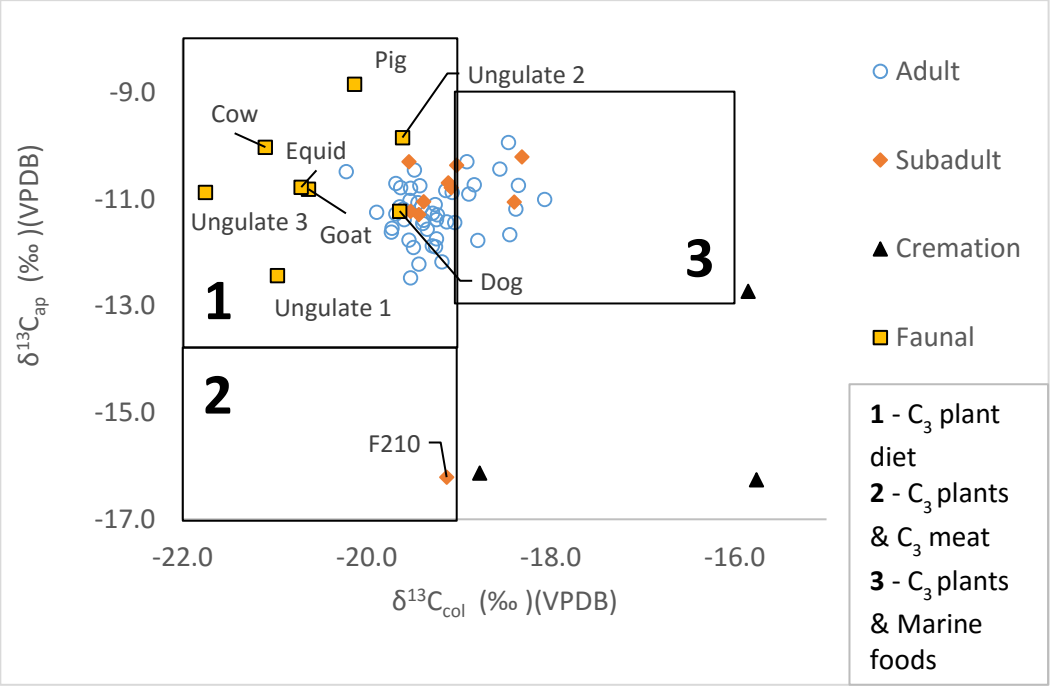
carbonate sample is presented in Table 5.8, and in Appendix C in full detail. The carbonate sample included adults (age-at-death >16 years) and subadults (age-at-death <15.9 years), but no infants or young children (age-at-death <3.9 years). Adult $\delta^{13}C_{ap}$ values range from -12.5% to -10.3‰ (mean -11.2 ± 0.5‰), and subadult $\delta^{13}C_{ap}$ values range from -11.3‰ to -10.2‰ (mean -11.3 ± 1.8 ‰). The ranges of total diet between adults and subadults are similar. If 12‰ is used for the fractionation from diet, the adjusted values range from -22.3‰ to -24.5‰ (mean -23.2 ± 0.5‰). As with the faunal results, the adjusted human $\delta^{13}C_{ap}$ values align with a diet based largely on terrestrial C_3 foods. Figure 5.7 plots $\delta^{13}C_{ap}$ versus $\delta^{13}C_{col}$ and demonstrates the pervasiveness of C_3 foods in the total diet at Vagnari. Some individuals are in the area of the graph (Box 3) typically occupied by consumers of marine foods, however the collagen isotope ratios from Vagnari are not indicative of marine food consumption as the $\delta^{15}N$ values are rather low. The individuals from Vagnari in Box 3 may have mixed foods such as freshwater fish or millet in their diet, resulting in more positive $\delta^{13}C_{col}$ values than individuals eating only C_3 terrestrial foods.

Table 5.8 – $\delta^{13}C_{ap}$ data for the human apatite sample.

Sample ID	$\delta^{13}C_{ap}$ VPDB (‰)	$\Delta^{13}C_{ap\text{-}col}$	$\Delta_{ap\text{-}diet}$	Sample ID	$\delta^{13}C_{ap}$ VPDB (‰)	$\Delta^{13}C_{ap\text{-}col}$	$\Delta_{ap\text{-}diet}$
B2	-10.7	-	-22.7	**F252**	-10.8	8.9	-22.8
B2A	-11.0	-	-23.0	**F253**	-12.2	7.0	-24.2
B5	-11.9	-	-23.9	**F254**	-11.9	7.4	-23.9
F100	-11.1	8.2	-23.1	**F280**	-11.0	-	-23.0
F104	-12.7	8.2	-24.7	**F286A**	-11.1	8.5	-23.1
F126	-11.9	7.6	-23.9	**F286B**	-11.2	8.3	-23.2

F127	-11.7	6.8	-23.7	**F287**	-11.4	7.9	-23.4
F200	-12.2	7.2	-24.2	**F289**	-10.3	9.3	-22.3
F201	-16.3	-0.5	-28.3	**F290**	-11.4	7.7	-23.4
F204	-11.3	8.0	-23.3	**F291**	-12.5	7.1	-24.5
F205	-11.3	8.4	-23.3	**F293**	-11.6	7.8	-23.6
F206	-11.5	7.9	-23.5	**F294**	-11.0	8.5	-23.0
F207	-10.7	8.7	-22.7	**F296**	-11.4	8.0	-23.4
F208	-10.4	8.7	-22.4	**F298**	-11.7	7.5	-23.7
F209	-10.7	8.4	-22.7	**F302**	-16.1	2.6	-28.1
F210	-16.2	2.9	-28.2	**F306**	-10.9	8.2	-22.9
F211	-11.1	8.4	-23.1	**F312**	-10.8	8.7	-22.8
F213	-11.8	7.8	-23.8	**F34**	-10.9	8.0	-22.9
F214	-11.6	8.1	-23.6	**F37**	-11.0	-	-23.0
F215	-11.2	8.7	-23.2	**F40**	-10.4	9.0	-22.4
F216	-10.5	9.7	-22.5	**F48**	-11.0	7.3	-23.0
F218	-11.3	8.2	-23.3	**F49**	-10.2	8.1	-22.2
F220	-10.7	9.0	-22.7	**F55**	-11.0	8.3	-23.0
F226	-10.8	8.3	-22.8	**F59**	-11.1	-	-23.1
F229	-11.8	7.0	-23.8	**F67**	-11.9	7.4	-23.9
F231	-11.3	7.9	-23.3	**F68**	-10.7	7.6	-22.7
F234	-10.4	8.1	-22.4	**F86**	-11.5	8.2	-23.5
F235	-11.2	8.4	-23.2	**F89**	-11.0	7.1	-23.0
F245	-10.8	8.3	-22.8	**F93**	-10.7	8.1	-22.7
F246	-11.1	8.3	-23.1	**F94**	-9.9	8.5	-21.9
F248	-11.4	8.2	-23.4	**F96A**	-11.1	7.7	-23.1
F249	-11.4	7.6	-23.4	**F96B**	-10.3	7.4	-22.3
F250	-10.3	8.6	-22.3	**F98**	-11.2	7.2	-23.2
Mean $\delta^{13}C_{ap}$	-11.4	**Mean $\Delta^{13}C_{ap\text{-}col}$**	7.7	**Mean $\Delta_{ap\text{-}diet}$**	-23.4		
SD	1.2	**SD**	0.5	**SD**	1.2		

Figure 5.7 - Carbon from collagen ($\delta^{13}C_{col}$) plotted against bone carbonate ($\delta^{13}C_{ap}$). Overlain boxes are adapted from Krueger & Sullivan (1984).



In Figure 5.7, most of the humans and animals occupy the same area representing diets heavy in C_3 plants. The faunal sample is more widespread, whereas the human values are more tightly clustered. Similar to what was seen with the collagen samples, the dog and ungulate 2 approximate human dietary values, meaning that their total diet was similar to humans. Additionally, individuals who were cremated have atypical $\delta^{13}C_{ap}$ values. Four outliers, including cremated individuals and one subadult (F210), are also depicted. Their $\delta^{13}C_{col}$ values range from ~-16‰ to -19.0‰, and $\delta^{13}C_{ap}$ from ~-16.0‰ to -13.0‰, which is atypical of the other human isotope values.

The $\delta^{13}C_{ap}$ data were also tested for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests, and significantly deviated from a normal distribution (p = < 0.05).

Non-parametric tests were also applied in statistical analyses of Vagnari carbonate isotope ratios.

5.6.2 Sex-based variation in diet from bone carbonate

Bone carbonate data were compared with an individual's sex to investigate variation in total diet at Vagnari. The human carbonate sample consists of 29 males and 21 females. A Mann-Whitney U test shows that there are no statistically significant differences between male and female $\delta^{13}C_{ap}$ values ($U = 226$, $p = 0.123$). A lack of significant variation in $\delta^{13}C_{ap}$ values suggests that the total diets of males and females were similar at Vagnari.

Table 5.9 - Carbonate sample divided by sex.

	n	**Min. $\delta^{13}C_{ap}$ VPDB (‰)**	**Max. $\delta^{13}C_{ap}$ VPDB (‰)**	**Mean**	**SD**
Male	29	-10.3	-12.5	-11.3	0.6
Female	21	-9.9	-11.7	-11.1	0.4
Unknown Adults	3	-10.3	-11.1	-10.8	0.5

5.6.3 Age-based variation in diet from bone carbonate

Collagen results indicated statistically significant variation in $\delta^{15}N$ with age-at-death, so $\delta^{13}C_{ap}$ values of an individual were compared with their age categories to see if this variation extended into total diet. The bone carbonate sample divided by age groups is presented in Table 5.10. There is a statistically significant difference in diet from $\delta^{13}C_{ap}$ between age groups using the Kruskal-Wallis H test ($\chi^2(3) = 8.493$, $p = 0.037$). A

correlation between $\delta^{13}C_{ap}$ and age categories indicates that diet changed in isotopically significant ways as an individual grew older.

Table 5.10 - Distribution of the $\delta^{13}C_{ap}$ values across age categories.

Age Category	***Age (years)***	***n***	**Mean $\delta^{13}C_{ap}$ VPDB (‰)**	**SD**
Infancy-Early Childhood	0-3.9 years	0	-	-
Childhood	4-14.9 years	8	-10.9	0.4
Adolescence	15-29.9 years	15	-11.1	0.5
Early Adulthood	30-44.9 years	8	-10.8	0.6
Mid-Late Adulthood	45+ years	12	-11.5	0.5
Unknown Adults		19	-11.2	0.5
Total		**62**		

5.6.4 Variation in $\delta^{13}C_{ap}$ values by burial date, burial type, and grave goods

Differences in burial treatment were also analyzed to explore individual variation in diet from bone carbonate at Vagnari. The $\delta^{13}C_{ap}$ values are analyzed by date of burial, type of burial, and size of grave good assemblage (Table 5.11). Date of burial was compared with $\delta^{13}C_{ap}$ values to see if total diet varied over time at Vagnari. A Kruskal-Wallis H test showed that there are no statistically significant differences in $\delta^{13}C_{ap}$ values between burial dates ($\chi^2(2) = 4.898$, $p = 0.086$). Diet as indicated by $\delta^{13}C_{ap}$ is isotopically similar from the 1st to 3rd centuries at Vagnari.

Burial type, which may indicate different social treatments of people in life and death, were compared with $\delta^{13}C_{ap}$ values. The distributions of $\delta^{13}C_{ap}$ values across different burial types are not statistically significant using a Kruskal-Wallis H test ($\chi^2(3) = 5.482$, $p = 0.140$). Grave good assemblages were also compared with $\delta^{13}C_{ap}$ values. The

number of grave goods an individual was buried with also is not significantly correlated with $\delta^{13}C_{ap}$ values ($r_s(57)= -0.014$, $p = 0.914$). These results illustrate that total diet was similar among individuals who were commemorated differently in death.

Table 5.11 - Burial treatments of the Vagnari apatite carbonate sample.

	n	**Mean $\delta^{13}C_{ap}$ VPDB (‰)**	**SD**
Date of Burial			
1st c. AD	2	-11.4	0.0
2nd c. AD	27	-11.2	0.6
3rd c. AD	6	-10.6	0.5
Unknown	27	-11.2	0.5
Total	**62**		
Burial Type			
Cappuccina	49	-11.1	0.5
Disturbed	3	-11.3	0.3
Libation	3	-11.0	0.3
Pit	4	-11.7	0.4
Unknown	3	-11.2	0.6
Total	**62**		
# of grave goods			
0-5	42	-11.2	0.5
6-10	13	-11.0	0.6
11-15	2	-11.0	0.4
16-20	0	n/a	n/a
21-25	2	-11.1	0.9
Unknown	3	-11.2	0.6
Total	**62**		

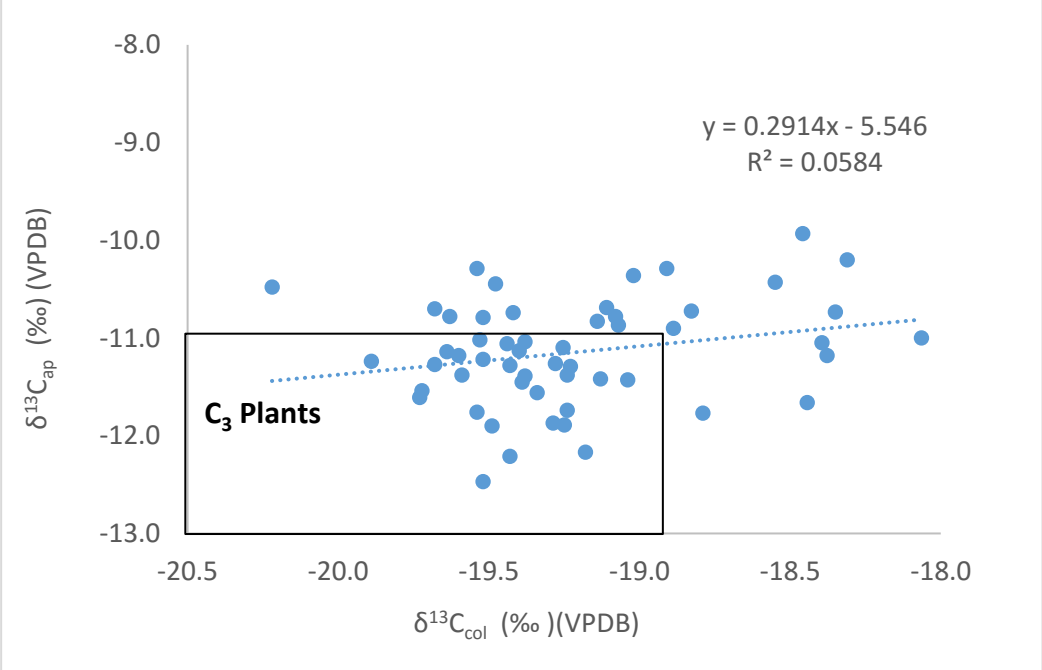
5.6.5 Apatite and collagen spacing

Apatite-collagen spacing is used to compare the protein content with the total diet, and indicates whether the diet of an organism is more herbivorous, omnivorous, or carnivorous (Krueger & Sullivan, 1984; Lee-Thorp et al., 1989). Vagnari apatite-collagen

spacing ($\Delta^{13}C_{ap\text{-}col}$) ranges from 6.78‰ to 9.74‰ (mean 8.1 ± 0.6‰) (see Table 5.8). Spacing in the Vagnari isotopic data is most similar to that of an herbivorous diet, which has an apatite-collagen spacing of 7‰ (Krueger & Sullivan, 1984).

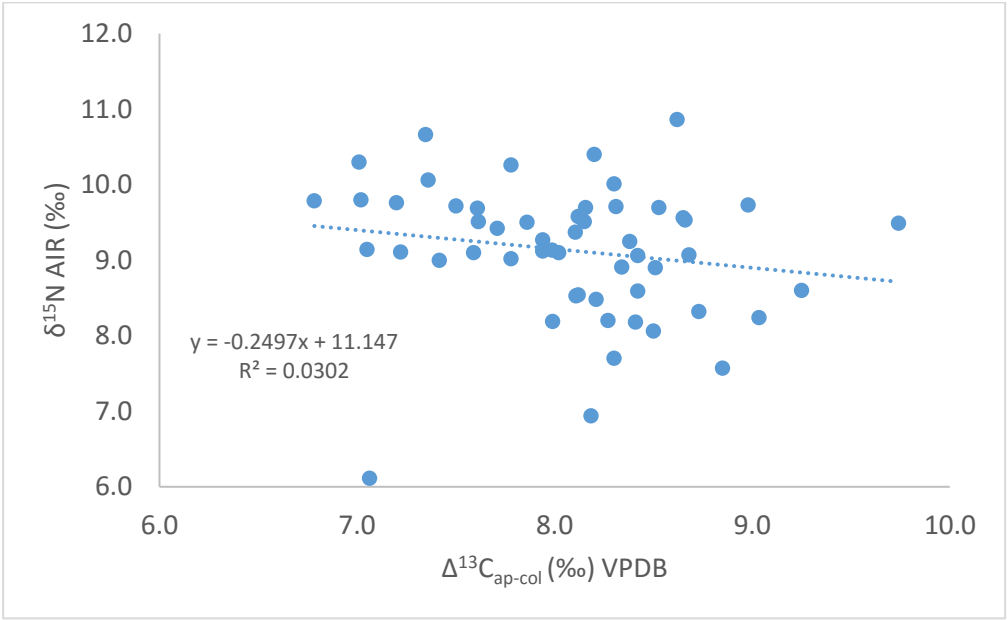
When values of $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ are compared, they are not significantly correlated (Spearman's $r_s(52)= 0.207$, $p = 0.133$). Comparisons of $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ from the human sample at Vagnari are illustrated in Figure 5.8. The relationship between $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ values of an individual are influenced by trophic level (Lee-Thorp et al., 1989), and there are indications of trophic level differences in diet at Vagnari. The absence of a clear linear correlation between $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ at Vagnari could signify diagenetic alteration in carbonate, or trophic level differences if there is a correlation between apatite-collagen spacing and $\delta^{15}N$ (Wright & Schwarcz, 1996).

Figure 5.8 - Relation between human $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ values.



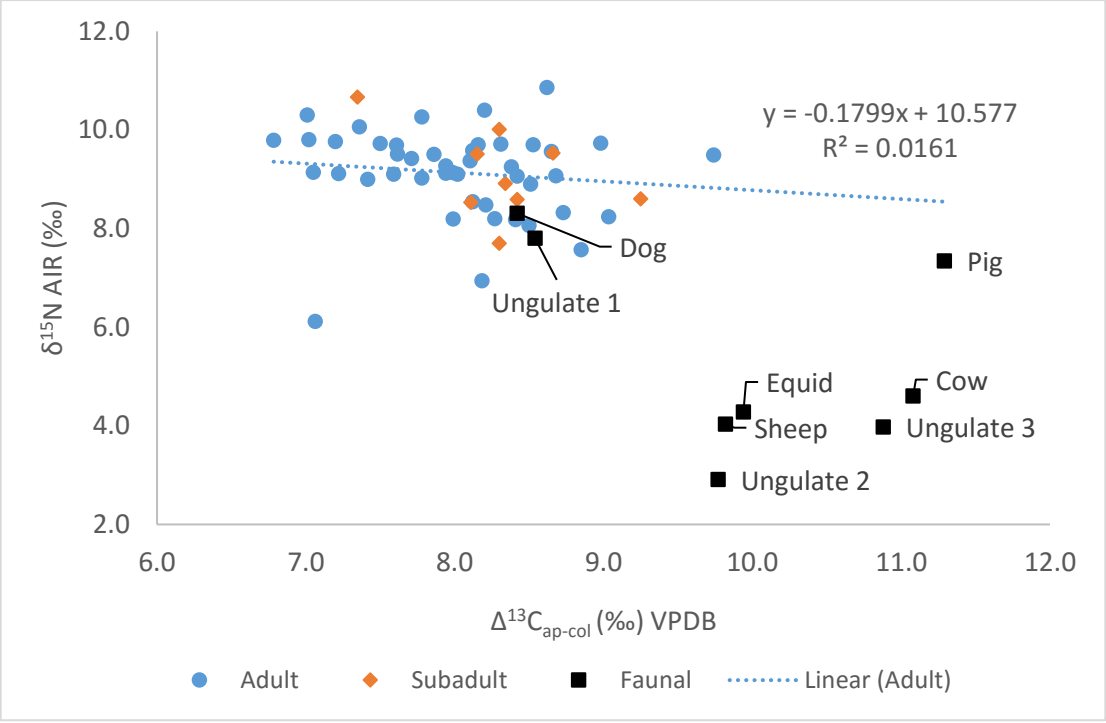
Since the FTIR results indicate that the apatite carbonate is well preserved for 19 of the 20 samples studied (Section 5.5), it is unlikely that a lack of correlation between $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ is due to diagenetic alteration. Comparisons of $\Delta^{13}C_{ap\text{-}col}$ and $\delta^{15}N$ are plotted in Figure 5.9, and a slight negative correlation is present between them (Spearman's $r_s(52)= -0.301$, $p = 0.027$). At Vagnari, diets with higher $\delta^{15}N$ values had smaller values of apatite-collagen spacing. Prowse and colleagues (2005) suggested that high apatite-collagen spacing, a lack of a linear $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ relationship, and a negative correlation between $\Delta^{13}C_{ap\text{-}col}$ and $\delta^{15}N$ are typically found in diets based on $\delta^{13}C$, non-protein foods. The same conditions are present at Vagnari, which suggests these people subsisted on a diet heavy in plant-based foods.

Figure 5.9 - Correlation between human apatite-collagen spacing ($\Delta^{13}C_{ap\text{-}col}$) and $\delta^{15}N$.



When $\Delta^{13}C_{ap\text{-}col}$ and $\delta^{15}N$ are compared between humans and animals at Vagnari (Figure 5.10) the two groups form separate clusters, though the dog, ungulate 1, and to some extent the pig approximate human values. The herbivorous species at Vagnari also have $\Delta^{13}C_{ap\text{-}col}$ values over the expected herbivore spacing of 7‰. There are distinct trophic level differences of approximately +3‰ between human and faunal diets, meaning their protein content differs between the two different largely plant-based diets. These results suggest that there were small protein components to the diet at Vagnari, though it was largely based on C_3 plants.

Figure 5.10 - Comparison of apatite-collagen spacing ($\Delta^{13}C_{ap\text{-}col}$) and $\delta^{15}N$ for humans and animals at Vagnari.



5.7 Conclusion

The stable isotope data indicate a largely plant-based human diet at Vagnari, but these people were not true herbivores. Collagen results show a reliance on C_3-plant based proteins incorporated in the diet. Results from the bone carbonate also indicate a plant-based total diet, with possible C_4 plants or freshwater fish mixed in with C_3 foods. Diet varied for individuals with age-at-death as a result of breastfeeding and other factors. Most variation in burial treatment did not vary with diet, but $\delta^{13}C$ values are correlated with burial type and $\delta^{15}N$ values are slightly correlated with the size of grave good assemblages. Overall, the diet among the Vagnari sample is very similar, with some variation based on age and different burial treatments.

6 Discussion

6.1 Introduction

Components of the diet at Vagnari, as well as individual variation in diet are discussed in this chapter. Results from stable isotope analysis are integrated with information from stable isotope literature, archaeological evidence, and Roman historical research to interpret diet at Vagnari. Correlations between diet and age-at-death, burial type, and grave good assemblages are explored. Published isotope data from Imperial period sites are also compared with Vagnari to investigate geographic variation in diet across Roman Italy. Dietary variation both within and beyond Vagnari will be explored in this chapter.

6.2 Plant-based Diets at Vagnari

Plants from the C_3 photosynthetic pathway were central to the diet of people living at Vagnari. Roman diet is conceived of as a Mediterranean triad of cereals, olives and wine (Garnsey, 1999). The components of the Mediterranean triad are mainly C_3 plants (with exceptions like millet), which overlaps with the stable isotope results at Vagnari. Many plants belong to the C_3 pathway, so it is difficult to establish precisely the types of plants people at Vagnari would have eaten from stable isotopes alone. Charred plant remains from a hearth at Vagnari were identified as durum wheat, a crop that was grown at the estate (Carroll, 2013). Wheat made up part of the agricultural lands at Vagnari and could have been exported for profit, but it is also likely that the site's

inhabitants could have eaten it. Cereals were most commonly eaten in the form of breads or porridges (Garnsey, 1999), so it is possible wheat could have been cooked and eaten in these forms at Vagnari. The prevalence of caries in both deciduous and permanent dentition at Vagnari also suggests a diet based on cereals (Prowse et al., 2014).

Absent from the stable isotope values at Vagnari are indicators of sole reliance on 'poor' Roman foods, such as legumes or millet. Legumes were eaten by people of various classes, but were relied upon by the poor as a source of protein and had little associated prestige (Garnsey, 1999). Legumes would have nitrogen isotope values close to 0‰ (AIR), and the $\delta^{15}N$ values of humans who ate a diet composed exclusively of legumes would be approximately 3‰ (Katzenberg, 2008). The Vagnari human $\delta^{15}N$ values range from 6.1‰ to 13.2‰, and exhibit a trophic level effect above the herbivorous animals found at the site, indicating the people were consuming these animals or their by-products (e.g., milk and cheese).

There are also no isotopic traces for the sole consumption of millet, a low-prestige grain for Romans. Millet, a C_4 plant, would have a distinct isotopic signal ($\delta^{13}C_{col}$ values of -9‰ to -16‰) in comparison with C_3 plants (Vogel & van der Merwe, 1977). People who ate strictly C_4 plant-fed animals would also have distinct isotopic signatures from C_3-based diets, so it is unlikely that C_4 plants were used as animal fodder at Vagnari, unless in combination with C_3 plants. Vagnari $\delta^{13}C_{col}$ values range from -20.2‰ to -17.1‰, indicating a diet based mainly on C_3 plants, but it is possible that C_4 foods

such as millet were mixed into the diet. At Vagnari there is no isotopic evidence of reliance only on lower-prestige foods, but foods such as millet may still have been incorporated into the diet in small portions.

Total diet from apatite ($\delta^{13}C_{ap}$) indicates a heavily plant-based diet at Vagnari, whereas collagen indicates the presence of an animal-based protein component, however small. These results align with suggestions from Garnsey (1999) that meat was not a staple of Roman diet. Romans ate meat, but it was not always the central component of a meal. Of the meats available, pork was the most commonly eaten by Romans. When the nitrogen isotope values of the pig and human values from Vagnari are compared, only 9 individuals not being breastfed or weaned have high enough $\delta^{15}N$ values to demonstrate a trophic level effect of +3‰ over the pig $\delta^{15}N$ value (7.3‰, see Appendix D). At Vagnari, there are skeletal remains of other animals that could have been eaten for meat (i.e. cow, sheep, ungulates), but it may have been more beneficial to the people to raise these animals for secondary products such as wool, milk, or cheese.

Almost all of the humans at Vagnari (*n* = 78) have $\delta^{15}N$ values high enough to demonstrate a trophic level effect over animals like the cow and sheep ($\delta^{15}N$ 4.0‰ to 4.6 ‰, respectively, see Appendix D). Humans exhibiting a trophic level effect over the nitrogen isotope ratios of animals does not necessarily mean that people were eating these animals. People at Vagnari could also be consuming milk or cheese from these animals, which isotopically looks no different than eating an animal's flesh. Small (2011)

suggests that workers at Vagnari were employed to herd and shear large groups of sheep, as well as make cheeses. Halstead (2012) suggests that sheep were kept by Romans as sources of both wool and mutton, but wool grew in importance from the Iron Age into the Roman Period. At a rural estate like Vagnari, workers could have specialized in dairying or cheese making for trade exports, as well as to feed themselves.

Animals at Vagnari including a dog, pig, and ungulate 1 had isotopically similar diets to the humans at Vagnari. Dogs and pigs may have more omnivorous diets closer to humans, as they can be fed scraps of human food. The similarity between human and ungulate $\delta^{15}N$ values could be due to the "manure effect." Animal manure is high in $\delta^{15}N$, and when applied to the soil as fertilizer, the nitrogen isotopes are incorporated into cereal crops (Bogaard, Heaton, Poulton, & Merbach, 2007; Fraser et al., 2011). Bogaard and colleagues' pilot study showed that manured crops can yield $\delta^{15}N$ values of 6‰ to 8‰, which would result in $\delta^{15}N$ values from 9‰ to 11‰ in organisms consuming manured crops (Bogaard et al., 2007). This ungulate could have been fed harvested cereal crops that were fertilized with manure, which resulted in $\delta^{15}N$ values that were isotopically similar to a human eating animal-based protein. Other animals at Vagnari, such as the cow or sheep, could have fed themselves by grazing on non-manured grasses, resulting in lower $\delta^{15}N$ values.

If some of the animals at Vagnari are exhibiting the manure effect, it is possible for this phenomenon to be present in humans as well. Nitrogen values resulting from the manure effect are similar to nitrogen isotopes from mixed plant and animal-based

protein diets (Bogaard et al., 2007). High nitrogen values from manured crops at Vagnari would also align with carbonate results at the site, which isotopically suggest a diet heavily based on C_3 plants and little protein. It is uncertain whether the human $\delta^{15}N$ at Vagnari came from eating animal flesh, animal by-products, fertilized cereals, or a combination of the three. There is an animal-based protein component to the diet at Vagnari, but it is unclear what foods people at Vagnari were eating to get their protein.

The diet exhibited at Vagnari is most likely that of ordinary Romans. Inhabitants at Vagnari were not indulging in luxuries such as fish, seafood, or high quantities of meat. They also were not solely dependent on low-prestige foods such as legumes or millet to survive. Inhabitants at Vagnari kept a diet high in C_3 plants consistent with the Mediterranean triad, along with some animal-based protein and C_4 plant contributions. From an isotopic perspective, the people at Vagnari were eating a diet that was common across the Roman Empire.

6.3 Similarities in Diet Across Sex

The foods eaten by males and females from Vagnari were isotopically very similar, suggesting that sex had a minimal influence over diet. Similar diets between sexes contrasts with patterns from the Vagnari dental health data, as well as recommendations from Roman dietetics for men and women to eat different foods to keep their humours balanced. Diets advised for women were based on dry cereals with non-fatty land-based protein (Garnsey, 1999; Prowse, 2011). Although the exact food types cannot be discerned from stable isotopes, at Vagnari it is observed that females

were eating a diet based on C_3 plants with terrestrial animal-based protein. The alignment of foods eaten by females at Vagnari with dietary recommendations could be intentional, or coincidental.

Roman men had much fewer restrictions from dietetics, but despite this the foods eaten by males from Vagnari are isotopically indistinguishable from foods eaten by females. A typical Roman male diet as indicated by Broekaert & Zuiderhoek (2012) was made up of cereal porridge, olive oil, legumes, pulses and cheap wine. Legumes appear to be absent from the diet at Vagnari, but C_3 plants made up a large portion of foods eaten by males. Isotope ratios of foods actually eaten by males at Vagnari affirm a typical diet for Roman men, but also align with recommended diets for Roman women.

Similarities in isotope ratios of foods between sexes can be observed at Vagnari, but the aim is to analyze gendered behaviours towards food. Gendered differences in food for Roman men and women were performative, and not solely based on the type of food they ate. One's occupation, role in society, or power within the household could give access to different types, qualities, and quantities of food. These behavioural aspects of food are not necessarily preserved in physical traces of sex and isotopic indicators of diet. Dental health data from Vagnari indicates males had more cavities and AMTL than females, suggesting that men ate a more cariogenic diet (Prowse et al., 2014). The foods eaten by men and women were from isotopically similar sources, but the forms they were eaten as could have differed with males eating more soft, sticky foods than females. Differences in oral health between males and females at Vagnari

could also relate to gendered differences in oral hygienic behaviours. Other gendered patterns of behaviour, such as the gendered division of labour are suggested from skeletal trauma at Vagnari (Prowse et al., 2014), but this may not have translated to differences in diet.

Another possibility is that gendered food behaviour may not have played out at Vagnari as recommended from medical texts. Medical treatises were written by upper class males who could afford to choose the types of food they ate (Garnsey, 1999), which does not represent the food options and choices other Romans may have faced. Proscribed gendered norms towards food may or may not have been followed at Vagnari; at the very least, they were not enacted to a degree where they resulted in significantly different isotopic compositions of male and female diets.

6.4 Age Related Variation in Diet

Results from both collagen and carbonate indicate age-related variation in diet. The first instance of age-related variation in diet at Vagnari is for individuals in the infancy-early childhood stage, during which breastfeeding and weaning takes place. Results of both $\delta^{15}N$ and $\delta^{13}C_{col}$ values compared with age-at-death show patterns of breastfeeding and weaning. Nitrogen and carbon isotopes are elevated in individuals 3 years of age or less, and at around age 3 the $\delta^{15}N$ and $\delta^{13}C_{col}$ values approach the adult female mean. These results are consistent with other isotopic studies of Roman infant feeding, which estimate weaning occurring by approximately age 3 in Roman Italy, Britain, and Egypt (Dupras et al., 2001; Dupras & Tocheri, 2007; Fuller et al., 2003; Fuller

et al., 2006; Prowse et al., 2008). After 3 years of age, and definitely by 5 years of age, the $\delta^{15}N$ and $\delta^{13}C_{col}$ values of subadults become similar to adult female means.

Historical sources indicate that Roman infants were weaned around age 1 using cereal-based foods, such as porridge or bread softened with honey or milk (Garnsey, 1999; Prowse, 2011). It is difficult to pinpoint an exact weaning age at Vagnari, as the sample of individuals from the weaning period is small (*n* = 7), and few are precisely aged. Though the timing of weaning is uncertain, physician-recommended weaning foods could have been used at Vagnari. Semi-liquid cereals were suggested as weaning foods by both Soranus and Galen (Garnsey, 1999; Harlow & Laurence, 2002). With weaning, subadult $\delta^{13}C_{col}$ values and $\delta^{15}N$ values approximate the mean adult female isotope ratios, which are based on foods such as C_3 plants and terrestrial proteins. Cereals such as wheat were grown at Vagnari and could have been used as a weaning food. Weaning-aged subadults could have also continued to drink milk, but from the cows or sheep at the site, as they exhibit a trophic level effect of +3‰ over the $\delta^{15}N$ values of these animals.

Another possible explanation for the elevated $\delta^{15}N$ levels of individuals in the infancy-early childhood category is nutritional stress. Proteins that are synthesized when an individual is nutritionally stressed have $\delta^{15}N$ values higher than the typical diet. These effects have been observed in the hairs of people experiencing nutritional stress from pregnancy, anorexia nervosa, and bulimia nervosa, long term illnesses, or infections (D'Ortenzio et al., 2015; Fuller et al., 2005; Hatch et al., 2006; Mekota, Grupe, Ufer, &

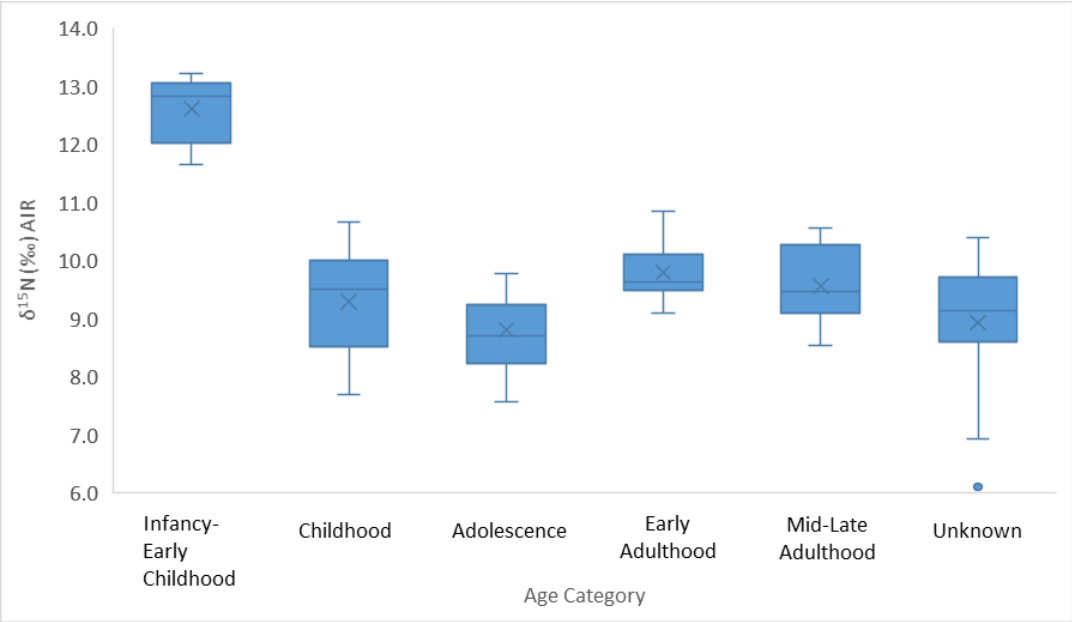
Cuntz, 2006). Stress-induced enrichment of ^{15}N influences other parts of the body including the skeleton, as Katzenberg and Lovell (1999) observed elevated $\delta^{15}N$ values in pathological bone, which would have remodelled during a period of stress.

The period of weaning is considered to be a stressful period in an infant's life (Katzenberg, Herring, & Saunders, 1996). Infants are more susceptible to disease and malnutrition with the transition in diet to solid foods. At Vagnari, individuals aged from 0 to 14 years had the highest incidences of stress as indicated by LEH (Prowse et al., 2014). The infants studied at Vagnari were non-survivors, and because they died around the time of weaning their $\delta^{15}N$ values have to be interpreted with caution. Interpretations of breastfeeding and weaning practices at Vagnari are also limited, because the sample of infants and young children is made up of non-survivors, whereas those who were successfully weaned survived and grew older. The Vagnari cemetery sample can give useful indications of breastfeeding and weaning activities, but the practices of the living cannot fully be interpreted from the deceased.

There are additional age-based differences in diet after individuals were weaned at Vagnari. A comparison of changes in $\delta^{15}N$ values over age categories at Vagnari is presented in Figure 6.1. During the infancy-early childhood stage individuals are at a high trophic level due to effects such as breastfeeding, nutritional stress, or a combination of the two. Individuals in the childhood stage have much lower $\delta^{15}N$ values (mean 9.3 ± 0.9‰), but the lowest mean $\delta^{15}N$ values are among individuals in the adolescent stage (8.8 ± 0.6 ‰). The next notable transition in $\delta^{15}N$ values is between the

age categories of adolescence and early adulthood, which shows an increase in $\delta^{15}N$ values. The $\delta^{15}N$ values remain relatively similar between categories of early adulthood (mean 9.8 ± 0.5 ‰) and mid-late adulthood (9.6 ± 0.6 ‰).

Figure 6.1 - $\delta^{15}N$ values by age categories at Vagnari.



Foods with higher trophic levels may have been more difficult for adolescents to access. The adolescent stage was a transitional period of life where they were not considered full adults (Harlow & Laurence, 2002). At Vagnari, skeletal trauma in individuals aged 15-30 years suggests that people were engaged in strenuous work from a young age, whereas LEH data indicates different experiences in stress between people aged 15-30 and 31-45 years (Prowse et al., 2014). Adolescence at Vagnari was a period where individuals had similar responsibilities as adults, but differing experiences of

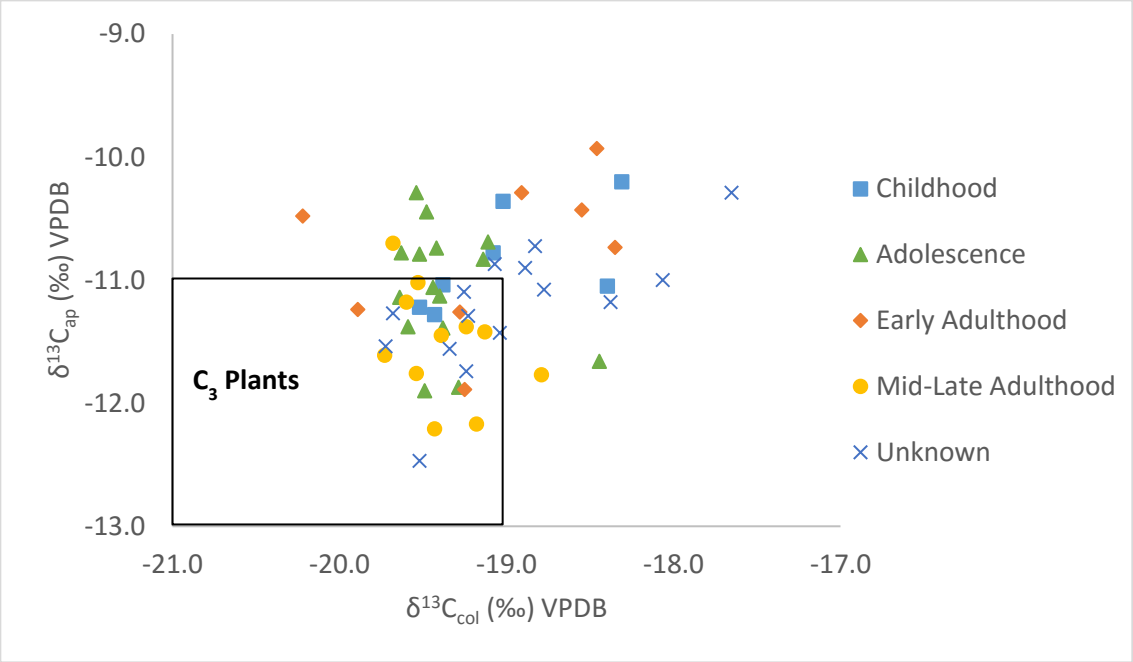
stress, which could influence differences in diet. Individuals in the adulthood categories may have had the most power in being able to access higher trophic level foods.

Individuals in the childhood, early adulthood, and mid-late adulthood categories at Vagnari had access to foods similar in trophic level. Roman childhood or *pueritia* was the time when a child's formal education began, or they took on new chores and responsibilities (Rawson, 2003). Children were thought to possess humours similar to women, and once weaned they were recommended to take on a diet similar to adult women (Garnsey, 1999). Adult females and males had isotopically indistinguishable diets, so it is uncertain whether this recommendation was intentionally followed at Vagnari. With the transition to childhood at Vagnari came a different diet that was isotopically similar to foods eaten by adults, which could align with new responsibilities on the estate.

Variation in total diet ($\delta^{13}C_{ap}$) also demonstrates age-related patterns. Total diet is similar between periods of childhood, adolescence and early adulthood. The most drastic difference is in $\delta^{13}C_{ap}$ values between categories of early (mean -10.8 ± 0.6‰) and mid-late adulthood (mean -11.5 ± 0.5‰). The total diet was similar from childhood to early adulthood, with a shift in diet occurring during mid-late adulthood. When values of $\delta^{13}C_{ap}$ and $\delta^{13}C_{col}$ are plotted for each age category (Figure 6.2), individuals from the mid-late adulthood category cluster in the region typical of high C_3 plant diets. The younger individuals outside of the C_3 box were likely mixing foods such as millet or

freshwater fish in their diet. This suggests the total diet of individuals from mid-late adulthood was more plant-based than diets of younger age categories.

Figure 6.2 - Plotted $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ values by age categories at Vagnari. Overlain box adapted from Krueger & Sullivan (1984).



Roman dieticians also made food recommendations based on age. Aging was though by Romans to be a process that dried and hardened the body and increased its fragility (Cokayne, 2003). Moist, warm foods that were easy to digest were recommended to balance the humours of older Romans (Cokayne, 2003). Foods to avoid included pork, cheese, and starches, while increased wine drinking was encouraged (Cokayne, 2003). The comparison of collagen and apatite $\delta^{13}C$ values indicates that the foods eaten by individuals in the mid-late adulthood stage were more plant-based. However, $\delta^{15}N$ values did not change significantly between individuals from

early and mid-late adulthood. Some meats were recommended by dieticians over others in old age, such as fowl because it was easy to digest (Cokayne, 2003). Additional dietary recommendations for older Romans included eating more frequently but in small amounts (Cokayne, 2003). At Vagnari this could indicate that older individuals still ate animal-based proteins, but different types or smaller amounts than the proteins eaten by younger individuals.

6.5 Variation in Diet and Burial Treatment

Burial treatment at Vagnari also provides interesting insights into diet at Vagnari. Bone samples from cremated burials were prepared for mass spectrometry in an effort to see if they could be used in stable isotope analysis. Measures of collagen preservation including percent yield and C:N ratios indicated that taphonomic processes affected isotope ratios in cremated bone. This post-mortem alteration was likely from the individuals being burned at high temperatures. Values of $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ from cremated bone tended to be more positive than the typical diet, and cremated $\delta^{15}N$ values tended to be much lower than the typical diet at Vagnari. These findings demonstrate that cremation alters an individual's stable isotope ratios to the point where they are no longer reliable representations of diet.

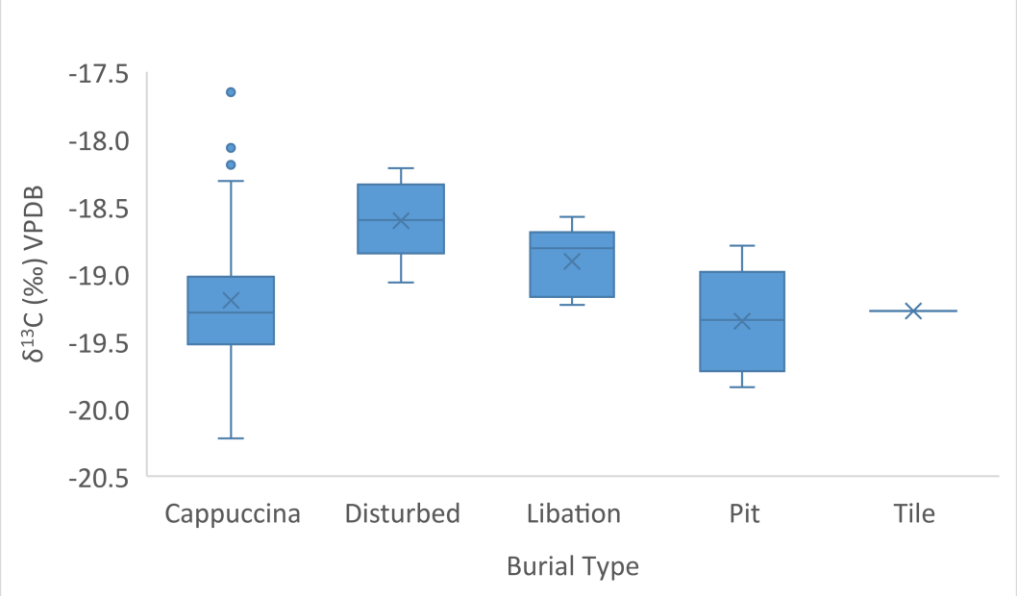
For the cemetery sample studied at Vagnari, individuals dating to different centuries did not have significantly different diets. Regional patterns suggested a period of instability from the 3rd century AD and onwards, with the Roman state weakening, trade diminishing, taxation increasing, and lands being abandoned (Kehoe, 2006).

Isotopically there is no evidence of instability in diet, as stable isotope ratios remained similar over the 1st to 4th centuries AD at Vagnari, although there are only a small number of samples from the 1st and 4th centuries. It is possible that the diet stayed the same during this period, or that any changes in diet were not isotopically distinguishable from foods previously eaten. These hypotheses are tentative, as the sample studied mainly contained individuals who were buried in the 2nd century AD. A more robust sample containing higher numbers of individuals from the 1st, 3rd, and 4th centuries AD would be needed to thoroughly investigate the changes in diet at Vagnari over time. With results from present materials, the isotope values of diet are very similar spanning the 1st to 4th centuries AD.

Carbon isotopes ($\delta^{13}C_{col}$) varied significantly across burial types at Vagnari. When burial type and $\delta^{13}C_{col}$ is compared, *cappuccina* burials have the greatest range of carbon values. *Cappuccina* burials were typical of ordinary Romans, so this suggests that ordinary Romans had a range of different $\delta^{13}C_{col}$ values in their diet. A pairwise Kruskal-Wallis test indicates the most significant differences in $\delta^{13}C_{col}$ values occur between disturbed and cappuccina burials ($p = 0.024$). Disturbed burials were any instances of post-mortem alteration of an individual's burial structure at Vagnari. Diagenetic alteration of the $\delta^{13}C$ values are not likely an explanation of this variation, as the only burial types with collagen yields and C:N ratios beyond accepted ranges were cremations (see Appendix E). It is unknown how people with disturbed burials were

intentionally buried, so correlations between burial type and stable isotope ratios cannot be further investigated.

Figure 6.3 - Variation in $\delta^{13}C_{col}$ by burial type at Vagnari.



The number of grave goods a person was buried with and their $\delta^{15}N$ values were correlated in the Vagnari cemetery. Patterns in grave good assemblages found by Brent (2012) were that the number of grave goods buried with an individual tended to increase with age, and adult males tended to be buried with more grave goods than adult females. Variation in grave good assemblages intersects with the age and sex of an individual at Vagnari, which in turn may intersect with age and sex-based dietary variation. Foods eaten by males and females at Vagnari were isotopically similar, but $\delta^{15}N$ values varied with age-at-death. Adult males tended to be most frequently possessing 5 or more grave goods in their funerary assemblage and with higher $\delta^{15}N$

values. The correlation between nitrogen isotopes and grave goods suggest that people at Vagnari had differential access to resources, with adult males having the greatest range of access in both foods and commemorative funerary materials.

Patterns in grave goods or burial type may indicate the social group at Vagnari with the greatest status or prestige, however status is challenging to assess from the archaeological record alone. Status does not merely amount to one's access to resources, as in a Roman context status depended on the gender, age, occupation, and legal status of the person, as well as the associating wealth or prestige with these roles. Comparisons of burial type and diet also have limited implications for status. The burial types used at Vagnari, such as *cappuccina* and libation, were common across Italy in the Imperial period (Small, 2007). A burial is also a particular representation of a person's life created by mourners, which may not be how the deceased was viewed in life.

Historical research suggests that slaves made up large portions of labour forces at industrial estates in Roman Italy (Kehoe, 2006). At Vagnari, there is no solid archaeological evidence for the presence of slaves. There were no distinctly 'poor' individuals buried in the cemetery; main burial types were typical of ordinary Romans, and grave goods accompanied the majority (91%) of burials. In addition, no isotopic indicators of poor foods such as millet or legumes were observed at the site. Slaves were often fed smaller quantities of food, and this is a distinction in diet which is not observable from isotopic analyses. Slaves are challenging to identify from the archaeological record alone because it is a legal status distinction, which may or may not

have implications on the types foods eaten or burial treatment. With current lines of evidence from burial type, grave goods, and stable isotopes of diet, slaves do not appear to be present at Vagnari, or they are indistinguishable from freeborn or freedmen in these regards.

The clearest examples of distinct status from burial conditions at Vagnari would be from cremated individuals who had distinct burial types, large grave good assemblages, and luxury items buried with them. A comparison with diet cannot be conducted for these individuals, as the isotope ratios in bone have been altered from the process of cremation. For the other burial types at Vagnari, what is likely occurring is dietary variation among individuals of relatively similar social standings, with slightly different expressions of identity through food and commemorative burials.

6.6 Variation in Diet across Imperial Roman Italy

Additional data from Imperial Roman sites were compared with Vagnari to better understand dietary variation within Italy. Published $\delta^{13}C$, $\delta^{15}N$ and $\delta^{13}C_{ap}$ data from Isola Sacra (Prowse et al., 2004), Velia (Craig et al., 2009), and the *suburbium* of Rome (Killgrove & Tykot, 2013) were chosen due to their similar geographic location, cultural-historical context, and dates of occupation. Imperial Roman sites were compared with Vagnari to investigate variation in Roman diet stemming from urban or rural situational factors.

Isotope ratios from Vagnari were compared with published isotope data from five different burial grounds in Roman Italy; Isola Sacra, Velia, Castellaccio Europarco,

the Casal Bertone Necropolis, and the Casal Bertone Mausoleum. The isotope ratios from any weaning-aged individuals at these sites were removed, so that only post-weaning variation in diet was considered. Results from the Kruskal-Wallis tests comparing these six sites are presented in Table 6.1. The distributions of $\delta^{13}C_{col}$, $\delta^{15}N$, and $\delta^{13}C_{ap}$ all significantly differed between the sites. Differences in isotope ratios suggest differences in diets between the people buried at these sites. A pairwise Kruskal-Wallis test was used to further explore the variation specifically between Vagnari and select sites, the results of which are discussed below.

Table 6.1 - Results of the Kruskal-Wallis tests comparing isotopic variation of diet between Vagnari, Isola Sacra, Velia, and the suburbium of Rome.

Inter-Site Variation (Kruskal-Wallis Test)	**$\delta^{13}C_{col}$ (‰) VPDB**	**$\delta^{15}N$ (‰) AIR**	**$\delta^{13}C_{ap}$ (‰) VPDB**
χ^2	160.204	132.8	43.832
df	5	5	4
p	0.000	0.000	0.000

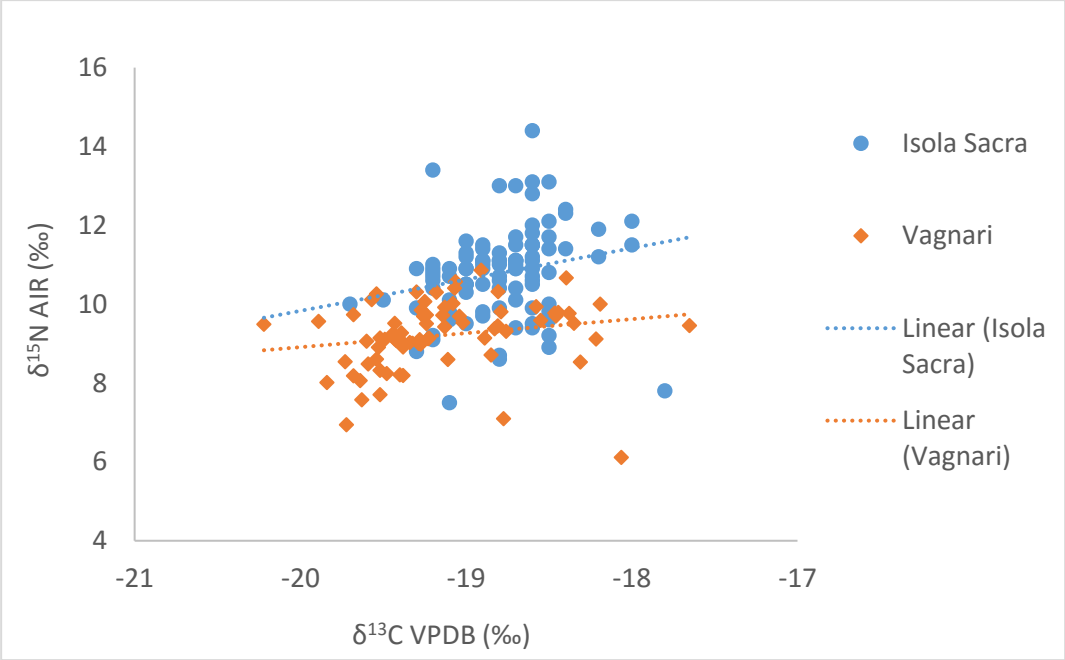
6.6.1 Vagnari and Isola Sacra

The urban, coastal site of Isola Sacra was compared with the rural, inland estate at Vagnari for isotopic differences in diet. Pairwise comparisons using the Kruskal-Wallis test noted differences in $\delta^{13}C$ ($p = 0.000$) and $\delta^{15}N$ values ($p = 0.000$) between Vagnari and Isola Sacra, but similar $\delta^{13}C_{ap}$ values ($p = 1.0$). The differences in isotope ratios from collagen are likely due to differences in consumption of fish between the sites. At Vagnari, there is no isotopic evidence of fish consumption, as any proteins eaten likely

came from terrestrial sources. Marine fish was an important part of the diet at Isola Sacra, resulting in higher $\delta^{15}N$ values (7.5‰ to 14.4‰, mean -10.8 ± 1.2‰).

Mean $\delta^{13}C_{ap}$ values were similar between Vagnari (-11.1 ± 0.5‰) and Isola Sacra (-11.4 ± 1.2 ‰). Similar patterns in $\delta^{13}C_{ap}$ values were observed at both sites, including a lack of correlation between $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$, high apatite-collagen spacing, and a negative correlation between $\Delta^{13}C_{ap\text{-}diet}$ and $\delta^{15}N$. The total diets at Vagnari and Isola Sacra were largely based on non-protein, C_3 plant foods. The protein contents of the diets differed in being mainly terrestrial at Vagnari and marine-based at Isola Sacra.

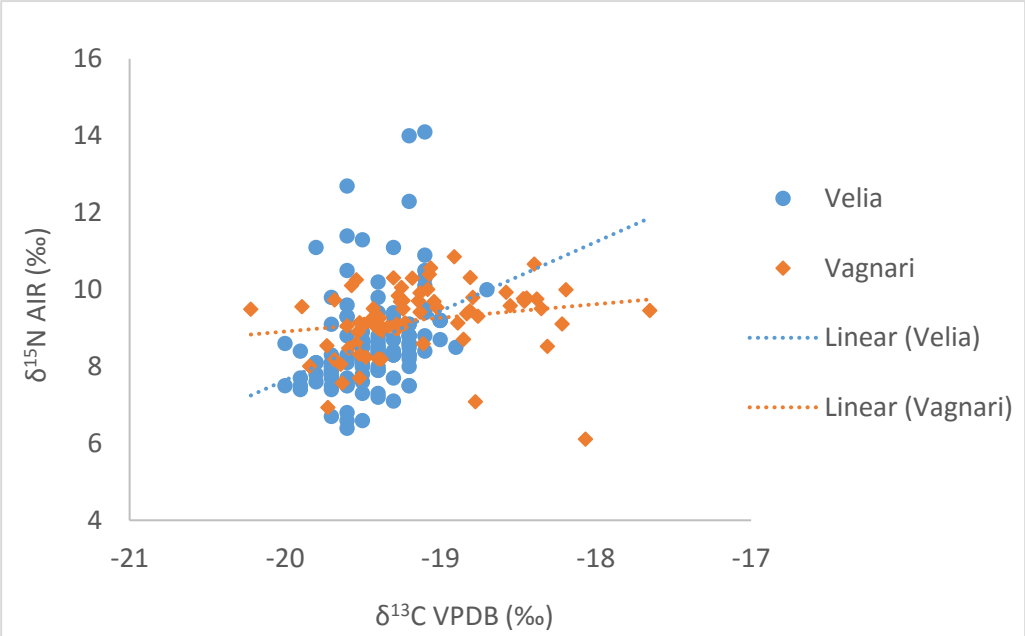
Figure 6.4 - Comparison of $\delta^{13}C$ and $\delta^{15}N$ values between the sites Vagnari and Isola Sacra.



6.6.2 Vagnari and Velia

Velia, another coastal city was compared with the rural estate Vagnari. Vagnari and Velia had significantly different $\delta^{13}C$ ($p = 0.000$) and $\delta^{15}N$ values ($p = 0.016$) as indicated by a pairwise Kruskal-Wallis test. Isotopes from carbonate were not studied at Velia, so the two sites could not be compared in this regard. The $\delta^{13}C$ values at Vagnari are much more widespread (-20.2‰ to -17.7‰), whereas the $\delta^{13}C$ values from Velia are clustered more tightly between -20‰ and -18.7‰. In comparison, Velia has a higher range of $\delta^{15}N$ values (6.4‰ to 14.1‰) than Vagnari (6.1‰ to 10.9‰). Diets from Velia also had contributions from marine fish, but to a lesser extent than Isola Sacra. Eating marine fish at Velia was more common among adult males, whereas at Isola Sacra eating marine fish was more common for everyone (Craig et al., 2009; Prowse et al., 2004). The protein content of the Velia diet came from a mixture of marine and terrestrial sources, but protein at Vagnari mainly came from terrestrial sources.

Figure 6.5 - Comparison of $\delta^{13}C$ and $\delta^{15}N$ values between the sites Vagnari and Velia.

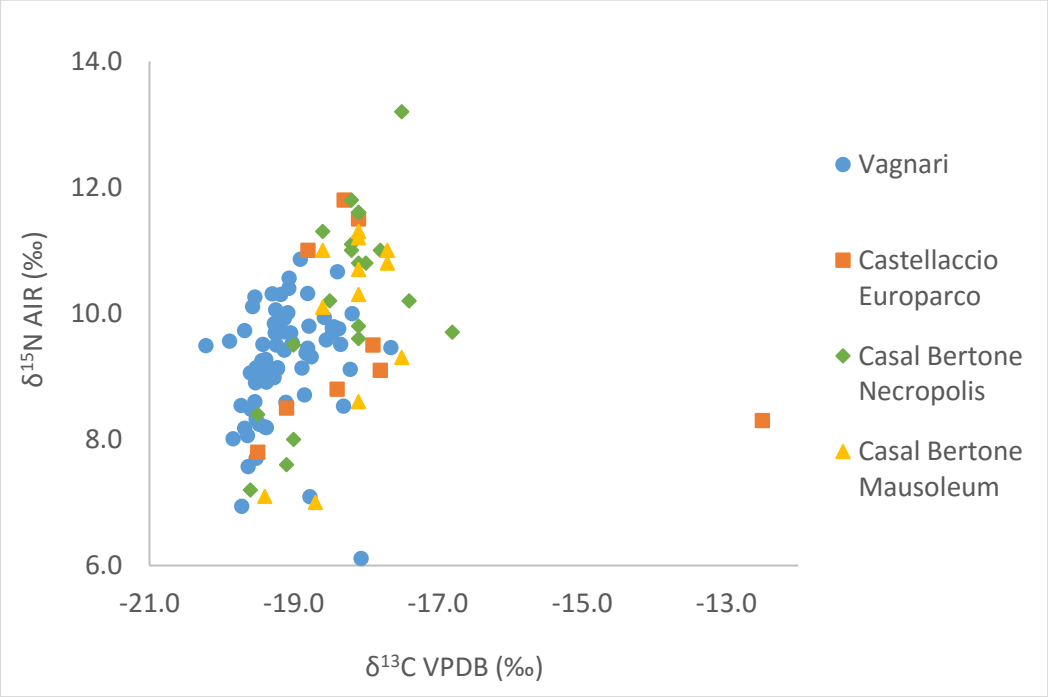


6.6.3 Vagnari and the Roman *suburbium*

The rural site Vagnari was also compared with the peri-urban Casal Bertone and suburban Castellaccio Europarco. Using a pairwise Kruskal-Wallis test, carbon isotope ratios ($\delta^{13}C$) differed significantly between Vagnari, the two burial grounds at Casal Bertone (p = 0.000 for both), and Castellaccio Europarco (p = 0.038). Nitrogen isotope ratios ($\delta^{15}N$) did not differ significantly between Vagnari and Castellaccio Europarco (p = 1.0), Casal Bertone Necropolis (p = 0.395) or Casal Bertone Mausoleum (p = 1.0) using a pairwise Kruskal-Wallis test. The similarities and differences in collagen isotope ratios from these sites are presented in Figure 6.6. The sites all heavily relied on C_3 plants and terrestrial-based proteins in their diet, though Killgrove and Tykot suggest possible contributions from marine fish, freshwater fish, or C_4 plants to the diet from the Roman

suburbium (Killgrove & Tykot, 2013). There was isotopic evidence of at least one individual primarily relying on millet consumption at Castellaccio Europarco (Killgrove & Tykot, 2013), but no sole isotopic indicators of millet or C_4 plants were observed at Casal Bertone or Vagnari. The people buried at Casal Bertone and Vagnari could still have mixed millet or fish into their diet.

Figure 6.6 – Comparison of $\delta^{13}C$ and $\delta^{15}N$ between Vagnari, Castellaccio Europarco, Casal Bertone Necropolis, and Casal Bertone Mausoleum.



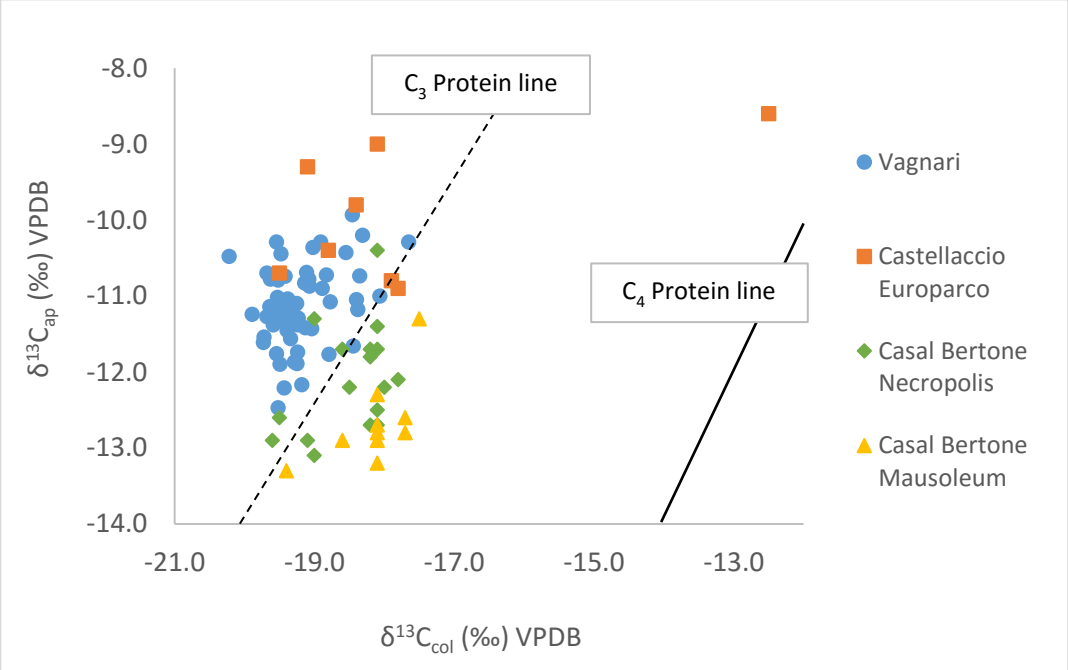
As indicated by Garnsey (1999), the Romans perceived millet as a sub-standard grain, and was more common fare for the poor. Murphy (2016) suggests that regardless of the perceptions surrounding millet, it was relied on as an affordable food source to protect against famine. Higher millet consumption at Castellaccio Europarco was

hypothesized by Killgrove and Tykot (2013) to be indicative of socioeconomic stratification between this suburban burial ground and the more urban burial grounds at Casal Bertone. The differences in carbon isotope ratios ($\delta^{13}C_{col}$) between the sites could be due to differences in socioeconomic status, which in turn could influence the types or amounts of plants (e.g. millet or wheat) and proteins eaten by people.

Similar trends are reflected in isotope ratios from carbonate. When $\delta^{13}C_{ap}$ values were compared with a pairwise Kruskal-Wallis test, the Casal Bertone Mausoleum (p = 0.000) and Necropolis (p = 0.001) differed significantly from Vagnari, but Castellaccio Europarco did not (p = 0.82). When they are graphed, Vagnari and Castellaccio Europarco tended to fall on the more negative $\delta^{13}C_{col}$ and more positive $\delta^{13}C_{ap}$ half of the C_3 protein line, while the Casal Bertone burial grounds tended to be on the more positive $\delta^{13}C_{col}$ and more negative $\delta^{13}C_{ap}$ half of the line (Figure 6.7). Higher $\delta^{13}C_{ap}$ values (e.g., -3.0‰) along the C_3 and C_4 protein lines indicate dietary energy coming predominantly from C_4 foods, whereas more negative $\delta^{13}C_{ap}$ values (e.g., -17.0‰) along these lines indicate dietary energy coming predominantly from C_3 foods (Kellner & Schoeninger, 2007; Killgrove & Tykot, 2013). Most individuals from Vagnari and Castellaccio Europarco cluster around $\delta^{13}C_{ap}$ values of -11.0‰ or higher, whereas the majority of individuals from the Casal Bertone burial grounds cluster around $\delta^{13}C_{ap}$ values of -12‰ or lower. The vertical positioning along the C_3 protein line suggests that the total diets from these sites were all primarily based on C_3 foods, but the amounts of

C_4 foods mixed in the diet differed, with Vagnari and Castellaccio Europarco drawing more dietary energy from C_4 foods.

Figure 6.7 – Plotted $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ values for Vagnari, Castellaccio Europarco, Casal Bertone Necropolis, and Casal Bertone Mausoleum. C_3 and C_4 protein lines are adapted from Kellner and Schoeninger (2007).



When total diet is considered, Vagnari and Castellaccio Europarco are more closely aligned, meaning they mixed more C_4 foods in their diet than the peri-urban burial grounds at Casal Bertone. Similarities in total diet could indicate similarities in socioeconomic status between the two more rural sites. The urban-rural dynamic as discussed earlier in Chapter 2 involved rural areas acting as supply centres to meet the demands of urban areas (Kehoe, 2006). Millet, an affordable grain and reliable food source during times of need, could be mixed more regularly in diets at rural sites such as Vagnari and Castellaccio Europarco. These rural sites could have produced food to be

eaten by urban residents like those buried at Casal Bertone, and urban dwellers could potentially draw upon multiple food sources through markets, thereby having a lesser need for millet.

Diet across Imperial Roman Italy tends to vary most by protein content, along with some variation in the incorporation of C_4 foods, from site to site. The types of protein eaten (i.e. marine vs. terrestrial) or the amount of protein in the diet could vary between each site. Coastal and urbanized locations tended to have higher trophic level proteins, such as marine fish, or more protein incorporated in the diet. Inland, rural populations tended to have mainly C_3 plant-based diets with some C_4 foods mixed in, and smaller contributions from terrestrial protein. These results align with recommendations from Garnsey (1999) that fish were not a staple for Romans. At coastal sites such as Isola Sacra and Velia the potential for incorporating marine foods into the diet is increased, due to their close proximity to the sea, increased occurrence of fishing activities, and their functions as port cities, which would expand market opportunities to sell or acquire different kinds of fish. Variation in diet across sites in Imperial Roman Italy could stem from established systems of rural production areas and urban consumption centres. Situational factors, such as the location of the site and the resources or trade networks accessible from that area could also factor into food choices.

6.7 Methodological Challenges and Limitations

A major limitation of stable isotope analysis is that it the results indicate broad categories of food, and not specific food types. More nuanced differences, such as the specific C_3 plants that were consumed, is not captured. Due to this restriction, only dietary variability within broad food types can be explored using isotopic analysis at Vagnari. Diet can still be researched in socially meaningful ways at Vagnari by incorporating contextual information from the archaeological record and Roman history.

In a Roman cultural context, some foods that are socially distinct are isotopically distinct as well. The C_4 plant millet was considered a poor grain by Romans, and is isotopically distinct from staple C_3 grains like wheat. In addition, diets heavy in seafood can be isotopically distinguished from diets based on terrestrial meat, or those that use legumes as a main source of protein. Isotope ratios of an individual can indicate differential access to protein sources with different associated prestige. Though there are some restrictions on what stable isotopes can specifically tell about Roman diet, some social distinctions in Roman food do align with isotopic distinctions of food types.

6.8 Conclusion

Diet at Vagnari was that of ordinary Romans, and aligns with food from the Mediterranean triad. Foods eaten at Vagnari were primarily plant-based, with potential protein sources including meat, milk and cheeses, or manured grains enriched in ^{15}N. Many aspects of dietary variation intersect at Vagnari, including patterns based on age, grave good assemblages, and to some extent type of burial. Age-related variation in diet

stems from a combination of potential factors, such as breastfeeding, different stressors with age, differential access to resources with age, or proscribed eating behaviours with age. Commemorative burial treatments and grave good assemblages could indicate individuals with differential access to resources or higher social standing at Vagnari, but post-mortem changes to burial conditions and stable isotope ratios prevent these patterns from being further explored.

Coastal-inland and urban-rural differences are also demonstrated when Vagnari is compared with other Imperial Roman sites in Italy. Isotopes of carbon and nitrogen from Vagnari were most similar to isotope values from the inland suburban site Castellaccio Europarco, who were eating some millet. Stable isotope indicators of diet at Vagnari are distinct from marine-based diets at the urban coastal sites Isola Sacra and Velia, particularly when comparing $\delta^{13}C$ and $\delta^{15}N$ values. Values of $\delta^{13}C$ and $\delta^{13}C_{ap}$ from Vagnari also differed from the inland peri-urban site of Casal Bertone. Results display geographic variation in Imperial Roman diet, with coastal sites having more access to marine foods and diets becoming increasingly terrestrial protein and plant-based when moving inland.

Though it is difficult to know precise types of food eaten from stable isotope values alone, using contextual historical and archaeological information can help to interpret diet in the past. Bioarchaeological data, such as the age and sex of individuals, can be used to analyze individual variation in stable isotope ratios. Information from Roman classical literature and history can help to interpret stable isotope ratios into

possible food types, and to understand the social context in which patterns of dietary variation occur. Incorporating these different sources of information can convey the types of food people ate and factors behind their food choices.

7 Conclusions

7.1 Diet at Vagnari – Concluding Remarks

This research has investigated diet at the Vagnari cemetery using stable isotope analysis. Isotopic evidence supports a diet at Vagnari similar to the historically suggested Mediterranean triad. The main foods eaten were C_3 plants, with small amounts of animal-based protein. The diet at Vagnari was commonplace by Roman standards, with no indications from the stable isotope ratios of the regular consumption of luxury foods (e.g. marine fish) or sole dependence on low-prestige foods (e.g. millet or lentils). Some millet was likely mixed into the Vagnari diet, though C_3 foods were the predominant dietary contributors.

Additional objectives of this research were to understand variation within diet at Vagnari, and between Vagnari and other sites. Hypotheses of sex-based variation in diet were not supported by stable isotope results, which contrast with the dental data, but significant differences in diet were apparent due to age. Food $\delta^{15}N$ values were highest in the infancy-early childhood category due to breastfeeding, and lowest among adolescents. Isotopes from carbonate indicate that total diet was very similar from childhood to early adulthood, with a shift in diet occurring in mid-late adulthood. Age-related patterns in diet also intersected with patterns in grave goods, as individuals with higher $\delta^{15}N$ values tended to be buried with more grave goods, and this was typically seen among males in the cemetery. Further investigations into the relationship between

status, burial treatment, and diet were halted since intentional burial treatment could not be assessed from disturbed burials, and stable isotope ratios were altered in cremated individuals.

Coastal and inland distinctions emerged from comparisons of diet between Vagnari and other sites in Roman Italy. The protein content was the most distinguishable element between the six sites, with urban coastal areas consuming more marine fish and diets becoming increasingly terrestrial protein and plant based moving inland. As hypothesized, stable isotope ratios from Vagnari aligned most closely with the suburban Castellaccio Europarco, and differed significantly from the peri-urban Casal Bertone and coastal sites Velia and Isola Sacra.

Though stable isotope analysis is a broad-brush technique for studying diet in the past, it provides important indicators of the foods eaten at Vagnari, which can be further interpreted by incorporating contextual information from Roman history and archaeology. The results of this research are significant because there is little historical representation about the diet of ordinary Romans, especially from outside the urban centres of the Roman Empire. Results from this thesis contributes to a growing body of knowledge on diet in Imperial Roman Italy, and has also provided insight to the lives of rural residents of the Empire.

7.2 Future Directions

Stable isotope analysis has provided an initial step to studying diet at Vagnari. Some questions still remain, such as the specific plant types and proteins eaten at

Vagnari. Foods common from the Mediterranean region, such as wheat, olives, and wine could be studied isotopically to give a baseline of plant values to interpret human diet from. Using different lines of evidence to study diet, such as analyses of archaeobotanical remains, faunal remains, or residues from ceramics could also help to clarify different food sources available at Vagnari.

As excavations continue at the Vagnari cemetery, more individuals are being recovered and can be added to analyses. Questions of variation in diet over time could be revisited if more burials from the 3rd and 4th centuries are recovered, as this was noted to be a period of instability in Roman Italy. This project did not place much emphasis on the diets of subadults (< 15.9 years of age), so more in-depth analyses of infant feeding, weaning, and early childhood diet could be further explored at Vagnari. Isotopic evidence could also be integrated with studies of palaeopathology at Vagnari to investigate nutritional adequacy of this diet for an industrial workforce.

Beyond Vagnari, it would be useful to have more rural sites to compare isotopes of diet between. Dietary variation between locations is more than a matter of urban and rural differences, as how the site is situated is important as well. Other important factors in dietary variation between sites could be distance to the coast, links with trade networks, or availability of lands for agriculture and animal husbandry. This study has just begun to examine the foods eaten in the rural Roman Empire and factors behind these food choices, which could be an important avenue for future research.

References

Alberici, L. A., & Harlow, M. (2007). Age and innocence: Female transitions to adulthood in Late Antiquity. In A. Cohen & J. B. Rutter (Eds.), *Constructions of childhood in Ancient Greece and Italy* (pp. 193–203). Princeton, NJ: The American School of Classical Studies at Athens.

Ambrose, S. H. (1990). Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archaeological Science*, *17*(4), 431–451.

Ambrose, S. H., Butler, B. M., Hanson, D. B., Hunter-Anderson, R. L., & Krueger, H. W. (1997). Stable isotopic analysis of human diet in the Marianas Archipelago, western Pacific. *American Journal of Physical Anthropology*, *104*(3), 343–361.

Ambrose, S. H., & Norr, L. (1993). Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In J. B. Lambert & G. Grupe (Eds.), *Prehistoric human bone* (pp. 1–38). Berlin: Springer-Verlag.

Bogaard, A., Heaton, T. H. E., Poulton, P., & Merbach, I. (2007). The impact of manuring on nitrogen isotope ratios in cereals: Archaeological implications for reconstruction of diet and crop management practices. *Journal of Archaeological Science*, *34*(3), 335–343.

Bonfiglioli, B., Brasili, P., & Belcastro, M. G. (2003). Dento-alveolar lesions and nutritional habits of a Roman Imperial age population (1st-4th c. AD): Quadrella (Molise, Italy). *Homo : Internationale Zeitschrift Fur Die Vergleichende Forschung Am Menschen*, *54*(1), 36–56.

Brent, L. (2012). *Artifacts and burial practices in the Vagnari cemetery*. Unpublished Master's Thesis. McMaster University.

Brent, L., & Prowse, T. L. (2014). Grave goods, burial practices, and patterns of distribution in the Vagnari cemetery. In A. M. Small (Ed.), *Beyond Vagnari: New Themes in the study of Roman South Italy* (pp. 99–109). Bari: Edipuglia.

Broekaert, W., & Zuiderhoek, A. (2012). Food systems in Classical Antiquity. In P. Erdkamp (Ed.), *A cultural history of food in antiquity, Volume 1* (pp. 41–56). New York, NY: Bloomsbury Academic.

Buikstra, J. E., & Ubelaker, D. H. (1994). *Standards for data collection from human skeletal remains*. Fayetteville, AR: Arkansas Archeological Survey.

Caplan, P. (1997). *Food, health and identity*. New York, NY: Routledge.

Carroll, M. (2013). Exploring the vicus at the Roman imperial estate at Vagnari (Comune Di Irsina, Provincia di Matera, Regione Basilicata). *Papers of the British School at Rome*, *81*, 381–384.

Chenery, C., Müldner, G., Evans, J., Eckardt, H., & Lewis, M. (2010). Strontium and stable isotope evidence for diet and mobility in Roman Gloucester, UK. *Journal of Archaeological Science*, *37*(1), 150–163.

Cheung, C., Schroeder, H., & Hedges, R. E. M. (2012). Diet, social differentiation and cultural change in Roman Britain: New isotopic evidence from Gloucestershire. *Archaeological and Anthropological Sciences*, *4*(1), 61–73.

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.

Clayton, F., Sealy, J., & Pfeiffer, S. (2006). Weaning age among foragers at Matjes River Rock Shelter, South Africa, from stable nitrogen and carbon isotope analyses. *American Journal of Physical Anthropology*, *129*(2), 311–317.

Cokayne, K. (2003). *Experiencing old age in Ancient Rome*. New York, NY: Routledge.

Craig, O. E., Biazzo, M., O'Connell, T. C., Garnsey, P., Martinez-Labarga, C., Lelli, R., … Bondioli, L. (2009). Stable isotopic evidence for diet at the Imperial Roman coastal site of Velia (1st and 2nd centuries AD) in Southern Italy. *American Journal of Physical Anthropology*, *139*(4), 572–583.

Craig, O. E., Bondioli, L., Fattore, L., Higham, T., & Hedges, R. (2013). Evaluating marine diets through radiocarbon dating and stable isotope analysis of victims of the AD 79 eruption of Vesuvius. *American Journal of Physical Anthropology*, *152*(3), 345–352.

Crowe, F., Sperduti, A., O'Connell, T. C., Craig, O. E., Kirsanow, K., Germoni, P., … Bondioli, L. (2010). Water-related occupations and diet in two Roman coastal communities (Italy, first to third century AD): Correlation between stable carbon and nitrogen isotope values and auricular exostosis prevalence. *American Journal of Physical Anthropology*, *142*(3), 355–366.

D'Ortenzio, L., Brickley, M., Schwarcz, H., & Prowse, T. (2015). You are not what you eat during physiological stress: Isotopic evaluation of human hair. *American Journal of Physical Anthropology*, *157*, 374–388.

DeNiro, M. J. (1985). Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature*, *317*(6040), 806–809.

DeNiro, M. J., & Epstein, S. (1978). Influence of diet on the distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta*, *42*(5), 495–506.

DeNiro, M. J., & Epstein, S. (1981). Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et Cosmochimica Acta*, *45*, 341 – 351.

Dixon, S. (1988). *The Roman mother*. London: Croom Helm.

Dupras, T. L. (1999). *Dining in the Dakleh Oasis, Egypt: Determination of diet using documents and stable isotope analysis*. Unpublished Doctoral Thesis. McMaster University.

Dupras, T. L., Schwarcz, H. P., & Fairgrieve, S. I. (2001). Infant feeding and weaning practices in Roman Egypt. *American Journal of Physical Anthropology*, *115*(3), 204–212.

Dupras, T. L., & Tocheri, M. W. (2007). Reconstructing infant weaning histories at Roman period Kellis, Egypt using stable isotope analysis of dentition. *American Journal of Physical Anthropology*, *134*(1), 63–74.

Erdkamp, P. (2012). Food security, safety and crises. In P. Erdkamp (Ed.), *A cultural history of food in antiquity, Volume 1* (pp. 57–74). New York, NY: Bloomsbury Academic.

Fogel, M. L., Tuross, N., & Owsley, D. W. (1989). Nitrogen isotope tracers of human lactation in modern and archaeological populations. In *Annual Report of the Director, Geophysical Laboratory, Carnegie Institution of Washington 1988-1989* (pp. 111–117).

Fraser, R. A., Bogaard, A., Heaton, T., Charles, M., Jones, G., Christensen, B. T., … Styring, A. K. (2011). Manuring and stable nitrogen isotope ratios in cereals and pulses: Towards a new archaeobotanical approach to the inference of land use and dietary practices. *Journal of Archaeological Science*, *38*(10), 2790–2804.

Fuglestvedt, I. (2014). Declaration on behalf of an archaeology of sexe. *Journal of Archaeological Method and Theory*, *21*(1), 46–75.

Fuller, B. T., Fuller, J. L., Harris, D. A., & Hedges, R. E. M. (2006). Detection of Breastfeeding and Weaning in Modern Human Infants With Carbon and Nitrogen Stable Isotope Ratios, *293*(May 2004), 279–293.

Fuller, B. T., Fuller, J. L., Sage, N. E., Harris, D. A., O'Connell, T. C., & Hedges, R. E. M. (2005). Nitrogen balance and δ15N: Why you're not what you eat during nutritional stress. *Rapid Communications in Mass Spectrometry*, *19*(18), 2497–2506.

Fuller, B. T., Molleson, T. I., Harris, D. A., Gilmour, L. T., & Hedges, R. E. M. (2006). Isotopic evidence for breastfeeding and possible adult dietary differences from Late/Sub-Roman Britain. *American Journal of Physical Anthropology*, *129*(1), 45–54.

Fuller, B. T., Richards, M. P., & Mays, S. A. (2003). Stable carbon and nitrogen isotope variations in tooth dentine serial sections from Wharram Percy. *Journal of Archaeological Science*, *30*(12), 1673–1684.

Galobardes, B., Morabia, A., & Bernstein, M. S. (2001). Diet and socioeconomic position: Does the use of different indicators matter? *International Journal of Epidemiology*, *30*(2), 334–340.

Gardner, J. F. (1993). *Being a Roman citizen*. New York, NY: Routledge.

Garnsey, P. (1999). *Food and society in Classical Antiquity*. Cambridge, U.K.: Cambridge University Press.

Giele, J., & Elder, G. (1998). *Methods of life course research: Qualitative and quantitative approaches*. Thousand Oaks, CA: Sage Publications.

Gowers, E. (1993). *The loaded table: Representations of food in Roman literature*. New York, NY: Clarendon Press.

Grimm, V. E. (2006). On food and the body. In D. S. Potter (Ed.), *A companion to the Roman Empire* (pp. 354–368). Malden, MA: Blackwell Publishing.

Grocock, C., & Grainger, S. (Eds.). (2006). *Apicius: A critical edition with an introduction and an English translation for the Latin recipe text Apicius*. Blackawton, UK: Prospect Books.

Halstead, P. (2012). Food production. In P. Erdkamp (Ed.), *A cultural history of food in antiquity, Volume 1* (pp. 21–40). New York, NY: Bloomsbury Academic.

Harlow, M., & Laurence, R. (2002). *Growing up and growing old in Ancient Rome: A life course approach*. New York, NY: Routledge.

Harrison, R. G., & Katzenberg, M. A. A. (2003). Paleodiet studies using stable carbon isotopes from bone apatite and collagen: Examples from Southern Ontario and San Nicolas Island, California. *Journal of Anthropological Archaeology*, *22*(3), 227–244.

Hatch, K. A., Crawford, M. A., Kunz, A. W., Thomsen, S. R., Eggett, D. L., Nelson, S. T., & Roeder, B. L. (2006). An objective means of diagnosing anorexia nervosa and bulimia nervosa using 15N/14N and 13C/12C ratios in hair. *Rapid Communications in Mass Spectrometry*, *20*(22), 3367–3373.

Hillson, S. (2008). Dental pathology. In M. A. Katzenberg & S. R. Saunders (Eds.), *Biological anthropology of the human skeleton* (2nd ed., pp. 301–340). Hoboken, NJ: John Wiley & Sons, Inc.

Hollimon, S. E. (2006). The archaeology of nonbinary genders in Native North American studies. In S. M. Nelson (Ed.), *Handbook of gender in archaeology* (pp. 435–450). Lanham, MD: AltaMira Press.

Katzenberg, M. A. (1989). Stable isotope analysis of archaeological faunal remains from southern Ontario. *Journal of Archaeological Science*, *16*, 319–329.

Katzenberg, M. A. (2008). Stable isotope analysis: A tool for studying past diet, demography, and life history. In M. A. Katzenberg & S. R. Saunders (Eds.), *Biological anthropology of the human skeleton* (pp. 413–442). Hoboken, NJ: John Wiley & Sons, Inc.

Katzenberg, M. A., Herring, D. A., & Saunders, S. R. (1996). Weaning and infant mortality: Evaluating the skeletal evidence. *American Journal of Physical Anthropology*, *39*, 177–199.

Katzenberg, M. A., & Lovell, N. C. (1999). Stable isotope variation in pathological bone. *International Journal of Osteoarchaeology*, *9*, 316–324.

Katzenberg, M. A., Schwarcz, H. P., Knyf, M., & Melbye, F. J. (1995). Stable isotope evidence for maize horticulture and paleodiet in Southern Ontario, Canada. *American Antiquity*, *60*(2), 335–350.

Keenleyside, A., Schwarcz, H., Stirling, L., & Ben Lazreg, N. (2009). Stable isotopic evidence for diet in a Roman and Late Roman population from Leptiminus, Tunisia. *Journal of Archaeological Science*, *36*(1), 51–63.

Kehoe, D. P. (2006). Landlords and tenants. In D. S. Potter (Ed.), *A companion to the Roman Empire* (pp. 298–311). Malden, MA: Blackwell Publishing.

Kellner, C. M., & Schoeninger, M. J. (2007). A simple carbon isotope model for reconstructing prehistoric human diet. *American Journal of Physical Anthropology*, *113*, 1112–1127.

Killgrove, K., & Tykot, R. H. (2013). Food for Rome: A stable isotope investigation of diet in the Imperial period (1st-3rd centuries AD). *Journal of Anthropological Archaeology*, *32*(1), 28–38.

Knapp, R. (2011). *Invisible Romans*. Cambridge, MA: Harvard University Press.

König, J. (2012). *Saints and symposiasts: The literature of food and the symposium in Greco-Roman and early Christian culture*. Cambridge, U.K.: Cambridge University Press.

Krueger, H. W., & Sullivan, C. H. (1984). Models for carbon isotope fractionation between diet and bone. *Stable Isotopes in Nutrition*, *258*, 205–220.

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

Lee-Thorp, J. A., Sealy, J. C., & van der Merwe, N. J. (1989). Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet. *Journal of Archaeological Science*, *16*(6), 585–599.

Lee-Thorp, J. A., & van der Merwe, N. J. (1987). Carbon isotope analysis of fossil bone apatite. *South African Journal of Science*, *83*(11), 712–715.

Lieverse, A. R. (1999). Diet and the aetiology of dental calculus. *International Journal of Osteoarchaeology*, *232*(February), 219–232.

Lightfoot, E., Ŝlaus, M., & O'Connell, T. C. (2012). Changing cultures, changing cuisines: Cultural transitions and dietary change in Iron Age, Roman, and Early Medieval Croatia. *American Journal of Physical Anthropology*, *148*(4), 543–556.

Longin, R. (1971). New method of collagen extraction for radiocarbon dating. *Nature*, *230*, 241–242.

Manzi, G., Salvadei, L., Vienna, A., & Passarello, P. (1999). Discontinuity of life conditions at the transition from the Roman imperial age to the early middle ages: Example from central Italy evaluated by pathological dento-alveolar lesions. *American Journal of Human Biology*, *11*(3), 327–341.

Manzi, G., Sperduti, A., & Passarello, P. (1991). Behavior-induced auditory exostoses in imperial Roman society: Evidence from coeval urban and rural communities near Rome. *American Journal of Physical Anthropology*, *85*(3), 253–260.

Mekota, A.-M., Grupe, G., Ufer, S., & Cuntz, U. (2006). Serial analysis of stable nitrogen and carbon isotopes in hair: Monitoring starvation and recovery phases of patients suffering from anorexia nervosa. *Rapid Communications in Mass Spectrometry*, *20*, 1604–1610.

Mikkilä, V., Räsänen, L., Raitakari, O. T., Pietinen, P., & Viikari, J. (2004). Longitudinal changes in diet from childhood into adulthood with respect to risk of cardiovascular diseases: The Cardiovascular Risk in Young Finns Study. *European Journal of Clinical Nutrition*, *58*(7), 1038–1045.

Müldner, G. (2013). Stable isotopes and diet: Their contribution to Romano-British research. *Antiquity*, *87*, 137–149.

Murphy, C. (2015). Finding millet in the Roman world. *Archaeological and Anthropological Sciences*, *8*, 65–78.

O'Doherty Jensen, K., & Holm, L. (1999). Preferences, quantities and concerns: Socio-cultural perspectives on the gendered consumption of foods. *European Journal of Clinical Nutrition*, *53*, 351–359.

Parker, H. (1998). Loyal slaves and loyal wives: The crisis of the outsider-within and Roman exemplum literature. In S. R. Joshel & S. Murnaghan (Eds.), *Women and slaves in Greco-Roman culture: Differential equations* (pp. 152–173). New York, NY: Routledge.

Passey, B. H., Robinson, T. F., Ayliffe, L. K., Cerling, T. E., Sphonheimer, M., Dearing, M. D., … Ehleringer, J. R. (2005). Carbon isotope fractionation between diet, breath CO_2, and bioapatite in different mammals. *Journal of Archaeological Science*, *32*(10), 1459–1470.

Patterson, J. R. (2006). *Landscapes and citites: Rural settlement and civic transformation in early Imperial Italy*. Oxford, UK: Oxford University Press.

Prowse, T. (2013). Vagnari cemetery (Comune di Gravina in Puglia, Provincia di Bari, Regione Puglia). *Papers of the British School at Rome*, *81*, 384–386.

Prowse, T. L. (2011). Diet and dental health through the life course in Roman Italy. In S. C. Agarwal & B. A. Glencross (Eds.), *Social bioarchaeology* (pp. 410–437). Malden, MA: Wiley-Blackwell.

Prowse, T. L., Saunders, S. R., Schwarcz, H. P., Garnsey, P., Macchiarelli, R., & Bondioli, L. (2008). Isotopic and dental evidence for infant and young child feeding practices in an Imperial Roman skeletal sample. *American Journal of Physical Anthropology*, *137*(3), 294–308.

Prowse, T. L., Schwarcz, H. P., Saunders, S. R., Macchiarelli, R., & Bondioli, L. (2005). Isotopic evidence for age-related variation in diet from Isola Sacra, Italy. *American Journal of Physical Anthropology*, *128*(1), 2–13.

Prowse, T., Nause, C., & Ledger, M. (2014). Growing up and growing old on an Imperial Roman estate. In A. M. Small (Ed.), *Beyond Vagnari: New themes in the study of Roman South Italy* (pp. 111–122). Bari: Edipuglia.

Prowse, T., Schwarcz, H. P., Saunders, S., Macchiarelli, R., & Bondioli, L. (2004). Isotopic paleodiet studies of skeletons from the Imperial Roman-age cemetery of Isola Sacra, Rome, Italy. *Journal of Archaeological Science*, *31*(3), 259–272.

Prowse, T., & Small, A. (2009). Excavations in the Roman cemetery at Vagnari, 2008 Preliminary report. *FOLD&R FastiOnLine Documents & Research*, *131*, 1–8.

Purcell, N. (2003). The way we used to eat: Diet, community, and history at Rome. *The American Journal of Philology*, *124*(3), 329–358.

Rawson, B. (2003). *Children and chilhood in Roman Italy*. New York, NY: Oxford University Press.

Redfern, R. C., Hamlin, C., & Athfield, N. B. (2010). Temporal changes in diet: A stable isotope analysis of late Iron Age and Roman Dorset, Britain. *Journal of Archaeological Science*, *37*(6), 1149–1160.

Richards, M. P., Mays, S., & Fuller, B. T. (2002). Stable carbon and nitrogen isotope values of bone and teeth reflect weaning age at the Medieval Wharram Percy site, Yorkshire, UK. *American Journal of Physical Anthropology*, *119*(3), 205–210.

Robb, J., Bigazzi, R., Lazzarini, L., Scarsini, C., & Sonego, F. (2001). Social "status" and biological "status": A comparison of grave goods and skeletal indicators from Pontecagnano. *American Journal of Physical Anthropology*, *115*(3), 213–222.

Rutgers, L. V., van Strydonck, M., Boudin, M., & van der Linde, C. (2009). Stable isotope data from the early Christian catacombs of ancient Rome: New insights into the dietary habits of Rome's early Christians. *Journal of Archaeological Science*, *36*(5), 1127–1134.

Scheidel, W. (1996). The most silent women of Greece and Rome: Rural labour and women's life in the ancient world (II). *Greece and Rome (Second Series)*, *43*(01), 1–10.

Schoeninger, M. J. (1985). Trophic level effects on 15N/14N and 13C/12C ratios in bone collagen and strontium levels in bone mineral. *Journal of Human Evolution*, *14*, 515–525.

Schoeninger, M. J., & DeNiro, M. J. (1984). Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta*, *48*(4), 625–639.

Schutkowski, H. (2008). Thoughts for food: Evidence and meaning of past dietary habits. *Cambridge Studies in Biological and Evolutionary Anthropology*, *1*(56), 141–164.

Schwarcz, H. P., Chisholm, B. S., & Burchell, M. (2014). Isotopic studies of the diet of the people of the coast of British Columbia. *American Journal of Physical Anthropology*, *155*(3), 460–468.

Schwarcz, H. P., & Schoeninger, M. J. (1991). Stable isotope analyses in human nutritional ecology. *Yearbook of Physical Anthropology*, *34*, 283–321.

Sealy, J. C., van der Merwe, N. J., Lee-Thorp, J. A., & Lanham, J. L. (1987). Nitrogen isotopic ecology in southern Africa: Implications for environmental and dietary tracing. *Geochimica et Cosmochimica Acta*, *51*(10), 2707–2717.

Shemesh, A. (1990). Crystallinity and diagenesis of sedimentary apatites. *Geochimica et Cosmochimica Acta*, *54*(9), 2433–2438.

Small, A. (2007). Excavation in the Roman cemetery at Vagnari, in the territory of Gravina in Puglia, 2002. *Papers of the British School at Rome*, *75*, 123–229.

Small, A. M. (2011). Introduction. In A. M. Small (Ed.), *Vagnari: The village, the industries, the imperial property* (pp. 11–36). Bari: Edipuglia.

Small, C. (2011). The surface collection. In A. M. Small (Ed.), *Vagnari: The village, the industries, the imperial property* (pp. 53–72). Bari: Edipuglia.

Sofaer, J. R. (2006). *The body as material culture: A theoretical osteoarchaeology*. New York, NY: Cambridge University Press.

Sofaer, J. R. (2011). Towards a social bioarchaeology of age. In S. C. Agarwal & B. A. Glencross (Eds.), *Social bioarchaeology* (pp. 285–311). Malden, MA: Blackwell Publishing.

Stirling, L. (2006). Art, architecture, and archaeology in the Roman Empire. In D. S. Potter (Ed.), *A Companion to the Roman Empire* (pp. 75–97). Malden, MA: Blackwell Publishing.

Strutt, K., Hunt, J., & Small, A. M. (2011). The geophysical surveys. In A. M. Small (Ed.), *Vagnari: The village, the industries, the imperial property* (pp. 73–86). Bari: Edipuglia.

Sullivan, C. H., & Krueger, H. W. (1981). Carbon isotope analysis of separate chemical phases in modern and fossil bone. *Nature*, *292*(5821), 333–335.

Tieszen, L. L., & Fagre, T. (1993). Effect of diet quality and composition on the isotopic composition of respiratory CO_2, bone collagen, bioapatite, and soft tissues. In J. B. Lambert & G. Grupe (Eds.), *Prehistoric human bone: Archaeology at the molecular level* (pp. 121–155). Berlin: Springer-Verlag.

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. *American Scientist*, *70*(6), 596–606.

van der Merwe, N. J., & Vogel, J. C. (1978). 13C content of human collagen as a measure of prehistoric diet in woodland North America. *Nature*.

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

Vogel, J. C., & van der Merwe, N. J. (1977). Isotopic evidence for early maize cultivation in New York State. *American Antiquity*, *42*(2), 238–242.

White, C. D., & Armelagos, G. J. (1997). Osteopenia and stable isotope ratios in bone collagen of Nubian female mummies. *American Journal of Physical Anthropology*, *103*, 185–199.

Wright, L. E., & Schwarcz, H. P. (1996). Infrared and isotopic evidence for diagenesis of bone apatite at Dos Pilas, Guatemala: Palaeodietary implications. *Journal of Archaeological Science*, *23*, 933–944.

Wright, L. E., & Schwarcz, H. P. (1999). Correspondence between stable carbon, oxygen and nitrogen isotopes in human tooth enamel and dentine: Infant diets at Kaminaljuyú. *Journal of Archaeological Science*, *26*, 1159–1170.

Appendix A

Collagen and Carbonate Samples Prepared for Mass Spectrometry

Sample ID	Bone sample	Prepared for	Sex	Age-at-death	% yield
Human					
F104	Femur	Collagen and Carbonate	-	-	2.77
F126	Femur	Carbonate only**	Male	15-29 yrs	-
F127	Femur	Carbonate only**	Female	15-29 yrs	-
F200	Femur	Collagen and Carbonate	Male	45-49 yrs	6.79
F201	Femur	Collagen and Carbonate	-	-	3.26
F202*	Femur	Collagen only	-	9 ± 3 months	0.22
F204	Femur	Collagen and Carbonate	Female	39.4 ± 9.1 yrs	2.34
F205	Femur	Collagen and Carbonate	Female	Adult	11.57
F206	Femur	Collagen and Carbonate	Female	Older Adult (50+ yrs)	3.18
F207	Femur	Collagen and Carbonate	Male	Young Adult (< 30 yrs)	11.11
F208	Femur	Collagen and Carbonate	-	12-14.5 yrs	10.95
F209	Femur	Collagen and Carbonate	Female	14-16 yrs	9.96
F210	Femur	Collagen and Carbonate	-	9 yrs ± 24 months	10.61
F211	Femur	Collagen and Carbonate	Female	Young Adult (< 30 yrs)	7.41
F213	Femur	Collagen and Carbonate	Male	35+ yrs	6.79
F214	Femur	Collagen and Carbonate	Male	45-59 yrs	8.33
F215	Femur	Collagen and Carbonate	Female	38.2 ± 10.9 yrs	8.77
F216	Femur	Collagen and Carbonate	Male	35.2 ± 9.4 yrs	8.1
F218	Femur	Collagen and Carbonate	-	<10 yrs	4.92
F220	Femur	Collagen and Carbonate	Male	Older Adult (50+ yrs)	8.44
F225	Rib	Collagen only	-	6 months ± 3 months	7.8
F226	Femur	Collagen and Carbonate	-	10-11 yrs	9.86
F228	Rib	Collagen only	-	1 year ± 4 months	4.15
F229	Femur	Collagen and Carbonate	Male	Older Adult (50+ yrs)	13.33
F231	Femur	Collagen and Carbonate	Male	Adult	9.38
F234	Femur	Collagen and Carbonate	Male	35.2 ± 9.4 yrs	5.11
F235	Femur	Collagen and Carbonate	Male	~50 ± 12.6 yrs	11.11
F245	Femur	Collagen and Carbonate	Female	19-22 yrs	8.33
F246	Femur	Collagen and Carbonate	-	Young Adult (< 30 yrs)	4.78
F247	Femur	Collagen only	Male	Adult	7.2
F248	Femur	Collagen and Carbonate	Male	20-24 yrs	4.68
F249	Femur	Collagen and Carbonate	Male	Adult	11.06
F250	Femur	Collagen and Carbonate	Male	35-39 yrs	8.87
F252	Femur	Collagen and Carbonate	Female	17-22.5 yrs	11.96
F253	Femur	Collagen and Carbonate	Male	48.8 ± 10.5 yrs	7.66
F254	Femur	Collagen and Carbonate	Male	35-45 yrs	10

F280*	Femur	Collagen only	Female	Adult	2.39
F284	Femur	Collagen only	Female	30-35 yrs	16
F286A	Femur	Collagen and Carbonate	Female	16-18 yrs	2.74
F286B	Femur	Collagen and Carbonate	-	13-14 yrs	3.65
F287	Femur	Collagen and Carbonate	Male	Older Adult (50+ yrs)	6.41
F288A	Femur	Collagen only	Male	30-40 yrs	9.33
F289	Femur	Collagen and Carbonate	-	15-16 yrs	7.27
F290	Femur	Collagen and Carbonate	Male	45+ yrs	10
F291	Femur	Collagen and Carbonate	Male	Adult	7.17
F292	Rib	Collagen only	-	2.5-3.5 yrs	10.24
F293	Femur	Collagen and Carbonate	Male	Adult	10.53
F294	Femur	Collagen and Carbonate	Male	Older Adult (50+ yrs)	8.57
F295	Rib	Collagen only	-	7 - 9 months	4.96
F296	Femur	Collagen and Carbonate	Female	25-29 yrs	6.77
F298	Femur	Collagen and Carbonate	Female	Adult	5
F299	Femur	Collagen only	-	4.5-6.5 yrs	7.37
F302	Femur	Collagen and Carbonate	-	Adult	2.65
F305	Rib	Collagen only	-	7 - 9 months	1.09
F306	Femur	Collagen and Carbonate	Female	Adult	7.6
F312	Femur	Collagen and Carbonate	Male	Young Adult (< 30 yrs)	7
F55	Femur	Collagen and Carbonate	-	5-6 yrs	6.64
F67	Femur	Carbonate only**	Male	15-29 yrs	-
Faunal					
Ungulate 1	Femur	Collagen and Carbonate	-	-	23.85
Dog	Femur	Collagen and Carbonate	-	-	8.7
Pig	Femur	Collagen and Carbonate	-	-	2.23
Sheep	Femur	Collagen and Carbonate	-	-	3.9
Cow	Femur	Collagen and Carbonate	-	-	5.3
Equid	Femur	Collagen and Carbonate	-	-	4.44
Ungulate 2	Femur	Collagen and Carbonate	-	-	5.34
Ungulate 3	Femur	Collagen and Carbonate	-	-	5.43

* Samples that did not undergo mass spectrometry
** Collagen results previously conducted, but not published
Dash (-) represents unknown or unavailable data

Appendix B

Collagen Sample Stable Isotope Data

Sample ID	Sex	Age-at-death	Age Category	Burial date	Burial type	Grave Goods	$\delta^{13}C$ VPDB (‰)	$\delta^{15}N$ AIR (‰)	% yield	C:N
F100	-	Adult	-	3rd c.	Cappuccina	3	-19.3	9.7		3.2
F104	-	-	-	2nd c.	Cremation	17	-15.9	7.2	2.8	9.1
F117	Female	15-29 yrs	Adolescence	2nd c.	Cappuccina	22	-18.5	9.8		3.1
F123	-	0-6 yrs	Infancy-Early Childhood	2nd c.	Cappuccina	2	-18.3	12.5		3.2
F126	Male	15-29 yrs	Adolescence	-	Cappuccina	3	-19.5	9.1		3.2
F127	Female	15-29 yrs	Adolescence	2nd c.	Disturbed	1	-18.4	9.8		3.1
F130	Female	15-29 yrs	Adolescence	-	Cappuccina	1	-19.3	9.7		3.2
F131	Male	30-49 yrs	Early Adulthood	2nd c.	Libation	6	-18.6	9.9		3.3
F132	Female	Older Adult (50+ yrs)	Mid-Late Adulthood	2nd c.	Disturbed	7	-19.1	10.6		3.1
F137 A	Male	15-29 yrs	Adolescence	2nd c.	Tile	0	-19.3	9.0		3.1
F137 B	-	Adult	-	2nd c.	Disturbed	6	-18.2	9.1		3.1
F200	Male	45-49 yrs	Mid-Late Adulthood	2nd c.	Cappuccina	8	-19.4	9.1	6.8	3.2
F201	-	-	-	2nd c.	Cremation	10	-15.8	1.0	3.3	11.2
F204	Female	39.4 ± 9.1 yrs	Early Adulthood	2nd c.	Cappuccina	5	-19.3	9.1	2.3	3.2
F205	Female	Adult	-	2nd c.	Cappuccina	4	-19.7	8.2	11.6	3.2
F206	Female	Older Adult (50+ yrs)	Mid-Late Adulthood	2nd c.	Cappuccina	3	-19.4	9.3	3.2	3.2

Sample ID	Sex	Age-at-death	Age Category	Burial date	Burial type	Grave Goods	$\delta^{13}C$ VPDB (‰)	$\delta^{15}N$ AIR (‰)	% yield	C:N
F207	Male	Young Adult (< 30 yrs)	Adolescence	-	Cappuccina	5	-19.4	9.1	11.1	3.2
F208	-	12-14.5 yrs	Childhood	-	Cappuccina	5	-19.0	9.5	11.0	3.2
F209	Female	14-16 yrs	Adolescence	-	Libation	15	-19.1	8.6	10.0	3.2
F210	-	9 yrs ± 24 months	Childhood	3rd c.	Cappuccina	10	-19.1	9.9	10.6	3.2
F211	Female	Young Adult (< 30 yrs)	Adolescence	-	Cappuccina	1	-19.4	9.3	7.4	3.2
F213	Male	35+ yrs	Mid-Late Adulthood	2nd c.	Cappuccina	21	-19.5	10.3	6.8	3.2
F214	Male	45-59 yrs	Mid-Late Adulthood	2nd c.	Cappuccina	4	-19.7	8.5	8.3	3.2
F215	Female	38.2 ± 10.9 yrs	Early Adulthood	-	Cappuccina	4	-19.9	9.6	8.8	3.2
F216	Male	35.2 ± 9.4 yrs	Early Adulthood	3rd c.	Cappuccina	23	-20.2	9.5	8.1	3.3
F218	-	<10 yrs	Childhood	-	Cappuccina	5	-19.4	9.5	4.9	3.2
F220	Male	Older Adult (50+ yrs)	Mid-Late Adulthood	-	Cappuccina	9	-19.7	9.7	8.4	3.2

Sample ID	Sex	Age-at-death	Age Category	Burial date	Burial type	Grave Goods	$\delta^{13}C$ VPDB (‰)	$\delta^{15}N$ AIR (‰)	% yield	C:N
F225	-	6 months ± 3 months	Infancy-Early Childhood	-	Cappuccina	0	-18.1	13.1	7.8	3.2
F226	-	10-11 yrs	Childhood	2nd c.	Cappuccina	3	-19.1	10.0	9.9	3.2
F228	-	1 year ± 4 months	Infancy-Early Childhood	3rd c.	Cappuccina	9	-18.0	13.2	4.2	3.2
F229	Male	Older Adult (50+ yrs)	Mid-Late Adulthood	2nd c.	Pit	0	-18.8	9.8	13.3	3.2
F231	Male	Adult	-	2nd c.	Libation	13	-19.2	9.1	9.4	3.2
F234	Male	35.2 ± 9.4 yrs	Early Adulthood	2nd c.	Cappuccina	4	-18.6	9.6	5.1	3.2
F235	Male	~50 ± 12.6 yrs	Mid-Late Adulthood	-	Pit	2	-19.6	9.1	11.1	3.2
F245	Female	19-22 yrs	Adolescence	2nd c.	Cappuccina	10	-19.1	9.7	8.3	3.2
F246	-	Young Adult (< 30 yrs)	Adolescence	-	Cappuccina	2	-19.4	8.2	4.8	3.2
F247	Male	Adult	-	1st c.	Cappuccina	7	-19.3	9.8	7.2	3.2
F248	Male	20-24 yrs	Adolescence	1st c.	Cappuccina	4	-19.6	8.5	4.7	3.2
F249	Male	Adult	-	1st c.	Cappuccina	5	-19.0	9.7	11.1	3.2
F250	Male	35-39 yrs	Early Adulthood	-	Cappuccina	2	-18.9	10.9	8.9	3.2
F252	Female	17-22.5 yrs	Adolescence	-	Cappuccina	1	-19.6	7.6	12.0	3.2

Sample ID	Sex	Age-at-death	Age Category	Burial date	Burial type	Grave Goods	$\delta^{13}C$ VPDB (‰)	$\delta^{15}N$ AIR (‰)	% yield	C:N
F253	Male	48.8 ± 10.5 yrs	Mid-Late Adulthood	-	Pit	4	-19.2	10.3	7.7	3.2
F254	Male	35-45 yrs	Early Adulthood	-	Cappuccina	5	-19.3	10.1	10.0	3.2
F284	Female	30-35 yrs	Early Adulthood	2nd c.	Cappuccina	7	-19.3	10.3	16.0	3.2
F286A	Female	16-18 yrs	Adolescence	-	Cappuccina	2	-19.6	8.1	2.7	3.2
F286B	-	13-14 yrs	Childhood	-	Cappuccina	0	-19.5	7.7	3.7	3.2
F287	Male	Old Adult	Mid-Late Adulthood	2nd c.	Cappuccina	9	-19.2	9.5	6.4	3.2
F288A	Male	30-40 yrs	Early Adulthood	2nd c.	Cappuccina	18	-19.6	10.1	9.3	3.2
F289	-	15-16 yrs	Adolescence	3rd c.	Cappuccina	2	-19.5	8.6	7.3	3.2
F290	Male	45+ yrs	Mid-Late Adulthood	-	Cappuccina	2	-19.1	9.4	10.0	3.2
F291	Male	Adult	-	2nd c.	Cappuccina	3	-19.5	9.1	7.2	3.2
F292	-	2.5-3.5 yrs	Infancy-Early Childhood	-	Tile	3	-18.6	11.7	10.2	3.2
F293	Male	Adult	-	-	Pit	2	-19.3	9.0	10.5	3.2
F294	Male	Older Adult	Mid-Late Adulthood	2nd c.	Cappuccina	9	-19.5	8.9	8.6	3.2
F295	-	7 - 9 months	Infancy-Early Childhood	-	Cappuccina	2	-18.1	12.8	5.0	3.2
F296	Female	25-29 yrs	Adolescence	-	Cappuccina	10	-19.4	8.2	6.8	3.2
F298	Female	Adult	-	-	Cappuccina	3	-19.2	9.7	5.0	3.2

Sample ID	Sex	Age-at-death	Age Category	Burial date	Burial type	Grave Goods	$\delta^{13}C$ VPDB (‰)	$\delta^{15}N$ AIR (‰)	% yield	C:N
F299	-	4.5-6.5 yrs	Childhood	-	Pit	2	-19.8	8.0	7.4	3.2
F302	-	Adult	-	2nd c.	Cremation	7	-18.8	9.5	2.7	5.9
F305	-	7 - 9 months	Infancy-Early Childhood	-	Cappuccina	0	-18.1	13.0	1.1	3.1
F306	Female	Adult	-	2nd c.	Cappuccina	2	-19.1	10.4	7.6	3.2
F312	Male	Young Adult	Adolescence	-	Cappuccina	0	-19.5	8.3	7.0	3.2
F34	Male	Adult	-	3rd c.	Cappuccina	5	-18.9	9.1		3.1
F35	Male	Old Adult	Mid-Late Adulthood	2nd c.	Libation	14	-18.8	10.3		3.2
F39	-	0-6 yrs	Infancy-Early Childhood	3rd c.	Cappuccina	2	-17.1	12.0		3.0
F40	Female	15-29 yrs	Adolescence	2nd c.	Cappuccina	0	-19.5	8.2		3.2
F42	Male	15-30	Adolescence	4th c.	Cappuccina	8	-18.8	8.7		3.2
F42A	Male	30-49 yrs	Early Adulthood	3rd c.	Disturbed	4	-18.8	9.3		3.1
F43	-	0-6yrs	Childhood	2nd c.	Cappuccina	3	-18.2	10.0		3.1
F48	-	0-6 yrs	Childhood	3rd c.	Cappuccina	4	-18.4	10.7		3.2
F49	-	7-14 yrs	Childhood	2nd c.	Cappuccina	2	-18.3	8.5		3.1
F55	-	5-6 yrs	Childhood	2nd c.	Cappuccina	8	-19.4	8.9	6.6	3.2
F59	-	0-6 yrs	Childhood	2nd c.	Libation	7	-18.8	9.4		3.1
F67	Male	15-29 yrs	Adolescence	2nd c.	Cappuccina	9	-19.3	9.0		3.2

Sample ID	Sex	Age-at-death	Age Category	Burial date	Burial type	Grave Goods	$\delta^{13}C$ VPDB (‰)	$\delta^{15}N$ AIR (‰)	% yield	C:N
F68	Male	30-49 yrs	Early Adulthood	-	Cappuccina	1	-18.3	9.5		3.1
F86	Female	Adult	-	2nd c.	Cappuccina	3	-19.7	6.9		3.1
F89	Female	Adult	-	-	Cappuccina	4	-18.1	6.1		3.0
F92	Male	40+	Mid-Late Adulthood	3rd c.	Cappuccina	3	-19.2	9.1		3.2
F93	Female	Adult	-	2nd c.	Cappuccina	6	-18.8	9.4		3.1
F94	Female	30-49 yrs	Early Adulthood	3rd c.	Cappuccina	6	-18.5	9.7		3.0
F96A	Male	Adult	-	2nd c.	Disturbed	1	-18.8	7.1		3.1
F96B	-	Adult	-	2nd c.	Cappuccina	6	-17.7	9.5		3.1
F98	Female	Adult	-	-	Disturbed	2	-18.4	9.8		3.1
Mean							**-19.0**	**9.4**		
S.D.							**0.8**	**1.6**		

Appendix C

Carbonate Sample Stable Isotope Data

Sample ID	Sex	Age-at-death	Age Category	Burial date	Burial type	Grave Goods	$\delta^{13}C_{ap}$ VPDB (‰)	$\Delta^{13}C_{ap\text{-}col}$	$\Delta_{ap\text{-}diet}$
B2	Male	-	-	-	-	-	-10.7	-	-22.7
B2A	Male	-	-	-	-	-	-11.0	-	-23.0
B5	Male	-	-	-	-	-	-11.9	-	-23.9
F100	-	Adult	-	3rd c.	Cappuccina	3	-11.1	8.2	-23.1
F104	-	-	-	2nd c.	Cremation	17	-12.7	8.2	-24.7
F126	Male	15-29 yrs	Adolescence	-	Cappuccina	3	-11.9	7.6	-23.9
F127	Female	15-29 yrs	Adolescence	2nd c.	Disturbed	1	-11.7	6.8	-23.7
F200	Male	45-49 yrs	Mid-Late Adulthood	2nd c.	Cappuccina	8	-12.2	7.2	-24.2
F201	-	-	-	2nd c.	Cremation	10	-16.3	-0.5	-28.3
F204	Female	39.4 ± 9.1 yrs	Early Adulthood	2nd c.	Cappuccina	5	-11.3	8.0	-23.3
F205	Female	Adult	-	2nd c.	Cappuccina	4	-11.3	8.4	-23.3
F206	Female	Older Adult (50+ yrs)	Mid-Late Adulthood	2nd c.	Cappuccina	3	-11.5	7.9	-23.5
F207	Male	Young Adult (< 30 yrs)	Adolescence	-	Cappuccina	5	-10.7	8.7	-22.7
F208	-	12-14.5 yrs	Childhood	-	Cappuccina	5	-10.4	8.7	-22.4
F209	Female	14-16 yrs	Adolescence	-	Libation	15	-10.7	8.4	-22.7
F210	-	9 yrs ± 24 months	Childhood	3rd c.	Cappuccina	10	-16.2	2.9	-28.2

Sample ID	Sex	Age-at-death	Age Category	Burial date	Burial type	Grave Goods	$\delta^{13}C_{ap}$ VPDB (‰)	$\Delta^{13}C_{ap\text{-}col}$	$\Delta_{ap\text{-}diet}$
F211	Female	Young Adult (< 30 yrs)	Adolescence	-	Cappuccina	1	-11.1	8.4	-23.1
F213	Male	35+ (older)	Mid-Late Adulthood	2nd c.	Cappuccina	21	-11.8	7.8	-23.8
F214	Male	45-59 yrs	Mid-Late Adulthood	2nd c.	Cappuccina	4	-11.6	8.1	-23.6
F215	Female	38.2 ± 10.9 yrs	Early Adulthood	-	Cappuccina	4	-11.2	8.7	-23.2
F216	Male	35.2 ± 9.4 yrs	Early Adulthood	3rd c.	Cappuccina	23	-10.5	9.7	-22.5
F218	-	<10 yrs	Childhood	-	Cappuccina	5	-11.3	8.2	-23.3
F220	Male	Older Adult (50+ yrs)	Mid-Late Adulthood	-	Cappuccina	9	-10.7	9.0	-22.7
F226	-	10-11 yrs	Childhood	2nd c.	Cappuccina	3	-10.8	8.3	-22.8
F229	Male	Older Adult (50+ yrs)	Mid-Late Adulthood	2nd c.	Pit	0	-11.8	7.0	-23.8
F231	Male	Adult	-	2nd c.	Libation	13	-11.3	7.9	-23.3
F234	Male	35.2 ± 9.4 yrs	Early Adulthood	2nd c.	Cappuccina	4	-10.4	8.1	-22.4
F235	Male	~50 ± 12.6 yrs	Mid-Late Adulthood	-	Pit	2	-11.2	8.4	-23.2
F245	Female	19-22 yrs	Adolescence	2nd c.	Cappuccina	10	-10.8	8.3	-22.8

Sample ID	Sex	Age-at-death	Age Category	Burial date	Burial type	Grave Goods	$\delta^{13}C_{ap}$ VPDB (‰)	$\Delta^{13}C_{ap\text{-}col}$	$\Delta_{ap\text{-}diet}$
F246	-	Young Adult (< 30 yrs)	Adolescence	-	Cappuccina	2	-11.1	8.3	-23.1
F248	Male	20-24 yrs	Adolescence	1st c.	Cappuccina	4	-11.4	8.2	-23.4
F249	Male	Adult	-	1st c.	Cappuccina	5	-11.4	7.6	-23.4
F250	Male	35-39 yrs	Early Adulthood	-	Cappuccina	2	-10.3	8.6	-22.3
F252	Female	17-22.5 yrs	Adolescence	-	Cappuccina	1	-10.8	8.9	-22.8
F253	Male	48.8 ± 10.5 yrs	Mid-Late Adulthood	-	Pit	4	-12.2	7.0	-24.2
F254	Male	35-45 yrs	Early Adulthood	-	Cappuccina	5	-11.9	7.4	-23.9
F280	Female	Adult	-	2nd c.	Cappuccina	8	-11.0	-	-23.0
F286A	Female	16-18 yrs	Adolescence	-	Cappuccina	2	-11.1	8.5	-23.1
F286B	-	13-14 yrs	Childhood	-	Cappuccina	0	-11.2	8.3	-23.2
F287	Male	Older Adult (50+ yrs)	Mid-Late Adulthood	2nd c.	Cappuccina	9	-11.4	7.9	-23.4
F289	-	15-16 yrs	Adolescence	3rd c.	Cappuccina	2	-10.3	9.3	-22.3
F290	Male	45+ yrs	Mid-Late Adulthood	-	Cappuccina	2	-11.4	7.7	-23.4
F291	Male	Adult	-	2nd c.	Cappuccina	3	-12.5	7.1	-24.5
F293	Male	Adult	-	-	Pit	2	-11.6	7.8	-23.6

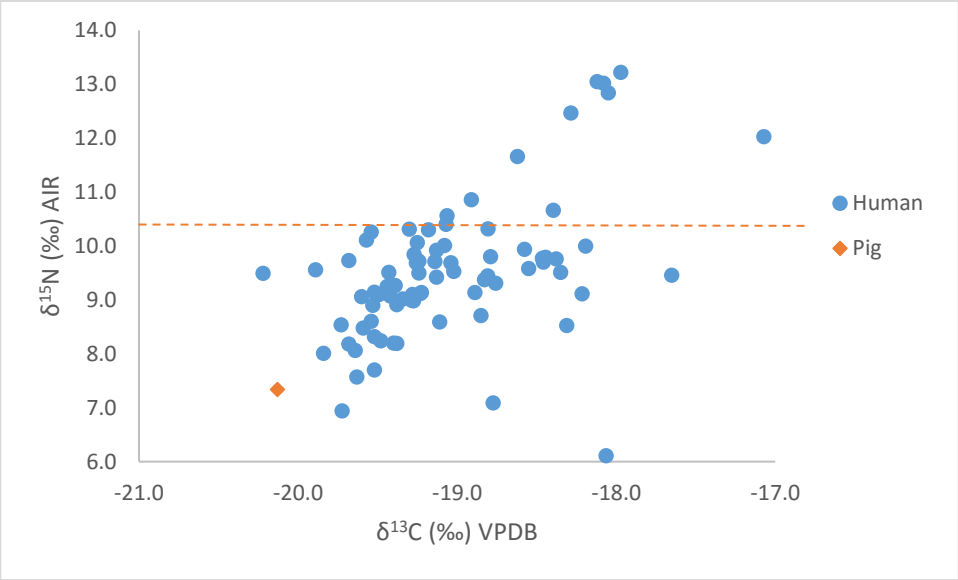
Sample ID	Sex	Age-at-death	Age Category	Burial date	Burial type	Grave Goods	$\delta^{13}C_{ap}$ VPDB (‰)	$\Delta^{13}C_{ap\text{-}col}$	$\Delta_{ap\text{-}diet}$
F294	Male	Older Adult (50+ yrs)	Mid-Late Adulthood	2nd c.	Cappuccina	9	-11.0	8.5	-23.0
F296	Female	25-29 yrs	Adolescence	-	Cappuccina	10	-11.4	8.0	-23.4
F298	Female	Adult	-	-	Cappuccina	3	-11.7	7.5	-23.7
F302	-	Adult	-	2nd c.	Cremation	7	-16.1	2.6	-28.1
F306	Female	Adult	-	2nd c.	Cappuccina	2	-10.9	8.2	-22.9
F312	Male	Young Adult (< 30 yrs)	Adolescence	-	Cappuccina	0	-10.8	8.7	-22.8
F34	Male	Adult	-	3rd c.	Cappuccina	5	-10.9	8.0	-22.9
F37	Female	45-49 yrs	Mid-Late Adulthood	2nd c.	Cappuccina	2	-11.0	-	-23.0
F40	Female	15-29 yrs	Adolescence	2nd c.	Cappuccina	0	-10.4	9.0	-22.4
F48	-	0-6 yrs	Childhood	3rd c.	Cappuccina	4	-11.0	7.3	-23.0
F49	-	7-14 yrs	Childhood	2nd c.	Cappuccina	2	-10.2	8.1	-22.2
F55	-	5-6 yrs	Childhood	2nd c.	Cappuccina	8	-11.0	8.3	-23.0
F59	-	5 yrs ± 16 months	Childhood	2nd c.	Libation	7	-11.1	-	-23.1
F67	Male	15-29 yrs	Adolescence	2nd c.	Cappuccina	9	-11.9	7.4	-23.9
F68	Male	30-49 yrs	Early Adulthood	-	Cappuccina	1	-10.7	7.6	-22.7
F86	Female	Adult	-	2nd c.	Cappuccina	3	-11.5	8.2	-23.5
F89	Female	Adult	-	-	Cappuccina	4	-11.0	7.1	-23.0

Sample ID	Sex	Age-at-death	Age Category	Burial date	Burial type	Grave Goods	$\delta^{13}C_{ap}$ VPDB (‰)	$\Delta^{13}C_{ap\text{-}col}$	$\Delta_{ap\text{-}diet}$
F93	Female	Adult	-	2nd c.	Cappuccina	6	-10.7	8.1	-22.7
F94	Female	30-49 yrs	Early Adulthood	3rd c.	Cappuccina	6	-9.9	8.5	-21.9
F96A	Male	Adult	-	2nd c.	Disturbed	1	-11.1	7.7	-23.1
F96B	-	Adult	-	2nd c.	Cappuccina	6	-10.3	7.4	-22.3
F98	Female	Adult	-	-	Disturbed	2	-11.2	7.2	-23.2
Mean							**-11.4**	**7.7**	**-23.4**
SD							**1.2**	**0.5**	**1.2**

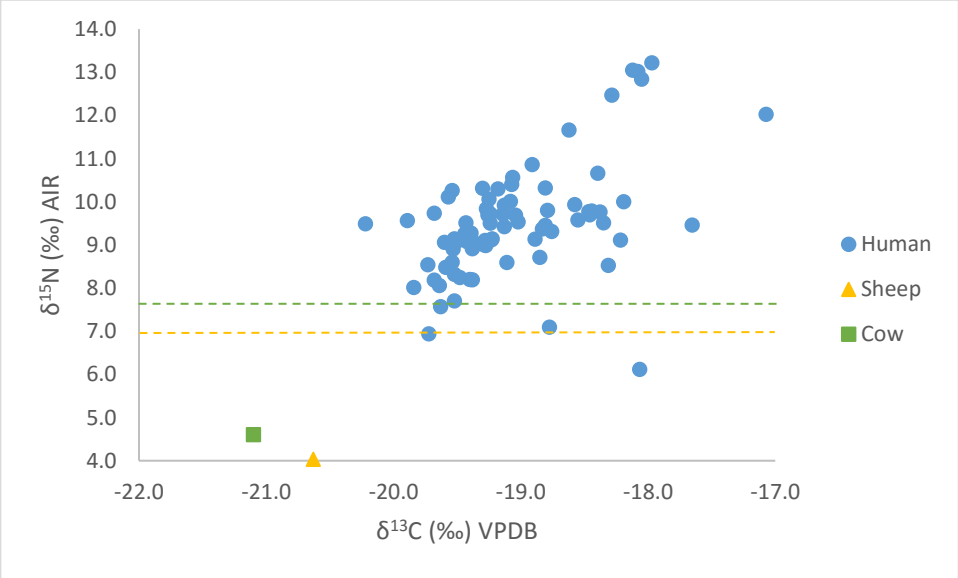
Appendix D

Comparison of trophic levels between human and faunal samples at Vagnari

Trophic level effect comparisons for humans and pig at Vagnari.



Trophic level effect comparisons for humans against the sheep and cow at Vagnari.



Appendix E

Comparison of Collagen yields and C:N ratios with Burial Type

Sample ID	Burial type	% yield	C:N
F100	Cappuccina	-	3.2
F104	Cremation	2.8	9.1
F117	Cappuccina	-	3.1
F123	Cappuccina	-	3.2
F126	Cappuccina	-	3.2
F127	Disturbed	-	3.1
F130	Cappuccina	-	3.2
F131	Libation	-	3.3
F132	Disturbed	-	3.1
F137 A	Tile	-	3.1
F137 B	Disturbed	-	3.1
F200	Cappuccina	6.8	3.2
F201	Cremation	3.3	11.2
F204	Cappuccina	2.3	3.2
F205	Cappuccina	11.6	3.2
F206	Cappuccina	3.2	3.2
F207	Cappuccina	11.1	3.2
F208	Cappuccina	11.0	3.2
F209	Libation	10.0	3.2
F210	Cappuccina	10.6	3.2
F211	Cappuccina	7.4	3.2
F213	Cappuccina	6.8	3.2
F214	Cappuccina	8.3	3.2
F215	Cappuccina	8.8	3.2
F216	Cappuccina	8.1	3.3
F218	Cappuccina	4.9	3.2
F220	Cappuccina	8.4	3.2
F225	Cappuccina	7.8	3.2
F226	Cappuccina	9.9	3.2
F228	Cappuccina	4.2	3.2
F229	Pit	13.3	3.2
F231	Libation	9.4	3.2
F234	Cappuccina	5.1	3.2
F235	Pit	11.1	3.2
F245	Cappuccina	8.3	3.2
F246	Cappuccina	4.8	3.2
F247	Cappuccina	7.2	3.2
F248	Cappuccina	4.7	3.2

F249	Cappuccina	11.1	3.2
F250	Cappuccina	8.9	3.2
F252	Cappuccina	12.0	3.2
F253	Pit	7.7	3.2
F254	Cappuccina	10.0	3.2
F284	Cappuccina	16.0	3.2
F286A	Cappuccina	2.7	3.2
F286B	Cappuccina	3.7	3.2
F287	Cappuccina	6.4	3.2
F288A	Cappuccina	9.3	3.2
F289	Cappuccina	7.3	3.2
F290	Cappuccina	10.0	3.2
F291	Cappuccina	7.2	3.2
F292	Tile	10.2	3.2
F293	Pit	10.5	3.2
F294	Cappuccina	8.6	3.2
F295	Cappuccina	5.0	3.2
F296	Cappuccina	6.8	3.2
F298	Cappuccina	5.0	3.2
F299	Pit	7.4	3.2
F302	Cremation	2.7	5.9
F305	Cappuccina	1.1	3.1
F306	Cappuccina	7.6	3.2
F312	Cappuccina	7.0	3.2
F34	Cappuccina	-	3.1
F35	Libation	-	3.2
F39	Cappuccina	-	3.0
F40	Cappuccina	-	3.2
F42	Cappuccina	-	3.2
F42A	Disturbed	-	3.1
F43	Cappuccina	-	3.1
F48	Cappuccina	-	3.2
F49	Cappuccina	-	3.1
F51	Libation	-	3.2
F55	Cappuccina	6.6	3.1
F67	Cappuccina	-	3.2
F68	Cappuccina	-	3.1
F86	Cappuccina	-	3.1
F89	Cappuccina	-	3.0

F92	Cappuccina	-	3.2
F93	Cappuccina	-	3.1
F94	Cappuccina	-	3.0
F96A	Disturbed	-	3.1
F96B	Cappuccina	-	3.1
F98	Disturbed	-	3.1