

**Diet and Ancient Maya Socioeconomic Status at
Xcambó, Yucatán, Mexico**

BY

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THESIS

Submitted as partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Anthropology
in the Graduate College of the
University of Illinois at Chicago, Chicago, 2017

Chicago, Illinois

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This thesis is dedicated to all my family.

ACKNOWLEDGMENTS

I would like to begin by offering my heartfelt gratitude to all of my mentors, colleagues, family and friends, whose help and support made this project possible. This project was funded by the Chancellor's Graduate Research Fellowship, awarded by the UIC Graduate College, to which I am likewise highly grateful.

I am very thankful to the members of my doctoral committee, Dr.'s Joel Palka, Sloan Williams, Vincent LaMotta, Jack Prost, Vera Tiesler, and Andrea Cucina, for their mentorship, expertise, and moral support. To Dr. Joel Palka, my committee chair, I thank you for your mentorship, encouragement, and patience throughout the years of graduate school and for being so generous with your time, advising me on my project, career plans and funding proposals. To Dr. Sloan Williams, I thank you for giving me a home away from home in your lab while I was conducting my research.

I would also like to thank Dr. William Pestle for training me in the techniques of collagen and apatite extraction and for kindly continuing to provide expert advice as my project progressed, even after he'd moved miles away from Chicago.

I would like to thank Dr. Thelma Sierra Sosa, who directed the excavations at Xcambó, and all her colleagues on the project for so generously allowing me to work with skeletal remains from their excavations, and I am also very grateful to Dr. Sierra Sosa for filing the paperwork for the permit to export samples from Mexico and to the Insitute Nacional de Antrpología e Historia (INAH) for granting the permit. My gratitude as well to Dr.'s Vera Tiesler, Andrea Cucina, and the late Dr. Christopher Götz and all their staff and students at the Universidad Autónoma de Yucatán (UADY) for so generously and kindly taking the time to assist me in the sampling

ACKNOWLEDGMENTS (continued)

process and providing me background information on the site. I would also like to thank Bety Hurtado for her assistance in procuring plant samples.

To Dr. Miquel Gonzalez-Meler, of the Department of Biological Sciences at UIC, I am very grateful for his expert advice and allowing me to use his laboratory facilities, and to his graduate students and staff for all their assistance. I would also like to thank Dr.'s Mary Ashley, Roberta Mason-Gamer, and Boris Igic for the use of their laboratory facilities. I am also very grateful to Elizabeth Olsen at Northern Illinois University (NIU) for being so generous with her time in running FTIR samples for me and for her advice.

I would also like to thank Melanie Kane, Kathy Rizzo, and Erica Haas-Gallo in the anthropology department for all their assistance in administrative matters. I am very thankful, as well, to all of my fellow graduate students for their camaraderie and moral support and to Alejandro Torres for his assistance in the lab.

I am very grateful to Dr.'s Pamela Crabtree and Rita Wright at New York University (NYU) for all their encouragement and support in my aspirations to go to graduate school.

Last but not least, I thank my husband, Haruki, my parents and all my family for all your love, support, and understanding. I couldn't have done this without you.

MHH

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LIST OF ABBREVIATIONS

AC	<i>Asentamiento Central</i>
ACA	<i>Área Ceremonial-Administrativa</i>
AIR	ambient inhalable reservoir
ANOVA	Analysis of Variance
APE	<i>Asentamiento Periférico Este</i>
APO	<i>Asentamiento Periférico Oeste</i>
ASTM	American Society for Testing and Materials
BPI	B-carbonate on phosphate indices
$\Delta^{13}\text{C}_{\text{CA-CO}}$	Apatite-collagen spacing
$\delta^{13}\text{C}_{\text{CA}}$	Carbonate $\delta^{13}\text{C}$
$\delta^{13}\text{C}_{\text{CO}}$	Collagen $\delta^{13}\text{C}$
CAM	Crassulacean Acid Metabolism
CI	Crystallinity Index
EDTA	Ethylene-diamine-tetra-acetic acid
FTIR	Fourier transform infrared spectrometry
HCl	hydrochloric acid
LEH	Linear enamel hypoplasia
NaOH	sodium hydroxide
NISP	Number of Identified Specimens
$\delta^{18}\text{O}_{\text{VPDB}}$	$\delta^{18}\text{O}$ values using Vienna Pee Dee Belemnite standard
PDB	Peedee <i>Belemnitella</i> / Pee Dee Belemnite
RNV	Relative Nutritive Value

SUMMARY

This project analyzes carbon and nitrogen stable isotope results of human bone collagen and apatite from 49 human individuals, as well as 4 botanical and 6 faunal samples as a comparative foodweb, in conjunction with contextual data obtained by the excavators, to examine Classic Maya diet at the site of Xcambó and its potential relationship to social organization. It also tests for diachronic change as the site underwent a significant shift in its economy.

Given that archaeologists located burials in houses and patios (Cetina Bastida 2003:58), associated architecture was used as an indicator of social status, in line with various studies in the Maya region (Carman 1991; Haviland 1981; Hutson et al. 2006; Palka 1997; Tourtellot 1988). Two hierarchies, one of structures and another of patio groups, were developed for statistical comparison. I tested these hierarchies for both broad patterns in diet with respect to social status and household-level differences.

The $\delta^{15}\text{N}$ results of the samples analyzed in the present study suggest a difference in the protein sources of the middle-ranking group. We did not find a significant difference by rank in $\delta^{13}\text{C}$ values. When we compared males and females, mean collagen $\delta^{13}\text{C}$ values were significantly more enriched for males, suggesting that males, overall, consumed more maize resources (possibly including maize-based beverages) and/or greater quantities of marine foods; if the latter, the difference in quantity was not so great as to produce a significant difference in $\delta^{15}\text{N}$ results. I did not find statistically significant diachronic changes in any of the stable isotope signatures. Both marine foods and maize were important components of the diet during both time periods.

SUMMARY (continued)

This study also investigates horizontal social differences for potential links to dietary variation. I explore differences among households by comparing isotope signatures of the four patio groups from which five or more individuals were sampled. Furthermore, I incorporate data from previous studies on cranial modification and dental decoration (Tiesler 2016), and strontium stable isotopes (Sierra Sosa et al. 2014; Sierra Sosa et al. n.d.) with the aim of gaining insight into the potential roles of group identity and geographic origins in shaping dietary differences.

This study enhances our understanding of variability in the Maya region in diet as it relates to social status, group identity, sex, and time period. The results align with studies that emphasize the important role of geography as a determinant of diet (Gerry 1997:60-66; Wright 1997:194). At the same time, there seems to be a relationship between social rank and protein source. There also appears to be a trend towards more depleted collagen and apatite $\delta^{13}\text{C}$ values and more enriched $\delta^{15}\text{N}$ with increasing patio group rank; however, this finding was not statistically significant. Descriptive statistics also suggest some dietary variation among the patio groups from which five or more individuals were sampled, but the results do not reach statistical significance.

1. INTRODUCTION

This thesis focuses on diet and Maya social organization at the site of Xcambó, in northwest Yucatán, which was occupied primarily during the Early and Late Classic periods (Sierra Sosa et al. 2014: 223). We extracted bone collagen and apatite from 49 individuals to analyze stable isotopes of carbon and nitrogen with the aim of answering the following questions:

- Did social status affect diet at Xcambó? If so, how was diet affected?
- Is there evidence that horizontal social differences, such as household or ethnic preferences, led to differences in diet at Xcambó?
- Were there differences in diet by sex?
- Is there evidence for diachronic changes in diet?

This study builds upon previous research investigating social patterning in ancient Maya diet through stable isotope analysis (Coyston et al. 1999; Gerry 1997; Howie et al. 2010; Scherer et al. 2007; White 1997; White et al. 2001; Whittington & Reed 1997; Wright 2006). Although, due to funding and time constraints, the sample size is admittedly small and the findings should therefore be considered preliminary, the aim of this research was to provide a starting point from which to explore dietary variation at Xcambó.

1.1 Diet and social status

A number of researchers have highlighted the social nature of food (Dietler 1996; Goody 1982; Gumerman 1997; Hastorf 1991; Hayden 1996; Hendon 2003; LeCount 2001; Panter-Brick

1996; Weismantel 1998). Food can be seen as a symbol of privileged access to resources of a particular group (Dietler 2006:92-99; LeCount 2001:935). Furthermore, certain foods may be considered appropriate for particular social classes or occupations (Damerow 1996; Goody 1982:99). At the same time, the context, including serving order and the vessels used for serving, in which food is consumed may convey messages about social relationships (LeCount 2001; Weismantel 1998:179). Moreover, while food may serve to differentiate segments of society, as at lavish elite feasts, it may also function to promote a sense of solidarity (Dietler 2006:92-99, LeCount 2001:935).

Status differences may lead to differential access to food resources for various reasons. High status individuals may have a more reliable and diverse supply of food resources as a result of tribute received (Roys 1943:61). For example, ethnohistoric accounts reveal that Maya rulers who held the title *halach uinic* received tribute that included "maize, beans, chile, poultry, honey... and game" and in coastal towns, fish and salt (Roys 1943:61). Town heads, or *batabs*, of the Cupul Province also received tribute (Roys 1943:61-63). While payment of tribute to religious officials was not required, Maya presented them with gifts, such as "cacao, game, poultry, maize, and other provisions" (Roys 1943:80). Consistently, Farriss's (1984:179) research on colonial documents reveals that high-status individuals known as *principales* had a more varied diet in that they had access to "delicacies such as honey, lard, cacao, squash, seeds, and spices...", and they had larger orchards. Furthermore, Farriss (1984:178-179) also highlights elites' preferential access to land in recounting that the high status *principales* and *batabs* owned "a larger orchard outside of town, *milpa* land and especially a privately owned *cenote*, and a well-stocked larder...", whereas commoners, with their smaller plots of land, were more limited in the range of foods they could cultivate. Moreover, the fact that only the elite could own

cenotes, natural sinkholes, meant that they had restricted access to the most fertile land (Farriss 1984:180).

Likewise, participation in public and religious ritual may provide elites access to a broader range of food resources (Cucina & Tiesler 2003:6; LeCount 2001:936). Among the Nasca, for example, Kellner and Schoeninger (2012:502) found dietary isotope evidence that the highest-ranking group consumed more protein and displayed greater dietary breadth than the lowest ranking group. At Chalcatzingo, strontium trace element analysis similarly revealed that the highest-ranking individuals, in this case identified based on differences in burial goods, consumed more meat (Schoeninger 1979:304-305). Drawing upon an example from yet another region, at a La Tène site in Bohemia, it was found that males interred with weapons, who were inferred to be of higher social status due to their role as warriors, had higher $\delta^{15}\text{N}$ values, meaning they consumed more protein, than those without weapons as burial goods (Le Huray & Schutkowski 2005:134, 144-145).

In the Maya region, various lines of archaeological evidence, including faunal remains, caries rates, and stable isotope analysis suggest links between diet and social status (Cucina & Tiesler 2003; Emery 2003; Sharpe and Emery 2015; White et al. 2001; Wright 2006). For example, Sharpe and Emery (2015) analyzed faunal remains from five sites believed to have been subordinate to Piedras Negras and Yaxchilan, comparing them to their respective primary centers. They also selected two secondary centers in the Petexbatun region for comparison to Aguateca, which was a center in the region (Sharpe & Emery 2015). Furthermore, they conducted intrasite comparisons among four Maya social status tiers at Piedras Negras and Aguateca (Sharpe & Emery 2015). Their findings revealed that elites at these two primary centers, and particularly mid-level elites, utilized a broader range of animal resources than non-

elites (Sharpe & Emery 2015:288, 292). The authors suggest that the reason for the highest-ranking elites showing less diversity may be that they utilized primarily a select group of species that would symbolically serve to differentiate them from lower-ranking social strata (Sharpe & Emery 2015:288, 292). It should be noted, however, that not all of these selected species would have been used as food; for example, wild cats may have been valued more for their fur, which was used to produce luxury items such as the cushions that adorned the thrones of Maya rulers (Miller & Martin 2004:19, 36; Sharpe & Emery 2015:288).

In line with this research on Maya social status, Cucina and Tiesler's (2003:4-5) comparison of dental caries rates across three northern Petén sites in the Guatemalan lowlands demonstrated that elite males had a lower incidence of caries than non-elite males. This pattern was reversed for females (Cucina & Tiesler 2003:4-5). When the sample was not divided by sex, elites showed overall lower caries rates, thus implying a more varied diet, containing a greater proportion of protein as opposed to carbohydrates, which are known to be cariogenic (Cucina & Tiesler 2003:4-6; Cucina, Perera, et al. 2011:560). Their findings on protein consumption are consistent with ethnographic evidence. Roys (1943:44), in describing the main meal of the day in Yucatec Maya households, reports that "The stew contained game or fish often in the homes of the upper class but rarely in those of commoners..."

Stable isotope studies have revealed variability as to specific food categories associated with high social status. For example, at the Late Classic Maya sites of Altar de Sacrificios and Dos Pilas, evidence suggested that high status was associated with greater meat consumption (Wright 2006:144, 152), while at other sites, such as Pacbitun and Piedras Negras, there was no notable difference in meat consumption (Coyston et al. 1999:239; Scherer et al. 2007:98). Furthermore, while higher status individuals tended to consume more C4 foods at many sites,

such as Early Classic Altun Ha (White et al. 2001:382), the findings at Copán revealed no significant difference in C4 food consumption (Whittington & Reed 1997:160-161). At Piedras Negras, although the high status group consumed more C4 foods than the low status, with the difference approaching significance (Scherer et al. 2007:92, 97), the low status group showed greater variability in $\delta^{13}\text{C}$ values.

While previous research at Xcambó (Cucina, Perera et al. 2011:561; Sierra Sosa 2004:180) reveals that social status differences were not highly marked, with no identifiable ruling elite, and with commoners, including farmers and fishermen, seemingly absent as well (Sierra Sosa 2004:99), one of the research goals was to use the stable isotope data generated in this study to test for dietary differences that may have resulted from more subtle rank distinctions.

At the same time, as Crumley (1995) points out, not all social differences need be of a hierarchical nature. Rather, differences among individuals or groups may be horizontal, or may exhibit flexibility in terms of how they may be ranked, such distinctions being referred to as "heterarchical" in nature (Crumley 1995:3). Thus, as relates to the present study, it is possible that differences in diet may be linked to differences in household or ethnic customs and preferences, or occupation. Therefore, I also compared stable isotope results of patio groups from which five or more individuals were sampled to test for potential differences among households, as patio groups are believed to have been the dwellings of extended families (Rice 1988:233; Willey 1980:257). It is to such differences linked to group identity that I turn to in the following section.

1.2 Households, geographic origins, and group identity

Researchers have defined a household as a group sharing common activities (Ashmore & Wilk 1988:4; Wilk & Rathje 1982:618), with functions that typically include "production, distribution, transmission, and reproduction" (Wilk & Rathje 1982:621). Vertical social differences among households, leading to differential access to resources, may arise through the "principle of first occupancy", whereby households that have resided at a given location for a longer period of time have preferential access to land and greater prestige (McAnany 2013: 23, 96-97, 116-117; Yaeger 2000 :131-133). McAnany (2013:7-8, 29, 97, 99-101) has proposed that, among the Maya, this privileged access to land was reinforced through the practice of ancestor veneration. However, inter-household differences need not always be hierarchical in nature. For example, there may be differences of ethnicity, local customs, or familial preferences.

Using various lines of evidence, such as ceramics, dental and cranial modification, oxygen stable isotopes for provenience information, and carbon and nitrogen stable isotopes for evidence of diet, Howie and colleagues (2010) investigated the role of food in establishing and maintaining horizontal, in addition to vertical, social distinctions at the Maya site of Lamanai, Belize. The present study follows a similar approach in examining multiple lines of evidence to explore the role of diet in expressing and reinforcing group identity.

1.3 Diet and gender

This study also compares the diets of Maya males (n=27) and females (n=22) at Xcambó, as possible differential participation in ritual events and inferred prestige associated with gender roles may lead to sex-based differences in diet (Hastorf 1991:149-152; Le Huray & Schutkowski 2005). Because leadership roles were typically, although not exclusively, held by males in

Classic Maya society, archaeologists have assumed that males would have participated more frequently in feasting, which would have led to dietary differences between the sexes (Cucina & Tiesler 2003:6; Houston & Inomata 2009:146; LeCount 2001:935). This position is in line with evidence from historic sources indicating that Maya males typically inherited property, or received the greater portion of an inheritance (Farriss 1984:134; Roys 1943:28), and would thus have had greater control over resources.

While various dietary isotope studies in the Maya region have found sex differences in diet (White et al. 1993:359-360; White et al. 2001:385, 387; Whittington & Reed 1997:160-163), a study pooling data from seven sites found that, although there was a significant difference in nitrogen isotopes by sex, the difference in means was small (0.5‰) and there was substantial overlap in ranges (Gerry 1997:57). At Xcambó, a study conducted by Cucina, Perera and colleagues (2011) revealed that females had a higher incidence of caries than males, although the cause of their higher numbers of caries could not be determined from the caries data alone. One of the aims of my project, therefore, was to help elucidate the nature of potential dietary differences between the sexes at this site by providing direct evidence on the amounts of maize and protein consumption by Maya men and women.

1.4 Diachronic change

To better understand potential causes of dietary variation at Xcambó, testing for temporal change provides important information, as the emphasis of Xcambó's economy changed from salt production in the Early Classic period to a more administrative role by the Late Classic (Cucina, Perera, et al. 2011:560, 565; Maggiano et al. 2008:470; Sierra Sosa et al. 2014:228; Wanner et al. 2007). Evidence exists for changes in trade routes (Sierra Sosa 2004:124-125;

Sierra Sosa et al. 2014:226), which could also impact the structure of socio-economic inequalities. Furthermore, osteological evidence for activity patterns indicates the lifestyle of Maya men became more sedentary in the Late Classic period (Maggianno et al. 2008:474-475; Wanner et al. 2007:264). As Cucina, Perera and colleagues (2011:565) point out, Maya males may consequently have eaten more frequently over the course of the day and perhaps increased their consumption of fermented drinks, such as *chicha* or *balche*. Since *chicha* is made from fermented maize (Cucina, Perera, et al. 2011:565; Foster 2002:313), its consumption will affect carbon stable isotope signatures, as highlighted in a study by Somerville and colleagues (2015). Furthermore, testing for diachronic change allows the population at Xcambó to be examined in a regional context, to determine whether it fits a pattern common to other Classic Maya sites, or whether it provides new information on the range of diachronic patterns of change in social status in the Maya region.

1.5 Dissertation outline

In the following chapter, I discuss the major models that have been put forth on Classic Maya social organization, as well as outlining the rationale for using architecture to identify elites archaeologically. I then go on to describe several examples of Maya skeletal studies that have investigated status- and sex-based differences in health and nutritional indicators, including Haviland's (1967) study at Tikal, which linked social status to stature differences. In Chapter 3, I discuss the basic principles of dietary stable isotope analysis and provide an overview of major dietary isotope studies in the Maya region, focusing on those of the Early through Terminal Classic periods. Chapter 4 describes the archaeological site of Xcambó and its role in the broader Maya region, as well as the bioarchaeological studies that have been conducted on the Xcambó

skeletal remains, including studies of paleopathology and stature (Cetina Bastida 2003, 2006; Cetina Bastida & Sierra Sosa 2005), dental caries (Cucina, Perera, et al. 2011) and activity pattern indicators (Maggiano et al. 2008; Wanner et al. 2007). In this chapter, I also discuss the archaeological evidence for diet at Xcambó. In Chapter 5, I describe the samples analyzed in the present study, the laboratory methods used, the processes of testing the collagen and apatite samples for diagenesis, and the statistical analyses conducted, including the coding of variables used as social status indicators, lines of evidence from prior studies used to infer group identity (Sierra Sosa et al. 2014; Sierra Sosa et al. n.d.; Tiesler 2016), and the rationale for choosing the specific statistical tests that were employed in this study. In Chapter 6, I provide the results of tests for diagenesis as well as the isotopic analysis, and I describe the statistical tests for comparisons by social status, patio group, geographic origin, sex, and time period. Chapter 7 interprets the results in terms of the overall diet of Xcambó's inhabitants as well as intrapopulation similarities and differences, and looks at diet through time. The final chapter explores the potential meaning of the results as relates to Classic Maya social organization. The findings at Xcambó are then compared to patterns at other sites, and directions for future research are suggested.

2. CLASSIC MAYA SOCIAL ORGANIZATION AND HEALTH

2.1 Introduction

This chapter will first discuss two major models of Classic Maya social organization, as well as various lines of evidence that serve as a basis for evaluating these models. In the following section, I discuss the rationale for using architecture to infer social status, including historic, ethnographic and archaeological evidence. Then I provide an overview of skeletal studies of Classic Maya health, with an emphasis on investigations of social patterning in Maya health and diet. Furthermore, I discuss the unique insight provided on ancient Maya social status by stable isotope studies and their role as a valuable complement to other lines of evidence.

2.2 Models of Classic Maya social organization

That Classic Maya society was hierarchical is now widely recognized, particularly given the information on royal lineages and non-royal nobles brought to light by hieroglyphic decipherment, as well as evidence for differences in wealth reflected in architecture, burial offerings, and grave construction (Chase 1992:31; Haviland 1965, 1981; Haviland & Moholy-Nagy 1992; Houston 1993; Houston & Inomata 2009:44-53, 131-192; Palka 1997). Nevertheless, there is disagreement as to the number of social tiers of which Maya society was comprised. The models that scholars have put forth for Classic Maya social organization fall into two broad categories, one of which is a "two-class model", which perceives Classic Maya society as highly stratified into an elite class of political-religious rulers and the non-elite masses (Marcus 1983:470; Marcus 1992; Marcus 1993:115-116; Sanders 1992:280; Sharer 1993:93). The other is referred to as the "complex" (Chase 1992:30) or "multiclass model" (Morley & Brainerd 1983:226). The latter views Maya social organization as including not only elites and

commoners, but also, at a minimum, a middle class, and potentially more than three classes consisting of various occupational groups (Becker 1973:397; Chase 1992:30, 32; Emery 2003:509; Morley & Brainerd 1983:226). This view also takes into consideration lineage groups, which may incorporate individuals from multiple social classes (McAnany 2013:158-159). In support of the complex model, Chase (1992:37, 40, 42) points out that the number of tomb burials at Caracol is so great as to be inconsistent with the very definition of "elites", and suggests that their large number more likely represents the presence of a middle stratum of Maya society. He further argues that the extent of variability evident when one examines evidence such as burial offerings and tomb volume and location likewise supports a multiclass model (Chase 1992:40-41).

Ethnohistoric evidence also seems to provide support for the complex model. As highlighted by Tozzer (1941:62-63, footnote No.292), Landa's explanation that "the houses of the richest" were located in the town center, with the dwellings "of those who were held in the highest estimation nearest to these, and at the outskirts of the town were the houses of the lower class", implies the presence of at least three social tiers. Roys (1943:33), drawing upon ethnohistoric sources, states that "Maya society was definitely divided into three classes: nobles, commoners, and slaves." At the same time, he hints at the presence of two tiers within the commoner class, stating that, "This class... seems to have had an upper and a lower fringe, of which we have little information", with the higher ranking tier comprised of commoners who had accrued greater wealth (Roys 1943:34).

Furthermore, Classic Maya inscriptions provide direct evidence for a range of noble titles, which became increasingly common in the inscriptions during the Late Classic period, that seem to suggest a multi-tiered social structure (Coe & Van Stone 2005:76-77; Houston &

Inomata 2009:171-176; Montgomery 2002:197-212). Not only was there a ruler, known as the *k'uhul ajaw* and royal families but there were also subsidiary nobles known as *sajals* (Coe & Van Stone 2005:74-79; Houston & Inomata 2009:172-173; Sharer & Traxler 2006:89), as well as high ranking individuals known by the title of *aj-k'uhuun*, glossed as "he of the holy paper" (Coe & Van Stone 2005:97), or "He of the Books" (Montgomery 2002:210). Furthermore, particularly prominent *ajaws* achieved the title of *Kaloomte'* (Coe & Van Stone 2005:76). Thus the inscriptions seem to lend support for a complex Maya social structure.

2.3 Architecture and social status

To distinguish between elites and nonelites, architecture has commonly been used in archaeological investigations in the Maya region (Carmean 1991; Haviland 1981:100-102; Haviland & Moholy-Nagy 1992; Hutson et al. 2006; Palka 1997; Tourtellot 1988; Willey & Levant 1979:81-83, 101-102). The basic premise of using architecture to infer social status is that through their privileged access to land and labor, elites have the resources to finance larger and more elaborate architecture (Carmean 1991:151-152, 154-155; Hendon 1991:894-895). Drawing upon studies of census records and tax documents from various geographic regions, Netting (1982) conducted a cross-cultural comparison using area of agricultural land or numbers of animals owned, for agriculturalists versus pastoralists, respectively, by a given household as measures of wealth. He found that greater wealth was associated with larger household size, and suggested that the broader resource base would allow for better nutritional status and survivorship of children, at the same time attracting kin and allies and allowing the household to afford servants (Netting 1982:642-643, 650-654). Furthermore, Netting (1982:641) argued that house floor area should logically correlate positively with household size, and thus, in

accordance with the results of his analysis, would be indicative of household wealth.

Consistently, in colonial period Yucatán, high ranking individuals had houses that, although similar in style, were larger than those of commoners (Farriss 1984:178).

In their ethnographic research at the Maya town of Chan Kom, Yucatán, Redfield and Villa Rojas (1971[1934]:33) observed that "The masonry house is an innovation and a luxury for the progressive and the ambitious; the thatched house is a necessity for everybody." Thus, the Maya ethnographic evidence likewise indicates that the wealthy distinguish themselves through architecture. Consistent with Netting's argument, they also noted that the heads of the two largest Maya households were also among the highest status individuals in Chan Kom (Goldkind 1965:871; Redfield & Villa Rojas 1971[1934]:91). Although Redfield and Villa Rojas (1971[1934]:101) nevertheless denied the existence of social classes, their analysis was critiqued by Goldkind (1965:866-867), who pointed out that certain families did, in fact, enjoy economic advantages; based upon data provided by Redfield and Villa Rojas (1934:53), he calculated that only 9 out of 46 *milpa* (field for cultivating corn) holdings measured 4 to 28 hectares, providing the owners with greater income from their surplus produce (Goldkind 1965:865, 867). Moreover, the wealthier families tended to be the same families who held high status leadership positions (Goldkind 1965:870).

Archaeological evidence from the Maya region likewise supports the link between wealth, as reflected in access to land, and size of architecture. At Seibal, for example, Tourtellot (1988:324-325, 336) found a statistically significant positive correlation between the floor area and volume of domestic units. When he subsequently divided platform volume, which he believed to be a reliable indicator of social rank, as it reflects one's ability to finance construction, by area he was able to identify four clusters of domestic units (Tourtellot 1988:331,

337). Tourtellot (1988:337) believed that these four clusters accurately reflected social class distinctions, as they differed from one another by approximately 100% in their volume/area ratio (Tourtellot 1988:331, 337). At Sayil, where Carmean (1991:161-162) examined area of vaulted architecture per household, and room area for those households that did not have vaulted architecture, she found that the "natural breaks in the distribution" were suggestive of three status tiers. At Chunchucmil, Hutson and colleagues (2006:91) found a correlation between houselot size and volume of associated architecture. At Dzibilchaltun, Kurjack (1974:93- 94) found that vaulted structures, which require greater investment of labor, were predominantly located within a 3km radius of the site center, whereas in more peripheral areas of the site, vaulted architecture was more dispersed. Furthermore, the range of variation in residential architecture led him to conclude "that there was considerable socio-cultural heterogeneity at Late Classic Dzibilchaltun" (Kurjack 1974:93), consistent with the multi-tiered model. Consistently, in her comparison of three patio groups at Copán, Hendon (1991:904-905) found differences in quality of architectural construction, as indicated by the percentage of structures made of stone versus perishable materials. There was also variation in the proportion of structures within each group bearing sculptural or hieroglyphic decoration (Hendon 1991:905). Differences were also evident within patio groups in terms of size and architectural quality of residences (Hendon 1991:906). The inference that the residents of the larger, more elaborate "superstructures" were of higher social rank was lent further support by the burial evidence in that tombs, as opposed to simple burials, were more often associated with such structures (Hendon 1991:906, 910). In addition, imported ceramics were more common in the highest ranking patio group and in the highest ranking structure within that group (Hendon 1991:907-908). Moreover, at Dos Pilas, Palka (1997:293-300) found that size of residential architecture and numbers of buildings within a given mound

group was consistent with other lines of evidence for social rank, such as quality of architecture and presence of non-local high quality ceramics.

2.4 Social patterning in Classic Maya health

Among the earliest studies to examine Classic Maya burials for evidence of social patterning in skeletal indicators of health was Haviland's (1967) study at Tikal. Haviland (1967:316, 319-321) analyzed the remains of 55 individuals dating from the Preclassic through Late Classic periods at Tikal and found that individuals in tomb burials were taller than those in non-tomb burials, a difference which was particularly pronounced for the Early Classic period, when the tomb population was, on average, 7 cm taller than the non-tomb population. As both genetics and adequate nutrition play major roles in determining stature, stature differences within a given population are considered to be an important line of evidence for differences in nutritional status (Danforth 1994:206; Larsen 1997:18-19; Steckel 1995:1903; Storey 1998:135). Furthermore, Haviland (1965:17, 22) found that tomb burials located in or near the Great Plaza or North Acropolis had wealthier offerings than household burials. He therefore inferred that the tomb burials were of higher social rank and had greater access to nutritional resources. His results also revealed sexual dimorphism, the overall female mean stature was 147 cm (female mean stature by time period is not provided but is said to have remained "relatively stable through time" [Haviland 1967:323]), whereas male mean stature was 164.5 cm during the Preclassic, reached its highest value of 167 cm during the Early Classic, and subsequently decreased to 157.4 during the Late Classic (Haviland 1967:323). Thus, male stature displayed a temporal trend, decreasing from the Early to the Late Classic period, but nevertheless remaining higher than the pooled mean stature of females (Haviland 1967:323). Haviland (1967:323)

attributed the sexual dimorphism to both genetics and "a lower status for women relative to men." Furthermore, he noted that stature displayed a broader range during the Late Classic, which he interpreted as reflecting a more complex social structure during this period (Haviland 1967:322).

Similarly, Saul (1972) tested for potential diachronic and social patterning in his analysis of skeletal remains from the Maya site of Altar de Sacrificios. His interest in ancient Maya health stemmed from debates regarding the Maya collapse, particularly theories involving famine and disease (Saul 1972:5). Saul (1972:28-29, 93) found an overall trend among males of decreasing stature from the Preclassic through Postclassic, although the mean increased slightly between the Early and Late Classic by 2.5 to 4cm, depending on the formula used, but there was no clear trend for stature increase for females (Saul 1972:29, 93). Furthermore, he found "few clear-cut associations between social status and stature" (Saul 1972:31). However, his sample sizes for the stature analysis were small, $n=12$ males and $n=8$ females (Saul 1972:93, 111). In addition to stature, Saul (1972:100-103) looked at various other health indicators, such as porotic hyperostosis, arthritis, and enamel hypoplasias with larger sample sizes (for most of these analyses, he was able to evaluate 63 adults and 27 subadults), and compared individuals by period but not by social rank. Porotic hyperostosis and cribra orbitalia are pitting of the cranial vault and orbital roofs, respectively, that result from diploic expansion in severe cases of anemia, as the bone marrow expands to increase red blood cell production (Stuart-Macadam 1985:394, 1998:46-47; Wright & White 1996:157). Because there were no genetic anemias in the Americas then, porotic hyperostosis and cribra orbitalia in the Precontact Americas are believed to have resulted from iron-deficient diets (Larsen 1997:40), and particularly in tropical regions, to have been exacerbated by parasitic infections (Saul & Saul 1989:298). Enamel hypoplasias are defects

in tooth enamel produced by metabolic stress (Larsen 1997:44; Storey 1998:135). Although Saul (1972: 69, 73) refrained from drawing inferences on diachronic trends in these conditions, he believed the evidence from Altar de Sacrificios indicated that health was "precarious" and that, in conjunction with other factors, such as civil unrest and potentially invasions, health issues may have contributed to the collapse.

More recently, Márquez and del Ángel (1997) have analyzed skeletal remains from a number of Maya sites, representing the Preclassic through Postclassic periods, to reassess potential diachronic patterns. They found a decrease in stature, using tibial measurements, of 2.29 cm among males from the Preclassic period to the Classic period and a smaller decrease of less than 1cm from Classic to Postclassic times (Márquez & del Ángel 1997:55-57). For females, femoral measurements indicated a slight decrease in stature and tibial measurements indicated a slight increase, in both cases less than 1cm, from Preclassic to Classic, although they note the small Preclassic female sample size (2 tibiae and 3 femora were measured) (Márquez & del Ángel 1997:55-56, 60). They also found a decrease of 2.04 cm in the transition to the Postclassic period (Márquez & del Ángel 1997:55-57,60). At the same time, they note that "there was a reduction of every bone between the Preclassic and Classic", the skeletal elements measured being the femur, tibia, humerus and ulna (Márquez & del Ángel 1997:57-58). However, comparisons were not made along social status lines, as the main focus of this study was testing for diachronic change (Márquez & del Ángel 1997).

At Copán, Storey (1998) compared stature and prevalence of porotic hyperostosis/cribra orbitalia and dental enamel hypoplasias by sex and social status, with a particular interest in whether male or female children were treated differently. She divided the sample into three status groups (Storey 1998:138). Both status groups 1 and 2 were individuals from an elite

compound, status 1 being the higher ranking of the two, and the status 3 group were individuals from rural households (Storey 1998:138-139). She found that lesions of porotic hyperostosis and cribra orbitalia were present in the majority of individuals in the lowest ranking of the three status groups, contrary to the two higher status groups (Storey 1998:140-141). Comparing males by social status, she found that status 2 males had the lowest prevalence of both conditions (Storey 1998:140-141). However, comparing females by status revealed that females of the lowest-ranking Maya group had a significantly higher prevalence of cribra orbitalia, suggesting greater access to resources for the highest-ranking group (Storey 1998:140). Enamel hypoplasia prevalence did not differ significantly by status and, although within the status 2 group the prevalence of two or more lesions was twice as high for males (62%) versus females (36%), presence of enamel hypoplasia was very common, affecting 92% of both males and females (Storey 1998:142-144). In her analysis of stature, Storey (1998:144-145) found a pattern resembling that at Tikal, where males of the highest-ranking group were significantly taller than those of the lowest-ranking group. There was no significant difference by status among females (Storey 1998:144). Thus, her study provided insight into potential effects of social organization on health at Copán by demonstrating that there were no significant differences in skeletal indicators of physiological stress by sex within status groups (Storey 1998:145). However, she found that people in the highest ranking status group, who attained a higher stature and had a lower prevalence of anemia, had been protected from stressors, such as disease and/or malnutrition (Storey 1998:145).

Studies of dental caries have likewise contributed to our understanding of potential effects of sex and social status on Maya diet (Cucina and Tiesler 2003; Cucina, Perera, et al. 2011; Whittington 1999). For example, comparing individuals from three Classic Maya sites,

Calakmul, Kohunlich, and Dzibanché, Cucina and Tiesler (2003:1, 4-5) found that the highest-ranking group had a lower prevalence of caries than the lowest status group. However, when the sample was divided by sex, the results revealed that while high status males had lower caries rates than low status males, high status females had a higher prevalence than low status females (Cucina and Tiesler 2003:4-5). However, there was no significant difference by sex among low status individuals (Cucina and Tiesler 2003:5-6). The results thus suggest that elites had a more varied diet, including more protein in proportion to cariogenic foods, such as maize (Cucina and Tiesler 2003:1, 6). Furthermore, elite males had a more varied diet than elite females (Cucina & Tiesler 2003:4-8). The authors (Cucina and Tiesler 2003:6) point out that this pattern may be related to gender roles, whereby males more commonly held positions of political authority and would therefore have participated more frequently in political and religious events involving feasting, providing them access to a diverse range of foods. In a study of commoners at Copán, Whittington (1999:158) found that females tended to have caries, whereas males did not, as demonstrated statistically through log-linear modeling. There were no significant associations between caries and site type, which Whittington (1999:153) divided into two status categories, based on Willey and Levanthal's (1979) system of site classification. He considered individuals from Type 1 sites, comprised of "three to five mounds, 0.25 to 1.25 m high" to be low status, and those from Type 2 sites, comprised of "as many as six or eight mounds up to 2.5 to 3.0 m high" to be "low-level elites" (Whittington 1999:153). He grouped individuals from "Aggregate" sites, which "are similar in size" to Type 1 sites but lack a central plaza, in the low status category (Whittington 1999:153). Likewise, there was no significant difference between individuals residing in the centrally located urban zones versus those in the peripheral rural zones (Whittington 1999:153, 158-159).

Along similar lines, stable isotope analyses of carbon and nitrogen have provided insight into ancient Maya diet, allowing bioarchaeologists to test for patterning by social status, sex, and chronology (Coyston et al. 1999; Gerry 1997; Gerry & Krueger 1997; Sierra Sosa et al. 2014; White et al. 1993; White et al. 2001; Whittington & Reed 1997; Wright 2006). Stable isotope analysis is particularly well-suited for identifying differential access to food because it provides information on the foods people actually consumed, as opposed to botanical and faunal analyses, which indicate potential food sources. Furthermore, stable isotope analysis provides evidence on the relative prominence of certain food categories in the diet (Ambrose 1993:59; Schoeninger & Moore 1992:249-252; Wright 2006:78). Moreover, carbon and nitrogen stable isotopes provide direct evidence on the diet of specific individuals, whereas faunal and botanical remains provide evidence on potential food sources utilized by groups (Pestle 2010b:2, 56; Schoeninger & Moore 1992:248, 252; White et al. 2001:372). In the following chapter, I discuss dietary isotope analysis in greater detail and I provide examples of how these techniques have been applied in the Maya region.

3. DIETARY ISOTOPE ANALYSES

In this chapter, I discuss the basic principles of reconstructing paleodiet from results of carbon and nitrogen stable isotope analysis, specifically the use of carbon isotopes to distinguish between consumption of C3 and C4 foods and the use of nitrogen isotopes to obtain information on consumption of protein, marine versus terrestrial resources, and legumes versus non-legumes. I then provide an overview of stable isotope studies that have been conducted in the Maya region at Early through Terminal Classic period sites and their findings as relates to diet and social status, sex, and time period.

3.1 Stable isotopes: basic principles

Stable isotope analysis has become a broadly accepted tool in bioarchaeology and physical anthropology. The application of this analysis to anthropology include exploring the adoption of agriculture (Bender et al. 1981; Larsen et al. 1992; van der Merwe & Vogel 1978), investigating the relationship between diet and social status (Ambrose et al. 2003; Kellner & Schoeninger 2012; Le Huray & Schutkowski 2005; White 2001), and exploring early hominid diet (Fizet et al. 1995; Sponheimer & Lee-Thorp 1999; Sponheimer et al. 2006).

The ability to draw inferences on diet from carbon stable isotope values is based on the fact that C3 and C4 plants have different $^{13}\text{C}/^{12}\text{C}$ ratios as a result of differences in their photosynthetic pathways, as demonstrated by Park and Epstein (1960). The designations C3 and C4 indicate the number of carbon atoms present in the first product of their respective pathways (Ambrose 1993:86; Schoeninger & Moore 1992:255). The C4 pathway, which leads to higher $^{13}\text{C}/^{12}\text{C}$ ratios, evolved more recently as an adaptation to stressful environmental conditions

(Smith & Epstein 1971: 384). Therefore, tropical grasses, such as maize, sugarcane, millet, and sorghum, are typically C4 plants with mean $\delta^{13}\text{C}$ values ranging from -14 to -12‰. (Ambrose & Norr 1993:2-3; Bender 1968; Hatch et al. 1967; Hatch & Slack 1970:148; Smith & Epstein 1971:380, 384). However, the majority of plants, including wheat, vegetables, root crops, and trees, are C3 plants, with a mean $\delta^{13}\text{C}$ in the range of -28 to -26‰ (Ambrose & Norr 1993:2-3; Park & Epstein 1961; Smith & Epstein 1971; Tieszen 1991:229). The third category, CAM (Crassulacean Acid Metabolism) plants, such as bromeliads and cacti (Ambrose 1993:86; Ambrose & Norr 1993:3), have $\delta^{13}\text{C}$ values in the range of -14 to -33‰, overlapping the ranges of C3 and C4 plants, as they may use either pathway in response to ambient light and temperature (Bender et al. 1973; Schoeninger & Moore 1992:255).

The experiments of DeNiro and Epstein (1978) proved that the isotopic signature of an organism's food sources are represented in its tissues, taking into account a fractionation factor, which is defined as the difference in isotope ratios "between source and product" (O'Leary 1981:554). Although estimates for the trophic level difference in $\delta^{13}\text{C}$ of bone collagen of 1‰ to 5‰ have commonly been provided (Larsen 1997:271; Lee-Thorp et al. 1989:594; Schoeninger & DeNiro 1984:625; Schoeninger & Moore 1992:258), controlled experiments conducted by Ambrose and Norr (1993:29) found that the diet-collagen spacing fluctuated with "the proportion of protein in the total diet and the difference in $\delta^{13}\text{C}$ value between protein and energy". By manipulating both the proportion of protein and the carbon stable isotope composition of the diet of laboratory rats, they obtained diet-collagen spacing values ranging from -2.2 to +9.6‰ (Ambrose & Norr 1993:13-14, 25-26). In contrast, they found the diet-carbonate spacing to be more consistent, at approximately 9.5‰ (Ambrose & Norr 1993:28). Thus, they demonstrated that protein is routed primarily to collagen, whereas apatite carbon reflects the isotopic

composition of the entire diet (Ambrose & Norr 1993:28). Therefore, because human diets tend to be comprised primarily of carbohydrates, apatite will more clearly reflect the carbohydrate source (Torres-Rouff et al. 2012:59-60).

As a result of macronutrient routing, further insight can be gained by comparing $\delta^{13}\text{C}$ results of collagen to those of apatite, represented as $\Delta^{13}\text{C}_{\text{CA-CO}}$ (Ambrose 1993:105), known as the "apatite-collagen spacing" (Lee-Thorp et al. 1989:587). As seen above, the difference between apatite $\delta^{13}\text{C}$ values and those of the actual diet are greater than those of collagen compared to diet (Ambrose 1993:105; Lee-Thorp et al. 1989:587). Moreover, the apatite-collagen spacing of carnivores is typically less than that of herbivores, the former ranging from approximately +3 to +5‰, the latter generally on the order of +7‰ (Ambrose 1993:105; White et al. 2001:375). This difference between carnivore and herbivore values was attributed by Krueger and Sullivan (1984:207, 213, 215) to the fact that lipids are isotopically lighter than both carbohydrates and protein and that lipids comprise a greater proportion of a carnivore's diet. While this may in part account for the difference, in broader terms, the apatite-collagen spacing will depend upon the difference in isotopic signatures between the animal's major protein source and that of the whole diet (Ambrose 1993:107-109; Ambrose et al. 2003:220; Ambrose & Norr 1993; White et al. 2001:375). Thus, if one consumes protein that is enriched in ^{13}C , one will have smaller $\Delta^{13}\text{C}_{\text{CA-CO}}$ values, mimicking the effects of a more carnivorous diet, particularly if the major carbohydrate source is isotopically light or in the case of high-protein diets (Ambrose 1993:107-108; Lee-Thorp et al. 1989:593-595). This finding was demonstrated in a study conducted by Lee-Thorp and colleagues (1989:585, 593), in which they analyzed human skeletal remains from a coastal population in southern Africa and found a mean $\Delta^{13}\text{C}_{\text{CA-CO}}$ of 2.6‰. Furthermore, determining the source of collagen carbon is complicated by the fact that essential

and semi-essential amino acids from dietary protein carbon together comprise approximately 65% of collagen carbon (Ambrose et al. 2003:219). Thus, dietary protein is the major but not the only source of collagen carbon (Ambrose et al. 2003:219). In contrast, determining the source of nitrogen is more straightforward in that "almost all nitrogen in collagen is derived from dietary protein" (Ambrose et al. 2003:219).

For this reason, nitrogen stable isotopes can provide key pieces of information pertaining to protein sources. For example, $\delta^{15}\text{N}$ values increase by approximately 3‰ with each successive level up the food chain (Minagawa & Wada 1984:1138; Miyake & Wada 1967:43-46; Schoeninger & DeNiro 1984:635; Schoeninger & Moore 1992:258). Therefore, in theory, an organism's $\delta^{15}\text{N}$ results can be compared with available protein resources to determine which of these likely played a more prominent role in the diet. However, $\delta^{15}\text{N}$ values can be affected by climate (Ambrose 1993:97-98). Studies conducted in East Africa have found that herbivores from regions with lower rainfall have more enriched $\delta^{15}\text{N}$ signatures compared to those from regions of higher rainfall (Ambrose 1991:293). This pattern can be explained by the fact that under conditions of water stress, the kidneys concentrate urine, which increases excretion of urea (Ambrose 1993:98). Urea is isotopically light relative to diet (Ambrose 1993:98). Such factors must be taken into consideration for accurate dietary reconstruction. In contrast to nitrogen isotopes, for $\delta^{13}\text{C}$ values, the extent of overlap between trophic levels make this analysis a less useful indicator (Schoeninger & DeNiro 1984 632-636).

Returning to nitrogen, because the nitrates that provide most of the nitrogen supply to marine plants are isotopically enriched, nitrogen isotopes can also be used to distinguish between marine and terrestrial food resources (Schoeninger & DeNiro 1984; Schoeninger & Moore 1992:256-258). The difference becomes more pronounced in marine animals as a result of the

fact that marine food chains are longer than terrestrial (Schoeninger and DeNiro 1984:635). In fact, Schoeninger and DeNiro (1984:625, 631) analyzed bone collagen from a broad range of animal species and found that the $\delta^{15}\text{N}$ values of marine animals were enriched by approximately 9‰ relative to terrestrial animals, with minimal overlap between the two groups. The one exception was found to be coral reef fish, which had unexpectedly low $\delta^{15}\text{N}$ relative to other marine fish, which the researchers attributed to high rates of nitrogen fixation in coral reefs (Schoeninger and DeNiro 1984:634-635). At the same time, because seagrasses and corals are enriched in ^{13}C , reef fish displayed unusually high $\delta^{13}\text{C}$ values (Keegan & DeNiro 1988:321; Schoeninger and DeNiro 1984:636). Although not as highly enriched as reef fish, other marine fauna likewise tend to have more enriched $\delta^{13}\text{C}$ values than terrestrial animals, although with greater overlap in ranges than for $\delta^{15}\text{N}$ (Schoeninger & DeNiro 1984:625, 635-636). Thus, in an environment in which both C4 plant foods and marine resources are available, discerning the relative contributions of C4 foods, such as maize, versus marine foods to the diet becomes more complicated, although examining $\delta^{15}\text{N}$ values in conjunction should help lend clarity (Ambrose 1993:94; Schoeninger & DeNiro 1984:636).

Lastly, consumption of legumes versus non-legumes can be discerned due to the fact that legumes have lower $\delta^{15}\text{N}$ values as a result of the symbiotic bacteria that allow them to fix molecular nitrogen (DeNiro & Epstein 1981:345-346). It should be noted, however, that Schoeninger and Moore (1992:260) have raised various concerns with this premise, such as the lack of supporting evidence from archaeologically recovered food residues and the fact that $\delta^{15}\text{N}$ values greater than the expected value of zero have been obtained (Schoeninger & Moore 1992: 260; Spielmann et al. 1990:757).

3.2 Maya stable isotope studies

Various studies in the Maya region have used carbon and nitrogen stable isotopes to investigate potential dietary patterns by sex, social rank, and time period. At the site of Altun Ha, in Belize, for example, the results of White and colleagues' (2001:382) stable isotope analysis revealed, for the Early Classic sample, that the individual suspected to be highest in status, based upon the archaeological evidence, showed the highest proportion of C4 food consumption (White et al. 2001:382). For the Late Classic, the authors compared three of the site's peripheral zones to one of the central zones and found that residents of the central zone, a location which is assumed, based on ethnohistoric accounts, to be associated with prestige (Tozzer 1941:25, 62), consumed a significantly greater proportion of reef resources or C4 foods (White et al. 2001:382-383). They also found that males had significantly higher $\delta^{13}\text{C}_{\text{CO}}$ and $\delta^{15}\text{N}$ values, suggesting that they consumed more marine foods (White et al. 2001:386-387). Similarly, at another site in Belize, Pacbitun, the difference between status categories was in maize, not meat, consumption (White et al. 1993:362-366). White and colleagues (1993:362-365) found that individuals believed to be of higher status because they were interred in crypts or cists, nearer the site core, and with wealthier burial offerings, consumed more C4 foods. There was also a difference in maize consumption between the sexes, with males consuming a significantly greater proportion of C4 foods, $\delta^{15}\text{N}$ results revealing no significant difference in protein consumption (White et al. 1993:359-360). At Lamanai, Belize, White and Schwarcz (1989:455) analyzed burials that were generally believed to be of high status; however, only two, one male and one female, both dating to the Early Classic, were interred in tomb burials. They found that the male tomb burial had the highest $\delta^{15}\text{N}$ value of all individuals sampled (White & Schwarcz 1989:458, 464).

In the Pasión region, Wright assessed social status by conducting univariate analysis as well as principal components and cluster analysis, using four major burial characteristics, "structural association, grave morphology, skeletal position, and grave furniture" (Wright 2006:43, 46). The data revealed some variation by site and time period in terms of which variables were most representative of status (Wright 2006:46-77). For example, at Early Classic Altar de Sacrificios, presence of stingray spines, worked bone, hematite and *Spondylus* valves, and burial positioning with the head towards the east were associated with high status (Wright 2006:53). During the Terminal Classic at Altar de Sacrificios, while worked bone was still associated with status, axial location within a residential structure and presence of bowls as offerings were more strongly associated with status than the previously mentioned variables (Wright 2006:58-59, 63). Wright (2006:44-45,144,152) found that at Altar de Sacrificios and Dos Pilas, for the Late Classic, $\delta^{15}\text{N}$ values reflected greater meat consumption among the burial clusters of higher social status. In contrast, at Seibal there was no rank-based patterning in $^{15}\text{N}/^{14}\text{N}$ or $^{13}\text{C}/^{12}\text{C}$ ratios (Wright 2006:148). Thus, the evidence from the Pasión region and the previously mentioned study of Altun Ha seem to suggest some regional or site-level variation with regards to specific food categories and their association with status (White et al. 1993:370). In terms of sex-based variation in diet, Wright (2006:142, 144) found no significant difference in stable isotope values at Altar de Sacrificios during the Preclassic period or Early Classic period. However, the Late Classic Altar de Sacrificios sample revealed that two royal individuals, one a female, the other of indeterminate sex, had relatively high $\delta^{15}\text{N}$ values compared to their lower status contemporaries (Wright 1997:192; Wright 2006:144, 148, Figure 7.11). While statistical results indicated a significantly higher $\delta^{15}\text{N}$ for females, Wright (1997:192) cautions that this may be an effect of the one unusually high value. While the Late Classic period sample size was

small and comparisons between the sexes not specifically discussed for this time, during the Terminal Classic she noted that $\delta^{13}\text{C}$ values have a tendency to be more enriched for males (Wright 2006:144, 148). However, this observation has not been proven statistically (Wright 2006:148). At Seibal, although the Preclassic sample revealed slightly more enriched $\delta^{13}\text{C}$ results for females, the sample size was too small to verify this distribution statistically (Wright 2006:148). The fact that there was only one female among the Late Classic period individuals precluded sex-based comparisons for that period, but during Terminal Classic times, females consumed less maize, as evidenced by more negative $\delta^{13}\text{C}$ values (Wright 2006:148, 152). There were no significant differences in $\delta^{15}\text{N}$ values between the sexes for the Terminal Classic period (Wright 2006:152). The Dos Pilas Late Classic sample revealed that male $\delta^{13}\text{C}$ values were statistically more enriched than those of females (Wright 2006:152). Unfortunately, the Terminal Classic sample was too small for statistical comparison (Wright 2006:152). At Itzan and Aguateca, there were no significant differences in stable isotope signatures by sex, and at Tamarindito the sample size was too small to draw inferences (Wright 2006:155).

The geographic variation in status-based differences suggested by Wright's data was further supported in a study by Gerry (1997), in which he conducted stable isotope analysis of human remains from seven Maya sites, including Copán and secondary sites as well as two sites each in Belize and the Petén. Although he found differences in mean $\delta^{13}\text{C}$ values by social status, with "High Elites" having more enriched values than "Junior" and "Petty Elites", who in turn were more enriched than commoners (Gerry 1997:58-59), he points out the substantial overlap among groups. Elites likewise had higher $\delta^{15}\text{N}$ values, but Gerry (1997:59) states that "the patterns on the $\delta^{15}\text{N}$ axis are also fairly subtle and insignificant". In comparing the sexes, he

found that the male mean $\delta^{15}\text{N}$ was significantly higher than that of females during the Late Classic period, but the difference between means was only 0.5‰ (Gerry 1997:57).

A study conducted by Scherer and colleagues (2007) analyzed dietary isotopes in human bone collagen in conjunction with dental caries and porotic hyperostosis at the site of Piedras Negras, in Petén, Guatemala. The investigators determined social status from "burial architecture, associated grave goods, and hieroglyphic information" (Scherer et al. 2007:88). As preservation conditions allowed for only 32 individuals to be evaluated for porotic hyperostosis, statistical comparisons could not be conducted by period, but prevalences were high, ranging from approximately 57 to 71% (Scherer et al. 2007:90). Among the 56 individuals evaluated for caries, they did not find notably different rates among status groups, although the sample sizes did not allow for statistical comparison by status (Scherer et al. 2007:90). The isotope results, representing 46 individuals, revealed that while the high status group had heavier $\delta^{13}\text{C}$ values, with a difference approaching statistical significance, the low status group displayed a broader range of isotope signatures (Scherer et al. 2007:90, 92). Comparing chronological periods, they found a narrowing range of $\delta^{13}\text{C}$ values during the earlier phase (625-750 A.D.) of the Late Classic period, followed by an increased range of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values during the later phase (750-825 A.D.) of this period (Scherer et al. 2007:85, 92). Furthermore, when they looked at the chronological patterning by social status, the data suggested that the lower ranking group, which consisted of both commoners and those of intermediate rank, consumed less maize during the latter part of the Late Classic period, possibly increasing their intake of riverine fish (Scherer et al. 2007:98). Although the reasons for this change remain unclear, the authors suggest that they are more likely sociopolitical than ecological in nature (Scherer et al. 2007:98-100).

For the Classic period in the northern lowlands, data is available for Xcambó (Sierra Sosa et al. 2014), as will be discussed in the following chapter, and for the sites of Yaxuná, an inland site, and Chunchucmil, 27 km distant from the Gulf of Mexico, (Mansell et al. 2006:174, 177). Although the sample size for Chunchucmil was small (n=5), the data suggested that the inhabitants of Yaxuná, consumed more maize than those of Chunchucmil, which the authors attribute to ecological differences between the two locations, in conjunction with Chunchucmil's access to maritime trade (Mansell et al. 2006:173-174, 180-181, 184). The poor preservation of the skeletal remains at the latter site precluded any comparisons by sex (Mansell et al. 2006:184). For the 22 individuals from Yaxuná, although no statistical comparisons were conducted, Mansell and colleagues (2006:177) note "a high degree of consistency in stable isotope values." Thus, as the authors point out, while this study seems to support the importance of location in determining diet, further data is needed to better understand the role of social factors (Mansell et al. 2006:184).

4. XCAMBÓ

4.1 Archaeological site

The archaeological site of Xcambó (Figure 1), located on an island in marshland along the Yucatán peninsula's northwest coast (Figure 2), was excavated by Sierra Sosa and colleagues from 1996 through 2000 (Cucina, Perera, et al. 2011:561-562). The major phases of occupation date from the Early Classic (A.D. 250-550) through the site's abandonment during the Late Classic period at approximately 700-750 A.D., yet the excavators found evidence for smaller populations dating as far back as the Middle Preclassic (Cucina, Perera, et al. 2011:561; Sierra Sosa et al. 2014:223). The only evidence for Postclassic occupation consists of four structures, which may have been used during seasonal visits for salt gathering (Sierra Sosa et al. 2014:225). Dating was accomplished through ceramic and lithic seriation (Sierra Sosa 2004:170). The Maya built the site, which measures approximately 150m by 700m in its north-south and east-west dimensions, respectively, at a distance of 1.5km from the coast, upon a natural elevation in a marshland (Sierra Sosa et al. 2014:223; Sierra Sosa 2004:6, 96; Sierra Sosa 2015:1).

Previous studies have divided the site into four sectors, including the "Área Ceremonial-Administrativa" [Central Administrative Area], ACA (Cetina Bastida 2003:68; Cetina Bastida & Sierra Sosa 2005:666). This area is comprised of a main plaza, surrounded by buildings which are believed, based not only upon their location but also size and quality of architecture, to have been the locus of religious and civic administrative functions (Sierra Sosa 2004: 96). Adjacent and to either side is an area known as the "Asentamiento Central" [Central Settlement], AC,

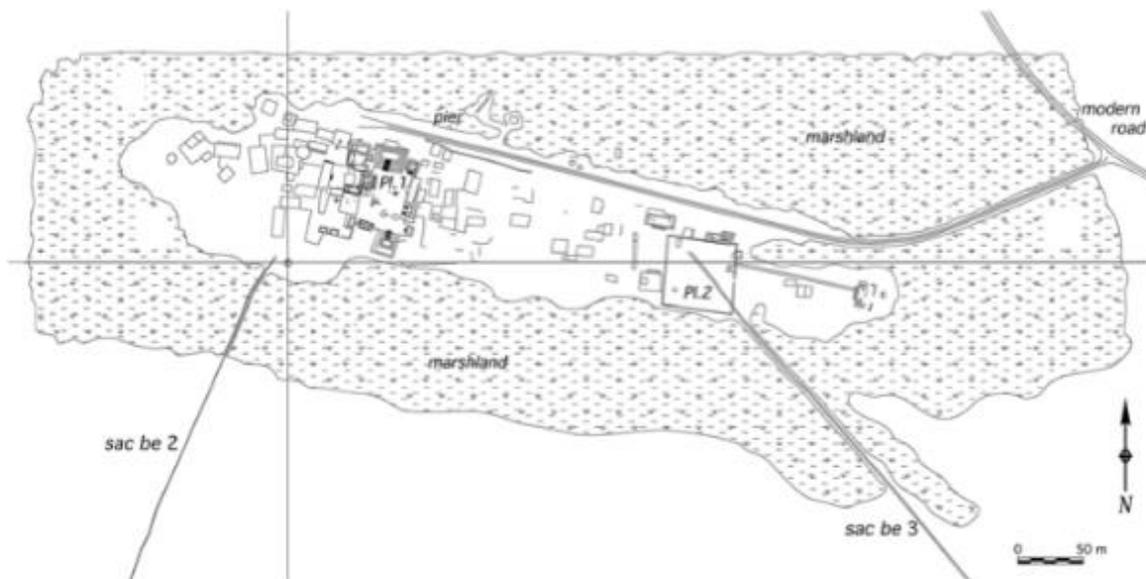


Figure 1. Map of the archaeological site of Xcambó (Sierra Sosa 2015:2, Fig.1.2; courtesy of Dr. Thelma Sierra Sosa and Dr. Andrea Cucina).

which includes various residences, three structures believed to have served public functions, and workshops (Segura 2009:47-48). Adjacent to this sector are, to one side, the "Asentamiento Periférico Este" [Eastern Peripheral Settlement] (Cetina Bastida 2003:68), APE, which consisted of residences believed to have been inhabited by nuclear families and constructed of perishable materials over stone foundations (Segura 2009:47). To the other side is the "Asentamiento Periférico Oeste" [Western Peripheral Settlement] (Cetina Bastida 2003:68), APO, where residences were built with masonry walls (Segura 2009:47). Despite the abovementioned differences among sectors, quality and distribution of burial goods as well as bioarchaeological evidence for nutritional status seemed to reflect a high status population



Figure 2. Map showing location of Xcambó and select Maya sites. Redrawn from map available courtesy of d-maps.com, url: http://d-maps.com/carte.php?num_car=1393&lang=en, and approximate site locations redrawn from (Andrews 1980: 25; Houston & Inomata 2009: Figure 1.1; Sierra Sosa 2015: Fig. 1.1; Webster 1997: Figure 1.1), using GIMP 2.8.18.

without marked differences in access to resources (Cetina Bastida & Sierra Sosa 2005:673-675; Cucina, Perera, et al. 2011:561; Sierra Sosa 2004:97, 99; Sierra Sosa 2015:9). The majority of the Xcambó burials were recovered from the central settlement (Medrano Chan 2005:77). However, Medrano Chan (2005:131, translation by author) notes this area “has been excavated more extensively and intensively.”

Xcambó's proximity to the coast, at a distance of only one mile, provided its inhabitants access to abundant maritime resources, including salt, which was critical to the site's economy (Cucina, Perera, et al. 2011:561; Maggiano et al. 2008; Sierra Sosa 2004). In fact, given that inland Maya salt sources were few and of relatively low yield, the northern coast of Yucatán was the major supplier of salt for much of the Maya lowlands (Andrews 1980:27-29). Xcambó's prominent role in the salt trade is inferred through various lines of evidence, including its ideal location for maritime trade, the presence of storage facilities recognizable as round features dug into the base of many Early Classic structures, a pier, and non-local trade goods, as well as roads connecting Xcambó to other sites (Sierra Sosa 2004:102, 114-125, 136; Sierra Sosa et al. 2014:223-226; Sierra Sosa 2015:1). More specifically, before or during the Early Classic period, the Maya built a *sak be* (meaning "white road" [Sierra Sosa et al. 2014:223]), leading to the nearby site of Misnay (Sierra Sosa 2015:1-2, 4), which is believed to have provided agricultural products and served as a source of labor for Xcambó (Sierra Sosa 2004:106-107, 153).

During the Late Classic, as the site's population was growing (Sierra Sosa et al. 2014: 223, 227), a second plaza was constructed to the east of the main plaza (Sierra Sosa 2004: 96). It is from this smaller plaza that the residents built a *sak be* leading to the site of Dzemul, which investigators believe was a major supplier of subsistence resources (Sierra Sosa 2004:97, 107). A second *sak be* linked this plaza to a residence at the easternmost extent of the site (Sierra Sosa

2004:97, 107). It was also during this period that the Maya expanded the main plaza and covered the storage facilities, while "residences... were built over the previous constructions" (Sierra Sosa 2015:4). At this time, a number of such storage facilities are found at the salt flat localities, suggesting storage functions were shifted to nearby locations, although it is also possible that storage was accomplished by alternate means at Xcambó (Sierra Sosa 2004:102; Wanner et al. 2007:264).

Xcambó was abandoned approximately 700 A.D. (Sierra Sosa et al. 2014:223). The only evidence dating to the Postclassic consists of two shrines, two altar-platforms, and incense burners (Sierra Sosa 2004:166; Sierra Sosa et al. 2014:224-225). Particularly given their non-local style, investigators have suggested that these Postclassic structures reflect seasonal occupation for purposes of salt gathering (Sierra Sosa et al. 2014:224-225).

4.2 Regional context

As reflected in the ceramic and lithic evidence, Xcambó maintained ties with the Petén, the Puuc and Chenes regions, a number of sites along the northern Yucatec coast, and northern Quintana Roo during the Early Classic period (Sierra Sosa 2004:117; Sierra Sosa et al. 2014:226). In addition, obsidian artifacts from El Chayal provide evidence for a link to highland Guatemala (Sierra Sosa et al. 2014:226). Furthermore, investigators have inferred that Xcambó was likely a political ally of Izamal, (Sierra Sosa 2015:10), one of the earliest polities to emerge in northern Yucatán that developed into a major political power during this period (Sharer & Traxler 2006:301; Sierra Sosa 2015:10). At the same time, the site of Xtampú is believed to have both depended on Xcambó and provided it with salt (Sierra Sosa 2004:145). Also during this period, Xcambó-style ceramics are present at Teotihuacan (Sierra Sosa 2004:118-119). Even if

they were procured through middlemen, such evidence demonstrates that Xcambó Maya were already building an extensive trade network (Sierra Sosa 2004:118-119). Xcambó's inhabitants traded not only for material goods, but investigators believe that they obtained agricultural staples from nearby sites (Sierra Sosa 2004:99). The broad range of faunal remains recovered suggests that trade with inland sites for terrestrial faunal resources took place but, likewise, over short distances (Götz & Sierra Sosa 2011:135; Sierra Sosa 2004:146).

During the Late Classic period, trade with Maya sites in Petén was maintained, whereas trade with the northeast of the peninsula ceased (Sierra Sosa et al. 2014:226). Also during this period, ties were established with sites in the north of Chiapas, the Grijalva River basin in Tabasco, and southern Veracruz (Sierra Sosa 2004:124-125; Sierra Sosa et al. 2014:226). Thus, Xcambó broadened its exchange network and access to resources (Sierra Sosa et al. 2014:226).

As mentioned above, the Maya abandoned Xcambó at approximately 700 A.D. (Sierra Sosa et al. 2014:223), which the excavator suggests may have been a consequence of efforts by major Late Classic centers "to centralize all production, and to have control of the movement of goods", ultimately severing Xcambó's access to its trade networks, as new ports under the control of these primary centers were established (Sierra Sosa 2004:164-165; Sierra Sosa 2015:10).

4.3 Previous bioarchaeological research at Xcambó

Over 500 skeletons were recovered from the site of Xcambó, which is an exceptionally large archaeological sample of an ancient Maya population (Sierra Sosa 2004:170; See examples, Figure 3). Dating was accomplished through ceramic and lithic seriation (Sierra Sosa 2004:170). The Xcambó Maya interred their deceased in various grave types, the most common being "simple burials... directly beneath the floors of residential platforms or nearby areas..."



Figure 3. Examples of burials from the site of Xcambó (Sierra Sosa 2015:9, Fig. 1.6; courtesy of Dr. Thelma Sierra Sosa and Dr. Andrea Cucina).

(translation by author, Cetina Bastida 2003:35) and cist burials, but also including burials in ceramic vessels, and one in a tomb (Sierra Sosa 2004:170; Sierra Sosa et al. 2014: 227; Vera Tiesler, 2013, information from field and lab notes). The prevalence of cist graves remained approximately the same across time, but was greater in the eastern versus the western sector of the site (Sierra Sosa et al. 2014:227). The majority of the dead were interred in an extended position, which did not vary significantly by sex (Sierra Sosa et al. 2014:227). Investigators

found that the spatial distribution of grave types and offerings were relatively homogeneous across the site (Cetina Bastida 2003:35; Sierra Sosa et al. 2014:227).

Evidence from osteological activity pattern indicators suggest there was an economic transition, particularly in male occupations, concurrent with Xcambó's expansion of trade, during the Early to Late Classic period transition, from a more direct involvement in salt production and seafaring, to a focus on trade administration (Cucina, Perera, et al. 2011:560-562; Maggiano et al. 2008; Wanner et al. 2007:262-264). This pattern is inferred from decreased robusticity measures of male humeri and femora, and reduced sexual dimorphism from the Early to Late Classic period; the greater robusticity among males during the Early Classic is consistent with activities such as canoeing and transporting heavy loads, while the Late Classic decrease would be expected if their role had become increasingly administrative (Maggiano et al. 2008:472-474; Wanner et al. 2007:262, 264). The daily activities of females, however, appear to have remained relatively unchanged, and their relatively more symmetrical upper limb measures are to be expected in association with use of *manos* and *metates* to grind maize (Wanner et al. 2007:262). These conclusions are further supported by an analysis of osteoarthritis at the site, which revealed a significantly decreased incidence in the Late Classic among males, whereas females showed a small but non-significant increase (Segura 2009:118-122). Furthermore, the archaeological evidence from this period provides contextual evidence for economic change. During the Late Classic period, Maya constructed residences over the storage units (Sierra Sosa 2015:4), and "transportation and storage tasks were apparently taken over by people living in the surrounding areas" (Wanner et al. 2007:264).

Another notable find was the surprisingly low percentages, particularly during the Late Classic period, of individuals falling within the 25-35 year age range (Cetina Bastida 2003:89;

Sierra Sosa 2004:105). To be more specific, in her paleodemographic analysis of a sample of 335 of the Xcambó individuals, Cetina Bastida (2003:89) found that only 10.20% of the Early Classic period individuals fell within this age bracket, and during the Late Classic period, the proportion dropped further still to 8.73%. Given that the site was small and surrounded by marshlands, it has been suggested that the site had reached its carrying capacity, and that the most likely to migrate were probably young adults with their children (Sierra Sosa 2004:177). Furthermore, a study of trace element analysis of teeth, specifically of Sr and Ba, used a technique that is based on the premise that concentrations of these elements in the first permanent molar should reflect the local geochemistry of the location where an individual resided from birth through three years of age, and uses these values as local references (Cucina, Tiesler, et al. 2011:1879-1881). Thus, 149 adults from Xcambó were compared to reference populations from three geographic regions, one of them being Xcambó itself, the others Campeche and Calakmul, and results indicated that 25% of the Late Classic population is non-local, whereas the Early Classic population showed values consistent with a local origin (Cucina, Tiesler, et al. 2011:1878, 1180-1883). These conclusions are further supported by analysis of cranial modification patterns, which revealed the appearance of a new pattern seen in Veracruz during the Late Classic period, as well as an overall increased diversity of head shapes among the adult population (Sierra Sosa et al. 2014:229). Because cranial modification is believed to have expressed group identity among the Maya (Tiesler 2012:34; 2014:4, 22-23), it is logical to infer the presence of foreign individuals at Xcambó from the new pattern (Sierra Sosa et al. 2014:228-229). Providing still further support is the recent analysis of strontium and oxygen stable isotopes, which can be used to investigate geographic origins in areas where there is sufficient geographic variation in values (Price et al. 2008; Sierra Sosa et al. 2014:231), and which provided further evidence that migration to

Xcambó became more common during the Late Classic (Sierra Sosa et al. 2014:231-233). Out of 131 individuals, one dating to the Early Classic period had a Sr isotope ratio not consistent with local values (Sierra Sosa et al. 2014:232-233). The value for this individual was, rather, consistent with "neighboring inland areas of the northern Yucatan" (Sierra Sosa et al. 2014:233). In contrast, nine Late Classic period individuals showed values in this range, and another ten from this period had values more in line with "the lower coastal fringes of the Yucatan or central Maya lowland inland areas" (Sierra Sosa et al. 2014:233).

In their paleopathological analysis, Cetina Bastida and Sierra Sosa (2005:669-670) did not find any significant difference in incidence of porotic hyperostosis, a skeletal indicator of anemia, by sex or site sector. Likewise, periostitis/osteomyelitis did not differ by sex or sector for the Late Classic (Cetina Bastida & Sierra Sosa 2005:668). However, the Early Classic sample size did not permit definitive conclusions to be drawn (Cetina Bastida & Sierra Sosa 2005:668). As to the cause of anemia, the positive correlation between indicators of anemia and infection led the authors to conclude that infection played a stronger role than diet to explain this condition (Cetina Bastida & Sierra Sosa 2005:672). Consistently, a study of linear enamel hypoplasia (LEH), a result of systemic stress while dental enamel is forming, in this population found no significant difference between males and females, and the authors believe that the high prevalence in both sexes, 99.07% for adult males and 100% for adult females, was due primarily to the tropical environment and the pathogenic microorganisms, and associated vectors, that thrive in such conditions (Méndez Colli et al. 2009:346, 348, 353-355). Furthermore, in comparing numbers of defects per tooth, using the three teeth found to be the most sensitive in terms of reflecting stress episodes (Goodman & Armelagos 1985:482, 486-487), between the two

site sectors with the largest sample sizes meeting the criteria of her study, the AC and ACA, Méndez Collí (2007:184-187) found no statistically significant differences.

Furthermore, investigators noted that stature, which is used by bioarchaeologists as a general indicator of nutritional status, was high for the Maya region, probably linked to access to marine protein (Cetina Bastida & Sierra Sosa 2005:672; Danforth 1994:206; Danforth 1999:4; Sierra Sosa et al. 2014:227). More specifically, of the approximately 15% of the study sample for which stature could be estimated, the average, based on femoral measurements, was 150.33 cm for females and 162.03 for males, or 151.17 cm and 161.72 cm for females and males, respectively, based on measurements of the tibia (Cetina Bastida 2003:157), compared, for example, to averages at Tikal of 147 cm for females and for males, 167 cm and 157.4 cm during the Early and Late Classic periods, respectively (Haviland 1967:319, 323). Furthermore, in a later study that focused exclusively on stature, in comparing 272 individuals divided by site sectors, Cetina Bastida (2006:47-48, Tables 9 & 10) noted that stature was relatively homogeneous by sector, although this could not be verified statistically because approximately half of the sample belonged to one of the four sectors.

While rates of anemia did not differ significantly, Cucina, Perera and colleagues (2011:560, 562-563) found that females at Xcambó had a higher incidence of dental caries than males, a difference which would typically have been interpreted as a consequence of a less varied diet for females, and was statistically significant for both the Early and Late Classic periods. However, they point out that the higher prevalence among females may be related to other variables, such as gendered cultural practices and physiological variables (Cucina, Perera, et al. 2011:565; Cucina & Tiesler 2003:7). Furthermore, they note that rates increased through time for both sexes and were unusually high for the Maya region broadly (Cucina, Perera, et al.

2011:563-564). The fact that caries rates increased in both sexes would be consistent with "increased access to local or imported cariogenic food", such as cacao and honey as Xcambó's trade network expanded during the later period (Cucina, Perera, et al. 2011: 565). However, the primary reason for the difference between the sexes could not be determined based upon the evidence to date (Cucina, Perera, et al. 2011:565). Like caries, dental enamel wear can also provide evidence on dietary quality due to the fact that coarse foods, such as plant foods, promote wear more so than softer foods, such as animal products (Buikstra & Ubelaker 1994:49; Chi Keb 2006:8-9). A study of enamel wear that analyzed 190 adult individuals from Xcambó did not find statistically significant differences between males and females (Chi Keb 2006:93).

Further insight into diet at Xcambó was provided by a trace element study that analyzed 26 individuals, which found high Sr/Ca and Zn/Ca ratios, consistent with marine food consumption (Tiesler Blos et al. 2002:757). This study also found greater variability in values among males (Tiesler Blos et al. 2002:757, 760).

Lastly, carbon, nitrogen, and oxygen stable isotope analysis was conducted on 12 of the Xcambó individuals (Sierra Sosa et al. 2014:230). The collagen $\delta^{13}\text{C}$ values, averaging -8.0‰, were consistent with a diet containing substantial amounts of maize and/or marine foods (Sierra Sosa et al. 2014:230). While, $\delta^{15}\text{N}$ results, which averaged 10.9‰ but ranged as high as 14.0‰, seem to suggest that fish comprised an important component of the diet, calculations based on apatite-collagen spacing indicated that maize still accounted for anywhere from 78 to 96% of the diet (Sierra Sosa et al. 2014:230). When the authors used bivariate plots to compare the results to data from the literature on inland sites and various food categories, they found that while seven of the Xcambó individuals fell within the range for inland sites, the other five showed elevated

$\delta^{15}\text{N}$ results, consistent with greater consumption of marine protein (Sierra Sosa et al. 2014:230-231).

4.4 Archaeological and faunal evidence for diet

Both artifacts and faunal remains recovered at Xcambó contribute to our understanding of diet, providing complementary lines of evidence whereby to interpret isotope results. Findings of *manos* and *metates*, as well as corn shuckers, attest to the prominence of maize in the diet (Sierra Sosa 2004:143, 147, 252).

Archaeological evidence for use of marine food resources comes from findings of fish net weights (Sierra Sosa 2004:115), and is corroborated by faunal evidence, which was obtained from the western sector of the site and revealed that fish and crustaceans comprised 38.8% and 7.7% of the overall NISP for the site, and consisted of species found along the coasts and swamps (Götz & Sierra Sosa 2011:124-125, 134). Of the mammal remains recovered, the most common were white-tailed deer (Götz & Sierra Sosa 2011:129-130). Marine mammals, specifically manatee, dolphin and monk seal, were also found, but each of the three represented less than 1% NISP (Götz & Sierra Sosa 2011:Table 2, p.130). Various bird species were found as well. Of those which could be identified, the most common were turkeys (*Meleagris spp.*) (Götz & Sierra Sosa 2011:128). Götz and Sierra Sosa (2011:135) noted that none of the taxa recovered indicate long-distance trade of faunal resources, yet the evidence did seem to suggest trade in faunal resources, including the ocellated turkey (*Meleagris ocellata*), white-tailed deer (*Odocoileus virginianus*) and brocket deer (*Mazama spp.*), over short distances with inland sites.

Furthermore, a study comparing faunal remains from Xcambó, another coastal site, Champotón, and three inland northern lowland sites has enhanced our understanding of coastal

versus inland Maya diets, demonstrating that the Maya at these sites made decisions regarding meat procurement based largely on local availability of species, which included a greater diversity of species at the coastal sites (Götz 2008:154, 163-164, 166-167).

5. METHODS

5.1 Foodweb samples

In terms of botanical food resources, ample evidence from ethnographic (Redfield & Villa Rojas 1962[1934]:37-40; Steggerda 1938:573-574), ethnohistoric (Tozzer 1941:89), iconographic (Miller & Martin 2004:52-58,66; Schele & Mathews 1998:78), and archaeological (Pohl et al. 1996) sources indicate that maize was the major Classic Maya staple, as it continues to be today. These include ethnohistoric descriptions of the *milpa* system, which recount that corn comprised the majority of the crop, noting that it was cultivated in conjunction with smaller quantities of beans (Roys 1943:38), as well as depictions of the Maize God and tamales in Classic Maya art (Miller & Martin 2004:52-58,66; Taube 1989). The Maya seasoned their foods with chili peppers, and various fruits were cultivated as well, including annonas, nance, and guava (Roys 1943:39-40; Tozzer 1941:64, 91). The breadnut was also consumed, prepared as a gruel or bread, and said to have been "of especial value in time of famine" (Roys 1943:40). The botanical samples selected for the present study consist of maize, common beans, and two species of chili peppers. Given findings that stable isotope ratios of a given species can vary by habitat, (Ambrose 1993:85; Thompson et al. 2005:456, 459-460; Tieszen 1991:227, 229-234, 244), botanical samples were selected from locations in the Yucatán as near to the study site as possible, so that the isotopic signatures would reflect those characteristic of Xcambó. The *Capsicum chinense* sample was obtained at a market in Progreso; the *Capsicum annuum*, kindly donated by Bety Hurtado, was from the town of Chablekal, in the northwestern Yucatán. The *Zea mays* and *Phaseolus vulgaris* samples, purchased at an agricultural fair, had been harvested in the town of Xoy/Peto, which is further inland in the State of Yucatán.

Choice of faunal species for sampling was based upon the previous analysis by Götz and Sierra Sosa (2011) of the Xcambó faunal material, with species selected from among those found to have relatively high NISP's and in consultation with Dr. Götz. Ethnographic and ethnohistoric evidence likewise played an important role in sampling decisions. Ethnohistoric documents note that deer were consumed (Roys 1943:41; Tozzer 1941:90). Domesticated turkeys and a hairless variety of dog were also consumed, although primarily in ceremonial contexts (Roys 1943:40-41), as were fish and "wild and tame birds" (Tozzer 1941:91). For the purposes of this study, one sample each of white-tailed deer and ocellated turkey were sampled. At the same time, because this is a coastal site, two species of fish, including the most commonly found genus, *Centropomus*, and two of marine turtles were also sampled, as sea turtles, in aggregate, comprised over 20% NISP (Götz & Sierra Sosa 2011:128-129). All samples are from the Xcambó archaeological material.

5.2 Human samples

The total number of human osteological samples procured for this study consisted of 50 samples from 49 individuals. Decisions regarding human osteological sampling were made in collaboration with Dr. Vera Tiesler (UADY). Given the research questions, the total sample for this study was selected so as to represent approximately equal numbers of males and females, all three social status categories, the two major periods of occupation, as well as the one Preclassic individual, and a broad sampling of patio groups. Based upon results of mass spectrometry and collagen and apatite quality indicators, a total of n=45 collagen samples and n=49 apatite samples were included in statistical analyses. Of the 45 collagen samples that met inclusion criteria (see section 5.8) for collagen percent yield and atomic C:N ratios, 25 were male, 20

female. The apatite samples, representing all 49 individuals (see section 6.4 for discussion of apatite quality assessment), consisted of 27 males (1 dating to the Preclassic, 4 Early Classic, 22 Late Classic), including probable males, and 22 females (5 of them Early Classic, 17 Late Classic), including probable females.

For the purposes of comparing social status categories, an effort was made to sample the three status categories, based on associated architecture, as equally as possible. Of the collagen samples that met inclusion criteria, excluding those individuals for whom the structure with which they were associated was unknown, the distribution was as follows: n=16 rank 1; n=13 rank 2; n=14 rank 3. For apatite, the distribution was: n=16 rank 1; n=14 rank 2; and n=16 rank 3. Each individual was also coded according to the rank of the patio group to which they belonged, with patio groups ranked into four tiers (see section 5.9). This latter system was developed based on the premise that patio groups represent extended families (Willey 1980:257), for the purpose of investigating whether the status of one's household/lineage affects diet. Therefore, in an effort to balance the aims of sampling broadly throughout the site with obtaining a sufficiently large sample from at least a portion of the patio groups to draw statistical comparisons, not all patio groups were sampled. In the easternmost area of the site are three patio groups from which no burials were recovered (Vera Tiesler, 2013, information from field and lab notes); therefore, this area is less heavily represented than the area nearer the main plaza. Nevertheless, four individuals from Patio XXIII, the group centered around Plaza II, were sampled.

As another means of exploring status differences, individuals from both cist and simple burials were sampled; however, the numbers of cist burials at Xcambó were fewer (Vera Tiesler, 2013, information from field and lab notes). Of the starting sample of 49 individuals, 12 were

cist burials, 36 simple, and one unidentified (see Table XII for numbers of samples meeting inclusion criteria). The one individual to be accorded a tomb burial at Xcambó (Vera Tiesler, 2013, information from field and lab notes), who was consequently deemed to be of highest status, had been previously analyzed by Sierra Sosa and colleagues (2014); therefore, this individual was not sampled again for the present study. Numbers of individuals by patio group are provided in Table XXVIII, Appendix B.

Furthermore, in order to test for diachronic patterns, nine Early Classic period individuals, as well as the sole Preclassic period individual recovered from the site, were sampled for comparison to 39 Late Classic period individuals. The collagen extracted from the one Preclassic individual did not yield carbon or nitrogen peaks, but the apatite sample did produce $\delta^{13}\text{C}$ results that were included in statistical analyses. For the Early Classic period, the sample sizes meeting inclusion criteria were $n=9$ for collagen and $n=9$ for apatite. For the Late Classic period, they were $n=36$ for collagen, $n=39$ for apatite. Osteological evidence indicates that Xcambó underwent an economic transition, involving a change in male occupation to a focus on trade administration during the Late Classic period, while archaeological evidence indicates concurrent economic growth and changes in trade routes (Cucina, Perera, et al. 2011:561-562,565; Maggiano et al. 2008; Sierra Sosa et al. 2014:225-226, 228; Wanner et al. 2007) (see chapter 4). Investigators hypothesized that such changes in lifestyle and economy may have resulted in dietary changes, which would be consistent with the increased caries rates of the Late Classic period (Cucina, Perera, et al. 2011).

5.3 Sample preparation

All human samples were procured, with the assistance of the staff of the bioarchaeology laboratory at The Universidad Autónoma de Yucatán (UADY), from long bones (See Table II for faunal elements sampled); cortical bone was sampled in order to reduce potential effects of diagenetic (post-mortem) change (Lambert et al. 1984:300), and elements were selected so as to minimize destructiveness to the remains, with fragments of long bones chosen when available, provided that they did not include diagnostically important features; otherwise, samples were cut with an electric or hand saw, usually the former. All osteological samples were photographed, and state of preservation and Munsell color were recorded in Excel databases. In order to remove any adhering soil and other potential contaminants, which could distort the biogenic isotopic signature, all osteological samples were first cleaned with a toothbrush dampened in deionized water and allowed to air dry overnight. Subsequently, any visibly contaminated areas or remaining mowithal, a substance used in conservation of archaeological materials (Zapata & Hernández 2011), on the sample surface were removed using dental tools and/or a Dremel tool. For samples containing visible cancellous bone, this was removed inasmuch as possible without excessive loss of sample material, again using dental tools and/or the Dremel tool. Samples were then ground by hand with a ceramic mortar and pestle, and sifted through geological screens into fractions of <0.125, 0.125-0.250, 0.5-1.0mm (Pestle 2010b:165). Mortars and pestles were acid washed before their initial use and between samples to prevent cross-contamination.

Botanical samples were sun dried in Mexico and subsequently frozen, freeze-dried, and ground in the United States. Faunal samples were selected from the Xcambó archaeological faunal collection, with the assistance of Dr. Christopher Götz and his staff. All samples were photographed. Faunal samples were cleaned following the same procedure as with the human

osteological samples. However, in the case of faunal samples, various elements were selected, as listed in Table II.

5.4 Collagen

The collagen extraction protocol employed in this study is based upon that detailed in Pestle (2010b), which is founded upon the procedures established by Longin (1971) and Ambrose (1990; 2007, cited in Pestle 2010b). The initial steps utilize a 60ml Buchner filter funnel, which is fused to a 3mm straight bore stopcock and held in place, over a 250ml sidearm vacuum flask, with a Teflon stopper (Ambrose 1990:434; Pestle 2010b:165). The first step entails weighing out approximately 0.75g of the 0.5-1.0mm fraction of ground bone; this is then poured over a wad of glass wool which has been placed over the filter (Pestle 2010b:165). Samples are demineralized in 30ml 0.1 or 0.2M HCl, "until the bone particles are translucent and float when stirred" (Pestle 2010b:165). In the present study, the duration of the acid treatment ranged from approximately 30 to 51 hours, with the HCl replaced after 24 hours. The purpose of this step of the protocol is to remove adsorbed carbonates and the mineral component of bone, apatite, as well as fulvates, which are found in soil and are isotopically heavy (Ambrose 1993:72; Tieszen 1991:241). Apatite must also be removed because it is analyzed separately, as collagen and apatite reflect different attributes of diet, collagen deriving primarily from protein sources whereas apatite yields the isotopic signature of the organism's whole diet (Ambrose & Norr 1993:28; Pestle 2010b:102). Because 0.1M HCl was used for the first batch of six samples processed, H1, H5, H8, H29, H38 and H43, and not all bone particles appeared translucent by the end of this stage, it was decided to utilize 0.2M HCl for subsequent batches.

The acid solution was then drained into a 250ml sidearm vacuum flask or Ehrlenmeyer flask, and samples rinsed a total of eight times with ASTM Type 1/Type 2 water (Pestle 2010b:165). Subsequently, samples were treated with 30ml 0.0625M NaOH, which removes another category of potential soil contaminant, humic acids, which are isotopically light (Ambrose 1990:435; Pestle 2010b:110, 165, 186; Tieszen 1991:241). After a period of approximately 20 hours, the solution is drained, samples are again rinsed following the previous protocol. The actual duration of the NaOH treatment in the present study ranged from approximately 18.5 to 22.5 hours. By the end of this stage, samples have been cleaned of both acid- and base-soluble contaminants, and the next stage of the protocol, gelatinization, therefore entails solubilizing the collagen into a "collagen broth" (Ambrose 1990:435), by adding a weakly acidic solution of 10^{-3} M HCl and placing the samples in an oven for five hours (Pestle 2010b:166); while there is variation among researchers (Ambrose 1990:435; Le Huray & Schutkowski 2005:138; Privat et al. 2002:783) in the temperature used at this stage, for the purposes of this study, a range of 65° to 95°C was considered acceptable, as Brown and colleagues' (1988:172-174, 176) study comparing the results of gelatinization at various temperatures, demonstrated that collagen fibers begin to denature at approximately 58°C. Next, 100µl of 1.0M HCl is added to facilitate solubilization of the collagen (Brown et al. 1988:173), evaporated 10^{-3} M HCl is replaced, and the samples are allowed to soak in the oven overnight (Pestle 2010b:166).

The following day, the collagen solution is drained to a 250ml sidearm vacuum flask and returned to the oven to condense to approximately 2ml (Pestle 2010b:166). While some researchers have substituted an ultrafiltration, rather than condensation, step for removal of fulvates (Brown et al. 1988; Le Huray & Schutkowski 2005), Pestle (2010b:171) found that this step reduced collagen yield by 75%; therefore, it was decided not to use ultrafiltration for the

present study. Once the sample is condensed, it is transferred to a scintillation vial and the flask is rinsed three times with 10^{-3} M HCl, which is likewise transferred to the scintillation vial to avoid losing sample, and the scintillation vials are placed in the oven until the solution once again condenses to 2ml. They are then frozen and subsequently freeze dried. The sample is subsequently weighed; this weight is then divided by the original sample weight to obtain the weight percent yield, which provides a means of assessing sample preservation (Ambrose 1990:435; Pestle 2010b:166).

5.5 Apatite

As for the collagen protocol, the apatite extraction protocol followed, with minor variations, that employed by Pestle (2010b:176-178), which is founded upon those of Ambrose (cited in Pestle 2010b:176) and Lee-Thorp (1989, cited in Pestle 2010b:176), and includes the vacuum treatment proposed by Krueger (1991). Samples were treated with 50% Clorox to remove organic contaminants (Ambrose 1993:80; Pestle 2010b:177). In this protocol, an aliquot of the $0.125 < 0.25$ fraction of each sample, weighing approximately 0.1g, is placed in a 50ml centrifuge tube, to which 30ml of 50% Clorox is added (Ambrose et al. 1997:352; Pestle 2010b:177). The tubes are capped, manually shaken, vortexed and then allowed to stand, uncapped, loosely covered in foil, overnight (Pestle 2010b:177). On the second day, they are vortexed again and then centrifuged; the Clorox solution is then decanted and another 30ml of fresh 50% Clorox is added, and the tubes are allowed to stand uncapped overnight once more (Pestle 2010b:177). They are subsequently shaken, vortexed, and centrifuged again, and the Clorox decanted. Next, the samples are rinsed with ASTM water (In this study, Type I/Type II was used.); approximately 30ml ASTM Type I/II water is added to the centrifuge tube, which is

then shaken and subsequently vortexed, following which the water is decanted; this procedure is repeated for a total of four rinses; samples are then treated with 0.1 M acetic acid, which removes non-biogenic carbonates (Ambrose 1993:80; Pestle 2010b:177). After soaking for two hours, samples are subjected to a vacuum treatment to facilitate carbonate removal, following which they are left to soak in the acetic acid for another two hours (Pestle 2010b:177). At the end of this time, the samples are shaken, vortexed, and centrifuged, then the acetic acid decanted and the samples subsequently rinsed four times as per the procedure described above (Pestle 2010b:177-178). Samples were then frozen, following which they were freeze-dried (Pestle 2010b:178). Once freeze-drying was complete, the centrifuge tubes, which had been weighed prior to the addition of sample, were weighed again.

5.6 **FTIR**

The state of preservation of apatite samples was evaluated through Fourier transform infrared spectrometry (FTIR), which was performed by Elizabeth Olson at Northern Illinois University (NIU). FTIR has become a broadly accepted tool for testing biological apatite for diagenesis (Pestle 2010b; White et al. 2001; Wright & Schwarcz 1996), and functions on the principle that when a sample is irradiated, the amount of infrared absorbed will vary depending upon its constituent chemical groups, which, in turn, determine "the intensity of absorbance" (Sponheimer & Lee-Thorp 1999:143). Also of importance in terms of evaluating sample preservation is the fact that infrared spectra allow us to distinguish among substances of different crystallographic structure (Sponheimer & Lee-Thorp 1999:143). The importance of testing for diagenesis was highlighted in a study by Wright and Schwarcz (1996), who analyzed FTIR data in conjunction with isotope results for apatite samples extracted from Late and Terminal Classic

Dos Pilas burials. They found that FTIR characteristics such as crystallinity index (CI), C/P ratios, and peaks at wavenumbers 710cm^{-1} and 1096 cm^{-1} , enabled them to identify diagenetically altered samples (Wright and Schwarcz 1996:936-940).

Consequently, it was decided to select 25% or more of the individuals from the Early and Late Classic periods for analysis, as well as four specific faunal apatite samples over which there was a concern regarding potential contamination. Therefore, 10 Late Classic individuals were selected, stratified by rank in the structure hierarchy, with individuals whose rank was unclear excluded from the sampling pool. The Early Classic sample was likewise stratified by rank; however, after two were excluded due to uncertainty about rank, the remaining sample pool ($n=7$) consisted of two individuals of rank 1, one of rank 2, and 4 of rank 3. Consequently, in order to make the final sample as representative as possible, one of the rank 1 individuals, the sole rank 2 individual, and two of the rank 3 individuals were selected. Both the Early and Late Classic subsamples, with the exception of the Early Classic rank 2 individual, were selected using random number tables; however, because two of the Early Classic Rank 3 individuals were from the same structure, in order to increase the representativeness of the sample from this period, it was decided not to sample them both. Thus, once one of the individuals from this structure had been selected, if the number of the other individual was reached on the random number table, it was ignored and the process continued. Also for purposes of representativeness, this same procedure was followed if a second Early Classic individual from the same patio group was drawn. The larger Late Classic sample does include two individuals from Plaza 1 and patio groups X and XIV; however, these represent different rank categories.

Because calculation of the crystallinity index requires measurement of absorbance peaks at wave numbers 565, 595, and 605 (Wright & Schwarcz 1996:936), the abovementioned

samples were sent to NIU for analysis, as indicated above. For comparative purposes, ground, untreated bone from one of the human individuals, sample H25, and from a modern ungulate sample which, despite exposure to the elements, was macroscopically well preserved, were also included in the analysis. The CI is the most commonly used indicator of apatite diagenesis, and acceptable limits for treated samples are 2.7 to 4.1 (Pestle 2010b:184-185). Others include the C/P ratio, for which two alternative definitions exist, depending on which peak one uses for phosphate (Wright & Schwarcz 1996:936); This study followed Wright and Schwarcz's (1996:936) definition, given as "the ratio between the absorbance of the CO₃ peak at the 1415 cm⁻¹ to that of the main PO₄ peak at 1035 cm⁻¹" (Wright & Schwarcz 1996:936), with accepted limits for treated samples of 0.101-0.41 (Pestle 2010b:185). The C/P ratio can then be used to calculate wt.% CO₂ yield (Pestle 2010b:182, 185; Wright & Schwarcz 1996:936), and the B-carbonate on phosphate indices (BPI), which is the ratio of the absorbance at wavenumber 1415 cm⁻¹ to that at 605 cm⁻¹, can be used to calculate wt.% CO₃ (Pestle 2010b:181; Webb et al. 2014:98). The acceptable limits for wt.% CO₂ and wt.% CO₃ for treated samples are 2.7-6.4% and 3-6.5%, respectively (Pestle 2010b:185). These indices were calculated and tested for correlations with δ¹³C and δ¹⁸O values. Because there was a statistically significant negative correlation between δ¹⁸O values and apatite weight percent yield, suggesting the results do not represent biogenic values (Pestle 2010b:219), as will be discussed further in chapter 6, the δ¹⁸O data was not used for statistical analyses or to draw any inferences. Scans were also examined for the presence of peaks at wavenumbers of approximately 710cm⁻¹, which would reveal contamination with calcite, and 1096cm⁻¹, which would demonstrate presence of francolite (Lee-Thorp & van der Merwe 1991:349; Pestle 2010b:117; Wright & Schwarcz 1996:936).

5.7 Mass spectrometry

Samples were sent to the Colorado Plateau Stable Isotope Lab (CPSIL) at Northern Arizona University for analysis by mass spectrometry. Analysis of carbon and nitrogen stable isotope composition by mass spectrometry entails combusting the sample, in the case of botanical and collagen samples, or chemically reacting the sample, in the case of apatite, to yield gaseous CO₂ and N₂ (Pestle 2010b:198; Schoeninger & Moore 1992:253). The molecules are ionized, producing a beam, and because of their different masses, molecules containing ¹²C, with a mass of 44, will undergo greater deflection than those containing ¹³C, with a mass of 45, which will, in turn, undergo greater deflection than those consisting of ¹²C, one atom of ¹⁸O and one atom of ¹⁶O, with a mass of 46, as they pass through a magnetic field (Ambrose 1993:68; Schoeninger & Moore 1992:253-254). The same principle separates N₂ molecules consisting solely of ¹⁴N from those composed of ¹⁵N + ¹⁴N (Schoeninger & Moore 1992:254). Thus, the beam is split; the resulting beams strike a set of detectors, and the voltages thus generated allow for calculation of isotope ratios (Ambrose 1993:68).

Results are expressed in delta notation according to the following formula: $\delta\text{‰} = (R_{\text{sample}}/R_{\text{standard}} - 1) \times 1000$, with ‰ representing parts per mil (per thousand) and R the ratio of the heavy to the light isotope (Ambrose 1993:65; Hu et al. 2006:1323; Preston 1992:1091). The standard reference used for carbon isotopes is known as Peedee *Belemnitella* (PDB), or Pee Dee Belemnite, a limestone named after the fossilized species of which it is composed and the Peedee formation of South Carolina from which it was procured (Ambrose 1993:65; Craig 1957:135; Pestle 2010b:89). Atmospheric nitrogen, referred to as ambient inhalable reservoir (AIR) (Schoeninger & Moore 1992:254), which was demonstrated by Mariotti (1983) to be homogeneous across various world regions, is the reference standard for nitrogen (Ambrose

1993:65). Because the PDB standard is isotopically heavier than the vast majority of food resources, $\delta^{13}\text{C}$ values are typically negative numbers (Ambrose 1993: 65). Such is not the case for the nitrogen standard, and $\delta^{15}\text{N}$ values therefore tend to be positive (Ambrose 1993:65, 67).

5.8 Testing for diagenesis: collagen

For collagen, the extent to which a sample has undergone diagenesis is typically evaluated through weight percent yield of collagen, C/N atomic ratios, and weight percent carbon and nitrogen (Pestle 2010b:111). Ambrose (1990:438-40) found that the boundary distinguishing well from poorly preserved prehistoric human bone falls in the range of approximately 1.2 to 1.8% collagen yield. Van Klinken (1999:689) recommends a cutoff of 1%, which was the cutoff used in this study. The acceptable range for C/N atomic ratios is considered to be 2.9 to 3.6 (Ambrose 1993:74; DeNiro 1985:807; Sealy et al. 2014:68). This is based on a study conducted by DeNiro (1985: 806), in which he analyzed C/N, $^{13}\text{C}/^{12}\text{C}$, and $^{15}\text{N}/^{14}\text{N}$ ratios of collagen extracted from various prehistoric marine and terrestrial animal species whose ecology is well understood and for which data is available on collagen carbon and nitrogen isotopes of contemporary animals with the same feeding patterns. He found that the animals whose carbon and nitrogen isotope ratios fell within the expected limits, based on comparison to their modern analogues, had C/N ratios within the 2.9 to 3.6 range (DeNiro 1985:807). Two additional useful indicators of collagen preservation are weight percent carbon and nitrogen. Ambrose (1990:441) found that collagen of modern animal bones consists of 15.3-47% carbon and 5.5-17.3% nitrogen by weight. However, he provides recommended cutoff points for archaeological samples of 4.5% for carbon and 0.9% for nitrogen (Ambrose 1990:443). The abovementioned quality indicators for the human samples were tested for correlations with

$\delta^{13}\text{C}_{\text{co}}$ and $\delta^{15}\text{N}$ values to determine whether they may have been altered by taphonomic factors (Pestle 2010b:219).

5.9 Coding of variables indicating social status

Based upon the evidence previously discussed upholding the association between size of architecture and social status, a site map of Xcambó produced by the original excavators was used to calculate the floor area of each structure in m^2 , and the structures within each patio group were ranked into three tiers based upon natural breaks in the data for the given patio group, with each tier inferred to correspond to a distinct rank with respect to social status; that is, they were classified into ordinal categories, with a rank of 1 assigned to the smallest structure(s) in each patio group, 3 representing the largest. For those patio groups consisting of only two structures, only ranks of 1 or 2 were assigned. In those cases in which the specific structure an individual was associated with could not be determined, as was the case for three of the 49 individuals sampled, their rank was left blank.

Furthermore, the various patio groups were ranked relative to one another in a 4-tier system, based upon the average floor area of the three largest structures in each patio group, or in the case of patio groups consisting of only two structures, the average of those two structures.

These tiers were defined as follows:

Rank 1: Average floor area $< 100\text{m}^2$

Rank 2: $100\text{m}^2 \leq$ average floor area $< 200\text{m}^2$

Rank 3: $200\text{m}^2 \leq$ average floor area $< 300\text{m}^2$

Rank 4: Average floor area $> 300\text{m}^2$

Another variable commonly used to draw inferences regarding social status is the amount of energy expended on funerary rites (Binford 1971:21-23; Brown 1981:28-32, 34-36; Chapman & Randsborg 1981:4, 7-10; Peebles & Kus 1977:431, 438-440; Tainter 1975, 1978:125-127). This is based on a concept proposed by Binford (1971:21) that the higher the social status of the deceased, the greater the extent to which mortuary rites "will interfere with the normal activities of the community." From this, Tainter (1975:2) inferred that there should be a positive correlation between an individual's status and "the amount of energy expended in the mortuary act." In order to gauge energy expenditure, he reasoned that one could use mortuary evidence such as grave "size and elaborateness", as well as grave offerings and method of burial, and from these draw inferences on social status (Tainter 1975:2; 1978:125). Therefore, for the purposes of this study, in addition to architecture, grave type and offerings were also used as social status indicators. All of the individuals analyzed in the present study, except for one of unidentified grave type) were buried in simple or cist burials (Vera Tiesler, 2013, information from field and lab notes) and were coded accordingly. A system for classifying burial offerings, utilizing information from the original excavations (Vera Tiesler, 2013, information from field and lab notes), was also developed, which examined both the quantity and quality of each category of objects. Quality was coded on a scale of 0 to 3 for ceramics and shell, and 0 to 2 for lithics, jade, and animal bones, the higher numbers corresponding to higher quality (for further details, see Appendix C). These variables were then tested for correlations with $\delta^{13}\text{C}$ values of collagen and apatite and with $\delta^{15}\text{N}$ values. In coding quantities of burial offerings, certain adjustments were made for the purpose of avoiding excessive skewness of the data. For example, among the offerings found with burial NE-34/146 were 680 beads (Guemes 1999:Appendices 10b, 10c) some of these of ceramic, some shell; these were counted as comprising two items in total, one

of ceramic and one of shell. Therefore, for the sake of consistency, burial offerings for all individuals analyzed in this study were coded along similar guidelines, wherein multiple beads of a given material were counted as one object unless the information from the excavation data specifically indicated that they comprised multiple items of jewelry, and in one case, a bead made of jade and shell was counted once in both the jade and shell categories.

Of the 49 individuals in the present study, 4 had no burial offerings, 13 were interred with a single ceramic vessel, commonly placed over the cranium (Guemes 1999:Appendix 10b; Sierra Sosa 1998:158-159; Sierra Sosa et al. 1996:154); two others had a single offering, in one case of animal bone (Sierra Sosa 1997, Tomo I;113-114), in the other of shell, whereas other burials had more abundant offerings; for example, Burial NE-21/16 was interred with two necklaces, one of them composed of 811 beads, as well as two bracelets, a ceramic vessel, earspools and a pectoral (Vera Tiesler, 2013, information from field and lab notes).

5.10 Evidence for provenience and group identity

Three lines of evidence were used to infer a shared group identity. One of these was geographic place of origin, for which evidence was obtained from a study conducted by Sierra Sosa and colleagues (2014; Sierra Sosa et al. n.d.). Strontium (Sr), which is present in dental enamel, is ultimately derived from local geology and remains unchanged following tooth mineralization, thus making it possible to determine where an individual resided during childhood (Price et al. 2008:168). Thus, in geographic regions where there is sufficient variability, $^{87}\text{Sr}/^{86}\text{Sr}$ ratios allow us to draw inferences on geographic origins (Sierra Sosa et al. 2014:231). In the Maya region, this variability does exist due to a north-south gradient in the age of the underlying geology (Price et al. 2008:168). Sierra Sosa and colleagues (2014:232-233)

have identified 0.7089 to 0.7092 as the local range for the northern and western coast of Yucatán.

The second line of evidence was data on cranial modification (Tiesler 2016), which was available for 20 of the individuals sampled in this study. Cranial modification, which would have been practiced by a child's mother, or potentially grandmother, or kin, is believed to have been symbolic of group identity and shared beliefs (Tiesler 2012:34; 2014:4-5, 22-23). Because there was a broad range of variation in head shapes at Xcambó (Tiesler 2016) and dividing the sample by specific variants would have led to sample sizes too small for statistical comparison in the majority of categories, statistical tests were not conducted with this data. Rather, the information on cranial modification was used to examine whether the individuals from patio groups with sample sizes of five or more, or any individuals with outlying isotope values, displayed cranial modifications that were typical of Xcambó or a form characterized by superior flattening, also referred to as *parallelepid*, which was not seen at Xcambó during the Early Classic period (Sierra Sosa et al. 2014:229; Tiesler 2014:77-78). In addition, because the prevalence of dental modification patterns displays geographic variability in the Maya region (Tiesler 2005:635, 638), data on dental modification patterns (Vera Tiesler 2016), was likewise examined for insight it may provide as to social diversity among patio groups. However, variation in the prevalence of specific types of dental decoration along status lines have also been noted (Tiesler 2005:638, 645-647).

5.11 Statistical analyses

Statistical analyses were conducted using IBM SPSS Statistics. Because sample sizes were small and many distributions were non-normal, nonparametric tests were used because they

do not assume normal distributions (Glantz 1997:37). For comparisons of males versus females, adults to adolescents, simple to cist burials, local versus nonlocal individuals, and Early versus Late Classic individuals, Mann-Whitney U tests were used. This is a nonparametric test for comparison of two randomly selected independent samples that assumes variables are measured at least on an ordinal scale (Blalock 1972:243, 249, 255). If both groups have sample sizes less than or equal to 10, this test provides the exact probability of obtaining the value of the test statistic when the null hypothesis is true (Siegel & Castellan 1988: 130). However, if either group has a sample size greater than ten, the test calculates Z statistics to determine that probability (Blalock 1972:259).

The Kruskal-Wallis test, the nonparametric analogue of one-way ANOVA (Agresti & Finlay 1997:439, 474), was used to test for differences by social rank, patio group (for patio groups from which five or more individuals were sampled), and patio group rank. When sample sizes are small, the Kruskal-Wallis test is preferred because it ranks the data, whereas ANOVA compares means, which can be unduly affected by individual values that depart from normality in such cases (Agresti & Finlay 1997:439, 474). When a Kruskal-Wallis test revealed a significant difference among groups, post-hoc pairwise comparisons including Bonferroni corrections were conducted. Given that the original excavations at Xcambó recovered only one Preclassic period individual, no attempt was made to statistically compare the Preclassic to other periods.

To test for correlations between each of the collagen and apatite quality indicators and isotope values, and between quality and quantity of burial good offerings in each of the five categories and isotope values, Spearman's rank correlation coefficients were used. This is a nonparametric method (Glantz 1997:257, 324-325), and was therefore chosen because quantities

of burial offerings do not follow a normal distribution for any of the five categories, and it can be used with ordinal data, such as the burial offering quality rating scale.

5.12 Evaluation of methodology

While collagen yields, at least in part, reflect sample preservation, they can also be affected by various stages of the protocol; for example, demineralization using high HCl concentrations can reduce collagen yield (Ambrose 1993:73), as may excessively long NaOH treatment (Chisholm 1989:26; Pestle 2010b:166). Given that samples from the Maya region commonly produce collagen yields of less than 5% (White et al. 2001:378) and that the mean collagen yield for the present study (time periods and sexes pooled) was 5.09%, it appears that the protocol generally did not cause excessive loss of collagen. Nevertheless, in future studies, it would be advisable not to allow the NaOH treatment to exceed 20 hours, as it did in the present study, with some samples being treated with NaOH as long as 22.5 hours, as concerns have been expressed that NaOH treatment could increase variability in $\delta^{13}\text{C}$ values (Chisholm 1989:26-27), although Ambrose (1993:73) points out that "the short pretreatment times normally used" are not likely to be an issue.

Four of the human osteological samples analyzed were noted to have a chalky consistency; the collagen samples extracted from two of these did not produce any peaks, while another sample yielded a N peak too small to be reliable and no C peak. Therefore, although apatite samples from these individuals did produce peaks and their apatite weight percent yields were not unduly low, ranging from 55.64% to 64.49% (See further discussion of apatite yields in chapter 6), it would be preferable not to use such samples in future studies so as to avoid problems with collagen analysis. If using such samples is necessary, the NaOH treatment should

be carefully limited to 20 hours, as mentioned above. A study comparing results of different HCl concentrations, from 0.05 to 0.2M, and treatment times found that varying the concentration within the given range did not produce notably different collagen yields or stable isotope signatures (Pestle 2010a:3124, 3127); therefore, it does not appear that issues with these sample results are attributable to the choice of concentration in the present study.

While apatite samples appear, according to Crystallinity Index results (See chapter 6) to be well preserved, in the future, it would be advisable to more strictly limit the duration of the acetic acid treatment to 4 hours (Actual treatment times ranged from approximately 4 hours, 10 minutes to 5 hours) so as to prevent recrystallization, which may lower $\delta^{13}\text{C}$ values, although this was found to be less problematic with concentrations of 0.1M, as used in this study, than 1.0M (Garvie-Lok et al. 2004:763, 773; Koch et al. 1997:420, 422, 424; Lee-Thorp & van der Merwe 1991:352; Pestle 2010b:115). It should also be noted that, while carbon stable isotopes appear to reflect biogenic values, statistical analyses revealing a significant correlation between apatite weight percent yield and $\delta^{18}\text{O}$ values (see section 6.4) indicate potential alteration of these values by taphonomic processes (Pestle 2010b:219). Thus, although it was hoped that stable oxygen isotope ratios from bone apatite carbonate would provide information on geographic origins of the individuals analyzed in the present study, the results were not used to draw inferences.

6. RESULTS

6.1 Introduction

In this chapter, I first present the results of the four botanical and six faunal foodweb samples. I then discuss the results of tests for diagenesis of collagen and apatite extracted from 50 human osteological samples, drawn from 49 individuals, and of the faunal samples. Subsequently, I discuss statistical analyses of the stable isotope results of the human osteological samples that met inclusion criteria, which consisted of 45 collagen samples and 49 apatite samples, including descriptive statistics of the overall sample as well as comparisons of individuals grouped by social status, patio group membership, local versus nonlocal geographic origin, sex, and time period.

6.2 Botanical samples

Four modern botanical samples were collected. Stable isotope results were as follows:

TABLE I. BOTANICAL C AND N STABLE ISOTOPE RESULTS

Species	Common name	$\delta^{13}\text{C}$	$\delta^{13}\text{C}$ with fossil fuel correction	$\delta^{15}\text{N}$
<i>Zea mays</i>	maize	-10.78	-9.28	2.75
<i>Phaseolus vulgaris</i>	common bean	-28.67	-27.17	1.95
<i>Capsicum chinense</i>	chili pepper	-29.56	-28.06	5.01
<i>Capsicum annuum</i>	chili pepper	-29.34	-27.84	6.09

From the table above, the $\delta^{13}\text{C}$ results for the maize sample was clearly distinct from those of C3 plants; at the same time, it is less negative compared to the average for C4 plants provided in the literature of -14 to -12‰ (Tieszen 1991:229). However, it is only slightly less negative than values obtained by Wright (2006:94-95) in the Pasión region of -11.02 and -11.20‰ and also approximates some of the values obtained in the U.S. Southwest, as in Creel and Long's (1986:828) study, in which they obtained values ranging from -11.5 to -9.7‰, and Matson and Chisholm's (1991:453) result of -9.9‰ from maize kernels recovered from the site of Turkey Pen. These findings are consistent with Smith and Epstein's (1971:383) observation "that a great deal of $\delta^{13}\text{C}$ variation can occur within a species" as a result of environmental variables. Dry conditions, for example, lead to enrichment in ^{13}C by requiring greater efficiency in photosynthesis (Smith & Epstein 1971:383). It is therefore logical that maize grown in northern Yucatán would show higher $^{13}\text{C}/^{12}\text{C}$ ratios than that grown in the southern lowlands.

The results for the bean and chili pepper samples are consistent with C3 plants and their $\delta^{13}\text{C}$ values fall within the range of C3 plants obtained by Wright (2006:92) of -27.88 +/- 1.64‰. Regarding $\delta^{15}\text{N}$ results for *P. vulgaris*, beans, the $\delta^{13}\text{C}$ value falls within those obtained by Wright (2006:94-95) of -27.75 and -27.12‰, but the $\delta^{15}\text{N}$ result is lighter than one value she obtained in her Pasión study of 3.94 and thus closer to the expected value of nearly 0‰ (Gerry & Krueger 1997:202; White et al. 2001:375; Wright 2006:80).

6.3 Faunal samples

Faunal samples, to serve as local references for potential faunal food resources (Ambrose 1993:82; Pestle 2010b:128; Wright 2006:81, 86), were procured from the Xcambó collection which was excavated by the team led by Dr. Thelma Sierra Sosa and was under the stewardship

of Dr. Christopher Götz. The results appear in Table II. The atomic C:N ratio for the *Ariopsis felis* sample is clearly outside the range for *bona fide* collagen and was therefore not used to draw any inferences, and that of *Chelonia mydas* is borderline high. The other four samples, however, fall within the acceptable limits of 2.9 to 3.6 (DeNiro 1985:807). The $\delta^{13}\text{C}$ result for the *Meleagris* sample falls within the range obtained by Wright (2006:99-100) of -9.93 to -8.11‰ for two specimens of *Meleagris gallopavo*, and the $\delta^{15}\text{N}$ value is nearly identical to the value of 8.29‰ obtained by Wright (2006:100). The $\delta^{13}\text{C}$ value for the *Odocoileus virginianus* sample falls within the range obtained by Wright (2006:98) of -18.13 to -21.48‰ for three specimens. The $\delta^{15}\text{N}$ value, however, is more enriched at 10.05‰ compared to Wright's (2006:98) results of 4.00 to 6.60‰, which may be due to the drier climate of northern Yucatán, as water stress leads to increased excretion of urea, which is isotopically light (Ambrose 1993:97-98). It should also be noted that it falls within the range obtained at Pacbitun, Belize (White et al. 1993:359), where five *O. virginianus* samples displayed $\delta^{15}\text{N}$ values ranging from 5.05 to 15.80‰. The collagen values of *C. mydas* differ, the $\delta^{13}\text{C}$ being relatively depleted and the $\delta^{15}\text{N}$ enriched, from those obtained by Keegan and DeNiro (1988:327) in the Bahamas, which were a $\delta^{13}\text{C}$ of -3.8‰ and $\delta^{15}\text{N}$ of 5.1‰. This may relate to a preservation issue, potentially indicated by the borderline high C:N ratio, or may be an effect of local ecological variation. For example, the ecosystem being studied by Keegan and DeNiro (1988:320-321) contained coral reefs and seagrass meadows, which are known to be enriched in $\delta^{13}\text{C}$ and depleted in $\delta^{15}\text{N}$ (Schoeninger & DeNiro 1984:633-636). The results for *Caretta caretta* differed, the $\delta^{13}\text{C}_{\text{CO}}$ being relatively enriched and the $\delta^{15}\text{N}$ depleted, from those obtained by Pestle (2010b:430) for collagen from an Atlantic specimen, with $\delta^{13}\text{C}$ of -14.6‰ and $\delta^{15}\text{N}$ of 20‰. Thus, there is clearly variation in stable isotope signatures across the ecosystems from which

these specimens were drawn, although the specific cause remains unclear. For *C. undecimalis*, a study conducted by Winemiller and colleagues (2010: Tables I and II, 792, 795, 797) in Belize, obtained $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ results of -26.27‰ and 12.88‰, respectively for muscle tissue from a modern-day specimen. Therefore, in order to compare to an archaeological collagen sample, one needs to add 4‰ and, for marine organisms, a fossil fuel correction of +3‰ to the $\delta^{13}\text{C}$ value (Pestle 2010b:203-209). For $\delta^{15}\text{N}$ values, one needs to subtract 1.7‰ to convert from flesh to collagen (Pestle 2010b:208-209). Thus, the equivalent for an archaeological collagen sample would be a $\delta^{13}\text{C}$ of -19.27‰, which is more depleted than the value obtained in the current study, and $\delta^{15}\text{N}$ of 11.18‰, which closely approximates the value of 10.91‰.

Apatite yields for faunal samples ranged from 19.89 to 61.97%. For comparative purposes, fresh bone is approximately 70% mineral, the major mineral component being hydroxyapatite (Klepinger 1984:75; Pestle 2010b:97). It should be noted that the *A. felis* sample from which the unusually low yield of 19.89% was obtained was a small neurocranial fragment, with an initial weight of 0.3 grams prior to any processing.

The four faunal samples, F1 to F4, selected for FTIR analysis were deliberately chosen due to concern over potential contamination during the course of the apatite protocol. Their CI values ranged from 2.80 to 3.50, which falls within the acceptable limits of 2.7 to 4.1 (Pestle 2010b:185). One of these samples, F4, however, gave low values on two of the other indices, the weight percent CO_2 and weight percent CO_3 , and was borderline low in its C/P ratio of 0.100. The FTIR scans did not reveal evidence for contamination with calcite or francolite.

TABLE II. FAUNAL SAMPLE DATA

Sample No.	Species	Common name	Provenience	Element	Atomic C:N ratio	Collagen % yield	wt% C	wt% N	$\delta^{13}\text{C}$ collagen	$\delta^{15}\text{N}$	Apatite wt. % yield	$\delta^{13}\text{C}$ apatite
F1	<i>Caretta caretta</i>	loggerhead turtle	Estr. NO-4, Pozo 45, Capa II	carapace fragment (pleural)	3.10	3.93	30.04	11.30	-11.83	11.68	49.64	-6.48
F2	<i>Odocoileus virginianus</i>	white-tailed deer	Estr. NE-3, Cuadro: 20-VIII, Capa I (liberación)	metapodial	3.10	7.12	35.05	13.19	-18.58	10.05	45.57	-10.27
F3	<i>Meleagris sp.</i>	turkey	Estr. SE-7, Cuadro 24 CIV, Capa Sup.	ulna fragment	3.17	4.53	29.17	10.74	-8.93	8.31	37.71	-3.50
F4	<i>Chelonia mydas</i>	green turtle	Estr. NO-1, Pozo 33, Capa II	carapace fragment (pleural)	3.64	2.20	17.64	5.66	-5.15	8.94	54.12	-1.72
F5	<i>Centropomus sp.</i>	snook	Estr. NE-313, Pozo 16, Capa II	vertebra	3.14	3.13	22.34	8.31	-16.76	10.91	61.97	-7.03
F6	<i>Ariopsis felis</i>	ariid catfish	Estr. NE-14, Pozo 19, Cuarto B, Capa IV	fragment of neurocranium	7.13	4.63	15.70	2.56	-10.53 ^a	9.1	19.89	-4.94

^a C peak too small to be reliable. Excluded from further analysis.

6.4 Human samples

Atomic C:N ratios for human collagen samples ranged from 3.13 to 3.63, with a mean of 3.23 ± 0.11 . Thus, the mean falls within the expected range of 2.9 to 3.6 (DeNiro 1985:807), with one borderline high value of 3.63, indicating that the human samples generally have not undergone excessive diagenetic change. Five samples did not yield peaks or yielded a peak that was inadequate for analysis. One of these was sample H1, extracted from a femur from Burial No. Patio XIII/244. Fortunately, in this case an alternate element, a fibula, was available for this individual; the collagen extracted from the fibula, sample ID No. H50, did yield peaks. However, due to concerns over possible contamination of the H50 apatite sample, the apatite sample extracted from H1 and the collagen sample from H50 were used to represent this individual in statistical analyses. The use of two different elements, one for collagen and one for apatite, to infer the diet of this individual is not believed to be of concern, since animal experiments conducted by DeNiro and Schoeninger (1983:202) revealed that stable isotope ratios of different elements from the same individual were not significantly different. Tests were conducted for correlation between $\delta^{13}\text{C}_{\text{co}}$ and $\delta^{15}\text{N}$ values of human samples and the following indicators of collagen preservation: C:N ratios, collagen wt.% yield, %C and %N. The purpose is to rule out the possibility that the isotope ratios may be attributable to a taphonomic factor as opposed to actual diet (Pestle 2010b:219). No significant correlations were found (Table III). Comparing these indicators between the Early and Late Classic using Mann-Whitney U tests revealed that both wt.%C and wt.%N differed significantly between time periods (Table IV). In fact, the mean is greater for the Late Classic in both cases, which seems to indicate degradation of collagen through time (Pestle 2010b:219, 259).

TABLE III. RESULTS OF SPEARMAN'S RHO (R_s), TESTING FOR CORRELATION^a BETWEEN COLLAGEN QUALITY INDICATORS AND STABLE ISOTOPE VALUES

	Atomic C:N ratio		Collagen wt.% yield		Wt.% C		Wt.% N	
	r_s	p	r_s	p	r_s	p	r_s	p
$\delta^{13}C_{CO}$	-0.212	0.161	0.061	0.693	0.067	0.661	0.098	0.522
$\delta^{15}N$	0.150	0.326	-0.076	0.619	-0.136	0.371	-0.126	0.408

^a N=45 in all of the above categories.

TABLE IV. COLLAGEN QUALITY INDICATORS COMPARED BY PERIOD, INCLUDING RESULTS OF MANN-WHITNEY U TESTS^a.

	Early			Late			U	p
	n	Mean	SD	n	Mean	SD		
Atomic C:N ratio	9	3.27	0.15	36	3.21	0.09	146.0	0.665
Collagen wt.% yield	9	4.20	2.17	39	5.38	2.60	126.0	0.199
Wt.% C	9	24.59	6.82	36	30.98	6.21	73.0	0.010
Wt.% N	9	8.86	2.70	36	11.29	2.40	76.0	0.013

^a Exact significance is reported for p values.

Apatite weight % yields for human samples ranged from 41.28 to 86.96%, with a mean of $53.87 \pm 7.86\%$. The unusually high value of 86.96% obtained for sample H36 seems to indicate that the protocol failed to remove all contaminants and/or non-mineral phases of bone (Pestle 2010b:178). It should be noted that results of Spearman's ρ revealed a statistically significant negative correlation between apatite weight percent yield and $\delta^{18}O_{VPDB}$ values for the human samples ($r_s = -0.474$, $p = 0.001$), which seems to suggest that the original biogenic $\delta^{18}O$ values have been altered by a taphonomic process (Pestle 2010b:219). This is not surprising, given that apatite carbonate has been found to be more subject to diagenesis than apatite phosphate (Kohn & Cerling 2002:457). There was no significant correlation between apatite percent yield and $\delta^{13}C$ values ($r_s = 0.085$, $p = 0.563$). In addition, the fact that a statistically significant correlation was found between collagen and apatite $\delta^{13}C$ values ($r_s = 0.484$, $p = 0.001$), which is what one would typically expect, further suggests that the apatite $\delta^{13}C$ values are biogenic (Wright &

Schwarcz 1996:937). FTIR scans of 14 human bone apatite samples (see chapter 5 for selection process) did not reveal any sharp peaks at wavenumbers 710cm^{-1} or 1096cm^{-1} , which would have indicated contamination with calcite or francolite (Wright & Schwarcz 1996:936). Crystallinity index (CI) values for the human samples ranged from 2.67 to 3.00, thus falling within the acceptable limits (Pestle 2010b:185), although the two samples with values of 2.67 are borderline low (Table V). In terms of C/P ratios, two of the samples, H18 and H28, were low, and one sample, H21, was borderline low at 0.10. In contrast, the %CO₂ as calculated from C/P ratios reveals seven of the human samples to be outside the acceptable range, whereas only two human samples gave low values for %CO₃, calculated from BPI. Nevertheless, given that the results fell within the acceptable range for CI, the most broadly used index (Pestle 2010b:184-185), these samples were included in statistical analyses. Furthermore, the indices calculated from FTIR were tested for correlations with $\delta^{13}\text{C}$ and $\delta^{18}\text{O}_{\text{VPDB}}$ values and no significant correlations were found (Table VI). Nevertheless, $\delta^{18}\text{O}_{\text{VPDB}}$ values were not used for any further analyses, for reasons stated above.

TABLE V. INDICES CALCULATED FROM FTIR

Sample ID	565.04	595.9	605.54	103.59	1415.5	CI	C/P	BPI	%CO ₂ from C/P	%CO ₃ de BPI
c1 (modern bone)	0.04	0.03	0.03	0.03	0.01	2.33	0.333	0.33	7.91	4.45
H25 (whole bone)	0.04	0.03	0.03	0.04	0.01	2.33	0.250	0.33	5.77	4.45
F1	0.10	0.06	0.07	0.12	0.03	2.83	0.250	0.43	5.77	5.38
F2	0.08	0.05	0.06	0.08	0.02	2.80	0.250	0.33	5.77	4.45
F3	0.04	0.02	0.03	0.04	0.01	3.50	0.250	0.33	5.77	4.45
F4	0.08	0.05	0.06	0.10	0.01	2.80	0.100	0.17	1.92	2.84
H7	0.14	0.08	0.08	0.17	0.02	2.75	0.118	0.25	2.38	3.65
H10	0.15	0.08	0.09	0.17	0.02	3.00	0.118	0.22	2.38	3.38
H11	0.17	0.09	0.10	0.20	0.03	3.00	0.150	0.30	3.21	4.13
H18	0.20	0.11	0.11	0.24	0.01	2.82	0.042	0.09	0.43	2.10
H21	0.17	0.09	0.09	0.20	0.02	2.89	0.100	0.22	1.92	3.38
H24	0.13	0.07	0.08	0.15	0.02	3.00	0.133	0.25	2.78	3.65
H25	0.15	0.09	0.09	0.16	0.03	2.67	0.188	0.33	4.17	4.45
H28	0.11	0.06	0.06	0.12	0.01	2.83	0.083	0.17	1.50	2.84
H30	0.10	0.06	0.07	0.12	0.02	2.83	0.167	0.29	3.63	3.99
H34	0.14	0.08	0.08	0.14	0.02	2.75	0.143	0.25	3.02	3.65
H42	0.15	0.08	0.08	0.15	0.02	2.88	0.133	0.25	2.78	3.65
H43	0.16	0.09	0.09	0.19	0.03	2.78	0.158	0.33	3.41	4.45
H44	0.09	0.05	0.05	0.09	0.01	2.80	0.111	0.20	2.21	3.16
H45	0.15	0.09	0.09	0.16	0.02	2.67	0.125	0.22	2.56	3.38

TABLE VI. SPEARMAN'S RHO RESULTS TESTING FOR CORRELATIONS^a BETWEEN INDICES OF APATITE QUALITY CALCULATED FROM FTIR AND APATITE $\delta^{13}\text{C}$ AND $\delta^{18}\text{O}_{\text{VPDB}}$ VALUES

	CI		C/P		%CO ₂ from C/P		%CO ₃ from BPI	
	r _s	p	r _s	p	r _s	p	r _s	p
$\delta^{13}\text{C}$	0.059	0.817	-0.196	0.436	-0.196	0.436	-0.197	0.433
$\delta^{18}\text{O}_{\text{VPDB}}$	-0.193	0.442	-0.013	0.958	-0.013	0.958	-0.079	0.754

^a N=18 for all of the above correlations. Of the 18 samples, 14 are human, 4 faunal.

The average carbon and nitrogen values, and apatite-collagen spacing for the full sample, sexes and time periods pooled, are provided in Table VII. In order to gain a more specific sense of the C4 versus C3 makeup of the diet, the percentage contribution of C4 foods to apatite carbon values was calculated using the equation provided by Ambrose and colleagues (2003:221, Footnote 4). The results reveal that the inhabitants of Xcambó were consuming anywhere from 55% to 85% C4 foods. Thus, based on the premise that human bone apatite reflects primarily carbohydrate consumption (Torres-Rouff et al. 2012:59-60), although maize was clearly a dietary staple, C3 plants comprised anywhere from 15% to 45% of the diet, with a possible error of up to 10% (Ambrose et al. 2003:221). The percentage of C4 foods contributing to collagen carbon was not calculated due to the variability in collagen-diet spacing (Ambrose & Norr 1993; Pestle 2010b:104, 217).

In Figures 4-7, the human collagen results of the present study are plotted against expected ranges for various categories of botanical and faunal resources. Isotope ranges for marine fish and marine mammal flesh values were obtained by adding the corrections used by Pestle (2010b:208-209) to the collagen data published by Schoeninger and DeNiro (1984:632, Table 2). For marine fish, this entailed subtracting 4‰ from $\delta^{13}\text{C}_{\text{co}}$ values and adding 1.7 to $\delta^{15}\text{N}$

TABLE VII. DESCRIPTIVE STATISTICS FOR HUMAN CARBON AND NITROGEN STABLE ISOTOPE VALUES, AND APATITE-COLLAGEN SPACING FOR ENTIRE SAMPLE

	n	Mean (‰)	Median (‰)	Mode (‰)	SD
$\delta^{13}\text{C}_{\text{CO}}$	45	-8.44	-8.24	-7.81	0.80
$\delta^{15}\text{N}$	45	11.35	11.50	11.58	0.81
$\delta^{13}\text{C}_{\text{CA}}$	49	-4.85	-4.60	-5.40	1.21
$\Delta^{13}\text{C}_{\text{CA-CO}}$	45	3.51	3.72	3.56	1.09

values, and for mammals, subtracting 2.5‰ from $\delta^{13}\text{C}_{\text{co}}$ values and adding 0.2 to $\delta^{15}\text{N}$ (Pestle 2010b:209, 211-212). Ranges for terrestrial mammal and terrestrial bird flesh were likewise obtained by applying Pestle's (2010b:208-212) corrections to the ranges obtained by Schoeninger and DeNiro (1984:632, Table 2); thus, for birds, 1.5‰ was subtracted from $\delta^{13}\text{C}_{\text{co}}$ values and 1.2‰ was subtracted from $\delta^{15}\text{N}$ (Pestle 2010b:208). The conversions to flesh values were made in order to obtain the ranges for the portion of the animals that would actually have been consumed (Pestle 2010b:105-106). Ranges for the other faunal categories were redrawn from White and colleagues (2001:Figure 2), as they were already provided as flesh values. Ranges for plant categories were likewise redrawn from White and colleagues (2001:Figure 2). For further comparison, Figure 8 displays results of human bone collagen plotted against those of the faunal foodweb samples, as faunal resources are expected to have comprised the major source of protein. The faunal values have been adjusted such that they represent values of the flesh of the animal; the white-tailed deer, turkey, and snook samples were corrected as detailed above for mammals, birds, and fish, respectively, and for the two turtle species, corrections of -2.6‰ to $\delta^{13}\text{C}_{\text{co}}$ and +0.3‰ to $\delta^{15}\text{N}$ values were applied, as per Pestle (2010b:212). The typical $\delta^{15}\text{N}$ fractionation is approximately 3‰ per trophic level (Minagawa & Wada 1984:1138; Schoeninger & DeNiro 1984:635; Schoeninger & Moore 1992:258); however, the actual human

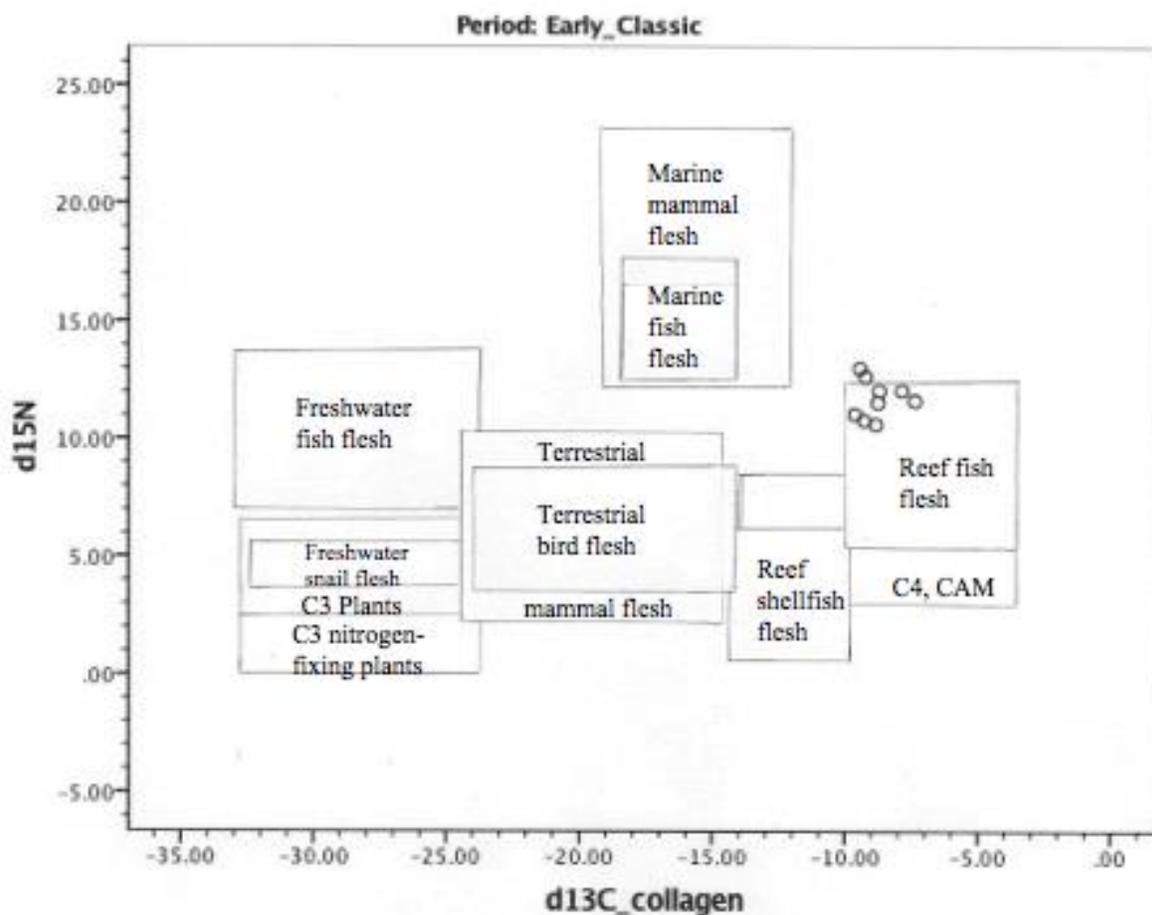


Figure 4. Collagen stable isotope results for Early Classic Xcambó human individuals sampled in present study, shown as circles, compared to ranges of various plant and animal categories. Ranges for flesh values for marine fish, marine mammals, terrestrial birds, and terrestrial mammals derived from data in Schoeninger and DeNiro (1984:628, 632), with corrections applied as per Pestle (2010b:208-212). All other ranges redrawn from White et al. (2001:Figure 2).

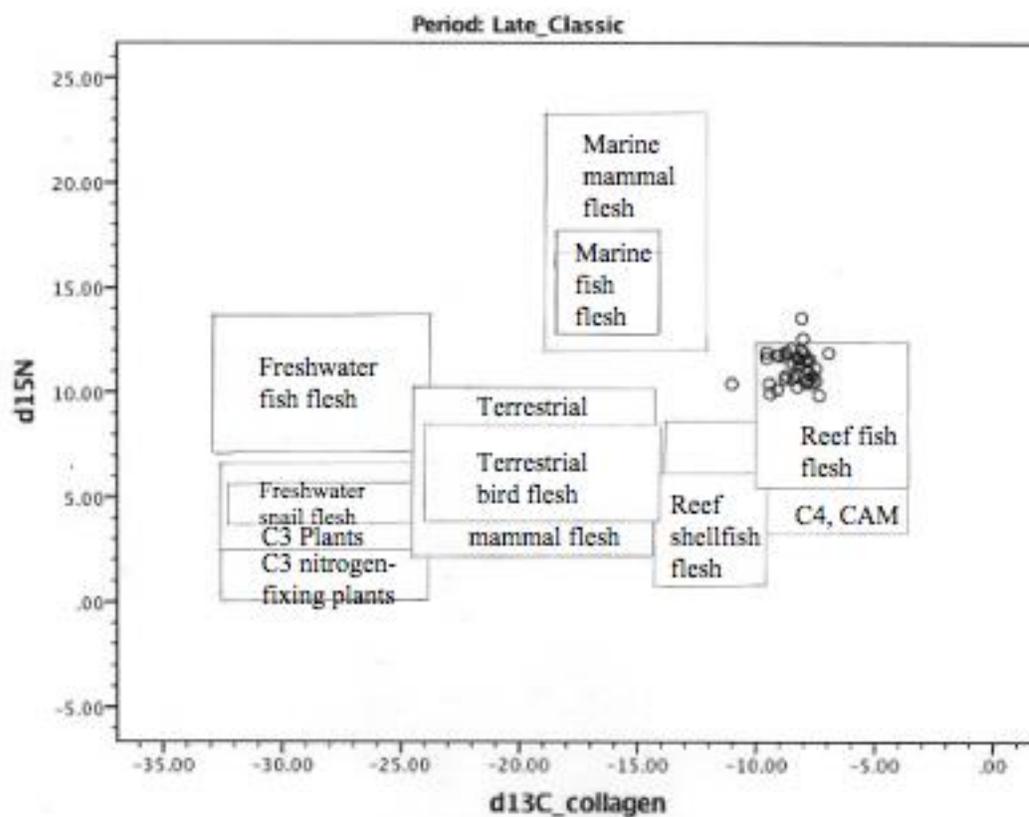


Figure 5. Collagen stable isotope results for Late Classic human individuals sampled in present study, shown as circles, compared to ranges of various plant and animal categories. Ranges for flesh values for marine fish, marine mammals, terrestrial birds, and terrestrial mammals derived from data in Schoeninger and DeNiro (1984:628, 632), with corrections applied as per Pestle (2010b:208-212). All other ranges redrawn from White et al. (2001:Figure 2).

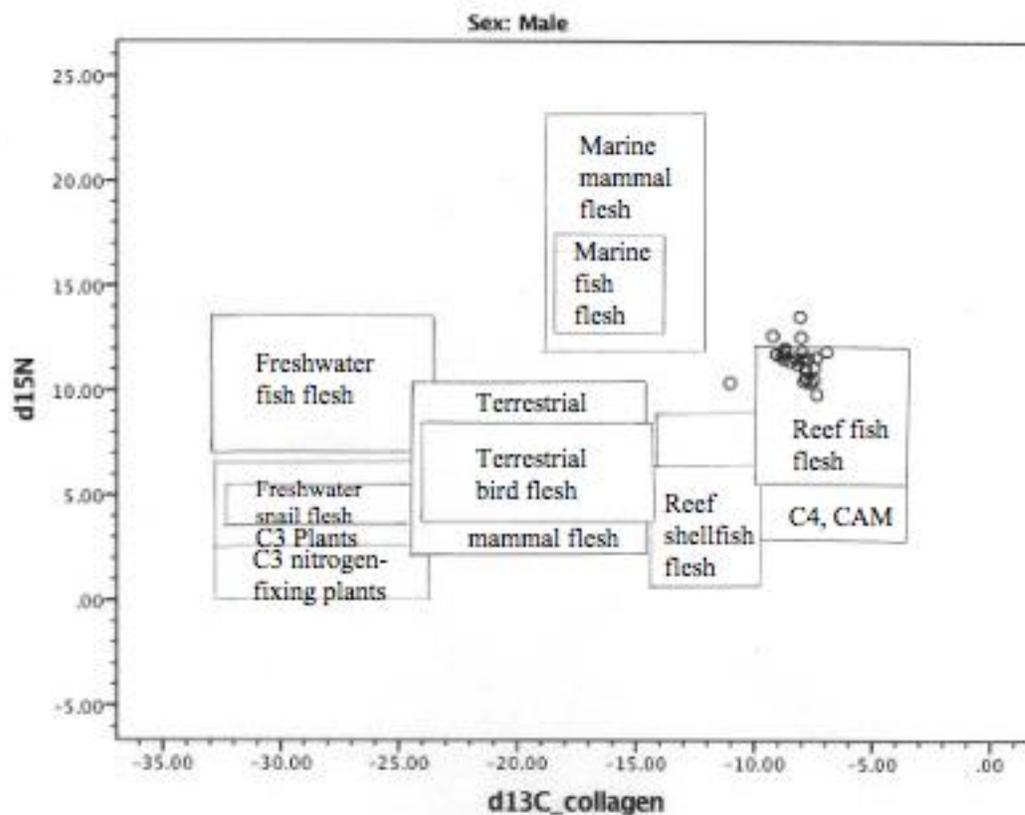


Figure 6. Collagen stable isotope results for Xcambó males sampled in present study, shown as circles, compared to ranges of various plant and animal categories. Ranges for flesh values for marine fish, marine mammals, terrestrial birds, and terrestrial mammals derived from data in Schoeninger and DeNiro (1984:628, 632), with corrections applied as per Pestle (2010b:208-212). All other ranges redrawn from White et al. (2001:Figure 2).

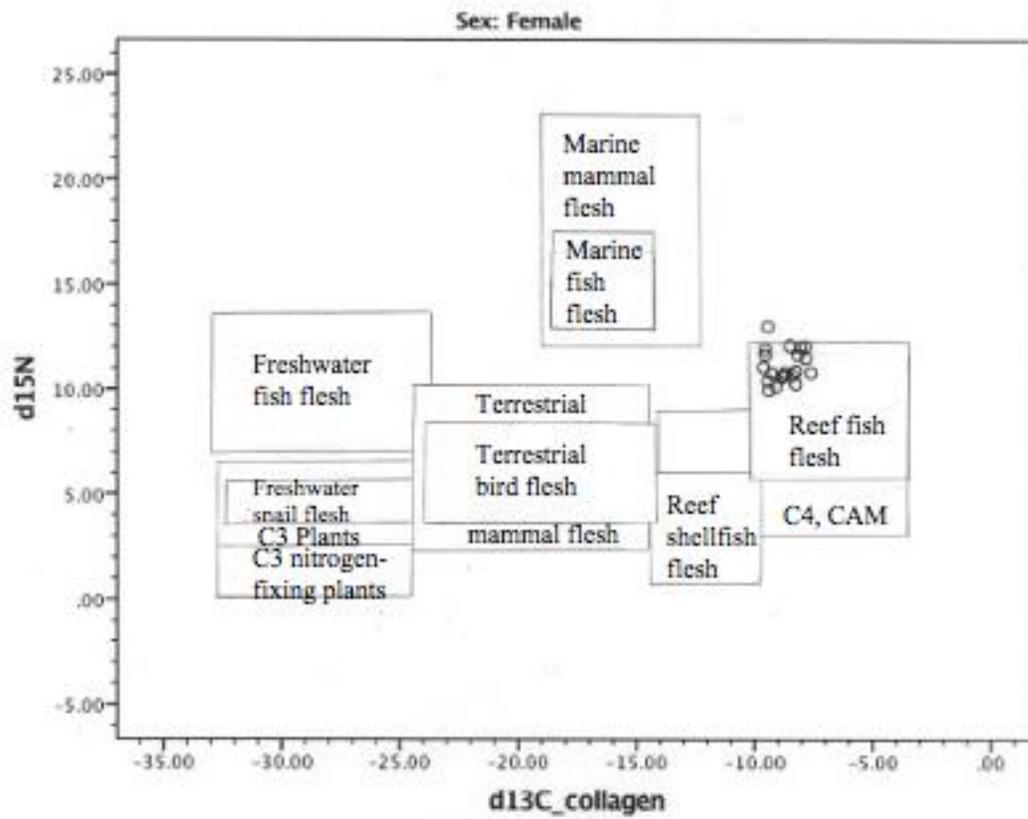


Figure 7. Collagen stable isotope results for Xcambó females sampled in present study, shown as circles, compared to ranges of various plant and animal categories. Ranges for flesh values for marine fish, marine mammals, terrestrial birds, and terrestrial mammals derived from data in Schoeninger and DeNiro (1984:628, 632), with corrections applied as per Pestle (2010b:208-212). All other ranges redrawn from White et al. (2001:Figure 2).

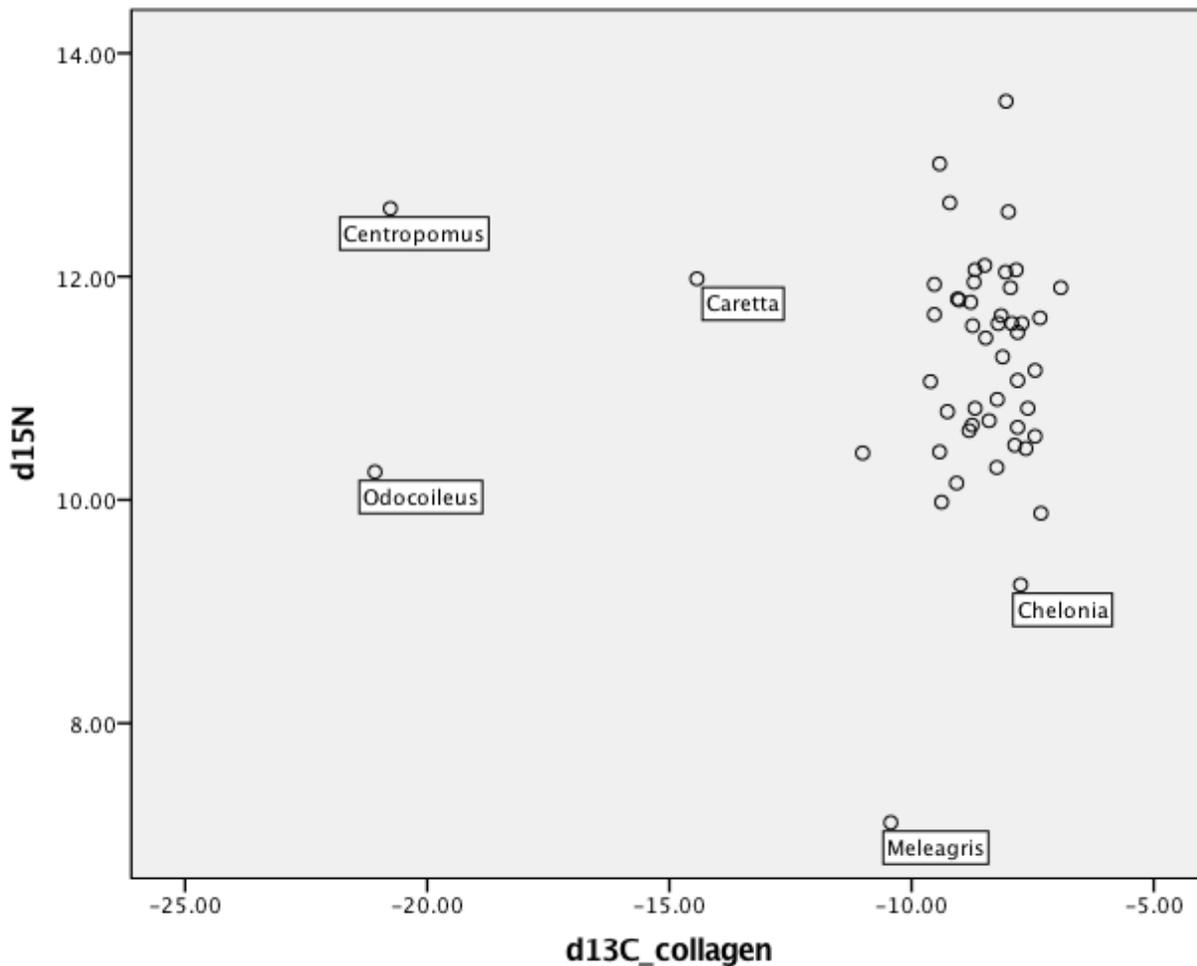


Figure 8. Faunal sample $\delta^{13}\text{C}_{\text{CO}}$ and $\delta^{15}\text{N}$ values compared to those of human samples (unlabeled circles). Tissue type corrections have been applied to faunal samples, as described above.

values will depend on the relative prominence of a particular food source in the diet (Ambrose 1993:83-84). As previously noted, the fractionation for $\delta^{13}\text{C}$ is more variable, and although estimates of 1‰ to 5‰ are commonly cited (Larsen 1997:271; Lee-Thorp et al. 1989:594; Schoeninger & DeNiro 1984:625; Schoeninger & Moore 1992:258), the experiments of Ambrose and Norr (1993:13-14, 25-26) obtained a range of -2.2 to +9.6‰.

In Figure 9, the overall mean $\delta^{13}\text{C}_{\text{co}}$ and $\delta^{15}\text{N}$ values for Xcambó are compared to those of various other Maya sites. The means for the 12 Xcambó individuals analyzed by Sierra Sosa and colleagues (2014:Table 2) are shown separately from those of the present study because they were chosen based on different selection criteria and they were processed by a different laboratory. Relative to other sites, the most notable difference is the high mean $\delta^{15}\text{N}$ for Xcambó, with the nearest mean being that of Altun Ha, Belize, a site which is 7km from shore and where abundant remains of marine fauna have been found (White et al. 2001:375), as well as the more enriched $\delta^{13}\text{C}_{\text{co}}$.

In order to rule out the possibility that any patterns found in the stable isotope data may be due to age-related differences, delta values were compared by age categories. Using information from the original bioarchaeological analyses (Vera Tiesler, 2013, information from field and lab notes), individuals were grouped into the broad categories of adults and adolescents, adults comprising the majority of the sample. Any individual over the age of 15 years was considered an adult. The two groups were compared using Mann-Whitney U tests (Table VIII), and no statistically significant differences were found.

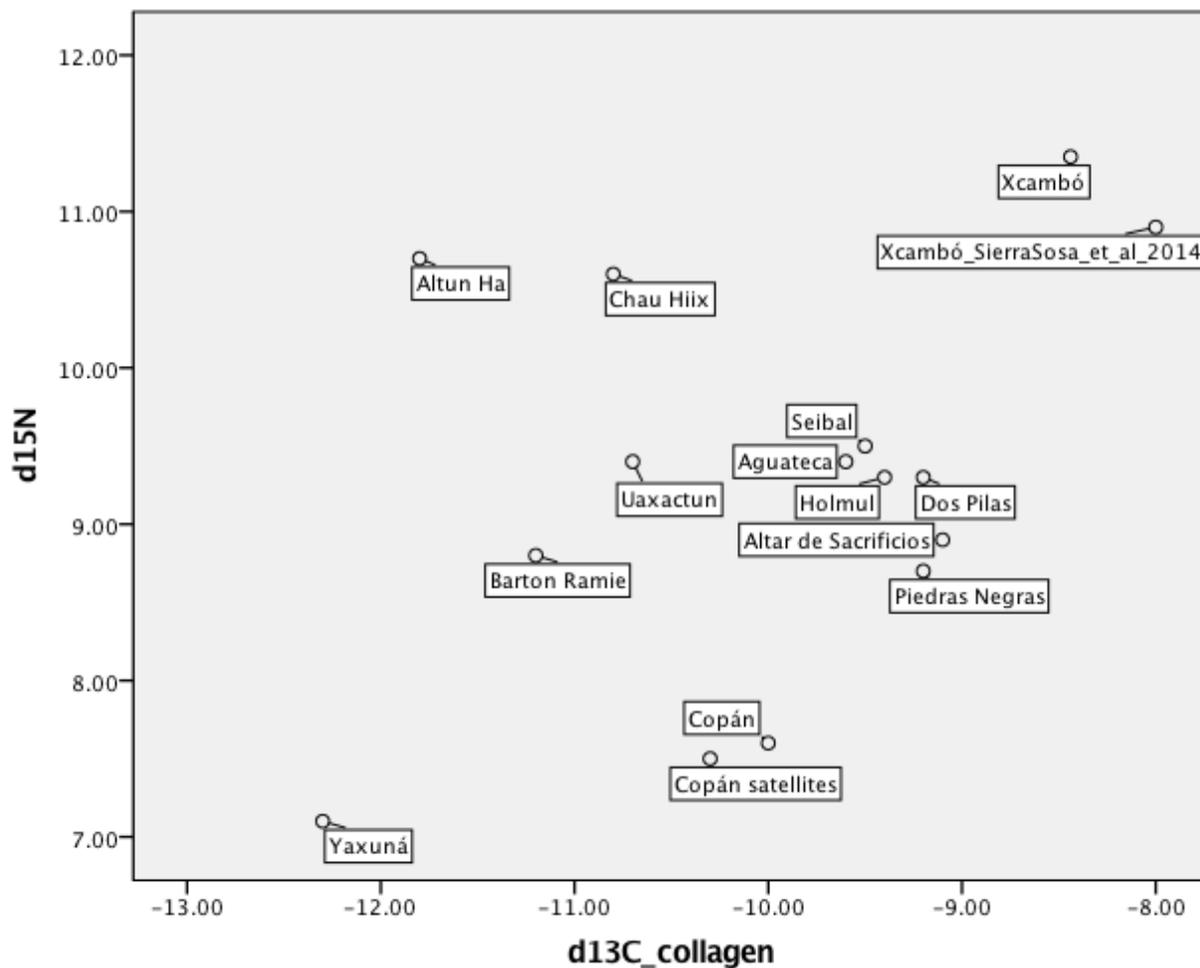


Figure 9. Mean $\delta^{13}\text{C}_{\text{collagen}}$ and $\delta^{15}\text{N}$ results for Xcambó compared to those of various other Maya sites. Data from sites other than Xcambó obtained from: Gerry and Krueger (1997:203); Mansell et al. (2006:175); Scherer et al. (2007:92); White et al. (2001:382); Wright (1997:189). The majority of the data represented above is Classic period; the Yaxuná and Dos Pilas data is Late to Terminal Classic (Mansell et al. 2006:175; Wright 1997:189). The Altun Ha data is Preclassic to Postclassic (White et al. 2001:371, 376), and the data from Chau Hiix is Late Classic to Historic (Metcalfe et al. 2009:24-25, 27).

TABLE VIII. RESULTS OF MANN-WHITNEY U TESTS^a COMPARING ADOLESCENTS TO ADULTS

	Adolescents	Adults	U	p
$\delta^{13}\text{C}_{\text{CO}}$	n = 5	n = 40	73.0	0.349
$\delta^{15}\text{N}$	n = 5	n = 40	76.0	0.407
$\delta^{13}\text{C}_{\text{CA}}$	n = 5	n = 44	83.0	0.393

^aExact significance is used.

6.5 Comparisons by rank

As previously mentioned, rank was determined from associated architecture (see section 5.9). Descriptive statistics for stable isotope results were as follows:

TABLE IX. DESCRIPTIVE STATISTICS^a FOR COLLAGEN $\delta^{13}\text{C}$ ($\delta^{13}\text{C}_{\text{CO}}$), $\delta^{15}\text{N}$ AND APATITE $\delta^{13}\text{C}$ ($\delta^{13}\text{C}_{\text{CA}}$) BY SOCIAL RANK

		n	Mean (‰)	Median (‰)	Mode (‰)	SD
$\delta^{13}\text{C}_{\text{CO}}$	Rank 1	16	-8.16	-8.14	-7.81	0.55
	Rank 2	13	-8.68	-8.69	-11.01	0.93
	Rank 3	14	-8.63	-8.88	-9.61	0.83
$\delta^{15}\text{N}$	Rank 1	16	11.46	11.48	10.29	0.77
	Rank 2	13	10.77	10.62	11.58	0.61
	Rank 3	14	11.81	11.80	10.79	0.66
$\delta^{13}\text{C}_{\text{CA}}$	Rank 1	16	-4.67	-4.22	-3.71	1.44
	Rank 2	14	-5.05	-4.77	-7.22	1.18
	Rank 3	16	-5.00	-5.24	-5.40	1.01

^a Three individuals had no rank data available and are therefore not included in the above statistics.

^b Rank 1 = lowest. Rank 3 = highest.

Rank 1, the lowest-ranking group, has the least negative mean $\delta^{13}\text{C}_{\text{CO}}$, whereas there is only a slight difference between the means for ranks 2 and 3. When outliers are excluded, the rank 3

group has the broadest range, consistent with more varied carbon sources compared to the two lower-status groups (Figure 10, Appendix D). Upon examining the boxplots for $\delta^{15}\text{N}$ (Figure 11, Appendix D), the rank 2 group appears to be distinct and, interestingly, its range includes lower values than either 1 or 3. The rank 3 group, with the highest mean, consumed the most protein or a greater proportion of this group's protein came from marine sources, although the highest outlier belongs to group 1. Because $\delta^{13}\text{C}_{\text{CO}}$ values are not normally distributed for each rank, a Kruskal-Wallis test was conducted to compare stable isotope signatures by rank and found no significant difference among the groups (Table X). As with $\delta^{13}\text{C}_{\text{CO}}$ results, rank 1 has the most enriched mean apatite $\delta^{13}\text{C}$ ($\delta^{13}\text{C}_{\text{CA}}$), while ranks 2 and 3 had nearly equal means with that of group 2 being slightly more depleted (Figure 12, Appendix D). Likewise, a Kruskal-Wallis test found no significant differences among the three groups in apatite $\delta^{13}\text{C}$ values (Table X) or $\Delta^{13}\text{C}_{\text{CA-CO}}$ ($\chi^2 = 0.035$, $df = 2$, $p = 0.983$).

TABLE X. RESULTS OF KRUSKAL-WALLIS TESTS FOR DIFFERENCES IN STABLE ISOTOPES SIGNATURES BY RANK

	Rank 1	Rank 2	Rank 3	χ^2	df	p
$\delta^{13}\text{C}_{\text{CO}}$	n = 16	n = 13	n = 14	3.867	2	0.145
$\delta^{15}\text{N}$	n = 16	n = 13	n = 14	12.931	2	0.002
$\delta^{13}\text{C}_{\text{CA}}$	n = 16	n = 14	n = 16	1.867	2	0.393

In contrast, the Kruskal-Wallis results show a statistically significant difference by rank in $\delta^{15}\text{N}$ values. Post-hoc pairwise comparisons with Bonferroni corrections (Table XI) revealed statistically significant differences between ranks 2 and 3, and the difference between ranks 1

TABLE XI. RESULTS^a OF POST-HOC PAIRWISE COMPARISONS OF $\delta^{15}\text{N}$ BY RANK WITH BONFERRONI CORRECTION

	p
Ranks 1 and 2	0.061
Ranks 1 and 3	0.500
Ranks 2 and 3	0.001

and 2 approached significance. The difference between groups 1 and 3 was not statistically significant.

When individuals in simple vs. cist burials are compared, they show only slight differences in mean $\delta^{13}\text{C}$ signatures (Table XII), and results of Mann-Whitney U tests revealed no significant differences in either $\delta^{13}\text{C}_{\text{CO}}$ ($U = 146.5$, $p = 0.516$) or $\delta^{13}\text{C}_{\text{CA}}$ ($U = 216.0$, $p = 1.00$). However, there is a statistically significant difference between these two groups ($U = 95.0$, $p = 0.035$) in $\delta^{15}\text{N}$ results. Contrary to expectations, the group interred in simple burials had a higher mean $\delta^{15}\text{N}$. Nevertheless, it should be noted that despite the difference in $\delta^{15}\text{N}$ values, a Mann-Whitney U test comparing $\Delta^{13}\text{C}_{\text{CA-CO}}$, which distinguishes between carnivorous and herbivorous diets (Ambrose 1993:107-108; Lee-Thorp et al. 1989:593-595), revealed no significant difference by burial type ($U = 160.0$, $p = 0.793$).

TABLE XII. STABLE ISOTOPE RESULTS BY GRAVE TYPE

Burial type	$\delta^{13}\text{C}_{\text{CO}}$			$\delta^{15}\text{N}$			$\delta^{13}\text{C}_{\text{CA}}$		
	n	Mean	SD	n	Mean	SD	n	Mean	SD
Simple	34	-8.42	0.84	34	11.50	0.82	36	-4.86	1.22
Cist	10	-8.54	0.66	10	10.92	0.62	12	-4.91	1.27

^a One individual whose grave type was unidentified is not included in the above results.

As another means of testing for potential relationships between diet and social rank, stable isotopes were compared by patio group rank (Table XIII). Except for a slight increase from rank 1 to rank 2, mean $\delta^{13}\text{C}$ values for both collagen and apatite seem to suggest a trend towards more depleted values, reflecting less C4 consumption, with increasing rank, while $\delta^{15}\text{N}$ results show a possible trend towards more enriched values with rank, possibly indicating greater meat consumption. However, results of Kruskal-Wallis tests did not reveal any statistically significant differences for $\delta^{13}\text{C}_{\text{CO}}$, $\delta^{13}\text{C}_{\text{CA}}$ or for $\delta^{15}\text{N}$ (Table XIV), nor were there any significant differences in $\Delta^{13}\text{C}_{\text{CA-CO}}$ ($\chi^2 = 0.539$, $df = 3$, $p = 0.910$).

In the analyses of the burial good data, results of Spearman's ρ to measure the degree of association between quality of each burial good category and isotope signatures revealed a statistically significant association (Table XV) only between $\delta^{13}\text{C}_{\text{CA}}$ and quality of animal bone offerings. Similarly, results of Spearman's ρ testing for correlations between delta values and quantity of burial offerings in the same categories found the only significant correlation to be a positive one between $\delta^{13}\text{C}_{\text{CA}}$ and quantity of animal bone offerings (Table XVI). Furthermore, to determine whether rank as assessed from burial offerings reflects social status as inferred from associated architecture, Spearman's ρ was also used to test the strength of association between rank and quality and quantity of burial offerings in each of the five categories (Tables XVII and XVIII). Statistically significant correlations were found between rank and quality of jade offerings and between rank and quantity of offerings in the ceramic and jade categories. These were negative correlations, suggesting that quantity and quality ratings of burial offerings are not measuring the same attribute as size of architecture.

TABLE XIII. STABLE ISOTOPE RESULTS BY PATIO GROUP RANK

	$\delta^{13}\text{C}_{\text{CO}}$			$\delta^{15}\text{N}$			$\delta^{13}\text{C}_{\text{CA}}$		
	n	Mean	SD	n	Mean	SD	n	Mean	SD
Rank 1	6	-8.28	1.12	6	11.08	0.83	8	-4.54	1.24
Rank 2	17	-8.23	0.58	17	11.29	0.63	18	-4.63	1.05
Rank 3	11	-8.52	1.04	11	11.39	1.13	11	-5.00	1.23
Rank 4	11	-8.75	0.60	11	11.54	0.75	12	-5.26	1.42

TABLE XIV. RESULTS OF KRUSKAL-WALLIS TESTS COMPARING STABLE ISOTOPE RESULTS BY PATIO GROUP RANK

	χ^2	df	p
$\delta^{13}\text{C}_{\text{CO}}$	3.757	3	0.289
$\delta^{15}\text{N}$	1.224	3	0.747
$\delta^{13}\text{C}_{\text{CA}}$	2.036	3	0.565

TABLE XV. RESULTS OF SPEARMAN'S CORRELATIONS TO DETERMINE STRENGTH OF ASSOCIATION BETWEEN QUALITY OF BURIAL OFFERINGS VERSUS $\delta^{13}\text{C}_{\text{CO}}$, $\delta^{15}\text{N}$, AND $\delta^{13}\text{C}_{\text{CA}}$

	$\delta^{13}\text{C}_{\text{CO}}$			$\delta^{15}\text{N}$			$\delta^{13}\text{C}_{\text{CA}}$		
	n	rho	p	n	rho	p	n	rho	p
Ceramics, quality	45	-0.109	0.477	45	0.050	0.745	49	-0.211	0.145
Lithics, quality	44	0.176	0.252	44	0.048	0.758	48	0.150	0.310
Jade, quality	45	0.146	0.339	45	-0.192	0.205	49	0.183	0.209
Shell, quality	45	0.191	0.209	45	-0.171	0.262	49	0.170	0.244
Animal bone, quality	45	0.194	0.201	45	-0.013	0.931	49	0.394	0.005

TABLE XVI. RESULTS OF SPEARMAN'S CORRELATIONS TESTS OF QUANTITY OF BURIAL OFFERINGS VERSUS $\delta^{13}\text{C}_{\text{CO}}$, $\delta^{15}\text{N}$, AND $\delta^{13}\text{C}_{\text{CA}}$

	$\delta^{13}\text{C}_{\text{CO}}$			$\delta^{15}\text{N}$			$\delta^{13}\text{C}_{\text{CA}}$		
	n	rho	p	n	rho	p	n	rho	P
Ceramics, quantity	45	-0.006	0.968	45	-0.067	0.663	49	0.072	0.621
Lithics, quantity	45	0.217	0.151	45	0.057	0.708	49	0.206	0.156
Jade, quantity	45	0.155	0.311	45	-0.191	0.208	49	0.180	0.215
Shell, quantity	45	0.128	0.402	45	-0.119	0.437	49	0.177	0.224
Animal bone, quantity	45	0.192	0.207	45	0.022	0.887	49	0.374	0.008

TABLE XVII. RESULTS OF SPEARMAN'S CORRELATIONS TO DETERMINE STRENGTH OF ASSOCIATION BETWEEN RANK AND QUALITY OF BURIAL OFFERINGS

	Rank		
	n	rho	p
Ceramics, quality	46	-0.172	0.252
Lithics, quality	45	-0.238	0.115
Jade, quality	46	-0.442	0.002
Shell, quality	46	-0.214	0.154
Animal bone, quality	46	-0.067	0.658

TABLE XVIII. RESULTS OF SPEARMAN'S CORRELATIONS TO DETERMINE STRENGTH OF ASSOCIATION BETWEEN RANK AND QUANTITY OF BURIAL OFFERINGS

	Rank		
	n	rho	p
Ceramics, quantity	46	-0.354	0.016
Lithics, quantity	46	-0.260	0.081
Jade, quantity	46	-0.444	0.002
Shell, quantity	46	-0.188	0.212
Animal bone, quantity	46	-0.087	0.563

6.6 Comparisons by patio group

Data on patio groups from which five or more individuals were sampled are provided in Table XIX. Comparing boxplots of $\delta^{13}\text{C}_{\text{CO}}$ values of the patio groups from which 5 or more individuals were sampled (Figure 13, Appendix D), one can see that Plaza 1 has the most negative mean value. Given that collagen stable isotope values are primarily indicative of one's protein sources, particularly in diets containing adequate protein intake (Ambrose & Norr 1993:8), this may indicate less consumption of marine resources, but given that Plaza 1 also has the lightest mean $\delta^{13}\text{C}_{\text{CA}}$, it is more likely that this group was consuming less maize (Schoeninger & DeNiro 1984:635; Schoeninger & Moore 1992:255-256,259-260). Patio Group XVI has the broadest interquartile range of $\delta^{13}\text{C}_{\text{CO}}$ values and, when one outlier is included, has

the broadest overall range. At the same time, boxplots of the $\delta^{13}\text{C}_{\text{CA}}$ data highlight the broader range of values for Plaza 1 (Figure 14, Appendix D). The $\delta^{15}\text{N}$ results reveal that, when the high outlier is excluded from patio group XVI, Plaza 1 has the broadest range of $\delta^{15}\text{N}$ results (Figure 15, Appendix D), indicating greater variation in protein sources. However, patio group 5 displays the highest mean $\delta^{15}\text{N}$, suggesting greater marine food consumption (Schoeninger & DeNiro 1984:633). Considering the broad ranges of Plaza 1, it may be of relevance that three of the individuals sampled from Plaza 1 have been identified as nonlocal based on Sr results, one from elsewhere in northern Yucatán, the other two as foreign (Sierra Sosa et al. n.d.). Furthermore, Plaza 1 is the only patio group of these four at which two styles of dental decoration are seen (Tiesler 2016), further highlighting the social diversity of this patio group.

In order to test for differences among the patio groups from which five or more individuals were sampled, Kruskal-Wallis tests were conducted and revealed no statistically significant results in stable isotope signatures (Table XX) or $\Delta^{13}\text{C}_{\text{CA-CO}}$ ($\chi^2 = 1.812$, $df = 3$, $p = 0.612$).

TABLE XIX. STATISTICS ON RANK AND C AND N STABLE ISOTOPE RESULTS FOR PATIO GROUPS FROM WHICH FIVE OR MORE INDIVIDUALS WERE SAMPLED

Patio Group	n ^a	Avg. floor area, 3 largest structures	Rank ^b of patio group	Mean $\delta^{13}\text{C}_{\text{CO}}$	Mean $\delta^{15}\text{N}$	Mean $\delta^{13}\text{C}_{\text{CA}}$
XI-XII	5	122.7	2	-8.12	11.13	-4.47
XVI	5	215	3	-8.64	11.25	-4.63
V	6	365.7	4	-8.59	11.96	-5.02
Plaza 1	6	528.3	4	-8.88	11.19	-5.49

^a n = number of individuals sampled per patio group.

^b Higher numbers represent increasing rank.

TABLE XX. RESULTS OF KRUSKAL-WALLIS TESTS COMPARING STABLE ISOTOPE RESULTS OF PATIO GROUPS FROM WHICH FIVE OR MORE INDIVIDUALS WERE SAMPLED

	χ^2	df	p
$\delta^{13}\text{C}_{\text{CO}}$	3.685	3	0.298
$\delta^{15}\text{N}$	4.885	3	0.180
$\delta^{13}\text{C}_{\text{CA}}$	0.989	3	0.804

6.7 Geographic Origins

To compare stable isotope signatures among groups of different geographic origins, data from a previous investigation of strontium stable isotope ratios (Sierra Sosa et al. 2014; Sierra Sosa et al. n.d.) was used to classify individuals into three groups, one of local origin, another from locations in northern Yucatán other than Xcambó, and a third group of more distant origin classified under the broad term of "foreign", and a bivariate plot of $\delta^{15}\text{N}$ and $\delta^{13}\text{C}_{\text{CO}}$ results was created (Figure 16, Appendix D). It is interesting to note that of the two individuals whose place of origin is elsewhere in northern Yucatán, one falls highest on the $\delta^{15}\text{N}$ axis while the other is among the lowest. In contrast, two of the foreign individuals fall near the middle of the nitrogen range. In terms of $\delta^{13}\text{C}_{\text{CO}}$ results, two of the foreign individuals fall within the more depleted end of the range.

For Mann-Whitney U tests, the group from other areas of northern Yucatán and the foreign group were both classified as nonlocal. The results revealed no statistically significant difference in stable isotope values between local versus nonlocal individuals (Table XXI) or in $\Delta^{13}\text{C}_{\text{CA-CO}}$ ($U = 27.0$, $p = 0.199$).

TABLE XXI. RESULTS^a OF MANN-WHITNEY U TESTS COMPARING STABLE ISOTOPE RESULTS BETWEEN GROUPS OF LOCAL VERSUS NONLOCAL GEOGRAPHIC ORIGIN.

	local	nonlocal	U	p
$\delta^{13}\text{C}_{\text{CO}}$	n = 18	n = 5	34.5	0.446
$\delta^{15}\text{N}$	n = 18	n = 5	42.0	0.857
$\delta^{13}\text{C}_{\text{CA}}$	n = 18	n = 5	25.5	0.150

^aExact significance is reported for p values.

6.8 Comparisons by sex

In comparing individuals by sex, statistical analyses were performed using two data sets; one in which probable males and females, as recorded by the bioarchaeologist who analyzed the given burial, were coded as "Indeterminate"; in the other data set, probable males were entered as males and probable females entered as females, such that no individual was classified as indeterminate. In the former data set, a total of 12 individuals were indeterminate, 18 were female, and 19 male. The sole Preclassic individual is a probable male (Vera Tiesler, 2013, information from field and lab notes).

With individuals from all periods pooled, using the dataset in which no individuals are classified as indeterminate, the mean $\delta^{13}\text{C}_{\text{CO}}$ for males of $-8.21 \pm 0.84\%$, is less negative than that for females at $-8.71 \pm 0.66\%$ (Table XXII). Because $\delta^{13}\text{C}_{\text{CO}}$ values by sex are not normally distributed, a Mann-Whitney U test was used for comparison and indicated that they were significantly different ($U = 134.5$, $p = 0.008$). There were no significant differences in $\delta^{15}\text{N}$ ($U = 200.5$, $p = 0.258$), $\delta^{13}\text{C}_{\text{CA}}$ ($U = 274.5$, $p = 0.651$) or apatite-collagen spacing ($U = 206.0$, $p = 0.315$). Boxplots are provided in Figures 17-19 (Appendix D) and indicate that the ranges of $\delta^{13}\text{C}_{\text{CA}}$ values are nearly equal. Because further subdividing the results by time period would

yield a sample of only n=4 males and n=5 females for the Early Classic, statistical comparisons are not shown.

TABLE XXII. STABLE ISOTOPE RESULTS BY SEX; TIME PERIODS POOLED

	$\delta^{13}\text{C}_{\text{CO}}$			$\delta^{15}\text{N}$			$\delta^{13}\text{C}_{\text{CA}}$		
	n	Mean	SD	n	Mean	SD	n	Mean	SD
Males	25	-8.21	0.84	25	11.49	0.81	27	-4.81	1.27
Females	20	-8.71	0.66	20	11.16	0.79	22	-4.90	1.16

Using the dataset in which an individual's sex was recorded as indeterminate if there was ambiguity (Table XXIII), the mean apatite results for males and females are again nearly equal. Males again have higher mean $\delta^{15}\text{N}$ and $\delta^{13}\text{C}_{\text{CO}}$ values. Results of Kruskal-Wallis tests revealed no significant differences in mean $\delta^{13}\text{C}_{\text{CO}}$, $\delta^{15}\text{N}$ or $\delta^{13}\text{C}_{\text{CA}}$ (Table XXIV). Consistently, a Kruskal-Wallis test comparing $\Delta^{13}\text{C}_{\text{CA-CO}}$ among the three groups found no significant difference ($\chi^2 = 0.870$, $df = 2$, $p = 0.647$).

TABLE XXIII. STABLE ISOTOPE RESULTS DIVIDED BY SEX; TIME PERIODS POOLED

	$\delta^{13}\text{C}_{\text{CO}}$			$\delta^{15}\text{N}$			$\delta^{13}\text{C}_{\text{CA}}$		
	n	Mean	SD	n	Mean	SD	n	Mean	SD
Males	18	-8.25	0.94	18	11.55	0.80	19	-4.81	1.26
Females	16	-8.65	0.64	16	11.12	0.68	18	-4.80	1.13
Indeterminate	11	-8.43	0.73	11	11.33	0.98	12	-5.00	1.35

TABLE XXIV. RESULTS OF KRUSKAL-WALLIS TESTS COMPARING STABLE ISOTOPE RESULTS AMONG MALE, FEMALE AND INDETERMINATE INDIVIDUALS

	χ^2	df	P
$\delta^{13}\text{C}_{\text{CO}}$	4.408	2	0.110
$\delta^{15}\text{N}$	1.559	2	0.459
$\delta^{13}\text{C}_{\text{CA}}$	0.300	2	0.861

6.9 Comparisons by period

The mean $\delta^{13}\text{C}_{\text{CO}}$ value for the Early Classic period of -8.77‰ (Table XXV) is consistent with consumption of C4 and/or marine protein sources (Klepinger 1984:85-86; Schoeninger & DeNiro 1984:636). During the Late Classic, consumption of C4/marine protein sources increased, as indicated by the increasing (i.e. less negative) mean $\delta^{13}\text{C}_{\text{CO}}$ of -8.35‰ (see also Figure 20, Appendix D). However, Mann-Whitney U results indicate that $\delta^{13}\text{C}_{\text{CO}}$ values are not significantly different between the two time periods (Table XXVI). While the broader range of $\delta^{13}\text{C}_{\text{CO}}$ values, from -11.01 to -6.92‰, for the Late Classic, as compared to -9.61 to -7.35‰ for the Early Classic, may reflect greater variability in protein sources, it may also be an effect of the small Early Classic sample size.

TABLE XXV. STABLE ISOTOPE RESULTS BY TIME PERIOD, SEXES POOLED

	Early Classic			Late Classic		
	n	Mean (‰)	SD	n	Mean (‰)	SD
$\delta^{13}\text{C}_{\text{CO}}$	9	-8.77	0.75	36	-8.35	0.80
$\delta^{15}\text{N}$	9	11.72	0.82	36	11.25	0.79
$\delta^{13}\text{C}_{\text{CA}}$	9	-4.83	0.88	39	-4.88	1.29

^a The one Preclassic individual, not shown in table above, yielded a $\delta^{13}\text{C}_{\text{CA}}$ value of -3.78‰.

TABLE XXVI. RESULTS OF MANN-WHITNEY U TESTS COMPARING STABLE ISOTOPE RESULTS BY TIME PERIOD, SEXES POOLED

	Early Classic	Late Classic	U	P
$\delta^{13}\text{C}_{\text{CO}}$	n = 9	n = 36	104.0	0.104
$\delta^{15}\text{N}$	n = 9	n = 36	109.0	0.138
$\delta^{13}\text{C}_{\text{CA}}$	n = 9	n = 39	167.0	0.835

^a Exact significance values are reported for p values.

Comparison of $\delta^{13}\text{C}_{\text{CA}}$ results seems to suggest that maize use remained fairly constant throughout the Classic period, with an Early Classic mean of -4.83‰ followed by -4.88‰ in the Late Classic (Table XXV; Figure 21, Appendix D). However, as can be seen from histograms by time period (Figures 22-23, Appendix D) the Late Classic distribution is bimodal, with a broader range of values during the Late Classic, including a less negative 75th percentile value of -3.88‰, compared to -4.11 for the Early Classic. While the collagen sample for the sole Preclassic individual, unfortunately, did not produce any peaks, the $\delta^{13}\text{C}_{\text{CA}}$ result of -3.78‰ is consistent with a maize-based diet (Schoeninger & Moore 1992:255-256); for obvious reasons, however, one cannot draw inferences about diachronic change from the Preclassic to Classic based on one individual.

With respect to $\delta^{15}\text{N}$ values, while they show an overall decrease from the Early to the Late Classic (Figure 24, Appendix D), the difference is not statistically significant, as seen in Table XXVI. It should also be noted that the apatite-collagen spacing did not change significantly through time, as indicated by results of Mann-Whitney U tests ($U = 109.0$, $p = 0.138$).

7. DISCUSSION

7.1 Inferences on overall diet

The findings from bivariate plots of $\delta^{13}\text{C}_{\text{CO}}$ and $\delta^{15}\text{N}$ values, comparing ranges of various categories of potential food sources with human results (Figures 4-7), and taking into account the 3‰ trophic level increase for $\delta^{15}\text{N}$ and a $\delta^{13}\text{C}_{\text{CO}}$ increase of approximately 1‰ to 5‰ per trophic level (Schoeninger & Moore 1992:258; Schoeninger & DeNiro 1984:625, 632), (although see Chapter 3 for discussion of causes of variability in $\delta^{13}\text{C}_{\text{CO}}$ fractionation), suggest a diet in which marine protein played a prominent role in the Maya population at Xcambó, but it also included terrestrial resources (Schoeninger and DeNiro 1984:636; Schoeninger & Moore 1992:Fig. 2). This finding is particularly evident in the $\delta^{15}\text{N}$ results, with an overall mean of 11.35‰, which more directly reflect protein intake than $\delta^{13}\text{C}_{\text{CO}}$, of which an estimated 65% is routed from dietary protein (Ambrose et al. 2003:219). For comparative purposes, a mean $\delta^{15}\text{N}$ of 11.4‰ was found at two sites on Ambergris Caye (Parker 2011:21-23,39-41), off the coast of northern Belize, where marine foods were likely important contributors to the diet, whereas the mean at Seibal, an inland site, was 9.5‰ (Gerry & Krueger 1997:203). At the same time, the values on the lower end of the $\delta^{15}\text{N}$ range, near 10‰, as seen in Figure 8, are consistent with consumption of terrestrial fauna.

As the diet at Xcambó does not appear to have been protein-deficient, but rather has an apatite-collagen spacing that is consistent with an omnivorous diet, it can be inferred that the $\delta^{13}\text{C}_{\text{CO}}$ results reflect primarily the protein portion of the diet (Ambrose & Norr 1993; Krueger & Sullivan 1984:216-217). Therefore, given that the $\delta^{13}\text{C}$ signatures of marine fauna tend to be

more enriched than terrestrial fauna, although with some overlap (Schoeninger & DeNiro 1984:635), and considering the location of the site, it seems logical to infer that the ^{13}C enrichment in bone collagen could be attributed, at least in part, to consumption of marine resources. Comparing the overall mean $\delta^{13}\text{C}_{\text{CO}}$ at Xcambó of $-8.44\text{‰} \pm 0.80$ to the means obtained by Gerry (1997) for the Petén, Belize and Copán regions of -9.5‰ , -11.2‰ and -10.2‰ , respectively, seems to support this inference. Therefore, considering the $\delta^{15}\text{N}$ results, it seems logical to deduce that the $\delta^{13}\text{C}_{\text{CO}}$ values reflect consumption of marine protein and maize, with maize making less of a contribution than is the case for apatite values. The apatite $\delta^{13}\text{C}$ values display a strong C4 signature. Considering the multiple lines of evidence for the importance of maize in the Maya diet, and findings of *manos* and *metates* at the site (Sierra Sosa 2004:130, 137, 140, 147), it seems reasonable to conclude that the apatite values, particularly, indicate significant maize consumption. The apatite results for the one Preclassic individual, although precluding further inferences for this period, are likewise consistent with reliance on C4 food sources. Nevertheless, using the equation from Ambrose and colleagues (2003:221, footnote 4) revealed that C3 plants comprised approximately 15% to 45% of the diet of the general population at Xcambó.

The evidence from both collagen and apatite indicate that dietary patterns did not change significantly through time. Combined with the stature evidence from Xcambó (Cetina Bastida & Sierra Sosa 2005:672-674; Sierra Sosa et al. 2014:227), the results suggest a well-nourished population from Early to Late Classic times that benefitted from a more diverse diet as compared to inland populations.

7.2 Social rank

In terms of differences by social status as inferred from associated architecture, the middle-ranking group emerges as distinct from rank 3 in terms of $\delta^{15}\text{N}$ values, and the difference between the middle ranking groups and rank 1 approaches significance. However, there were no statistically significant differences among the three groups in $\delta^{13}\text{C}$ values or in $\Delta^{13}\text{C}_{\text{CA-CO}}$. The Kruskal-Wallis results revealed group 2 to have the lowest mean rank, which may indicate less protein consumption, although if they were obtaining a greater proportion of their protein from legumes, that would likewise lower their $\delta^{15}\text{N}$ values (DeNiro & Epstein 1981:345-346; White et al. 2001:375). However, if the rank 2 group were consuming less meat, one would also expect a significant difference in $\Delta^{13}\text{C}_{\text{CA-CO}}$, showing increased spacing, which would reflect a more herbivorous diet (Ambrose 1993:105). The fact that $\Delta^{13}\text{C}_{\text{CA-CO}}$ did not vary significantly among groups suggests, rather, that the lower mean $\delta^{15}\text{N}$ of the rank 2 group is a result of a difference in the type of protein they consumed as opposed to the overall quantity of meat in their diet. At the same time, it is also worth noting that the range of $\delta^{15}\text{N}$ values of the rank 2 group was equally broad as that of group 3, the highest ranking group. Given that the mean $\delta^{13}\text{C}_{\text{CO}}$ and $\delta^{13}\text{C}_{\text{CA}}$ values of the rank 2 and rank 3 groups are nearly equal, the results suggest that these two groups consumed proportionately similar quantities of maize.

Thus, the data point to a difference in protein consumption, consistent with evidence from various, although not all, Maya sites (Cucina & Tiesler 2003; Emery 2003; Sharpe and Emery 2015; White et al. 2001; Wright 2006). Nevertheless, the lack of a significant difference in $\Delta^{13}\text{C}_{\text{CA-CO}}$ is consistent with Gerry's (1997:62) suggestion that differences in diet among social ranks were "probably qualitative rather than quantitative" and at the same time highlight the need to assess each site on an individual basis.

In terms of outlying values, it is worth bearing in mind that, for $\delta^{13}\text{C}_{\text{CO}}$ values by rank, the low outlier for the Rank 1 group is an individual who was determined to be foreign based on Sr isotope results (Sierra Sosa et al. n.d.). Therefore, this low value may be reflecting a difference in local or ethnic food customs rather than social rank. The same may be true of the high Rank 1 outlier for $\delta^{15}\text{N}$ values, burial NE-4/45, who researchers have determined to be from a location elsewhere in northern Yucatán (Sierra Sosa et al. n.d.). The $\delta^{15}\text{N}$ value of this individual was also unusually high for his patio group (See Figure 15).

While mean $\delta^{13}\text{C}$ values of collagen and apatite seem to display a trend towards decreasing consumption of C4 resources with increasing patio group rank, these differences do not reach statistical significance. Comparing mean $\delta^{15}\text{N}$ values by patio group rank suggests a potential trend towards more enriched values with increasing rank, possibly indicating greater meat consumption, but does not reach statistical significance. Thus, considering both the carbon and nitrogen stable isotope results, it appears that the rank of one's patio group affected one's diet, but the effect was not highly pronounced.

In terms of the difference in $\delta^{15}\text{N}$ results between those interred in simple versus cist burials, the higher mean $\delta^{15}\text{N}$ of the group in simple burials, which would be consistent with greater consumption of marine protein (Schoeninger & DeNiro 1984), cannot easily be ascribed to social status differences, as higher rank should theoretically lead to access to more varied resources (Cucina & Tiesler 2003:6; LeCount 2001:936; Schoeninger 1979:304-305). Therefore, the possibility that the diet of the two groups differed due to horizontal social differences, such as ethnic or familial preferences merits consideration. Particularly given the evidence for migrants at Xcambó (Cucina, Tiesler, et al. 2011; Sierra Sosa et al. 2014:228-229, 231-234) the

potential role of ethnicity in contributing to dietary variation at the site warrants further exploration, examining both provenience and dietary isotope data.

With respect to quality and quantity of burial good offerings, given that, out of the five burial good categories, the only statistically significant associations are between $\delta^{13}\text{C}_{\text{CA}}$ values and animal bone quality and quantity, the results do not seem to suggest a very strong link between isotope signatures and status as assessed from burial offerings. Given that results of dietary studies in the Maya region show substantial overlap in carbon and nitrogen stable isotope signatures (Gerry 1997:57-59) by social status as well as variation in how status was, or was not, expressed in specific attributes of diet, particularly maize and protein consumption (Parker 2011:49-54; White 1997:175-176; Wright 2006:142-155), it would appear that architecture has given more consistent results as a reflection of social rank, with various studies (Hutson et al. 2006; Kurjack 1974; Palka 1997) demonstrating a congruence between architectural evidence and other indicators of wealth and prestige.

7.3 Household differences in diet

The data from the present study suggest that there was variation in diet among patio groups, which are believed to have been inhabited by extended families (Rice 1988:233; Willey 1980:257). The residents of Plaza 1 appear to have consumed less maize than members of the other patio groups from which five or more individuals were sampled, as indicated by their relatively depleted $\delta^{13}\text{C}_{\text{CA}}$ and $\delta^{13}\text{C}_{\text{CO}}$ values. While this seems contrary to the images of feasts at which tamales were a prominent food (Miller & Martin 2004:118; Taube 1989), the Plaza 1 group does have the broadest range of apatite $\delta^{13}\text{C}$ and, when outliers are excluded, of $\delta^{15}\text{N}$ values as well, suggesting greater dietary variability, as previously mentioned. At the same time,

of the four patio groups, Group V has the highest mean $\delta^{15}\text{N}$ value of 11.96‰, which may indicate greater seafood consumption (Schoeninger et al. 1983:1382). Given that Patio Group V and Plaza 1 are both of equal rank, the evidence suggests that the difference in protein source is horizontal in nature, possibly a difference in household or ethnic preference. Unfortunately, the geographic origins of the residents of Group V cannot be determined with certainty from the data available to date, as only one of these individuals been analyzed for Sr, but the results for that individual indicated a local origin (Sierra Sosa et al. n.d.). Head shaping data is available for the latter individual and one other member of this patio group, both of whom exhibit the local variant (Tiesler 2016; Vera Tiesler, 2017, personal communication). Thus, the evidence seems to suggest that the high $\delta^{15}\text{N}$ of this patio group may be the result of longtime residents of the site utilizing local resources, although further data on provenience would be required to confirm this inference.

Patio group XVI has two outliers, one of these being burial No. NE-4/45, as previously discussed. The other, burial No. NO-1/54, has unusually low $\delta^{13}\text{C}_{\text{CO}}$ and $\delta^{13}\text{C}_{\text{CA}}$ for his patio group. Although Sr and cranial deformation data is not available for this individual, he shows the IK pattern of dental modification (Tiesler 2016), which was the more common form of dental filing found among Xcambó's inhabitants (Sierra 2004:179-180). Therefore, it seems logical to infer that this difference in diet is not due to differences in geographic origins and local customs.

While it is difficult to draw conclusions regarding differences among patio groups from the small samples sizes, the ranges of both the $\delta^{15}\text{N}$ and apatite $\delta^{13}\text{C}$ values displayed by the inhabitants of Plaza 1 suggest a greater dietary breadth, which may be the result of Plaza 1 being the focus of political and religious activity (Sierra Sosa et al. 2014:223). At the same time, considering that three of the six individuals sampled from Plaza 1 were migrants to Xcambó, one

from the northern lowlands and two from locations further south in the Maya region (Sierra Sosa et al. 2014; Sierra Sosa et al. n.d.), this variability may also be the result of cultural diversity within this patio group. This is further reinforced by the fact that this is the only one of the four patio groups where two styles of dental decoration are seen (Tiesler 2016).

7.4 Comparisons by sex

The difference in collagen $\delta^{13}\text{C}$ values between males and females is difficult to interpret in light of the lack of any statistically significant differences in $\delta^{15}\text{N}$ values, given that collagen reflects primarily one's protein sources (Ambrose & Norr 1993; Lee-Thorp, et al. 1989:588-589). Non-reef marine foods are enriched in both $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values (Schoeninger & DeNiro 1984). Therefore, if men were consuming more marine resources, one would also expect that enrichment to be evident in nitrogen stable isotopes. However, although males showed a higher mean $\delta^{15}\text{N}$, the mean ranks were not significantly different as compared to females. On the other hand, if males were consuming more maize, one would expect to find evidence in apatite $\delta^{13}\text{C}$ values, which reflects the isotopic signature of one's entire diet (Ambrose & Norr 1993:2), yet the differences are only slight. A potential explanation for this difference in collagen $\delta^{13}\text{C}$ values, with no corresponding difference in $\delta^{15}\text{N}$, is suggested in an article by Somerville and colleagues (2015), who found a similar pattern in Tiwanaku colonies in Moquegua, Perú. Based upon studies such as those of Hamad and Fields (1979:456,458-459), who found that fermentation increases lysine bioavailability and % Relative Nutritive Value (RNV) of maize, and of Umoh and Fields (1981:905), which demonstrated that fermented cornmeal is enriched in both lysine and tryptophan, they suggest that more enriched $\delta^{13}\text{C}$ values among males can be attributed to consumption of a maize-based beer known as *chicha* by males at feasts and other public events

(Somerville et al. 2015:409, 412, 417-419). Furthermore, it has been suggested that ceramics found at the Preclassic sites of Cuello, Belize, and Cival, in the Petén may have been used for *chicha* (Estrada-Belli 2006:58,61; Kosakowsky 2003:65); therefore, a potential association between maize-based drinks and isotopically heavier $\delta^{13}\text{C}_{\text{CO}}$ values among males seems worth exploring further.

As for potential causes of the higher caries prevalence among females revealed in Cucina, Perera and colleagues' (2011) study, given that neither the $\delta^{13}\text{C}_{\text{CO}}$ nor the $\delta^{13}\text{C}_{\text{CA}}$ results suggest that females were consuming greater quantities of maize, the hypothesis that the results may be linked to gendered division of labor may apply at Xcambó. In this scenario, women, who would have been performing household tasks, would have had more ready access to food throughout the day, increasing their exposure to cariogenic food (Cucina & Tiesler 2003:7; Larsen et al. 1991:197-198; Lukacs 2008:901, 904-905). Another potential contributor may be physiological variables, such as effects of estrogen, a lower saliva flow rate, and physiological changes that occur during pregnancy, such as immune suppression and changes in saliva composition (Cucina, Perera, et al. 2011:563, 565; Lukacs 2008: 901, 905). Increasing the Early Classic sample size such that statistical tests could be performed comparing the sexes by period may further assist in ruling out differences in maize consumption.

At the same time, it should be noted that caries rates increased from the Early to Late Classic period, by approximately 6 to 7% for both sexes (Cucina, Perera, et al. 2011:562-563, 565) but the isotope data to date does not demonstrate a significant temporal change in maize consumption. However, it is still possible that, as Cucina, Perera and colleagues (2011:565) suggest, Xcambó's success in trade brought greater access to cariogenic foods containing honey and/or cacao. Both honey and cacao have $\delta^{13}\text{C}$ signatures in the C3 range (Elflein & Raezke

2008:574; Padovan et al. 2003:633, 636; Wright 2006:94-95). Therefore, carbon stable isotopes cannot differentiate between consumption of these foods versus other C3 sources. Nevertheless, the caries evidence suggests that the new food source was available to both sexes (Cucina, Perera, et al. 2011:565). Thus, the data to date are consistent with a scenario in which males did play a more prominent role in political life, but in terms of overall access to dietary resources, such as maize and animal protein, and new goods acquired by Xcambó through its extensive trade network, gender relations were more balanced. This is lent support by the fact that, although the difference between the sexes in $\delta^{13}\text{C}_{\text{CO}}$ values was statistically significant, the difference between the means is small at 0.5‰.

7.5 **Diachronic comparisons**

The lack of statistically significant differences between the Early and Late Classic periods in $\delta^{13}\text{C}_{\text{CO}}$, $\delta^{15}\text{N}$ and $\delta^{13}\text{C}_{\text{CA}}$ values indicates that the economic changes experienced by the site (Maggiano et al. 2008; Sierra Sosa 2015:4; Wanner et al. 2007:262-264) did not result in major changes in protein consumption or in whole diet and the apatite results, specifically, provide strong evidence that maize reliance did not change from the Early to the Late Classic. It would thus seem that, while Xcambó's role became increasingly administrative (Cucina, Perera, et al. 2011:561; Maggiano et al. 2008; Wanner et al. 2007), its ongoing active participation in trade ensured its inhabitants access to a broad range of dietary resources, including adequate amounts of protein, as evidenced by $\Delta^{13}\text{C}_{\text{CA-CO}}$ values of +3.94‰ and +3.41‰ for the Early and Late Classic, respectively. These values fall within the typical range expected for carnivores and thus seem to reflect a prominent role for marine foods in the diet, which lead to enriched $\delta^{13}\text{C}_{\text{CO}}$ values (Ambrose 1993:105; Lee-Thorp et al. 1989:593). In the following chapter, I discuss how

the isotope results by time period, as well as tests for social patterning, compare to other sites in the Maya region.

8. CONCLUSION

8.1 Diet and social organization at Xcambó

Sierra Sosa (2004:99, 180; 2015:9) has inferred, based on burial offerings and architecture, that the highest and lowest status tiers were not present at Xcambó. For comparison, at the nearby site of Dzibilchaltun, Kurjack (1974) found a greater extent of architectural variability. He identified "261 platform or terrace complexes" at the site which varied in size from those comprised of only two structures to one comprised of 16 (Kurjack 1974:74-75), whereas at Xcambó, the largest patio group, Plaza 1, consisted of 10 structures (Vera Tiesler, 2013, information from field and lab notes), lending support to Sierra Sosa's (2004:99, 180; 2015:9) argument that there was less pronounced status differentiation at Xcambó. Considering this evidence, the fact that a statistically significant difference by status was found seems to point towards the presence of more subtle rank distinctions which led to differences in terms of protein resources, not maize, with the middle-ranking group emerging as distinct in consuming less protein and/or marine foods.

Alternatively, it is possible that the distinction in protein consumption is linked to horizontal differences, such as differences in familial or ethnic preferences, or occupation. Although the differences between local and nonlocal individuals were not statistically significant, this may be an effect of the small sample sizes for which provenience data was available, and when $\delta^{15}\text{N}$ and $\delta^{13}\text{C}_{\text{CO}}$ are plotted together, the findings seem to suggest a potential difference in the diets of individuals from other areas of northern Yucatán. Additional Sr data would assist in clarifying whether this is, in fact, the case.

Thus, the possibility that the social status of mid-ranking groups led to differences in their diet seems worth exploring further at other sites, keeping in mind that the lowest and highest ranks at Xcambó may not correspond directly to those at larger sites with a broader range of status variation. Also, given the variability throughout the Maya region in terms of which food categories were or were not linked to social status, which I will discuss more fully in section 8.2, it is possible that rank differences may have manifested differently by site, depending on local circumstances and ecological resources.

Furthermore, although the sample sizes from individual patio groups were small and there were no statistically significant differences among patio groups from which 5 or more individuals were analyzed, the differences in descriptive statistics, such as the lower mean $\delta^{13}\text{C}_{\text{CA}}$ and $\delta^{13}\text{C}_{\text{CO}}$ values of Plaza 1 and the higher mean $\delta^{15}\text{N}$ of Patio Group V suggest that interhousehold variation in diet warrants further investigation with larger sample sizes. In addition, the greater social diversity of Plaza 1, suggests that horizontal differences, such as differences in local customs, may have played a role and would therefore be a fruitful line of further investigation.

8.2 Regional context

When the overall mean collagen results of Xcambó are compared to those of other Maya sites (see Figure 9), the more enriched in $\delta^{13}\text{C}_{\text{co}}$ in conjunction with the elevated $\delta^{15}\text{N}$ at Xcambó are consistent with a diet relatively high in marine foods (Ambrose 1993:86, 94-95; Schoeninger & DeNiro 1984; Sierra Sosa et al. 2014:230), which is logical, given the site's location. When overall mean carbon and nitrogen stable isotope signatures of Xcambó are compared to the results obtained by Gerry (1997:60) for the Petén, Copan, and Belize regions, the mean $\delta^{13}\text{C}$

values for both collagen and apatite at Xcambó are more enriched relative to all three regions, as is the mean $\delta^{15}\text{N}$. Taken together, this is consistent with greater consumption of marine foods (Schoeninger et al. 1983; Schoeninger & DeNiro 1984), and is in line with Scherer and colleagues' (2007:93-95) observation that there is a lower prevalence of porotic hyperostosis in Yucatecan and Belizean sites compared to Copán, Piedras Negras, and sites in the Pasión region, although they caution that, in their comparison, they include sites which are not Classic period from the Yucatán and Belize. It is also notable that the two sites which fall nearest to Xcambó in their $\delta^{15}\text{N}$ values are the two Belizean sites, Altun Ha, near the Caribbean coast (White et al. 2001:375), and Chau Hiix, from which the Caribbean can be reached by river (Metcalf et al. 2009:19). At the same time, there are differences in social patterning at the three sites in that at Chau Hiix, in contrast to Xcambó, there were no sex-based differences in diet, and prestige, at least during the Early Classic, was associated with a diet enriched in reef resources (Metcalf et al. 2009:28, 31), whereas at Altun Ha males consumed more marine foods than females, and in the Early Classic status was associated with C4 food consumption, although in the Late Classic this may have shifted to an association with reef resource consumption (White et al. 2001:382-383, 387).

The higher mean $\delta^{13}\text{C}_{\text{CO}}$ and $\delta^{13}\text{C}_{\text{CA}}$ values of the lowest-ranking group compared to the two higher-ranking at Xcambó, reflecting greater C4 food consumption by the former, are consistent with the results of Cucina and Tiesler's (2003:5-6) study of three Petén sites which found higher caries rates among lower-ranking groups, and Storey's (1999:175-177) findings at Copán, which revealed higher rates of anemia among both males and females of the lowest-ranking group. At the same time, it is worth noting that Maya stable isotope studies reveal variability in terms of association of specific food categories with social status, with the evidence

at some sites suggesting an association between C4 foods and social status (Scherer et al 2007:92; White 1997:176; White et al. 2001:382-383), others suggesting a closer link to protein consumption (Wright 2006:144, 152), and no clear patterning by status at Seibal (Wright 2006:148, 152).

In terms of differences by sex, the pattern found at Xcambó, wherein males have significantly enriched $\delta^{13}\text{C}_{\text{CO}}$ values, has also been found at the Maya sites of Altun Ha and Pacbitun, in Belize (White et al. 1993:359-361; White et al. 2001:387), indicating that males were consuming more C4 and/or marine protein, and at Dos Pilas in the Pasión region (Wright 2006:152), suggesting greater consumption of C4-enriched protein sources by males. At Copán, Honduras the difference in $\delta^{13}\text{C}_{\text{CO}}$ values was significant when male outliers were excluded and males also had significantly higher $\delta^{15}\text{N}$ values (Whittington & Reed 1997:160-161, 163). Furthermore, males had significantly lower caries rates (Whittington 1999:158), consistent with a diet richer in protein versus cariogenic foods (Cucina, Perera, et al. 2011:560). In the Pacbitun example, it was noted that more male burials were found in the site core, whereas more female burials were located in the periphery (White et al. 1993:361). The authors therefore suggested that the dietary differences may be linked to differences in social status, rather than solely an effect of gendered division of labor (White et al. 1993:361). Furthermore, their finding is in line with males playing a more prominent role in public events, which may have given them access to more varied resources (Cucina & Tiesler 2003:6). Nevertheless, this pattern in isotope values is not found at all sites; for example, at Altar de Sacrificios, the evidence for dietary differences by sex was more equivocal (Wright 1997:192; Wright 1996:142, 144, 148), and in the study conducted by Gerry (1997:57), although male $\delta^{15}\text{N}$ values were significantly higher, the actual difference in means was less than 1‰.

The consistency in isotope signatures through time is likewise seen at the sites of Dos Pilas and Copán (Whittington & Reed 1997:160-161; Wright 2006:137, 139). However, at Altar de Sacrificios, a possible trend towards increasing $\delta^{13}\text{C}_{\text{CO}}$ values from the Preclassic through the Late Classic was noted but was only significant for the change between the Preclassic and subsequent periods (Wright 2006:131-132). At Piedras Negras, individuals dated to 725-850 A.D. had significantly more enriched $\delta^{15}\text{N}$ values than those of the preceding period (Scherer et al. 2007:87, 92). At Lamanai, significant changes in $\delta^{13}\text{C}_{\text{CO}}$ and $\delta^{13}\text{C}_{\text{CA}}$ did not occur until the Terminal Classic to Postclassic transition, but there was a significant decrease in $\delta^{15}\text{N}$ values between the Early and Late Classic periods (Coyston et al 1999:231-232). In comparing the pooled results of the seven sites of his study between the Early and Late Classic periods, Gerry (1997:43, 56-57) found a significant decrease in $\delta^{13}\text{C}_{\text{CA}}$, although the difference in means was only 0.8‰. Thus, there is some variability in temporal trends in terms of dietary stability and the nature of dietary change, thus highlighting the need to understand each site on an individual basis.

In conjunction, the prominence of marine foods at Xcambó and the variability evident in the Maya region in terms of diachronic trends and effects of social status on diet seem to support Gerry's (1997:61-63) point regarding the importance of geography as a determinant of diet. The similarity of the Xcambó mean $\delta^{15}\text{N}$ values to those of Altun Ha versus sites further inland is consistent with use of locally available marine resources and with Götz's (2008:154, 164, 166-167) findings from five northern lowland sites, including Xcambó, indicating that local ecology was the major determinant of differences between coastal versus inland sites in consumption of faunal resources. Although the mean $\delta^{13}\text{C}$ at Xcambó falls relatively close to those of certain inland sites, particularly Dos Pilas, Altar de Sacrificios, and Piedras Negras, where one would

expect that more maize was being consumed, that may be an effect of the ^{13}C enrichment characteristic of marine foods (Schoeninger & DeNiro 1984).

Compared to larger Maya sites, differences in nutritional status by social rank appear less marked at Xcambó. Although a statistically significant difference in $\delta^{15}\text{N}$ values was found at Xcambó when social rank groups were compared, the $\Delta^{13}\text{C}_{\text{CA-CO}}$ values obtained in the present study as well as the results of previous bioarchaeological studies at the site, including findings that the prevalence of porotic hyperostosis was relatively low and that there were no significant differences by site sector and that stature was relatively high (Cetina Bastida and Sierra Sosa 2005:669-670, 672-673), without obvious disparity by site sector (Cetina Bastida 2006:47-48, Tables 9 & 10), indicate that Xcambó's population was well nourished and that any social status differences did not result in pronounced differentials in access to nutritional resources. This contrasts, for example, to the situation at Tikal, one of the largest Classic period Maya sites, where higher ranking individuals attained higher stature (Haviland 1967:316, 319-321), or at Copán, where the lowest ranking group displayed evidence for higher rates of anemia and where the highest ranking males were taller than the lowest ranking, with no difference among females (Storey 1998:140-141, 144-145). Thus, at the two major centers, high social rank was clearly associated with health benefits in protecting people from anemia and metabolic stress that may hinder growth.

8.3 Understanding dietary patterns at Xcambó

The reasons for the differences described above when Xcambó is compared to larger Maya sites may stem from Xcambó's role in trade networks, both during the Early Classic, when the site's economy was more focused on salt production, and in the Late Classic, when it took on

a more administrative function (Cucina, Perera, et al. 2011:561; Maggiano et al. 2008:470; Wanner et al. 2007:264). Xcambó's prosperity would have provided its inhabitants a reliable and varied supply of food resources, allowing them to complement locally available marine foods with resources from nearby inland sites (Götz & Sierra Sosa 2011:134-135). Given the small size of Xcambó, it is possible that all the inhabitants may have benefitted from the site's economic specialization. Furthermore, Xcambó's coastal location provided its residents with a readily available supply of protein sources. Although, as Sierra Sosa (2015:4) points out, the population density at Xcambó was high, this does not appear to have strained food resources, as evidenced by continuity in stable isotope signatures, including $\Delta^{13}\text{C}_{\text{CA-CO}}$ values reflecting a diet containing protein-rich marine foods. This may be due, as Sierra Sosa (2004:177) suggests, to emigration by young adults, which would account for the low percentage of this age group (Cetina Bastida 2003:90; Sierra Sosa 2004:105).

Although the evidence from the present study suggests that there was a difference in diet linked to social status, the difference appears to have been in the type of protein consumed by the rank 2 group and not the overall quantity. This may likewise have resulted from Xcambó's role in trade promoting widespread access to a varied range of foods, such that, as Gerry (2007:62) suggests, differences were more symbolic in nature. Thus, it is possible that status differences in diet at Xcambó are not highly marked due to the site's economically specialized role having a leveling effect in terms of access to resources, and because neither the sector of Maya society engaged primarily in subsistence activities, such as fishermen and agriculturalists, nor high-level elites were residing at the site (Sierra Sosa 2004: 99, 180; 2015:9). Furthermore, given that the full range of status categories is not present at the site, the fact that a statistically significant

difference along status lines was found suggests that there were internal subdivisions within Classic Maya social classes.

The evidence also seems to suggest that there were dietary variation linked to horizontal differences, which may have been household preferences, ethnicity, or occupation. However, the data available to date does not allow us to determine the precise nature of these differences but suggests an avenue for further investigation, as additional data on geographic origins and cranial modification may shed light on these issues.

The difference in isotope signatures between the sexes is consistent with greater consumption by males of fermented maize-based drinks, which may have resulted from their greater involvement in political affairs and, by extension, in ritual events. If further research proves this hypothesis to be correct, it may be that the cariogenic food(s) which caused the rise in caries rates in both sexes (Cucina, Perera, et al. 2011) was not specifically reserved for ceremonial contexts but was used more broadly or that it may have been used in food or drink prepared for family feasts as opposed to more exclusive political events.

Thus, the multiple lines of evidence for Xcambó enhance our understanding of social organization and dietary patterns through time at a non-urban and economically specialized Maya site, providing a point of departure for comparison and formulating hypotheses to be tested at other such sites in the Maya region. They also highlight the importance of taking into account that small and/or specialized Maya sites may not represent the full cross section of broader Maya society. Furthermore, they demonstrate that by combining both contextual and individual-level data, we can gain insight into horizontal social differences, as by household and ethnicity, as well as hierarchical differences. Moreover, they increase our understanding of diet and social organization at coastal compared to inland Maya sites, which would be further enhanced by

increasing the sample size from Xcambó as well as other coastal sites. It is to directions for future research such as this that I turn to in the following section.

8.4 Two-class versus complex models and directions for future research

The contextual evidence from Xcambó suggesting the absence of the highest and lowest status tiers (Sierra Sosa 2004:99, 180; 2015:9) in conjunction with the dietary evidence, seems to support a complex model with internal variation within classes, although the dietary findings are preliminary pending a broadening of the sample size. At the same time, this study highlights the utility of examining the effects of both hierarchical and heterarchical social relationships on diet, while also bearing in mind the interaction between such factors and the decisions people make regarding use of ecological resources.

For future research, increasing the sample size of both the botanical and faunal reference foodweb would assist in determining the diet of Xcambó's inhabitants with greater specificity. If the local C3 and C4 end-member values, that is, the $\delta^{13}\text{C}$ values of the foods that would represent the endpoints of the C4-C3 spectrum (Ambrose 1993:82; Tykot et al. 1996:359), as well as the $\delta^{15}\text{N}$ end-member values for marine versus terrestrial resources, can be determined with greater confidence, then the percentages of the diet represented by C4 and C3 foods, and marine versus terrestrial, could be calculated using local values, as opposed to global averages, for a more accurate representation of the local diet (Ambrose 1993:85; Pestle 2010b:128). Furthermore, dietary isotope data from a broader faunal reference sample from the northern Yucatán could be compared to results from elsewhere in the Maya region to determine whether the differences

noted in values obtained in the present study compared to results in the literature are due to ecological variation.

Furthermore, increasing the sample size from the patio groups from which five or more individuals have already been sampled would help shed light as to whether or not there were dietary differences among households. However, it would remain to be determined whether any dietary differences were due to differential access to resources, or to horizontal social differences. Therefore, further information on geographic origins may provide insight into the causes of potential dietary differences. To date, 39 Xcambó individuals (Sierra Sosa et al. 2014:232) have been analyzed for oxygen stable isotopes, of which 4 are individuals who were also analyzed in the present dietary study, and 131 have been analyzed for strontium (Sierra Sosa et al. 2014:231-233). Because analysis of both isotopes in conjunction may allow place of origin to be determined with greater specificity (Sierra Sosa 2014:231), having both oxygen and strontium data on additional individuals from the present study would allow us to further assess whether individuals with outlying $\delta^{15}\text{N}$ and $\delta^{13}\text{C}_{\text{CO}}$ signatures (see Figures 10-11, 13-17, 19, Appendix D) were local or nonlocal. Given that the turnover rate for bone collagen is approximately 10 to 30 years (Ambrose 1993:83), knowledge of their place of origin would affect interpretations of their isotopic signatures; for example, enriched $\delta^{13}\text{C}_{\text{CO}}$ values in a recent migrant from an inland location would more likely reflect greater maize consumption as opposed to marine foods (Ambrose 1993:86, 94; Schoeninger & DeNiro 1984:636). Furthermore, having provenience data on more of the individuals sampled in this study would assist in characterizing potential differences in diets of nonlocal versus local individuals and may allow for statistical comparison among the group of individuals from Xcambó, those from other locations in the northern Yucatán, and foreign individuals. This information may also provide insight into the

causes of dietary variation among households. For example, if specific patio groups were found to be comprised largely of immigrants, that would suggest that variations in isotopic signatures may be the result of differences in local or ethnic food customs, pointing to more horizontal as opposed to hierarchical causes. In addition, the findings from dietary isotopes and strontium and/or oxygen, particularly when examined in conjunction with other lines of evidence such as cranial modification and dental decoration data, may enhance our understanding as to how the Classic Maya may have used food to express group identity.

Moreover, stable isotope data from additional Classic period coastal sites would provide further insight into the extent to which diet, and potential social patterning in diet, at coastal sites did or did not differ from that at inland sites. Larger sample sizes may allow us to conduct parametric statistics, in line with the methods employed by Gerry (2007) to discern which variable, whether geographic location or any of the social variables identified in this study was the major determinant of dietary differences, potentially lending further support to the results of Götz's (2008) study. The results would thus enhance our understanding of the causes of dietary variability within the Maya region.

APPENDICES

APPENDIX A, TABLE XXVII: RESULTS OF HUMAN OSTEOLOGICAL SAMPLES

Sample No.	Burial No.	# DOC	Sex	Age cat. ^a	Period	Rank ^b	Grave type	Patio group	Atomic CN ratio	Collagen % yield	wt% C	wt% N	$\delta^{13}\text{C}$ collagen	$\delta^{15}\text{N}$	Apatite wt. % yield	$\delta^{13}\text{C}$ apatite	$\Delta^{13}\text{C}_{\text{CA-CO}}$
H01	Patio XIII/244	94255	M?	ADOL	Late		S	XIII		2.42					55.64	-3.09	4.24
H02	NO-7/2	94018	F	ADU	Early	1	S	XVII	3.18	5.02	28.37	10.41	-7.84	12.06	55.10	-4.12	3.72
H03	NE-37/185	94486	M	ADU	Late	3	S	XV		1.48					57.31	-4.37	
H04	NE-37/257	94513	M	ADU	Late	3	S	XV	3.18	10.14	39.28	14.42	-9.02	11.79	53.95	-5.46	3.56
H05	NO-1/54	94442	M	ADU	Late	2	S	XVI	3.24	6.40	30.83	11.09	-11.01	10.42	45.33	-6.78	4.23
H06	NE-17/3	94003	F?	ADOL	Early	3	C	VIII	3.16	4.69	28.93	10.69	-9.26	10.79	54.28	-4.60	4.66
H07	NE-4/41	94048	M	ADU	Late	1	S	XVI	3.18	7.94	37.09	13.61	-7.45	11.16	41.28	-3.89	3.56
H08	NE-4/45	94049	M	ADU	Late	1	S	XVI	3.32	5.42	25.6	9.00	-8.05	13.57	47.83	-4.31	3.74
H09	NO-5/74	94179		ADU	Late	3	S	XVII	3.19	9.72	38.73	14.15	-9.05	11.8	52.54	-5.42	3.63
H10	NO-8/236A	94250	F?	ADU	Late	1	S	XVII	3.17	6.31	36.59	13.46	-7.81	11.5	46.91	-4.10	3.71
H11	NO-1/48	94282	F	ADU	Early	2	S	XVI	3.16	9.27	36.23	13.38	-8.81	10.62	52.55	-4.25	4.56
H12	Patio V/128A	94204	M?	ADU	PreCl		C	V		1.71					64.49	-3.78	
H13	NE-53/2	94436	M	ADU	Late	2	C	XXIII	3.22	2.50	19.68	7.14	-7.81	10.65	53.66	-4.72	3.09
H14	NE-53/6	94433	F	ADU	Late	2	C	XXIII		1.65					60.93	-4.82	
H15	SE-4/1	94235	F	ADU	Late	1	C	XXIII	3.15	4.20	29.54	10.94	-8.24	10.29	64.77	-3.71	4.53
H16	SE-4/2	94236	F	ADU	Late	1	C	XXIII	3.3	2.17	16.41	5.81	-8.15	11.65	57.36	-3.33	4.82
H17	NO-9/66	94176	M	ADU	Late	1	S	V	3.19	3.58	27.14	9.92	-8.71	11.95	54.79	-7.00	1.71
H18	NE-29/180	94484	M	ADU	Early	1	S	XI-XII	3.51	2.26	15.33	5.09	-7.35	11.63	59.13	-3.71	3.64
H19	NE-7/130A	94208	F	ADU	Late	3	S	V	3.16	4.57	35.41	13.06	-8.06	12.04	42.08	-5.26	2.80
H20	NE-36/137	94458	M	ADU	Early	3	S	XIV	3.15	2.55	20.26	7.50	-8.69	12.06	52.25	-6.35	2.34
H21	NO-2/59	94166	M?	ADOL	Late	2	C	V	3.15	2.91	36.85	13.67	-8.21	11.58	47.96	-4.59	3.62
H22	NE-28/249	94342	M	ADU	Late	1	C	IX	3.17	4.63	31.53	11.61	-7.64	10.46	51.29	-6.76	0.88
H23	NE-7A/125 Patio N	94199	M	ADU	Early	3	S	V	3.17	3.92	24.28	8.94	-8.74	11.56	56.05	-4.10	4.64
H24	NE-27/279	94358	M	ADU	Late	3	S	IX	3.18	5.79	35.7	13.11	-6.92	11.9	44.47	-3.65	3.27
H25	NE-23/3	94055	M	ADU	Late	3	S	Plaza 1	3.2	9.06	34.97	12.73	-7.72	11.58	49.57	-3.68	4.04
H26	NE-22/3	94123	M	ADU	Late	1	S	Plaza 1	3.16	4.86	33.87	12.52	-8.78	11.77	51.70	-4.59	4.19
H27	NE-21A/6	94228	F?	ADU	Late	2	C	Plaza 1	3.3	3.37	24.32	8.61	-9.38	9.98	62.03	-7.22	2.16
H28	NE-7A/34	94046	M	ADU	Early	3	S	V	3.33	3.74	23.22	8.14	-9.21	12.66	51.79	-5.40	3.81

TABLE XXIII, APPENDIX A: RESULTS OF HUMAN OSTEOLOGICAL SAMPLES (continued)

Sample No.	Burial No.	# DOC	Sex	Age cat. ^a	Period	Rank ^b	Grave type	Patio group	Atomic CN ratio	Collagen % yield	wt% C	wt% N	$\delta^{13}\text{C}$ collagen	$\delta^{15}\text{N}$	Apatite wt. % yield	$\delta^{13}\text{C}$ apatite	$\Delta^{13}\text{C}_{\text{CA-CO}}$
H29	NE-22/1	94120	F	ADU	Late	1	S	Plaza 1	3.41	4.12	24.7	8.45	-9.53	11.93	50.64	-7.35	2.18
H30	NE-22C/14	94133	M	ADU	Late	1	C	Plaza 1	3.18	4.63	27.62	10.13	-8.47	11.45	58.06	-6.44	2.03
H31	NE-2/29	94097	M	ADU	Late		S	II	3.13	7.41	34.41	12.81	-7.96	11.9	53.01	-5.40	2.56
H32	NE-35/197	94248	F	ADU	Late	2	S	XI-XII	3.17	10.26	41.92	15.45	-8.69	10.82	47.71	-4.96	3.73
H33	NE-29/192	94308	F	ADU	Late	1	S	XI-XII	3.16	8.86	34.55	12.76	-8.23	10.9	46.62	-4.50	3.73
H34	NO-5/103	94192	F	ADU	Early	3	S	XVII	3.26	4.23	28.95	10.37	-9.61	11.06	53.28	-5.40	4.21
H35	NE-2/30	94098	F	ADU	Late	2	S	II	3.28	4.93	27.61	9.81	-8.49	12.1	56.65	-5.53	2.96
H36	NE-35/188	94488	M?	ADU	Late	2	S	XI-XII	3.23	3.52	23.86	8.61	-7.93	11.58	86.96	-4.16	3.77
H37	NE-14/13	94226	M	ADU	Late	2	S	VII	3.14	4.96	29.29	10.87	-7.45	10.57	51.96	-5.18	2.27
H38	NE-10/13	94028	M	ADU	Late	1	S	VII	3.25	10.23	37.59	13.49	-8.12	11.28	41.40	-3.12	5.00
H39	NE-29/259	94347	F	ADU	Late	1	S	XI-XII	3.16	5.43	32.15	11.87	-8.40	10.71	45.14	-5.00	3.40
H40	NE-14/4	94152	F	ADU	Late	2	S	VII	3.19	6.79	32.74	11.98	-9.07	10.15	62.32	-7.03	2.04
H41	NE-36/161	94224	M?	ADU	Late	3	S	XIV	3.16	4.94	30.41	11.24	-8.00	12.58	55.84	-7.08	0.92
H42	NE-32/210	94314	M	ADU	Late	1	S	X	3.17	4.87	30.44	11.19	-7.81	11.07	58.65	-2.84	4.97
H43	NE-34/146	94219	F	ADU	Late	2	C	X	3.23	10.26	36.70	13.27	-8.75	10.67	46.12	-3.88	4.87
H44	NE-36/160	94306	F	ADU	Late	3	S	XIV	3.19	6.80	35.13	12.85	-7.6	10.82	45.60	-5.21	2.39
H45	NE-21/16	94116	F	ADOL	Late	2	S	Plaza 1	3.18	2.91	29.59	10.85	-9.42	10.43	60.84	-3.68	5.74
H46	NO-1/53	94440	M?	ADU	Late	2		XVI	3.63	2.34	15.20	4.89	-7.87	10.49	59.18	-3.93	3.94
H47	NE-27/280	94359	F	ADU	Late	3	S	IX		1.82					66.96	-3.26	
H48	NE-2/1	94069	F?	ADOL	Early	3	S	II	3.52	2.12	15.76	5.23	-9.42	13.01	53.85	-5.56	3.86
H49	NE-17/2	94002	F	ADU	Late	3	C	VIII	3.22	4.33	30.05	10.90	-9.53	11.66	51.84	-5.12	4.41
H50	Patio XIII/244	94255	M?	ADOL	Late			XIII	3.17	3.66	27.74	10.20	-7.33	9.88	47.34	-4.01 ^c	

^a Age cat. = Age category; ADOL = adolescent; ADU = adult

^b Determined from the structure with which the individual was associated. For further details, see section 5.3.

^c Not used in statistical analyses due to possible contamination of apatite sample H50.

APPENDIX B, TABLE XXVIII: STATISTICS ON RANK AND C AND N STABLE ISOTOPE RESULTS FOR ALL PATIO GROUPS SAMPLED IN THE PRESENT STUDY

Patio Group	n ^a	Avg. floor area, 3 largest structures	Rank of patio group ^b	Mean $\delta^{13}\text{C}_{\text{CO}}$	Mean $\delta^{15}\text{N}$	Mean $\delta^{13}\text{C}_{\text{CA}}$
Plaza 1	6	528.3	4	-8.88	11.19	-5.49
II	3	236	3	-8.62	12.34	-5.50
V	6	365.7	4	-8.59	11.96	-5.02
VII	3	267	3	-8.21	10.67	-5.11
VIII	2	69.7	1	-9.40	11.23	-4.86
IX	3	75	1	-7.28	11.18	-4.56
X	2	124	2	-8.28	10.87	-3.36
XI-XII	5	122.7	2	-8.12	11.13	-4.47
XIII	1	25.3	1	-7.33	9.88	-3.09
XIV	3	166.7	2	-8.10	11.82	-6.21
XV	2	54.7	1	-9.02	11.79	-4.92
XVI	5	215	3	-8.64	11.25	-4.63
XVII	4	172	2	-8.58	11.61	-4.76
XXIII	4	110.3	2	-8.07	10.86	-4.15

^a n = number of individuals sampled per patio group.

^b Rank 1 = lowest; Rank 4 = highest.

APPENDIX C: BURIAL OFFERINGS

Burial good inventory for Xcambó individuals sampled in the present study:

Burial numbers with offerings¹

Patio XIII / 244

Offerings: 1 complete tripod pot, placed over the cranium.

NO-7 / 2

Offerings: 1 orange pot with basal rim
3 shells
shell fragments
fish vertebrae

NE-37 / 185

Offerings: 1 miniature tripod pot (with supports)
1 orange tripod plate (with supports)
1 animal bone
1 shell valve

NE-37 / 257

Offerings: None

NO-1 / 54

Offerings: 1 small pot
2 polychrome pots (one of them placed as though a lid over the small pot)

NE-17 / 3

Offerings: 1 composite silhouette pot (Sierra Sosa et al. 1996:154)

NE-4 / 41

Offerings: 1 tripod plate, placed over the cranium

NE-4 / 45

Offerings: plate rim fragments, one with partial bird profile.

NO-5 / 74

Offerings: 1 fragmented pot
1 animal bone

¹ The information on burial offerings was obtained from data provided by Vera Tiesler (2013), except where otherwise noted.

APPENDIX C (continued)

NO-8 / 236A

Offerings: 1 fragmented tripod pot, with decoration in the form of a jaguar head in the front
2 jade earspool fasteners

NO-1 / 48

Offerings: 1 pot
shell fragments
1 shell bead

Patio V / 128A

Offerings: None

NE-53 / 2

Offerings: 1 tripod pot, red-slipped, with supports

NE-53 / 6

Offerings¹:

6 tripod pots (Sierra Sosa 1998:162-163). [Of these 4 are orange/red, with supports, another is painted red and black, the sixth is unspecified (Information obtained from data provided by Vera Tiesler, 2013.)]
ceramic fragments, possible pot
2 shell beads
2 jade beads
1 poison bottle

SE-4 / 1

Offerings: 1 pot (Baca red)
1 small pot, fine grey, incised
1 poison bottle, with appliqué, painted
1 shell
fragments of worked shell
2 jade beads
remains of a turtle

SE-4 / 2

Offerings: 2 greenstone beads
1 pyrite appliqué
1 ceramic base

¹ Information on offerings for burial NE-53/6 from Sierra Sosa (1998:162-163), except where otherwise noted.

APPENDIX C (continued)

NO-9 / 66

Offerings: 1 pot, bichrome, incised

NE-29 / 180

Offerings: 1 fine orange vase
 1 fine grey pot, incised
 1 flint knife, biface
 3 shell beads
 1 animal bone pendant
 1 orange plate (with supports)
 1 jade bead
 2 jade earplugs

NE-7 / 130A

Offerings: None

NE-36 / 137

Offerings: 1 monochrome pot, slipped, with incising

NO-2 / 59

Offerings: 1 tripod plate, monochrome (orange)
 1 shell pectoral, with an image of a seated person

NE-28 / 249

Offerings¹: 1 pot, fine paste, with supports and red painting
 half of a fine grey pot
 1 poison bottle, fine grey
 1 jadeite bead
 1 fragment of obsidian knife

NE-7A / 125 Patio N

Offerings: 1 plate

NE-27 / 279

Offerings: 1 tripod pot
 fragments of a fine ceramic pot
 1 shell pendant
 1 mother-of-pearl pendant with 2 perforations
 1 flint fragment (function unknown)
 1 net weight

¹ Information on offerings found with burial NE-28/249 from Cetina Bastida (1999:n.p.).

APPENDIX C (continued)

NE-23 / 3

Offerings: 1 bird bone (Sierra Sosa 1997:113-114)

NE-22 / 3

Offerings¹: 1 ceramic pot, orange
 1 jade bead
 jade fragments, resembling those used in mosaics

NE-21A / 6

Offerings²: 1 bowl, painted
 1 vase, fine grey, incised

NE-7A / 34

Offerings: 1 ceramic vessel (*apaxtle*), red, over black paste

NE-22 / 1

Offerings: 1 plate
 1 pot
 2 poison bottles
 1 miniature pot
 1 effigy vessel
 1 obsidian arrowhead
 3 obsidian prismatic blades
 1 spindle, probably flint, flower-shaped
 button, probably pyrite
 1 shell object
 7 shell rings

NE-22C / 14

Offerings: 1 tripod pot, Baca red, with zoomorphic ornament
 1 fine paste vase with impressed designs
 1 tripod pot, Baca red
 1 tripod pot with supports, painted
 4 jade pieces comprising part of 2 earspools
 various pieces of shell that were likely part of a funerary mask
 1 poison bottle
 1 pot
 8 jade beads
 1 jade ring

¹Information on offerings found with burial NE-22/3 from Sierra Sosa (1998:127-128)

²Information on offerings found with burial NE-21A/6 from Sierra Sosa (1998:82)

APPENDIX C (continued)

NE-2 / 29

Offerings: 1 bichrome pot
1 *mano*

NE-35 / 197

Offerings: 1 fine grey vase

NE-29 / 192

Offerings: 1 shell spoon
1 shell net weight
1 small axe made of shell
1 flint core
1 limestone polisher
1 deer antler

NO-5 / 103

Offerings: 1 plate

NE-2 / 30

Offerings: 1 tripod vessel, with support
1 large rib, possibly manatee

NE-35 / 188

Offerings: 1 polychrome pot
1 deer antler

NE-14 / 13

Offerings: several shells
1 small shell axe, unfinished

NE-10 / 13

Offerings: 2 worked shells
1 needle made of animal bone
1 fragmented mother-of-pearl shell
2 shell earspools
1 partial shell earspool
4 fragments of different shell earspools
fish vertebrae, number unspecified
1 orange pot
1 incised bone fragment

NE-29 / 259

Offerings: 1 tripod vessel, with supports

APPENDIX C (continued)

NE-14 / 4

Offerings: None

NE-36 / 161

Offerings: 1 polychrome pot, fine paste, with zoomorphic designs
 2 perforated shells, possibly pendants
 3 unworked shells

NE-32 / 210

Offerings: 1 pot, incomplete
 1 pot, fluted
 1 plate, with red painting and pedestal base
 1 figurine, incomplete
 1 small knife

NE-34 / 146

Offerings¹: 1 tripod pot, Baca red
 680 beads made of shell and ceramic
 1 spindle, made of shell (Guemes 1999:Appendix 10b, n.p.)
 fragment of obsidian blade
 3 shell rings
 1 bone ring (made from fish vertebra)

NE-36 / 160?

Offerings: 1 shell

NE-21 / 16

Offerings: 1 tripod pot, with supports
 2 bracelets made of 50 shell beads
 1 necklace made of 811 shell beads
 1 necklace made of 24 beads, 4 of them jade, 20 shell
 1 pectoral, shell
 2 shell earspools

¹ Inventory for burial NE-34/146 from (Guemes 1999: Appendix 10b, n.p.)

APPENDIX C (continued)

NO-1 / 53

Offerings: 2 polychrome pots
1 vase
1 shell pectoral, with an engraved figure
1 jade and shell bead
1 pair of jade earspools
1 shell button (?)
1 shell
1 animal bone bead (?)

NE-27 / 280

Offerings: 1 pot (Nimún Café)
fragment of the neck of a pot (Nimún Café)
fragment of a corn shucker, made of deer bone
piece of a net weight, lithic

NE-2 / 1

Offerings: bichrome vessel

NE-17 / 2

Offerings: 1 polychrome plate

APPENDIX C (continued)

Burial good quality indices used in this study

0 = No offerings in the given category

Ceramics

1 = plain ceramics or monochrome (not specified as fine)

ceramic beads

poison bottles, not specified as fine

2 = monochrome fine ceramics

bichrome ceramics

bichrome with decorative motifs not specified as incised

monochrome ceramics (or ceramics not specified as mono-, bi- or polychrome)

with incised design(s), appliqué, or unspecified type of decoration.

figurines

poison bottles specified as being of fine ceramic or decorated

effigy vessels

3 = polychrome pottery with or without incising

vessel specified as composite silhouette

pottery specified as fine, with incising, whether monochrome, polychrome.

bichrome and incising

Jade¹

1 = beads, or unidentified jade objects

2 = fasteners; earplug (not specified as incised)

jade objects/fragments resembling those used in mosaics; rings

Lithics

1 = net weights; *manos*; polisher; flint core; flint bifaces; obsidian core

2 = obsidian blades, knives or arrowheads

pyrite appliqué

spindle (flint), flower-shaped

Shell

1 = unworked shell; net weight

2 = worked shell: incised or made into bead, pendant, or ornament, shell rings,

pectoral, not specified as incised; spindle

3 = spoon; small axe; pieces of a funerary mask; earspools

pectoral, incised

¹ Greenstone was counted as jade.

APPENDIX C (continued)

Animal bones

1 = unworked

2 = worked or incised (including made into a ring)

APPENDIX C (continued)
TABLE XXIX: BURIAL OFFERING DATA

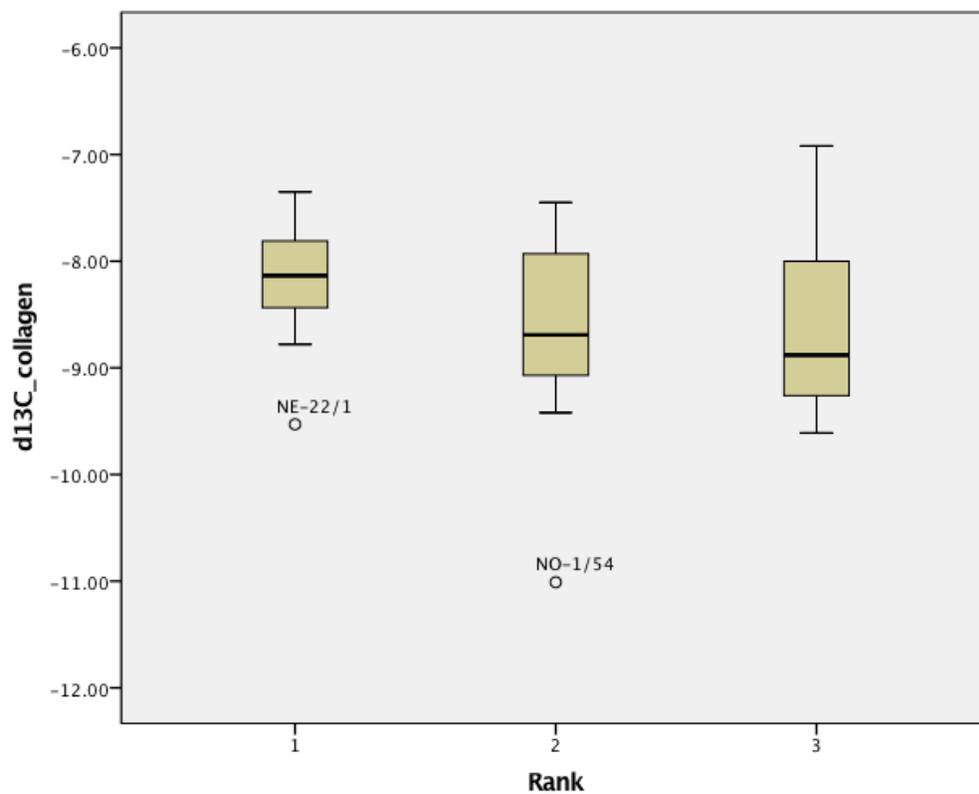
Burial No.	#DOC	Sex ^a	Ceramics quantity	Ceramics quality	Lithics quantity	Lithics quality	Jade quantity	Jade quality	Shell quantity	Shell quality	Animal bone quantity	Animal bone quality
Patio XIII/244	94255	M	1	1	0	0	0	0	0	0	0	0
NO-7/2	94018	F	2	1	0	0	0	0	4	1	2	1
NE-37/185	94486	M	2	1	0	0	0	0	1	1	1	1
NE-37/257	94513	M	0	0	0	0	0	0	0	0	0	0
NO-1/54	94442	M	3	3	0	0	0	0	0	0	0	0
NE-17/3	94003	F	1	3	0	0	0	0	0	0	0	0
NE-4/41	94048	M	1	1	0	0	0	0	0	0	0	0
NE-4/45	94049	M	2	2	0	0	0	0	0	0	0	0
NO-5/74	94179	M	1	1	0	0	0	0	0	0	1	1
NO-8/236A	94250	F	1	2	0	0	2	1	0	0	0	0
NO-1/48	94282	F	1	1	0	0	0	0	2	2	0	0
Patio V/128A	94204	M	0	0	0	0	0	0	0	0	0	0
NE-53/2	94436	M	1	1	0	0	0	0	0	0	0	0
NE-53/6	94433	F	8	3	0	0	1	1	1	2	0	0
SE-4/1	94235	F	3	3	0	0	1	1	2	2	1	1
SE-4/2	94236	F	1	1	1	2	1	1	0	0	0	0
NO-9/66	94176	M	1	3	0	0	0	0	0	0	0	0
NE-29/180	94484	M	3	3	1	1	3	2	1	2	1	2
NE-7/130A	94208	F	0	0	0	0	0	0	0	0	0	0
NE-36/137	94458	M	1	2	0	0	0	0	0	0	0	0
NO-2/59	94166	M	1	1	0	0	0	0	1	2	0	0
NE-28/249	94342	M	3	3	1	2	1	1	0	0	0	0
NE-7A/125 Patio N	94199	M	1	1	0	0	0	0	0	0	0	0
NE-27/279	94358	M	2	2	2	1	0	0	2	2	0	0
NE-23/3	94055	M	0	0	0	0	0	0	0	0	1	1
NE-22/3	94123	M	1	1	0	0	2	2	0	0	0	0
NE-21A/6	94228	F	2	3	0	0	0	0	0	0	0	0
NE-7A/34	94046	M	1	2	0	0	0	0	0	0	0	0
NE-22/1	94120	F	6	2	6	2	0	0	8	2	0	0
NE-22C/14	94133	M	6	3	0	0	4	2	1	3	0	0
NE-2/29	94097	M	1	2	1	1	0	0	0	0	0	0
NE-35/197	94248	F	1	2	0	0	0	0	0	0	0	0
NE-29/192	94308	F	0	0	2	1	0	0	3	3	1	1

APPENDIX C (continued)
TABLE XXV: BURIAL OFFERING DATA

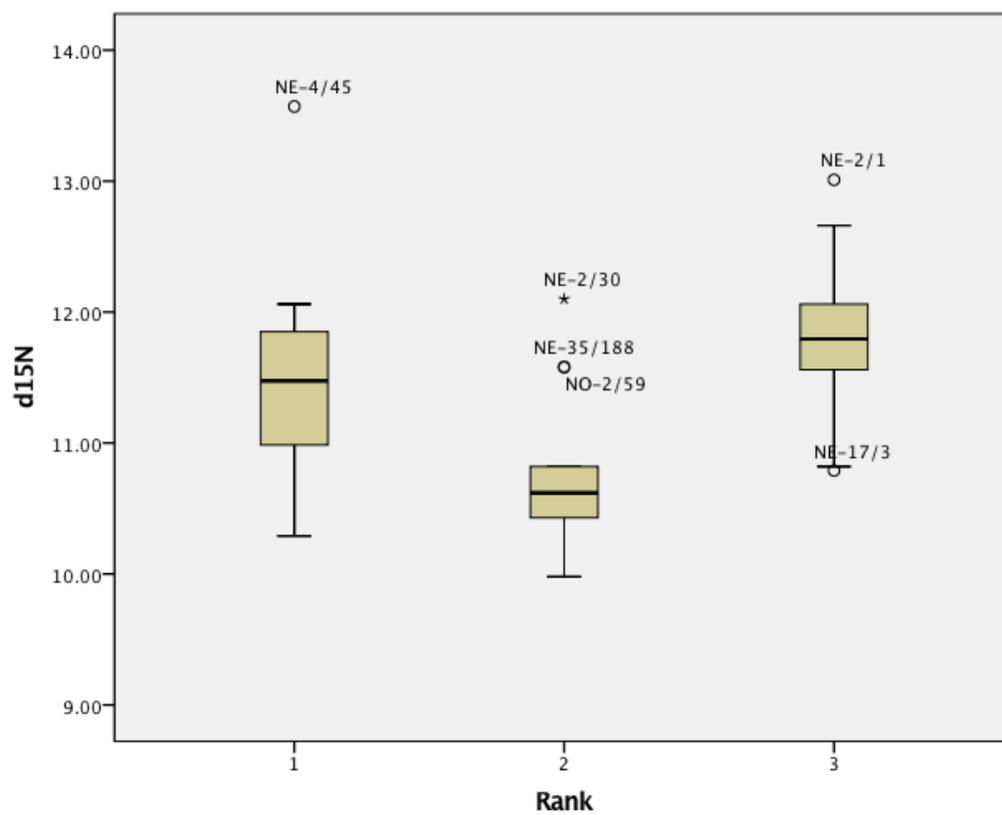
Burial No.	#DOC	Sex	Ceramics quantity	Ceramics quality	Lithics quantity	Lithics quality	Jade quantity	Jade quality	Shell quantity	Shell quality	Animal bone quantity	Animal bone quality
NO-5/103	94192	F	1	1	0	0	0	0	0	0	0	0
NE-2/30	94098	F	1	1	0	0	0	0	0	0	1	1
NE-35/188	94488	M	1	3	0	0	0	0	0	0	1	1
NE-14/13	94226	M	0	0	0	0	0	0	3	3	0	0
NE-10/13	94028	M	1	1	0	0	0	0	8	3	4	2
NE-29/259	94347	F	1	1	0	0	0	0	0	0	0	0
NE-14/4	94152	F	0	0	0	0	0	0	0	0	0	0
NE-36/161	94224	M	1	3	0	0	0	0	5	2	0	0
NE-32/210	94314	M	4	2	1	1	0	0	0	0	0	0
NE-34/146	94219	F	2	1	1	2	0	0	5	2	1	2
NE-36/160?	94306	F	0	0	0	0	0	0	1	1	0	0
NE-21/16	94116	F	1	1	0	0	1	1	7	2	0	0
NO-1/53	94440	M	3	3	0	0	3	2	4	3	1	2
NE-27/280	94359	F	2	1	1	1	0	0	0	0	1	2
NE-2/1	94069	F	1	2	0	0	0	0	0	0	0	0
NE-17/2	94002	F	1	3	0	0	0	0	0	0	0	0

^aThis table includes probable males, coded as M, and probable females, coded as F.

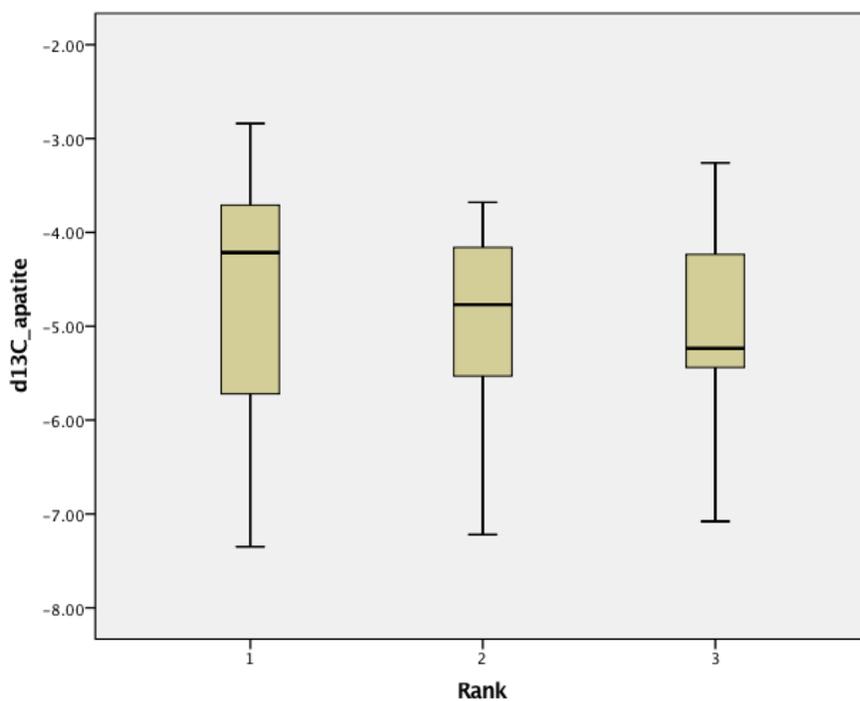
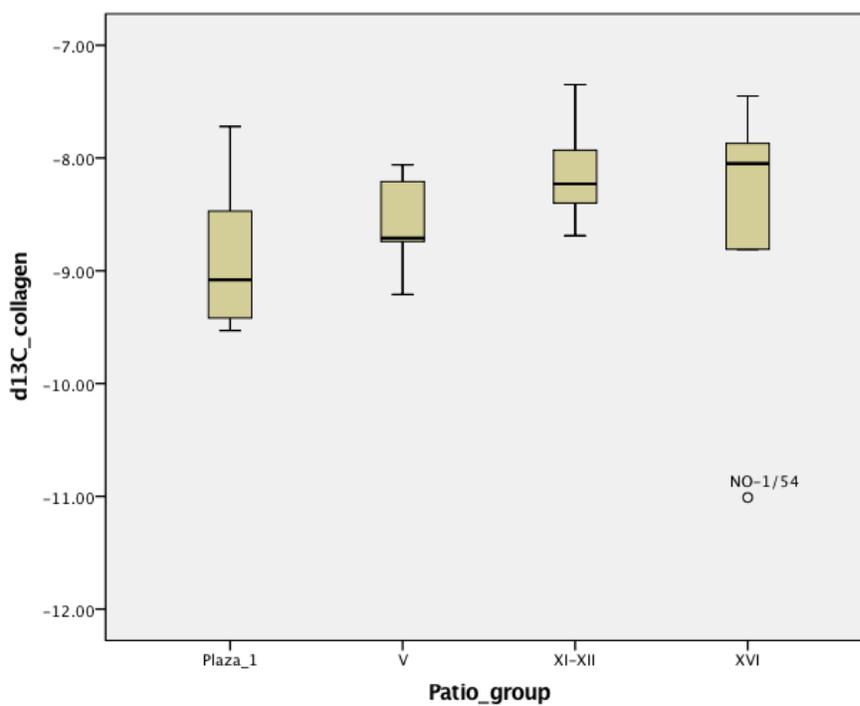
APPENDIX D: STATISTICAL FIGURES

Figure 10. Collagen $\delta^{13}\text{C}$ by rank.

APPENDIX D (continued)

Figure 11. $\delta^{15}\text{N}$ by rank.

APPENDIX D (continued)

Figure 12. Apatite $\delta^{13}\text{C}$ by rank.Figure 13. Collagen $\delta^{13}\text{C}$ statistics for patio groups from which 5 or more individuals were sampled.

APPENDIX D (continued)

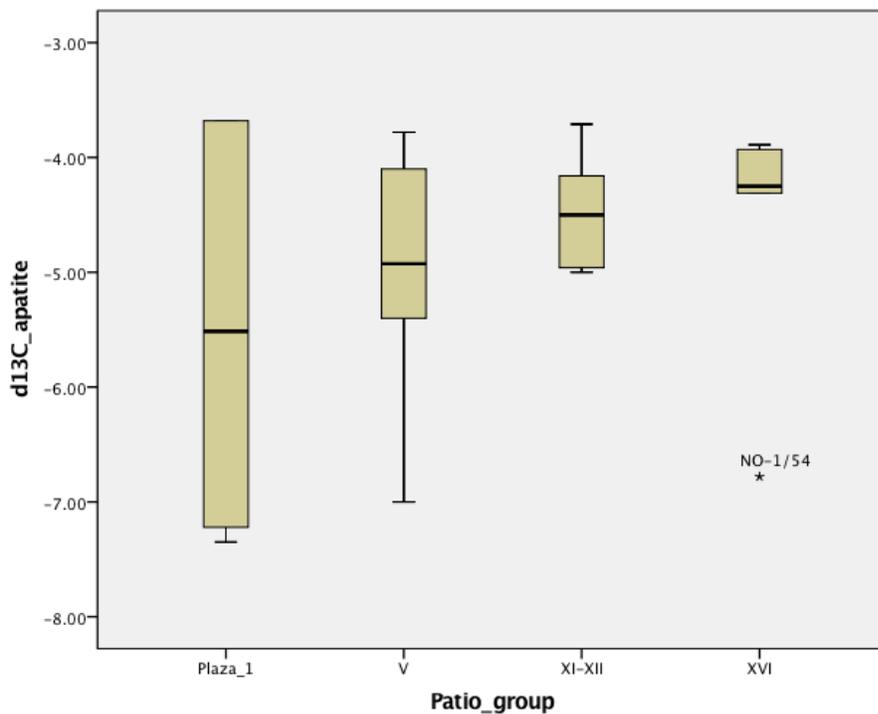


Figure 14. Apatite $\delta^{13}\text{C}$ statistics for patio groups from which 5 or more individuals were sampled.

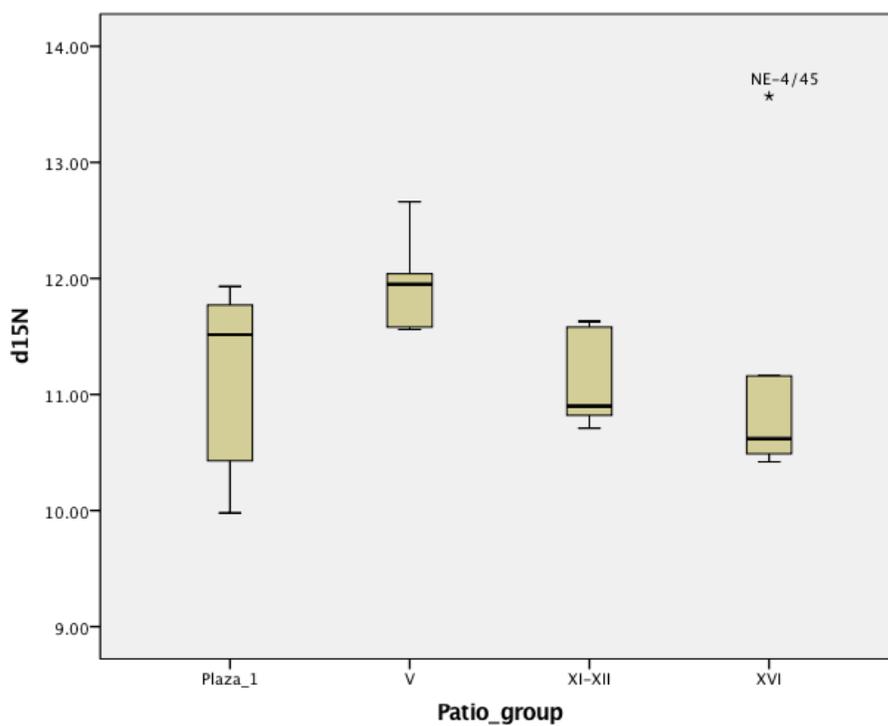


Figure 15. $\delta^{15}\text{N}$ statistics for patio groups from which 5 or more individuals were sampled.

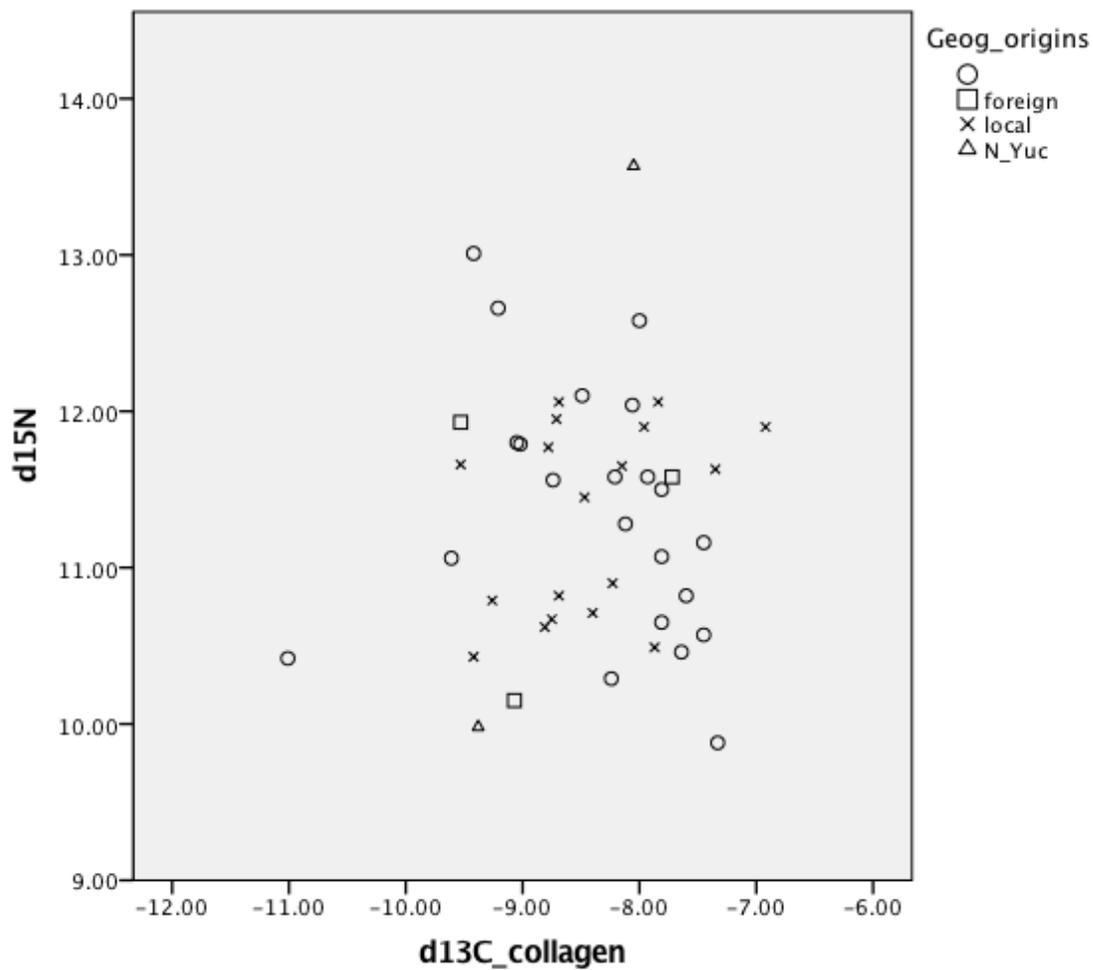
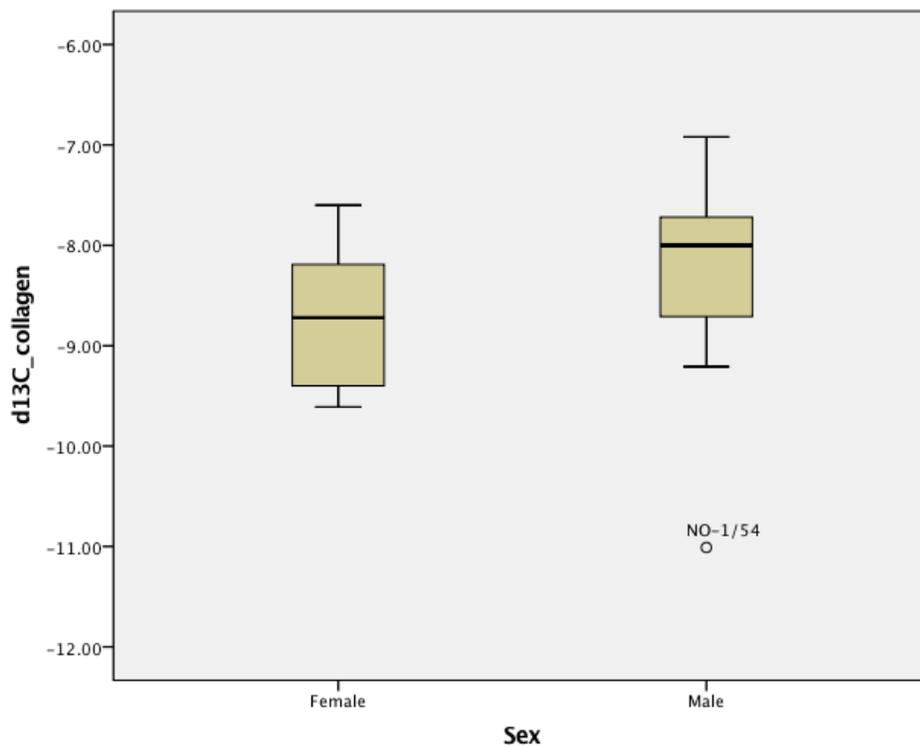
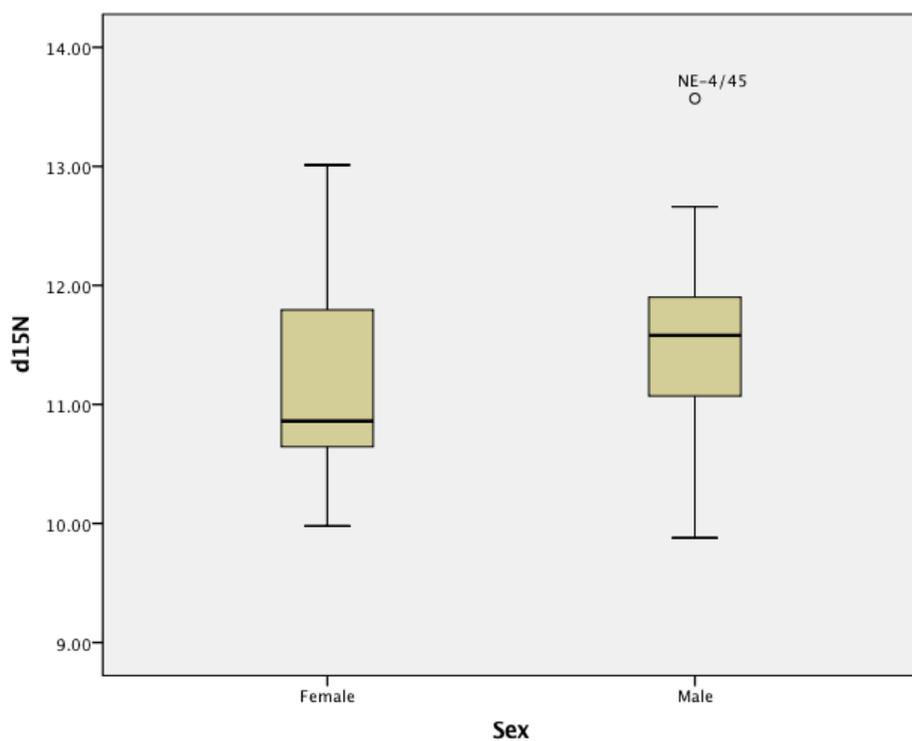


Figure 16. Results of $\delta^{15}\text{N}$ with $\delta^{13}\text{C}_{\text{CO}}$ with individuals classified by geographic origins. Data on geographic origins from (Sierra Sosa et al. n.d.). Empty circles represent individuals for whom data was not available.

APPENDIX D (continued)

Figure 17. Collagen $\delta^{13}\text{C}$ values by sex, time periods pooled.Figure 18. $\delta^{15}\text{N}$ values by sex, time periods pooled.

APPENDIX D (continued)

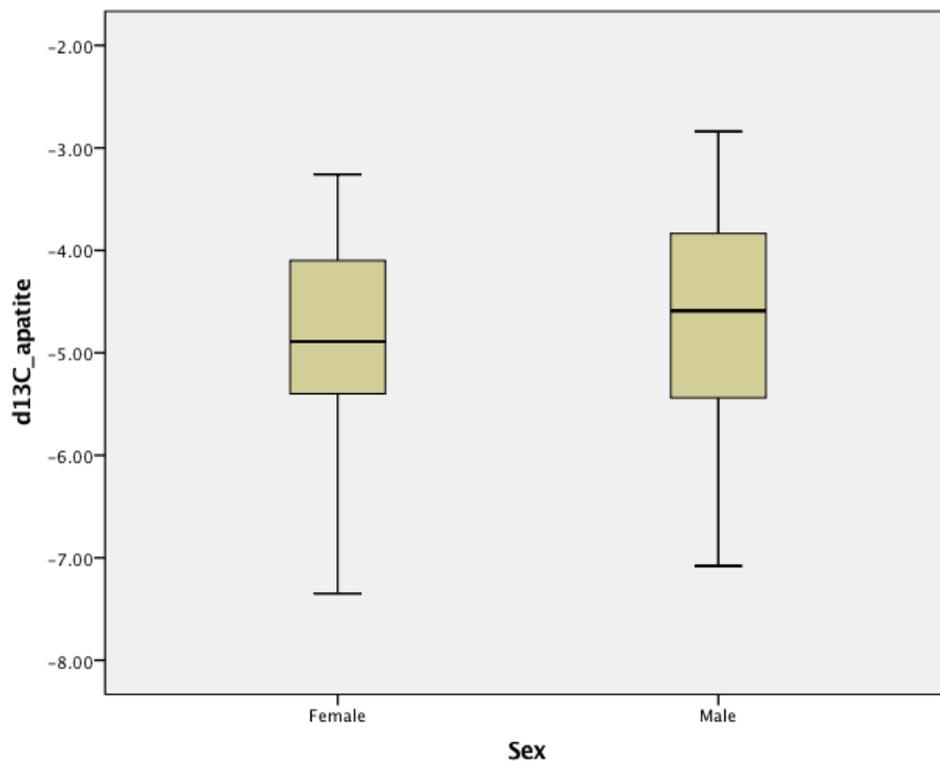
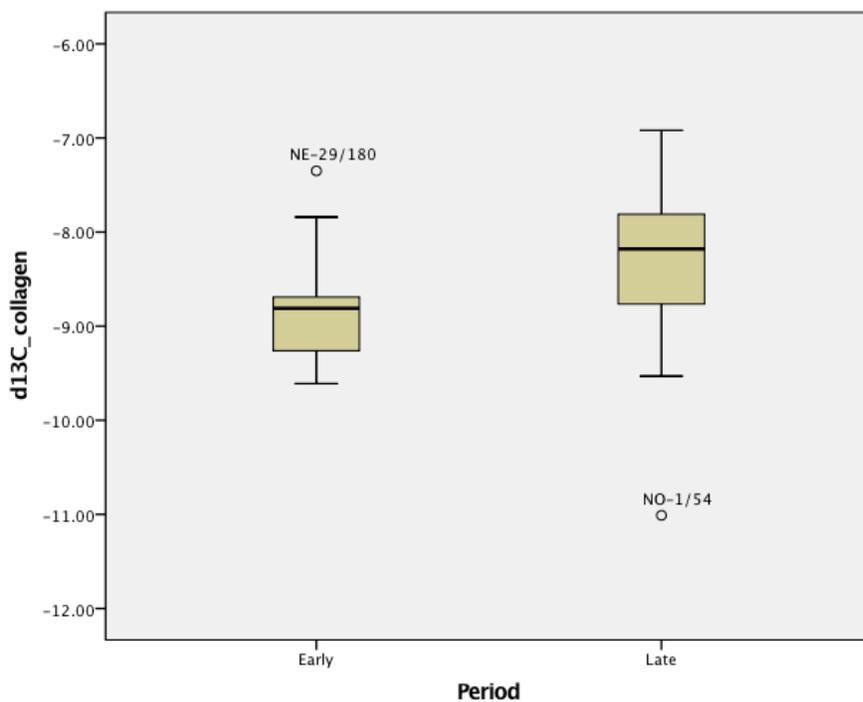
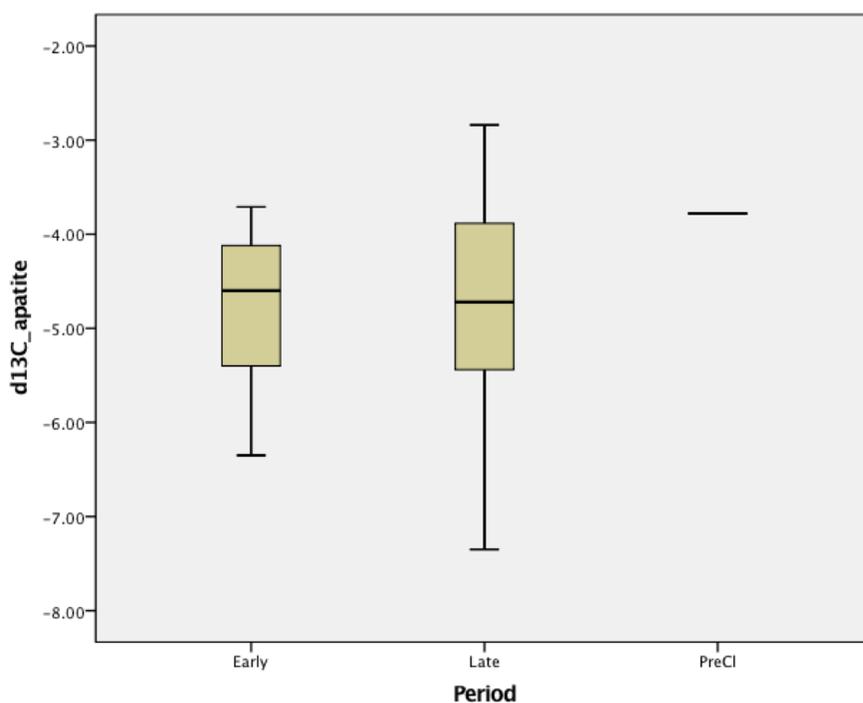


Figure 19. Apatite $\delta^{13}C$ values by sex, time periods pooled.

APPENDIX D (continued)

Figure 20. Collagen $\delta^{13}\text{C}$ statistics by time period, sexes pooled.Figure 21. Apatite $\delta^{13}\text{C}$ statistics by time period, sexes pooled.

APPENDIX D (continued)

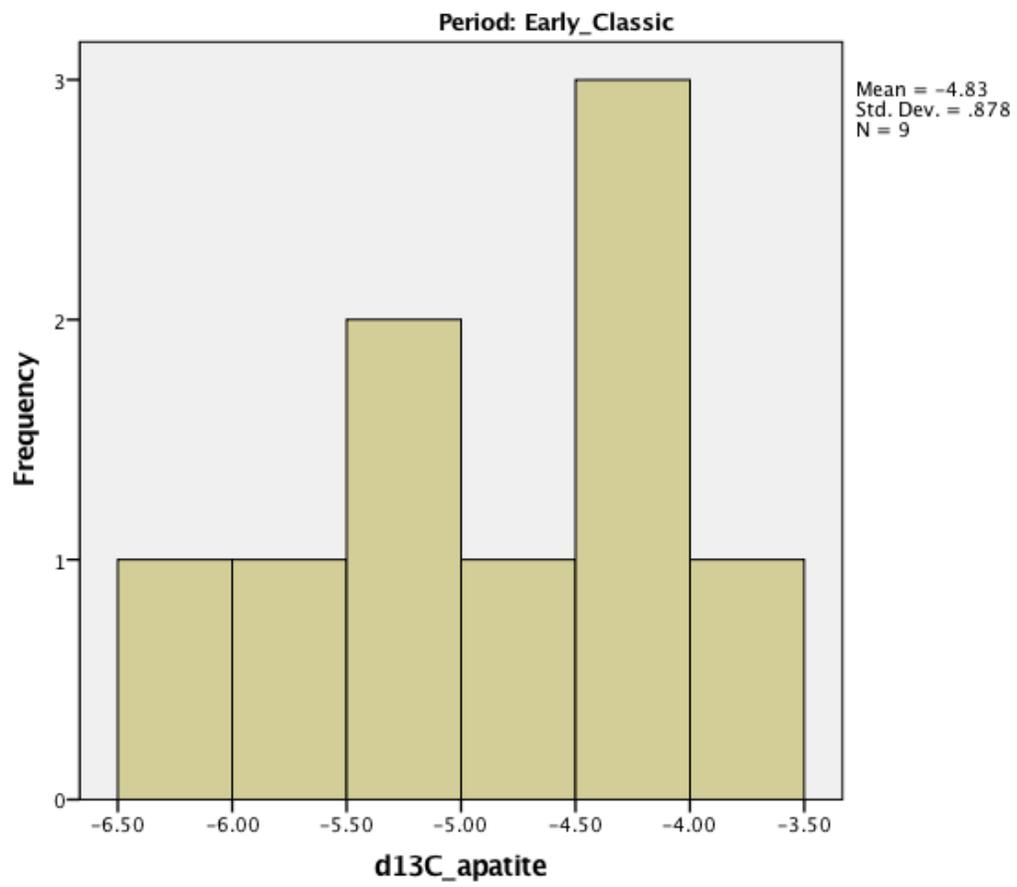


Figure 22. Distribution of $\delta^{13}\text{C}_{\text{CA}}$ results for Early Classic, sexes pooled.

APPENDIX D (continued)

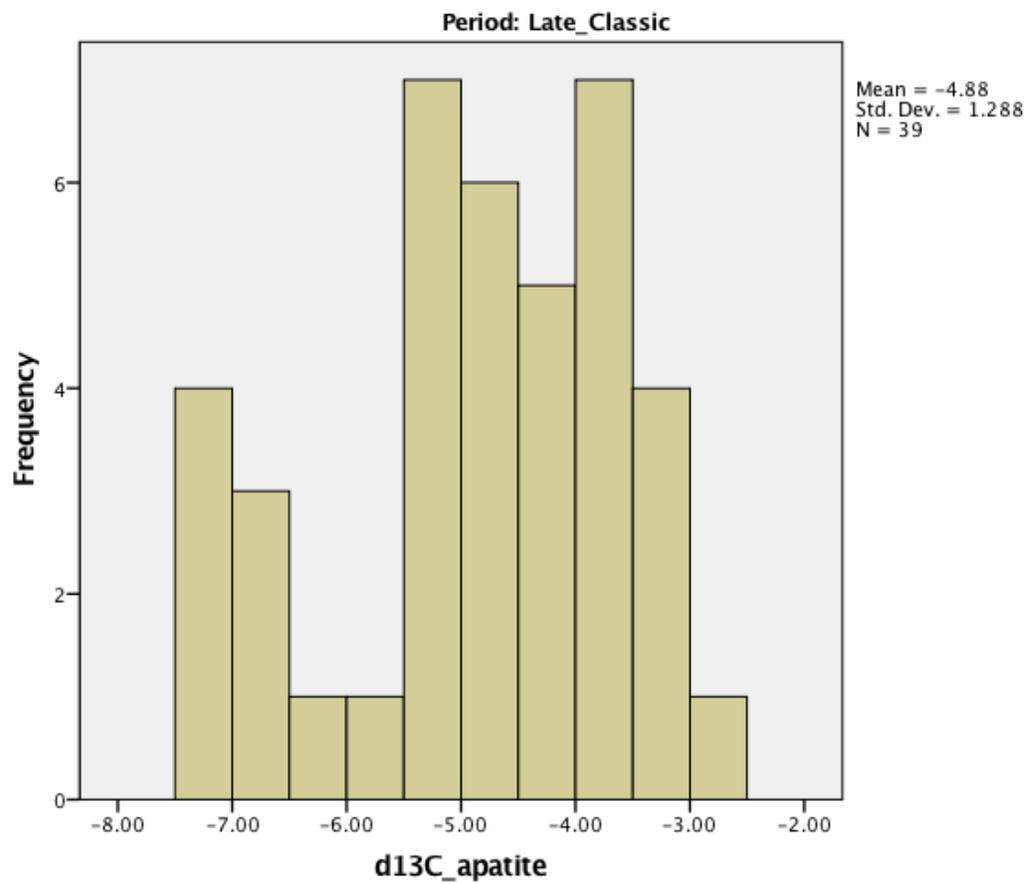


Figure 23. Distribution of $\delta^{13}\text{C}_{\text{CA}}$ results for Late Classic, sexes pooled.

APPENDIX D (continued)

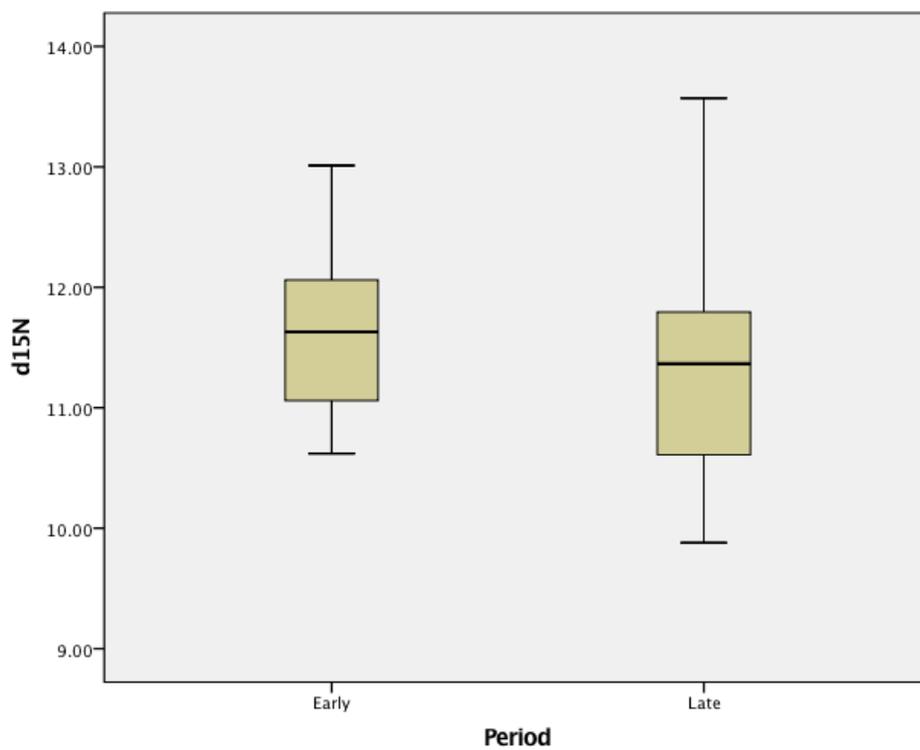


Figure 24. $\delta^{15}\text{N}$ statistics by time period, sexes pooled.

APPENDIX F: IMAGE USE POLICIES, D-MAPS.COM

The screenshot shows a web browser window with the address bar displaying "d-maps.com". The browser's tab bar shows several tabs, including "Worldwide - MSU Map Library: Links to Useful Sites - Lib...", "https://www.cdc.gov/careerpaths/scienceambassador/do...", "Blank Map Caribbean Sea Related Keywords & Sugges...", and "Terms and conditions of use". The website header features the "d-maps.com" logo with "free maps" underneath, a "Google Custom Search" box with a "Search" button, and a language selection menu with flags for UK, France, Spain, Germany, and Italy. A blue navigation bar contains the text "d-maps.com > Terms and conditions of use".

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Bioarchaeology, Mesoamerica, stable isotopes, paleodiet.

PUBLICATIONS

Bauer, Brian S., Madeleine Halac-Higashimori and Gabriel E. Cantarutti
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Bauer, Brian S., Teófilo Aparicio, Jesús Galiano, Madeleine Halac-Higashimori and Gabriel Cantarutti
 2014 *Muerte, entierros y milagros de Fray Diego Ortiz: Política y religión en Vilcabamba, S. XVI.* Cusco, Peru: Ceques editores.

Bauer, Brian S. and Madeleine Halac-Higashimori
 2013 *Baltasar de Ocampo Conejeros y la Provincia de Vilcabamba.* Cuzco, Peru: Ceques Editores.

FIELD EXPERIENCE

Proyecto Arqueológico Chicoloapan Viejo 6/13 – 7/13
 Graduate Research Assistant; Assisted in excavation as well as oversight and documentation, including plan maps and profile drawings; collection of samples; processing and analysis of artifacts.

Mensabak Archaeological Project: Chiapas, Mexico 6/6/11 – 6/18/11
 Assisted in mapping locations of human remains at site of Sak Tat.

Contisuyo Archaeological Field School: Moquegua, Peru 6/10 – 7/10
 As a student participant, learned techniques of archaeological excavation and artifact processing.

RESEARCH EXPERIENCE**University of Illinois at Chicago 1/11 – 9/12**

Research Assistant: Translating, with Dr. Brian S. Bauer, colonial Peruvian documents from Spanish to English.

Laboratory of Dr. Pamela Crabtree, New York University 9/08 – 5/09

Volunteer: Assisted with curation of faunal materials from Godin Tepe, Iran

MUSEUM EXPERIENCE**Harvard Museums of Science and Culture 9/16 - Present**

Volunteer: Acting as sketching facilitator, drawing at the Harvard Museum of Natural History and inviting visitors to participate to encourage them to observe objects in the galleries more closely, and assisting at HMSC public talks and family festivals.

American Museum of Natural History, Education Department 10/08 – 7/09

Volunteer, Education department: Teaching children about museum exhibitions, with primary focus on Pre-Columbian cultures of Mesoamerica, by discussing dioramas and using hands-on instruction tools.

CONFERENCE PRESENTATIONS

Halac-Higashimori, Madeleine, Thelma Sierra Sosa, Christopher Göetz, Vera Tiesler, Andrea Cucina, Joel Palka, and Sloan R. Williams. 2015. *Diet and socioeconomic status at Xcambó, Yucatán*. Poster presented at the Midwest Bioarchaeology & Forensic Anthropology Association conference. October 24.

Halac-Higashimori, Madeleine, Brian S. Bauer and Laura Nussbaum-Barberena. 2013. *Martin Hurtado de Arbieta and the Spanish colonization of Vilcabamba (1572-1589)*. Paper presented at the Midwest Andeanist Conference on Andean and Amazonian Archaeology and Ethnohistory. DeKalb, Illinois. February 23 and 24.

Bauer, Brian S. and Madeleine Halac-Higashimori. 2013. *The strange death and interments of Diego Ortiz*. Paper presented at the Midwest Andeanist Conference on Andean and Amazonian Archaeology and Ethnohistory. DeKalb, Illinois. February 23 and 24.

Palka, Joel W. and Madeleine Halac-Higashimori. 2012. *Maya parentage statements: A statistical approach*. Paper presented at the Midwest Mesoamericanists meeting. East Lansing, Michigan. March 9 and 10.

TEACHING

2016 - Present	Spanish tutor and teacher at Boston Area Spanish Exchange, Boston.
2015	Teaching Assistant – ANTH 100: The Human Adventure
	Teaching Assistant - ANTH 105: Introduction to Human Evolution
2014	Instructor – ANTH 277/LALS 270: Ethnography of Mesoamerica
2013	Teaching Assistant – ANTH 100: The Human Adventure
2010	Teaching Assistant - GEOG 151: Introduction to Cultural Geography.

AWARDS

Abraham Lincoln Fellowship, University of Illinois at Chicago

GRANTS

Chancellor's Graduate Research Fellowship, University of Illinois at Chicago. Diet and socioeconomic status at Xcambó, Yucatán.

LANGUAGES

Bilingual Spanish