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ISOTOPIC PERSPECTIVES ON ANCIENT MAYA DIET IN CENTRAL BELIZE

by

Morgan E. McKenna, B.S.

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To the Graduate Faculty:

The members of the committee appointed to examine the thesis of MORGAN E. MCKENNA find it satisfactory and recommend that it be accepted.

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ISOTOPIC PERSPECTIVES ON ANCIENT MAYA DIET IN CENTRAL BELIZE

Thesis Abstract- Idaho State University (2019)

Ancient diet was assessed for individuals from Central Belize using stable carbon and nitrogen isotope analysis of human skeletal materials. Samples were recovered from eight archaeological sites, and ranged in time from the Late Preclassic (300 BCE-100 CE) to the Postclassic (between 925 and 1530 CE) periods. The diet in Central Belize during this timeframe was revealed to be based on maize and maize-fed or marine proteins, supplemented with $C_3$ food sources. Variation was detected between the individuals, and the site of Pakal Na was a clear outlier, having the greatest reliance on $C_4$ maize. Temporal change in diet was also measured for nine individuals using samples of bone, tooth dentin, and tooth enamel, which revealed that dietary changes from childhood to adulthood were not uniform. This study demonstrates that variation in diet between individuals is likely caused by a number of factors.

**Keywords:** Ancient Maya, Belize, stable isotopes, diet, carbon, nitrogen, collagen, carbonate.

# Chapter 1: INTRODUCTION

The reconstruction of ancient human diet can give insights into the health and well-being of peoples from the past. Identifying what individuals and groups were eating aids in answering important anthropological questions, including their relationship with the environment, the cultural importance placed on certain foods, and daily activities. Isotope-based dietary studies have demonstrated their ability to improve our understanding of the archaeological record by successfully providing specific information about the quality and quantity of paleodietary sources, and are currently the most direct way to measure prehistoric food consumption. Stable isotope data, in combination with contextual archaeological information, can be used to create a broad and more accurate picture of the day to day lives of prehistoric populations. The goal of this study is to discover more information about the dietary patterns of ancient Maya individuals that lived in Central Belize from the Late Preclassic to the Postclassic periods (ranging from 300 BCE-1530 CE) using stable isotope ratio analysis to understand more about their lives and culture.

Stable isotope based dietary reconstructions have become a commonly employed method for archaeologists to understand more about ancient Maya culture. The goals of these dietary studies have ranged from deciphering the level of importance of maize in the diet (Hill 2011), discovering dietary differences based on the highly-stratified Maya social system (White 1988; White and Schwarcz 1989; Reed 1999; Wright 2006), learning about the earliest development of animal management (Sharpe et al. 2018), and testing the theory that environmental degradation triggered the "collapse" of the Maya during the Classic period (Wright 1997). With each new application of stable isotope data in the Maya region, our knowledge of this highly diverse group of people grows.

The first question that is explored in this study pertains to differences in diet across the geographic range of sampled individuals, or differences between each of the sites. The ancient Maya utilized a variety of different subsistence strategies and agricultural practices to obtain food, and the local environment dictated which resources were available (Gerry 1993; White et al. 1993). If diet is most affected by geographic location, more so than time period or social status, it would be expected for there to be differences in diet based on which food sources are more readily available at each location. It is hypothesized that differences between the sites will be detected.

A second question focuses on dietary variation throughout time. Studies of change in diet throughout time within a single location have demonstrated a high variability in the way in which diet changed. Research has shown that maize was a staple in the diet of the ancient Maya of Belize, but the waxing and waning of its importance through time was not universal across sites. For example, bone collagen $\delta^{13}C$ data was compiled for nineteen sites to demonstrate how the consumption of maize varied during the occupation of each site (Hill 2011). Although maize consumption remained stable from the Preclassic to the Postclassic at Hill's study site of Kichpanha in Northern Belize, many other sites experienced changes in their $\delta^{13}C$ values. Because change was detected over time for several archaeological sites in the region (Hill 2011) it is hypothesized that there will be dietary changes over time at the sites included in this study as well, due to changing importance and/or accessibility of subsistence items.

Dietary variation dependent upon site type raises a third question. The three different types of sites included in this study are surface, rockshelter, and cave. The assumption inherent in this question is that there is a correlation with burial type/location and social status. Recent studies of rockshelter and cave burials in Central Belize have shown that rockshelter burials are

associated with low-status rural individuals, while dark-zone cave burials are thought to be representative of those of higher status, though this may be an oversimplification (Glassman and Bonor 2005; Peterson 2006; Wrobel et al. 2009). Surface sites may include burials of all statuses, which may be inferred from burial features including proximity to site core and presence and quality of grave goods. If individuals of higher social status have more access to higher-status foods than those of low-status, a difference in diet may be detected, as was found at Altun Ha, Pacbitun, and Chau Hiix (White et al. 1993, 2001; Metcalfe et al. 2009). It is hypothesized that differences will be detected between the different site types.

The final question that this thesis addresses relates to individual change throughout life, and explores how an individual's diet may have changed within their own lifetime through analyses of skeletal materials that develop at different times. Studies in the Maya area regarding age-based dietary differences have shown varying trends, including subadults consuming fewer $C_4$ foods (maize and maize-fed animals) than adults (White et al. 1993), subadults consuming a greater amount of $C_4$ foods than adults (Reed 1994; Metcalfe et al. 2009), and no dietary difference between subadults and adults at all (White 1988; Parker 2011). Though there appears to be variability in the way in which diet changed throughout life, it is hypothesized that there will be a change in diet from childhood to adulthood.

To address these four questions, I examined stable carbon and nitrogen isotopic data collected from samples of human bone, tooth dentin, and enamel from eight different archaeological sites across Belize (Figure 1), as these material types record isotopic values during life with some fidelity and can be shown to be resistant to alteration.

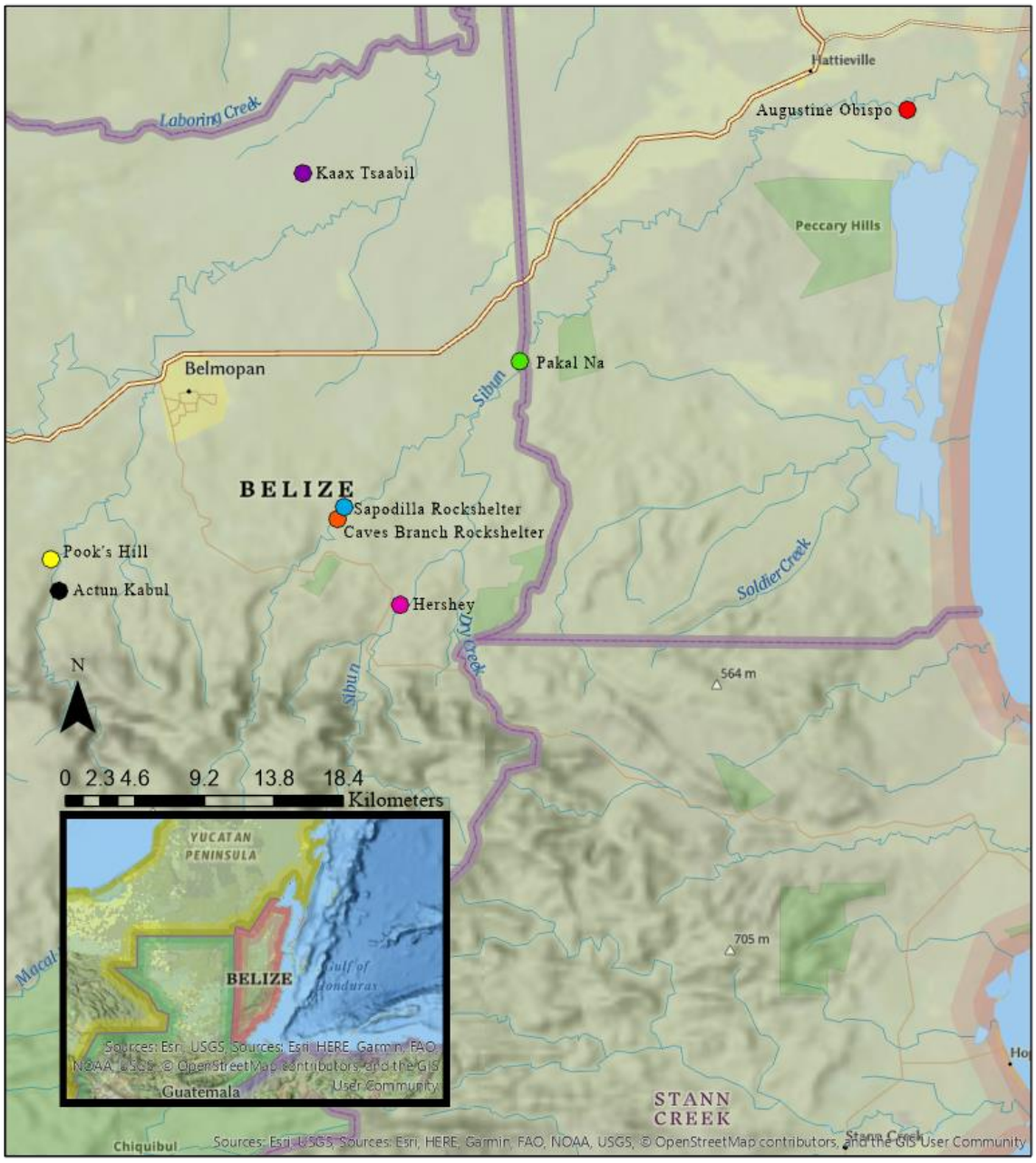


**Figure 1.** Map of the study sites in Belize

## Chapter 2: BACKGROUND

### Elements and Isotopes

An element is determined by the number of protons in an atom's nucleus. Most elements have more than one isotope, in which the number of neutrons in the nucleus differs. This has a variety of effects on the element, including varying atomic weights, abundance in nature, and elemental behaviors. Isotopes are separated into two main types, stable and unstable. Unstable isotopes are also referred to as radioactive isotopes and are the basis for radiometric dating methods. Unlike radioactive isotopes, stable isotopes do not decay overtime, and, barring diagenetic alteration, will remain unchanged within the archaeological artifact or bone through time. Carbon, nitrogen, oxygen, and strontium are the most commonly studied stable isotopes in archaeology. Carbon and nitrogen are often used to answer questions about diet, while isotopes of oxygen and strontium are used to construct ancient climate and migration (Katzenberg 2008).

### Stable Isotope Analysis in Archaeology

Several important studies in the 1970s and 1980s provided archaeologists with information on the relationship between isotope ratios found in food sources and those found in human bone. (DeNiro and Epstein 1978, 1981; Lee-Thorp et al. 1989; Smith and Epstein 1971; Tauber 1981; Schoeninger et al 1983). This research helped archaeologists understand how isotopes of carbon and nitrogen could be used to infer ancient diets. It also confirmed the idea that it is possible to estimate the relative contributions of certain types of foods in the human diet, because the carbon and nitrogen isotopes in the plants and animals that individuals eat get incorporated into their tissues in a predictable and measurable way.

For diet reconstruction, archaeologists are most interested in stable isotopes of carbon and nitrogen. The isotope ratio mass spectrometer (IRMS) measures the amount of the heavier isotope compared to the lighter isotope: $^{13}C/^{12}C$ and $^{15}N/^{14}N$. These ratios are calculated in parts per thousand, or per mil (‰), relative to the international reference standards Vienna Pee Dee Belemnite (VPDB) for carbon, and air for nitrogen (Katzenberg 2008). Calcified tissues, like bones and teeth, are the most commonly used sample materials for paleodietary studies because they are often the only tissues to survive in archaeological contexts. Collagen (organic portion) and/or carbonate (inorganic portion) extracted from bone, tooth dentin, and enamel can be analyzed for these studies.

Stable Carbon Isotopes

Carbon isotopes can be used to distinguish between the consumption of $C_3$ or $C_4$ plants, as the $\delta^{13}C$ values will vary depending on the photosynthetic pathway of the plant. There are three different photosynthetic pathways for terrestrial plants: $C_3$ (Calvin-Benson), $C_4$ (Hatch-Slack), and CAM (Crassulacean Acid Metabolism) photosynthesis. $C_3$ plants in the Maya region include beans, squash, roots, and fruits, and will have an average $\delta^{13}C$ value of around -27‰ in modern plants. The main $C_4$ plant in Mesoamerica is maize (*Zea mays*), but others include amaranth (*Amaranthus spp.)* and epazote (*Chenopodium ambrosioides*). $C_4$ plants are more enriched in $^{13}C$ than $C_3$ plants, and will be around -13‰ on average for modern plants. CAM plants include cacti, succulents, and pineapple, and have $\delta^{13}C$ values in between (and overlapping) $C_3$ and $C_4$ plants (Wright and White 1996). It is likely that CAM plants were not as important to ancient Maya diet as $C_3$ and $C_4$ plants, as there is no evidence of them being staple foods (White et al. 2006b). Archaeological $\delta^{13}C$ values for plants will be slightly different from modern plants due to the Suess effect, which is the change in atmospheric concentrations of lighter isotopes of

carbon due to the burning of fossil fuels. It is expected that $\delta^{13}C$ values for archaeological plants will be approximately 1.5‰ higher (more positive) than the values found in modern plants (Marino and McElroy 1991).

The controlled diet experiments of Ambrose and Norr (1993) demonstrated that dietary protein is routed directly to collagen synthesis, resulting in a dietary underrepresentation of carbohydrates and lipids in the bone collagen. This means that the $\delta^{13}C$ values found in bone collagen are primarily informative of the protein portion of the diet. In contrast, Ambrose and Norr (1993) concluded that the $\delta^{13}C$ values of bone carbonate is representative of the entire diet, including carbohydrates, lipids, and proteins.

Fractionation is the separation of the light isotopes from the heavy isotopes that occurs between two different materials (Hoefs 2009). Fractionation causes $\delta^{13}C$ values to differ between diet and different consumer tissues. The diet-carbonate spacing in humans is on average 9.5‰ (Ambrose and Norr 1993; DeNiro and Epstein 1978; Jim et al. 2004; Kellner and Schoeninger 2007), and the diet-collagen spacing is approximately 5‰ (Ambrose and Norr 1993; van der Merwe and Vogel 1978). Carbon isotopes may also exhibit a trophic level effect of approximately 1‰ (DeNiro and Epstein 1978; Schoeninger and DeNiro 1984).

Stable Nitrogen Isotopes

The $\delta^{15}N$ values derived from bone collagen can be useful in distinguishing between marine and terrestrial based foods, as well as their trophic level. These values are used to determine the source of protein in the diet (terrestrial plants and animals, legumes, or marine foods). In terrestrial systems, legumes associated with nitrogen fixation have $\delta^{15}N$ values of 0-1‰, other plants average about 3‰, terrestrial herbivores will range from 4-7‰, and terrestrial

carnivores will range from 8-11‰ (Tykot 2002). Marine plants and animals are more enriched in $^{15}N$ compared to terrestrial plants and animals in most parts of the world. In part, this is due to the higher number of trophic levels in marine environments (Figure 2) The higher the trophic level of an animal, the higher their $\delta^{15}N$ value will be, with a ~3-5‰ enrichment at each trophic level (DeNiro and Epstein 1981). Marine resources may also have higher $\delta^{15}N$ values because the resources at the base of their food webs, such as phytoplankton and algae, can be as high as 10‰. It is important to know the local isotopic values of the food sources, because the same plants and animals in different locations may have different isotopic values due to differing environments (Wright 1994).

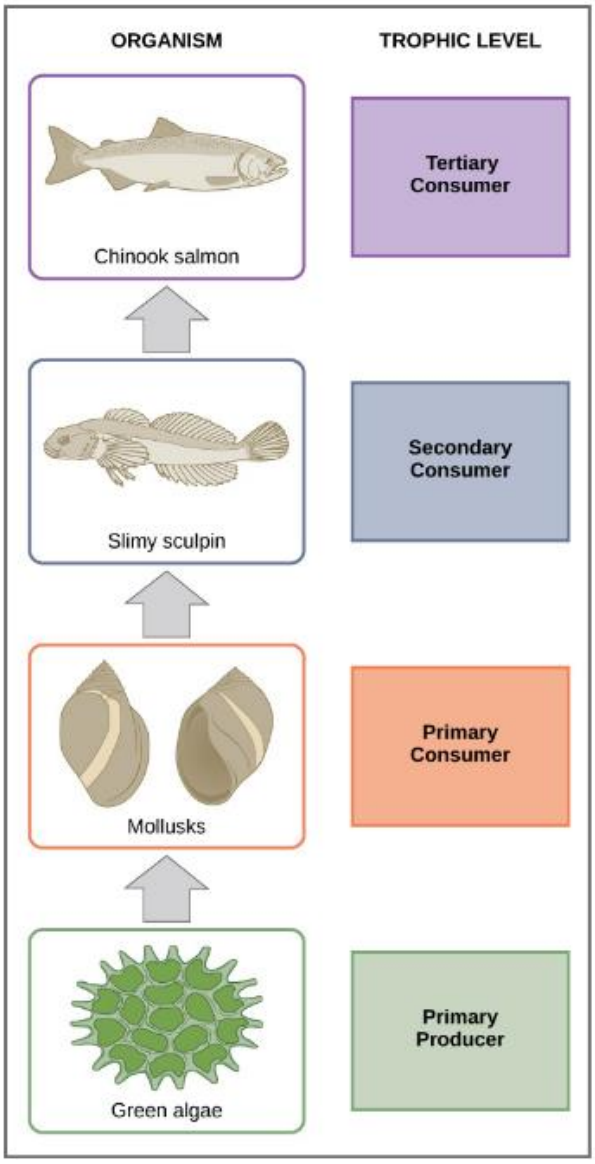


**Figure 2.** Example of the trophic levels in an aquatic setting. Image from Ecology of ecosystems, by OpenStax College, Biology, CC BY 4.0.

Different Skeletal Elements and Diet

The isotope ratios found in teeth and adult bone integrate diet at different times during an individual's life. Once the growth of tooth dentin has been completed, it does not regularly replace itself throughout life, so it provides a snapshot of the individual's diet during the period of formation (for example, when using only the apical portion of the root, it may represent diet around nine years of age for the first molars around 18 years of age for the third molars). Sampling only the apical portion of the tooth root will provide information on diet during the years that the root was completed, and will bypass the breastfeeding signal that may be present towards the crown of the tooth that was formed during times of breastfeeding. Like dentin, enamel also does not undergo remodeling, and will represent an even earlier diet than tooth dentin (for example, the enamel on the first molar will represent diet from birth to 3 years of age, and the enamel on the third molar will represent diet from seven to 16 years of age) (Gage et al. 1989). Because the timing of tooth development is known, archaeologists can analyze different teeth to gather information about diet at a particular time during an individual's childhood or early teenage years (Table 1).

The isotope ratios found in bone will represent diet during the last several years of an individual's life, as bones are constantly remodeling themselves. This affects the interpretation of isotope data because direct comparisons between samples can only be made if they are from the same biological material. An individual that is only represented by a tooth sample cannot be directly compared to an individual who is only represented by an adult bone sample because there may be differences between diets during different life stages. Comparing the isotope ratios found in tooth and bone for the same individual will provide insights into how their diet may

have changed throughout their life, and analyzing samples of both bone and teeth from the same site may shed light on differences in subadult and adult diet.

**Table 1.** Timeline for the development of permanent human teeth from Nelson and Ash (2010) p. 31.

| | | | | Maxillary Teeth | | | | |
|---|---|---|---|---|---|---|---|---|
| | I1 | I2 | C | P1 | P2 | M1 | M2 | M3 |
| Initial Calcification | 3-4 mo | 10-12 mo | 4-5 mo | 1.5-1.75 yr | 2-2.25 yr | at birth | 2.5-3 yr | 7-9 yr |
| Crown Completed | 4-5 yr | 4-5 yr | 6-7 yr | 5-6 yr | 6-7 yr | 2.5-3 yr | 7-8 yr | 12-16 yr |
| Root Completed | 10 yr | 11 yr | 13-15 yr | 12-13 yr | 12-14 yr | 9-10 yr | 14-16 yr | 18-25 yr |
| | | | | Mandibular Teeth | | | | |
| Initial Calcification | 3-4 mo | 3-4 mo | 4-5 mo | 1.25-2 yr | 2.25-2.5 yr | at birth | 2.5-3 yr | 8-10 yr |
| Crown Completed | 4-5 yr | 4-5 yr | 6-7 yr | 5-6 yr | 6-7 yr | 2.5-3 yr | 7-8 yr | 12-16 yr |
| Root Completed | 9 yr | 10 yr | 12-14 yr | 12-13 yr | 13-14 yr | 9-10 yr | 14-15 yr | 18-25 yr |

The Maya

Ancient Maya individuals lived throughout the Yucatan Peninsula, southern Mexico, Guatemala, Belize, and the western parts of Honduras and El Salvador. Archaeologists divide this vast expanse of geography into three main regions that encompass ecological and environmental variation: The Northern Lowlands, the Southern Lowlands, and the Highlands (Figure 3). Unlike the Aztecs or the Inca, the Maya were not unified under a single ruling body. Instead, they formed many city-states with complex economic, political, and cultural relationships with each other (McKillop 2004).

Evidence from the Archaic period in the Maya area is sparse but is improving. The first archaeological evidence of Maya culture existing in this region dates to the Early Preclassic period, beginning around 1800 BCE (Table 2). By the Late Preclassic, archaeologists find a rise in cultural and social complexity evidenced by painted temples and the emergence of elite rulers. Long distance communication and trading for high-status good begins taking place during this time period as well (McKillop 2004). The Classic period saw a new level of sociopolitical complexity, with mighty kings and queens supported by farmers who provided food and labor to the royalty. These Maya groups that were initially governed by chiefdoms had now formed into states with powerful centralized leaders who legitimized their rule through their political relationships and divine heritage. Maya civilization reached its peak during the Late Classic when monumental building projects, artistic activities, and populations were at their highest. Social inequality began leading to warfare and political unrest among the lowland Maya city-states during the Terminal Classic, which was accompanied by a steep decline in population numbers and the abandonment of major city centers (McKillop 2004).


**Figure 3.** The 3 major Maya regions: Northern Lowlands, Southern Lowlands, and Highlands. from https://www.reed.edu/uxmal/galleries/Full/Other/IntroMaps/Other-IntroMaps-2.htm.

**Table 2.** Time periods associated with Maya culture (Pendergast 1993; Coe and Houston 2015, 10).

| Time Period | Dates | Description |
|---|---|---|
| Archaic | 3000-1800 BCE | Hunting, fishing, and gathering, with the beginnings of maize horticulture |
| Early Preclassic | 1800-1000 BCE | Beginnings of Maya village life, pottery, and social stratification |
| Middle Preclassic | 1000-300 BCE | Earliest Maya villages and temple centers in the Lowlands |
| Late Preclassic | 300 BCE-100 CE | Massive pyramid building in the Lowlands |
| Protoclassic | 100-250 CE | Transition period between the Preclassic and Classic periods |
| Early Classic | 250-600 CE | First dated stone monument found at Tikal |
| Late Classic | 600-800 CE | Height of Maya Civilization |
| Terminal Classic | 800-925 CE | The Great Collapse of the Southern Lowlands |
| Early Postclassic | 925-1200 CE | Rise of the Northern Lowlands |
| Late Postclassic | 1200-1530 CE | League of Mayapan, Spanish Conquest |

The "Great Collapse" of the Terminal Classic period is described by Mayanists as a time of increased warfare, a decline in trade, disintegration of alliances, an increased death rate, and an almost total cessation of the large construction projects that defined the Classic period (Coe and Houston 2015). There are many theories as to what caused the Classic Maya collapse, ranging from peasant revolt, outside invaders, environmental instability, drought, and overpopulation (Chase and Chase 2004; Coe and Houston 2015). The reversal of growth that occurred at many sites during this time is believed by many to have been caused by a combination of factors, with a main catalyst being a changing environment exacerbated by

deforestation and the over-use of agricultural land to try to sustain large and growing populations of people. Wright (1997) showed that the collapse was not likely caused by environmental instability alone, because no paleopathological or isotopic evidence of declining health during this time was found on the skeletal remains sampled, as would be expected during times of famine. Because of this, some argue that an explanation of the collapse should also include other factors such as political violence, warfare, and social inequality (Wright 1997).

By around 925 CE, most of the important Classic cities in the Southern Lowlands had been abandoned. This ushered in the Postclassic period, when Mayanists see more evidence of the Northern Lowlands flourishing. During the Late Postclassic period, there was an expansion of settlements along the eastern coast of the Yucatan, as well as the rise of Mayapan in the interior of the Northern Maya Lowlands. Mayapan was a densely populated, walled city with political power over multiple other sites. The Postclassic period came to an end in 1530 CE, when the Spanish arrived (McKillip 2004).

## Site Descriptions and Background

Central Belize, located in the Southern Lowlands of the Maya region, has been historically understudied compared to other regions within the Maya area. The individuals included in this study came from eight different archaeological sites in this region. These sites include Pakal Na, Hershey, and Augustine Obispo in the Sibun River Valley; Pook's Hill and Actun Kabul in the Roaring Creek River Valley; Caves Branch Rockshelter and Sapodilla Rockshelter in the Caves Branch River Valley; and Kaax Tsaabil in the Belize River Valley (Figure 1). These represent a variety of surface, rockshelter, and cave sites, occupied at different times (Table 3).

**Table 3.** Archaeological sites included in this study and the time periods associated with sampled human remains.

| Site Location | Site Type | Time Period Associated with Sampled Individuals |
|---|---|---|
| Caves Branch Rockshelter (CBR) | Rockshelter | Late Preclassic |
| Sapodilla Rockshelter (SDR) | Rockshelter | Protoclassic to Early Classic |
| Hershey | Surface | Late/Terminal Classic |
| Pook's Hill | Surface | Late/Terminal Classic |
| Actun Kabul | Cave | Late/Terminal Classic |
| Pakal Na | Surface | Late Classic to Postclassic |
| Augustine Obispo Site (AOS) | Surface | Terminal Classic to Postclassic |
| Kaax Tsaabil | Surface | Terminal Classic to Postclassic |

*Caves Branch Rockshelter (CBR)*

Caves Branch Rockshelter (CBR), located in the Caves Branch River Valley, has been excavated several times and is thought to contain over four hundred burials (Glassman and Bonor 2005; Wrobel and Tyler 2006; Wrobel et al. 2007, 2009). Individuals of all ages and sexes are represented at CBR. Grave goods including chert flakes, jute shells, and net weights were found here. These types of utilitarian grave goods are consistent with those found in rural, non-elite burials, suggesting that those interred here were not high-status individuals (Wrobel et al. 2007). The use of this rockshelter for mortuary ritual was long-term, spanning from the Middle Preclassic into the Classic period, with the most intensive use evidenced during the Late Preclassic (Wrobel 2008).

*Sapodilla Rockshelter (SDR)*

Sapodilla Rockshelter (SDR) is found along a small tributary in the northern part of the Caves Branch River system, about 1 km away from CBR. SDR appears to be the site of specialized activity. Complex deposits that included primary burials, scattered human and faunal bones, ceramics, and lithics were excavated, comparable to what was discovered in the nearby Caves Branch Rockshelter (Glassman and Bonor 2005; Wrobel et al. 2007). It appears that rural agrarian groups were utilizing SDR in similar fashion as CBR, demonstrating that non-elites in the area were utilizing mortuary spaces outside of their immediate living spaces. Although CBR is much larger than SDR and contained more commingled burials, SDR was also likely used by groups who ritually revisited and maintained the space. The majority of ceramics recovered from SDR were Protoclassic and Early Classic, which suggests that the duration of the use of the site was shorter than at CBR (Andres et al. 2011).

*Hershey*

The Hershey site, named for the ancient and modern production of cacao, is the largest archaeological site in the Sibun Valley, located at the base of the Maya Mountains. It appears to be the only site in this valley that has pyramidal architecture and is believed to have been an important location for the circum Maya Mountain trade routes (McAnany and Thomas 2003). The site contains architecture that is reminiscent of Classic period Petén (located in present day Guatemala), and features a small ballcourt. Pottery sherds found at Hershey also demonstrate an affiliation with Petén, and it is hypothesized that the Hershey site served as residence for the ruling elites originally from the Petén Basin (Harrison-Buck et al. 2007).

*Pakal Na*

Pakal Na is located north of Hershey, in the middle of the Sibun valley. Archaeologists have found evidence suggesting this site's survival during the decline that generally characterizes the Terminal Classic period (800-925 CE). The site thrived from the Late Classic to the Postclassic. It appears to have a later development compared to many other sites in the region that were occupied beginning in the Pre-Classic and Early Classic periods, and substantial interaction with the Caribbean coast. The style and composition of the grave goods found at Pakal Na point to an outside influence, likely coming in from Chichén Itzá (present day Mexico). The Terminal Classic association of Pakal Na with northern political alliances is further indicated by the introduction of Yucatec-style circular architecture and pottery style at sites throughout the middle and lower Sibun Valley, but not at Hershey. While Hershey and other sites associated with the Petén were shrinking, the Yucatec and Pakal Na were flourishing, indicating a political and economic shift in power.

It is estimated that at least one of the individuals sampled from Pakal Na (Burial 1A/1C) in this study are of elite status. This is based on the quality and nature of grave goods, as well as the evidence for postmortem curation of the remains over an extended period, a common practice for venerated ancestors of the ancient Maya (Storey 2004). Osteological evidence, including the indicators of robust muscle attachments on the shoulder and a prominent *linea aspera* on the femur, suggests an active lifestyle, which led archaeologists believe that this individual may have been a prominent warrior (Harrison-Buck et al. 2007).

*Augustine Obispo*

The Augustine Obispo site is one of four sites found in the Hattieville area of the Sibun Valley. It is believed to have been occupied from the Late Classic into the Postclassic. Although

Augustine Obispo is one of the smallest sites found in the Sibun Valley, it is the location of two of the four stone monuments discovered in this area. These stone monuments appear to have a ritual use. Not much is known about this small site, but it is believed to be a part of a collection of sites centered around the larger Oshon site, located two kilometers away from Obispo, and the location of the other two stone monuments (Morandi 2003).

*Pook's Hill*

Pook's Hill is found west of the Roaring Creek River, approximately 14 km southwest of Belmopan (Helmke 2000). Most of the ceramic sherds found here date from the Early Classic to the Terminal Classic, with at least one Late Preclassic and two Early Postclassic sherds as well (Helmke 2000). It has been estimated that a high-status extended family or lineage and its dependents lived at this site (Kelso 2006). The individuals living here regularly used caves, such as Actun Tunichil Muknal, for ritual purposes. In fact, Pook's Hill was first investigated to better understand the caves themselves because of their evident connections.

*Actun Kabul (AKB*)

Actun Kabul (AKB) is a large, dark zone cave located in the Roaring Creek River Valley. Initial reports (Gibbs and Weinberg 2002) and the excavations that followed (Wrobel 2013) established that the front chambers of this cave contained a large number of ceramic sherds and ash, and the terminal chamber held the commingled and fragmentary remains of approximately 150 to 200 individuals (Wrobel 2013, 2015). The human remains consisted of subadults and young adults of both sexes. Because only one instance of articulation was noted, the extreme commingling in the terminal chamber and near absence of smaller bones suggests that the individuals likely decomposed somewhere else before they were placed in AKB. Ceramic

analyses suggest that the cave was used during the Late/Terminal Classic period. The individuals buried here were likely from Tipan Chen Uitz, a major civic-ceremonial center located within 1 kilometer of AKB. If this is correct, these individuals would have been of higher status (Wrobel, Gabriel. 2019. E-mail message to author, September 8).

*Kaax Tsaabil*

Located two kilometers north of the Belize River, Kaax Tsaabil is made up of a series of architectural complexes built atop natural limestone hills (Harrison-Buck 2013). One of the largest settlements excavated by the Belize River East Archaeology (BREA), archaeologists note that Kaax Tsaabil is an anomaly in the region, being much larger and more elaborate compared to the other nearby sites, pointing to the importance of this location. Kaax Tsaabil is believed to have been a key site on at least one of the travel and trade routes that connected the Belize River, one of the main means of entry into the Petén, to the Yucatán (Kaeding et al. 2013).

*Summary of Archaeological Sites in This Study*

Individuals from eight different archaeological sites in Central Belize were sampled for this study. The sites vary in size, location, and time of occupation, which allows for the investigation of many causes for dietary variation. Though these sites may not have much in common, none of these sites are major Maya civic-ceremonial centers (though the individuals buried at AKB potentially lived at a major center during life), which adds to the growing data set of those living in the peripheral sites.

Previous Research on Ancient Maya Diet

Work on reconstructing ancient Maya diet began primarily as an attempt to investigate the varying theories on civilization collapse, but ultimately led to a greater understanding of regional diversity of food consumption and alternative strategies of meeting subsistence needs (Wright and White 1996; Gerry and Krueger 1997; White 1997). The previously held perception of a pan-Mesoamerican diet was challenged through these findings, and it was demonstrated that ancient Maya diet was not homogenous across the entire Maya region (White et al. 2006b).

Maize was first domesticated in Mexico, and it is believed to have reached the Maya area sometime during the Archaic period. During the Archaic period, subsistence strategies mainly involved foraging, with the first instances of maize horticulture beginning near the end of the period. By the time the Early Preclassic period began, the ancient Maya were effective farmers, which was necessary to sustain the growing populations living within the now densely populated villages (Coe and Houston 2015).

The Classic lowland Maya utilized household gardens and *milpas,* or cleared lots of land used for agriculture, and highly productive raised fields and terraces to provide themselves with food. The basis of all Classic Maya diet is believed to have consisted of maize, beans, and squash (the so-called "Mesoamerican Trinity"), with a variety of other foods gathered from different ecological niches filling out the dietary subsistence base. In the Maya region, zooarchaeological, paleobotanical, and ethnohistoric evidence has identified the most common foods as several species of deer, domestic dog, peccary, rabbit, opossum, raccoon, agouti, armadillo, tapir, freshwater turtle, maize, beans, squash, root crops, and fruits. Zooarchaeological data suggests that hunting wild animals for their meat was a significant part of Maya diet even after the establishment of villages and urban development. Those living on the coast or near estuaries

were taking advantage of aquatic resources like fish and shellfish in addition to the other foods (Tykot 2002). There is evidence that fish from the offshore coral reef were brought upriver as a valuable trade commodity (McAnany and Thomas 2003).

Isotope-Based Food Webs

The analysis of stable carbon and nitrogen values of modern and archaeological flora and fauna can be used to generate food webs, which show the isotopic composition of the different food resources available at a certain location. Local or site-specific food webs can be created by analyzing the plants and animals found at a particular location or archaeological site. It is important to gather site-specific data due to the variation in carbon and nitrogen stable isotopes found over the world. Without these site-specific food webs, it is difficult or impossible to interpret the meaning of the isotope ratios present in the human skeletal samples.

Although it can be argued that similar types of environments will yield similar isotopic ratios in plants and animals (for example, the environmental conditions in the Bahamas are similar to Coastal Belize), it has been confirmed that the $\delta^{13}C$ values of $C_3$ plants are very susceptible to microenvironmental variations (van der Merwe 1989; Tiezen 1991). Another factor influencing Coastal Belize food webs is that the nitrogen fixing blue-green algae off the coast has been shown to lower the $\delta^{15}N$ levels of the marine resources, causing ancient Maya individuals that had a marine-based diet to display $\delta^{15}N$ values that are lower than individuals consuming marine foods in other parts of the world (Schoeninger et al. 1983).

There are several food webs that have been generated for different locations in Belize, including Ambergris Cay (Williams et al. 2009), Chau Hiix (Metcalfe et al. 2009), Altun Ha (White et al. 2001), and Caledonia (Rand 2011). Figure 4 shows $\delta^{13}C$ and $\delta^{15}N$ patterns using

mean and standard deviations for different food groups calculated from several different studies in the Maya area and Bahamas (Williams, White, and Longstaffe 2009; White et al. 1993; Keegan and DeNiro 1988; Wright 2006; Norr 1991; White and Schwarz 1989) as well as values from this study. Values for each of the food resources used in creation of the foodweb can be found in Appendix E.

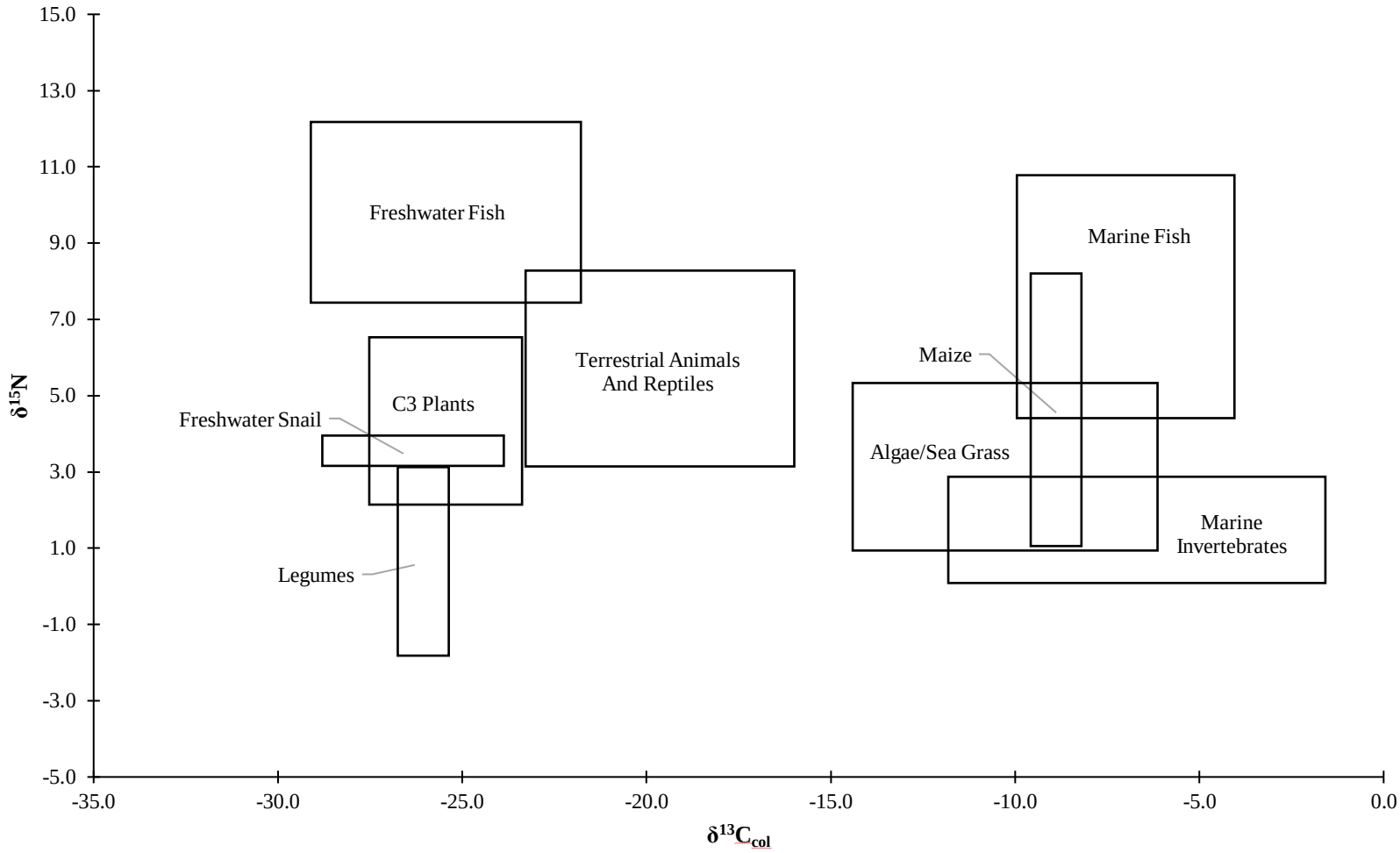


**Figure 4.** Food web of commonly eaten foods for the ancient Maya using averages calculated from values found in Keegan and DeNiro (1988), White and Schwarz (1989), Norr (1991), White et al. (1993), Wright (2006), Williams, White, and Longstaffe (2009), and data from this study.

Review of Stable Isotope Analysis of Ancient Maya Diet

The relationship between Maya diet and factors like age, sex, and socioeconomic status, as well as variation between different time periods and regions, has been a popular topic of investigation since the late 1980s (White and Schwarcz 1989; Gerry 1993, 1997 White et al. 1993, 1994, 2001, 2006a, 2006b; Reed 1994, 1999; Tykot et al. 1996; Wright and Schwarcz 1996; Wright 1994, 1997, 2006; Wright and White 1996; Whittington and Reed 1997; Coyston et al. 1999; Powis et al. 1999; White 1999, 2005; Henderson 2003; Mansell et al. 2006; Scherer et al. 2007; Metcalfe et al. 2009; Hill 2011; Parker 2011; Stronge 2012; Sommerville et al. 2013; Rand et al. 2015). Contextual and demographic information included in stable isotope studies give insight into the cultural practices and social life of the Maya, and aid in the identification of culturally significant dietary differences between individuals and groups. Dietary distinctions based on sex, age, and social class have been found to vary, but there are some observable trends. Elite members of society, usually defined by mortuary context, seem to consume more maize and more protein in comparison with the lower classes, but differences between sex or age are less commonly observed (White et al. 1993; Reed 1994; Coyston et al. 1999; Powis et al. 1999; Chase et al. 2001; Wright 2006; Scherer et al. 2007; Metcalfe et al. 2009; Rand 2011).

Due to poor preservation in the Maya region in general, uncertain burial context, and other environmental factors, it is not always possible to estimate sex, age, or status. The degradation of bone that often occurs in tropical environments hinders the ability to obtain demographic information for individuals. This further complicates the analysis for dietary differences among individuals, as full comparison cannot take place without this demographic information (Mansell et al. 2006; Rand et al. 2015).

Even without complete demographic information on individuals, there are many probative comparisons that can be made, including the variation in diet among the Maya at different locations and time periods. This variation is likely due to changing population size, environment, methods of food procurement, and shifting political alliances, which can cause disruptions in food production and distribution (Scherer et al. 2007). The availability of food stuffs is largely due to environmental availability. For example, groups living on islands relied heavily on marine items, and likely depended on trade to get the majority of their terrestrial meats and plants (Parker 2011). Another important environmental factor was the quality of farmlands. This influenced the production of maize, and likely an economic effect in turn, as maize was an important staple for many Maya sites across the region and throughout time (White et al. 2001; Mansell et al. 2006; Scherer et al. 2007; Stronge 2012; Rand et al. 2015). Table 4 and Figure 5 include the isotopic data from nine archaeological sites in Belize, two from Guatemala, one from Honduras, and two from Mexico, which serves as a comparison and as context for the Central Belize isotope data in this study. The sites are also displayed on a map in Figure 6. It is important to note that this data includes the isotopic means for each site, so it does not take into consideration possible differences based on age, sex, social status, or time period.

**Table 4.** Data averages for humans from a selection of archaeological sites in Belize, Guatemala, Honduras, and Mexico. Time period abbreviations: PrC=Preclassic, C=Classic, EC=Early Classic, LC=Late Classic, TC=Terminal Classic, PC=Postclassic

| Site | Time Period | Mean $\delta^{13}C_{col}$ | Mean $\delta^{15}N$ | Mean $\delta^{13}C_{carb}$ | Reference |
|---|---|---|---|---|---|
| Altun Ha, Belize | PrC-PC | -11.8 | 10.7 | -8.1 | White et al 2001 |
| Baking Pot, Belize | LC | -11.0 | 9.2 | -6.6 | Gerry 1993<br>Tykot 2002 |
| Barton Ramie, Belize | EC-LC | -11.2 | 8.8 | -7.4 | Gerry 1993<br>Tykot 2002 |
| Caledonia, Belize | EC-LC | -10.0 | 8.9 | -6.0 | Rand 2011 |
| Chau Hiix, Belize | EC-PC | -10.8 | 10.6 | -7.5 | Metcalfe et al. 2009 |
| Chac Balam & San Juan, Belize | LC-TC | -8.3 | 11.4 | -6.7 | Parker 2011 |
| Lamanai, Belize | EC-PC | -11.0 | 9.9 | -6.4 | White and Schwarcz 1989<br>Coyston et al. 1999 |
| Minanha, Belize | PrC-PC | -10.9 | 9.0 | -5 | Stronge 2012 |
| Pacbitun, Belize | EC-PC | -10.2 | 9.1 | -5.3 | White et al. 1993<br>Coyston et al. 1999 |
| Holmul, Guatemala | EC-LC | -9.4 | 9.3 | -4.3 | Gerry 1993 |
| Seibal, Guatemala | PrC-TC | -9.7 | 9.5 | -6.3 | Gerry 1993<br>Wright 1994 |
| Copán, Honduras | EC-LC | -10.2 | 9.4 | -5.3 | Gerry 1993<br>Reed 1998 |
| Chunchucmil, Mexico | EC-LC | -14.7 | 7.0 | -5.4 | Mansell et al. 2006 |
| Yaxuná, Mexico | EC-TC | -12.3 | 7.3 | -3.2 | Mansell et al. 2006 |

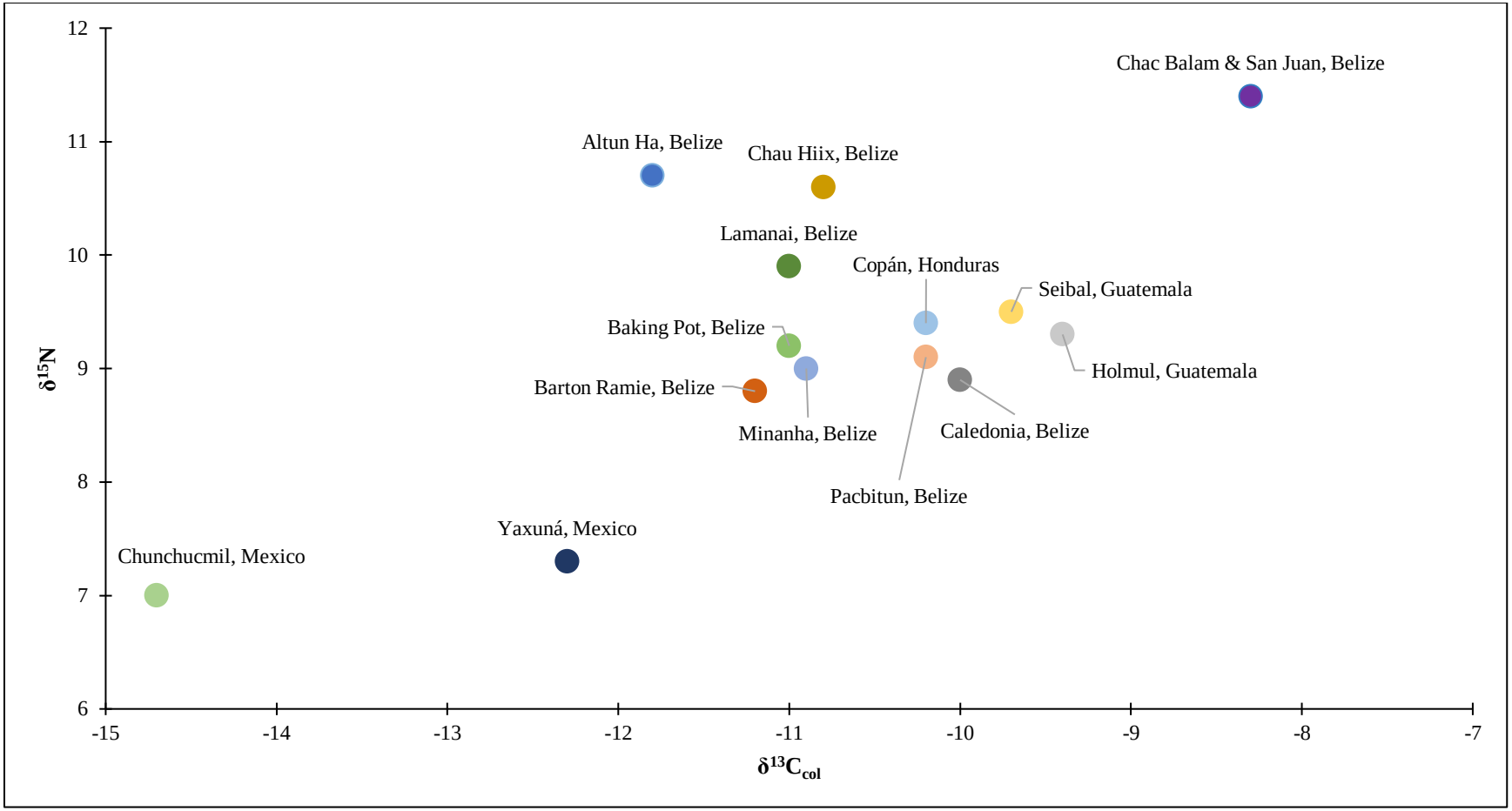


**Figure 5.** Biplot of average $\delta^{13}C_{col}$ and $\delta^{15}N$ data for humans from fourteen other Maya sites for comparison.

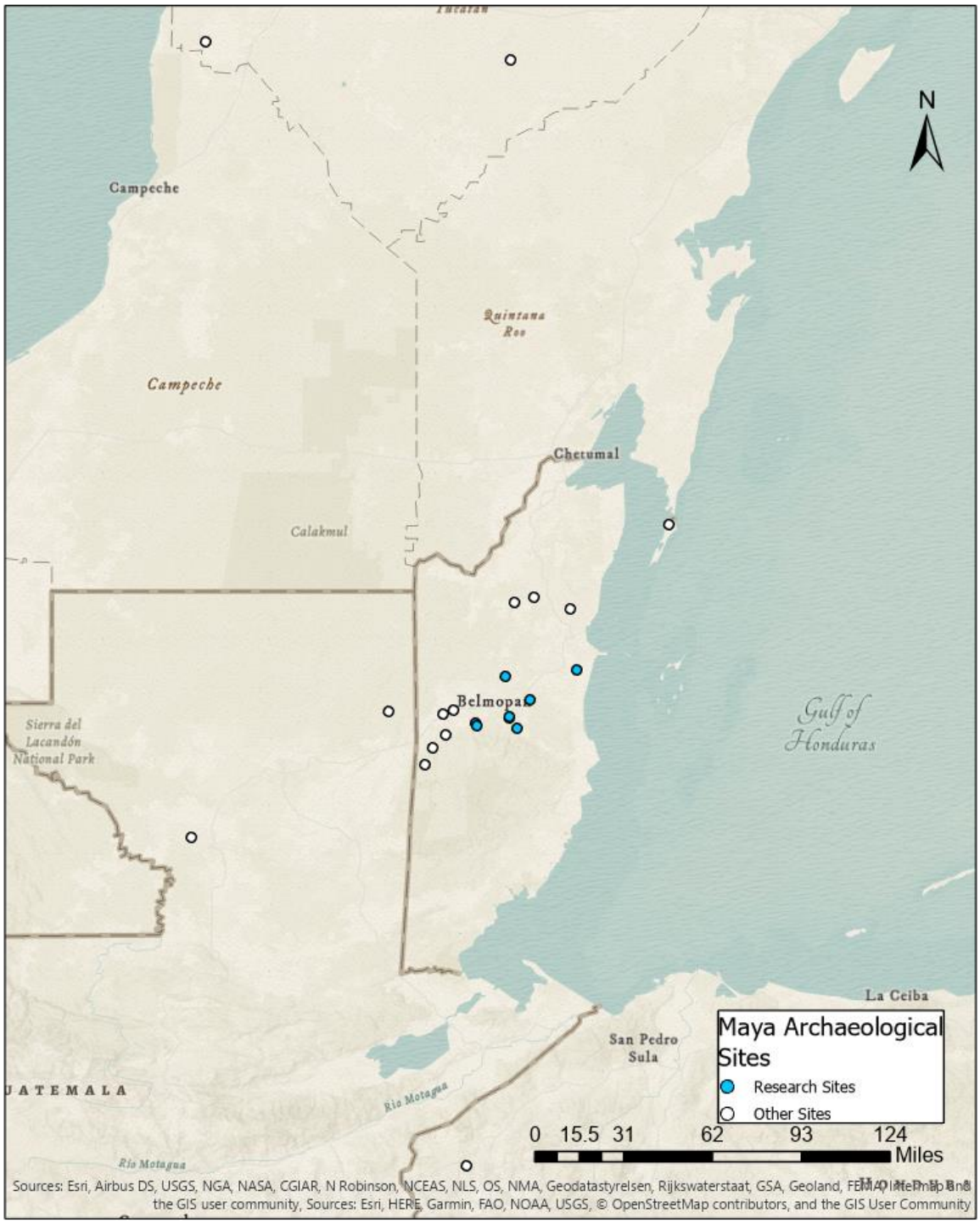


**Figure 6.** Map of the Maya area with the research sites in blue and the fourteen other Maya sites for comparison in white.

*Stable Isotope Data from a Sample of Other Archaeological Sites in Belize*

White et al.'s (2001) study at Altun Ha found that the individuals had a predominantly maize-based diet, with a relatively significant marine/reef dietary component. Located just 7 km from the Caribbean coast in Northern Belize, the residents at Altun Ha had a substantial relationship with the sea. It was also noted that high status individuals and males consumed a greater amount of $C_4$ foods, possibly including $C_4$ fed animals, than the lower status individuals and females. White et al. (2001) clarifies that the combination of macronutrients derived predominantly from maize, proteins, and lipids derived from marine/reef sources explains the low difference in $\delta^{13}C$ values between carbonate and collagen ($\Delta^{13}C_{carb\text{-}col}$) at this site.

The two Belizean sites included in Gerry's (1993) study were Baking Pot and Barton Ramie. Both are located in West-Central Belize, about 5 km from each other. Baking Pot was occupied from the Preclassic to Postclassic times, but most of the site was built during the Late Classic period. The residents at Baking Pot are believed to have been of higher social status than those at Barton Ramie. Barton Ramie is a good example of a rural settlement where Classic Period commoners lived, because of the lack of both large-scale public architecture and clear site boundaries. Gerry's (1993) study, which included 178 individuals from eight locations, found that biggest factor influencing diet was geographic location, and although the individuals analyzed from Baking Pot and Barton Ramie represent two different social classes, no significant differences were found between the two.

The isotopic data from Caledonia, a site in the Cayo district of Belize, suggests a diet dependent on maize, with evidence for the consumption of maize-fed terrestrial animals, as well as some $C_3$ fed terrestrial animals and freshwater mollusks. Four of the analyzed individuals exhibited $\Delta^{13}C_{carb\text{-}col}$ value**s** that may be the result of marine resource consumption. Rand (2011)

concludes that the isotopic values of the individuals of Caledonia were more similar to those found in the Pasión Valley region of Guatemala than many of the sites in Belize, and archaeological evidence suggests that Caledonia was influenced by the Petén of Guatemala. Rand (2011) hypothesizes that as a minor center under the influence of Caracol and the Petén, it is possible that the Maya at Caledonia were emulating both the material culture and the diet of these larger controlling sites.

Chac Balam and San Juan are two archaeological sites on Ambergris Caye, Belize's largest island. Parker (2011) concluded that the individuals at Chac Balam and San Juan were consuming a majority of foods from the sea, and supplemented their diet with terrestrial $C_3$ plants, $C_3$ fed animals, and small amounts of maize. The enriched $\delta^{13}C$ and $\delta^{15}N$ values and low $\Delta^{13}C_{carb\text{-}col}$ values are indicative of a diet based on marine resources, which would be typical for an island dwelling community.

Isotopic studies conducted on human remains from Lamanai (White and Schwarcz 1989; Coyston et al. 1999) found that the inhabitants were reliant on maize, but less so than other inland sites. They also consumed more aquatic and marine resources than other inland sites. Lamanai's location in northern Belize, near a diverse range of habitats with access to the Caribbean coast, provided Lamanai with a wide variety of foods.

The archaeological site of Minanha is found in the north Vaca Plateau of West-Central Belize, which is one of the least studied regions in the Maya area. The isotopic data collected by Stronge (2012) revealed that the individuals here had a diverse diet consisting of $C_3$ resources, including beans, tubers, and wild terrestrial animals, as well as $C_4$ resources, including maize and maize fed animals. The mean collagen ($\delta^{13}C_{col}$) and carbonate ($\delta^{13}C_{carb}$) $\delta^{13}C$ values suggest a greater reliance on the $C_4$ resources than $C_3$. The $\delta^{15}N$ values are consistent with the consumption

of terrestrial plants and lower-level terrestrial animals including deer, rabbit, agouti, peccary, and paca, which is also supported by faunal analyses from this site (Stronge 2012).

Pacbitun is located in the Cayo district of Belize. White et al. (2003) found that maize was significantly more important to the diet of the individuals here than at Lamanai, with up to 30% more maize or maize-feeding animals being consumed. White et al. (2003) consider that this distinction is caused by the limitations of local environments rather than any food preference or symbolism.

It is clear from the preceding section that the stable isotope analysis of skeletal material can provide an important data set for interpreting the constituents of diet of the ancient Maya, and that observed variation in these constituents can help archaeologists understand the relationship between food distribution and demographics/social status.

# Chapter 3: MATERIALS AND METHODS

## Materials

Skeletal materials were provided by Dr. Gabriel Wrobel, Director of the Central Belize Archaeological Survey (CBAS) and associate professor at Michigan State University. Samples were chosen based on availability. Because of poor preservation, the same bone element could not be analyzed for all individuals. This should not adversely affect the results of this analysis, however, because it has been established that the mean carbon and nitrogen isotopic values extracted from different bones within the same individual is not significantly different (DeNiro and Schoeninger 1983). The individuals in this study include 7 males, 4 females, and 28 individuals of unknown sex. Of those, 5 were juveniles, 26 were adults, and 18 individuals were of unknown age.

Skeletal samples were prepared and analyzed at the Center for Archaeology, Materials, and Applied Spectroscopy (CAMAS) at Idaho State University. Paired collagen and carbonate data were acquired from 18 samples of human bone and 29 samples of tooth dentin, representing 38 individuals (Table 5, with more information about individual burials in Appendix A). Carbonate data was acquired for samples of tooth enamel from each of the 29 teeth as well. Of the 38 individuals from which data was successfully attained, nine had paired samples of bone and tooth from the same individual.

To create a local foodweb, collagen was extracted from twenty-four samples of animal bone as well (Appendix B). Unfortunately, the animal bones sampled were much more poorly preserved than the human samples, and nineteen of the samples were unusable. The creation of a site-specific foodweb was not possible in this project due to the low number of usable samples.

A proxy foodweb was constructed for this analysis using data compiled from other studies conducted in the Maya area (Figure 4).

**Table 5.** Sex, age, and sample type information for each site.

| Site | #M, #F, #? | #Juv., #Adult, #? | Sample Type |
|---|---|---|---|
| Pakal Na | 7, 0, 1 | 0, 7, 1 | 3 bones, 5 teeth |
| Augustine Obispo | 2, 0, 0 | 0, 2, 0 | 1 bone, 1 tooth |
| Hershey | 0, 0, 6 | 1, 0, 5 | 3 bones, 3 teeth |
| Pook's Hill | 4, 0, 5 | 0, 8, 1 | 4 bones, 5 teeth |
| Caves Branch Rockshelter | 0, 3, 3 | 2, 4, 0 | 6 bones, 0 teeth |
| Sapodilla Rockshelter | 2, 0, 1 | 0, 3, 0 | 0 bones, 3 teeth |
| Kaax Tsaabil | 0, 1, 0 | 0, 1, 0 | 1 bone, 0 teeth |
| Actun Kabul | 0, 0, 12 | 2, 1, 9 | 0 bones, 12 teeth |

Collagen Extraction Protocol

A whole-bone collagen extraction method was used for this project. This method was chosen because it allows for closer monitoring of more poorly preserved samples. At least 150 mg of bone or tooth dentin was weighed out and put into ashed borosilicate glass tubes. To achieve a sample size of 150 mg, the samples were cut with a Dremel tool. The teeth were sectioned by separating the crown from the root, to only sample the apical portion of the root, which will represent the post-weaning diet. Eight mL of a 2:1 mixture of chloroform-methanol, the purpose of which is to extract lipids from the sample, was added to the tubes and placed in

the fume hood. After 8 hours, the samples were decanted and allowed to dry in the fume hood overnight. Once all the chloroform-methanol had evaporated, the samples were placed on 0.2-0.3M hydrochloric acid (HCl) at room temperature until the release of $CO_2$ was no longer observed and the bone was demineralized. This step removed all inorganic biomineral from the samples and took between one and 20 days. The HCl was decanted and the samples were rinsed with 18MΩ water at least three times, until the samples were back to neutral pH. Thoroughly rinsing every sample is a crucial step, as this prevents salt formation (e.g., NaCl, $CaCl_2$) which can occur when mixing residual amounts of HCl and sodium hydroxide (NaOH). Afterward, the samples were soaked in 0.1M NaOH for 20 hours at room temperature to remove soil contaminants, such as humates or other soil-derived acid complexes. After 20 hours, they were decanted and rinsed three more times with 18MΩ water, until the samples were back to neutral pH again. Finally, the samples were gelatinized in 0.01M HCl at 70°C for sixteen to twenty-four hours. The gelatinized samples were then filtered using Millex-HV 0.45 µm filters into frozen scintillation vials. The samples were frozen overnight and then freeze-dried for at least 48 hours. Approximately 0.5 mg of each collagen sample was weighed out into tins for analysis on a Costech Elemental Analyzer routed onto a ThermoScientific Delta Advantage stable isotope ratio mass spectrometer (IRMS) (Waltham, MA USA; Coleman, 2012) at CAMAS.

Carbonate Extraction Protocol

*Bone and Tooth Dentin*

Carbonate extraction utilized approximately 20 mg of powdered bone or tooth dentin. The samples were ground using a mortar and pestle, and then placed into 2 mL tubes with 0.8 ml of 2% bleach (approximately 0.04 mL per mg of sample). The samples soaked in bleach at room temperature for two days, and the bleach was replaced with fresh bleach after 24 hours. After 48

hours, the bleach was poured off the samples and they were rinsed with 18MΩ water three times. They were then placed on 0.8 ml of 0.1M acetic acid for four hours. After the four hours, they were rinsed with 18MΩ water three more times, and placed in the drying oven at 60° C until dry. Approximately 1.5 mg of each bone/dentin carbonate sample was weighed out for analysis on a GasBench II routed onto the IRMS at CAMAS.

*Enamel*

The surface of the enamel was first cleaned using a Dremel tool to remove the outer layer of calculus and expose the clean enamel underneath. This powder was discarded, and approximately 10 mg of enamel was collected for carbonate extraction using a clean Dremel tip. The samples were powdered using a mortar and pestle when large pieces were present due to chipping. The powders were placed into 2 mL tubes and 0.4 ml of 2% bleach were added and left to soak for 24 hours. After 24 hours, the samples were rinsed with 18MΩ water three times. They were then placed in 0.4 mL 0.1M acetic acid for four hours. After the four hours, they were rinsed with 18MΩ water three more times, and placed in the drying oven at 60° C until dry. Approximately 1.5 mg of each enamel carbonate sample were used for IRMS analysis.

Testing for Preservation

After burial, many different factors can affect the preservation of bone. Length of time of the burial, soil microenvironment, and weathering conditions including pH, soil moisture, and heat all may negatively affect the ability to retain accurate isotope ratios from bone. When bone has undergone diagenesis, the post-mortem biomolecular changes caused by time and burial context, the stable isotope values may no longer reflect diet, but instead reflect the post-depositional environment and/or chemical alteration of bone due to diagenetic processes. Various

analytical techniques have been developed to investigate the effects on the isotopic ratio changes that occur in archaeological bone and teeth.

*Collagen*

Although collagen can be preserved within bone long after burial, it is not entirely resistant to diagenetic alteration. Three different quality indicators of collagen preservation are used for this study, including measuring the collagen yield, the carbon to nitrogen ratio, and the carbon and nitrogen content in each sample. These three techniques determine if a sample is well-preserved or if it has been contaminated by exogenous materials.

Collagen yield is calculated by dividing the weight of the final collagen product by the original weight of the sample. A sample that has a collagen yield above 1% is considered well-preserved and able to produce accurate isotopic data (White et al. 1993; van Klinken 1999). When the collagen yield falls below 0.5%, it is believed that the contamination of the sample is difficult to remove (van Klinken 1999). Studies have shown that modern animal collagen has nitrogen concentrations (wt % N) between 5.5% and 17.3% and carbon concentrations between 15.3% and 47% (Ambrose 1990:441), though it is acceptable for archaeological samples to have a wt % C as low as 13%, and wt % N as low as 4.8% (Ambrose 1990; Ambrose and Norr 1993). The atomic C:N ratio, another measure of sample integrity, can be found using the ratio of carbon to nitrogen in the sample. Modern bone samples have atomic C:N ratios between 2.9 and 3.6 (DeNiro 1985). If the collagen sample falls within these ideal ranges, it is believed to be well preserved and suitable for isotopic analysis.

*Carbonate*

Fourier transform infrared (FTIR) spectroscopy has recently been used to examine diagenetic alteration of powdered bone samples. Attenuated total reflection (ATR-FTIR) was used for this study to directly examine the powders with minimal preparation. The crystallinity index (CI), or splitting factor, is a measure of the relative size of the crystals and order of the atoms within a bone (Weiner and Bar Yosef 1990). Figure 7 shows an example of FTIR-ATR spectra for tooth dentin. CI values will increase when a bone has undergone diagenesis because the crystal structures have become larger and more organized. The CI range for modern human bone is between 2.8 and 4.0, and any value above 4.0 is considered to have been altered (Wright and Schwarcz 1996). For tooth enamel, the CI range for modern samples is between 3.8 and 4.4 (Keenleyside et al. 2011). It is expected that archaeological bone will have a greater CI than modern bone due to diagenetic processes (Weiner and Bar-Yosef 1990). The crystallinity indices from this experiment are in Appendix D.

Statistical Analyses

Data management and analysis were performed using Microsoft Excel and JMP Pro 14 predictive analytics software. On JMP, Analysis of Variance (ANOVA) tests were performed to determine if the differences between the sets of variables were significant. If the ANOVA indicated that the differences were significant, another test, called the Tukey's Honest Significant Difference test, was performed. While the ANOVA can determine if a statistically significant difference is present within the sample set, it cannot tell you where the differences lie. This is where the Tukey test is helpful, because it will determine which specific group's means are different from the others.

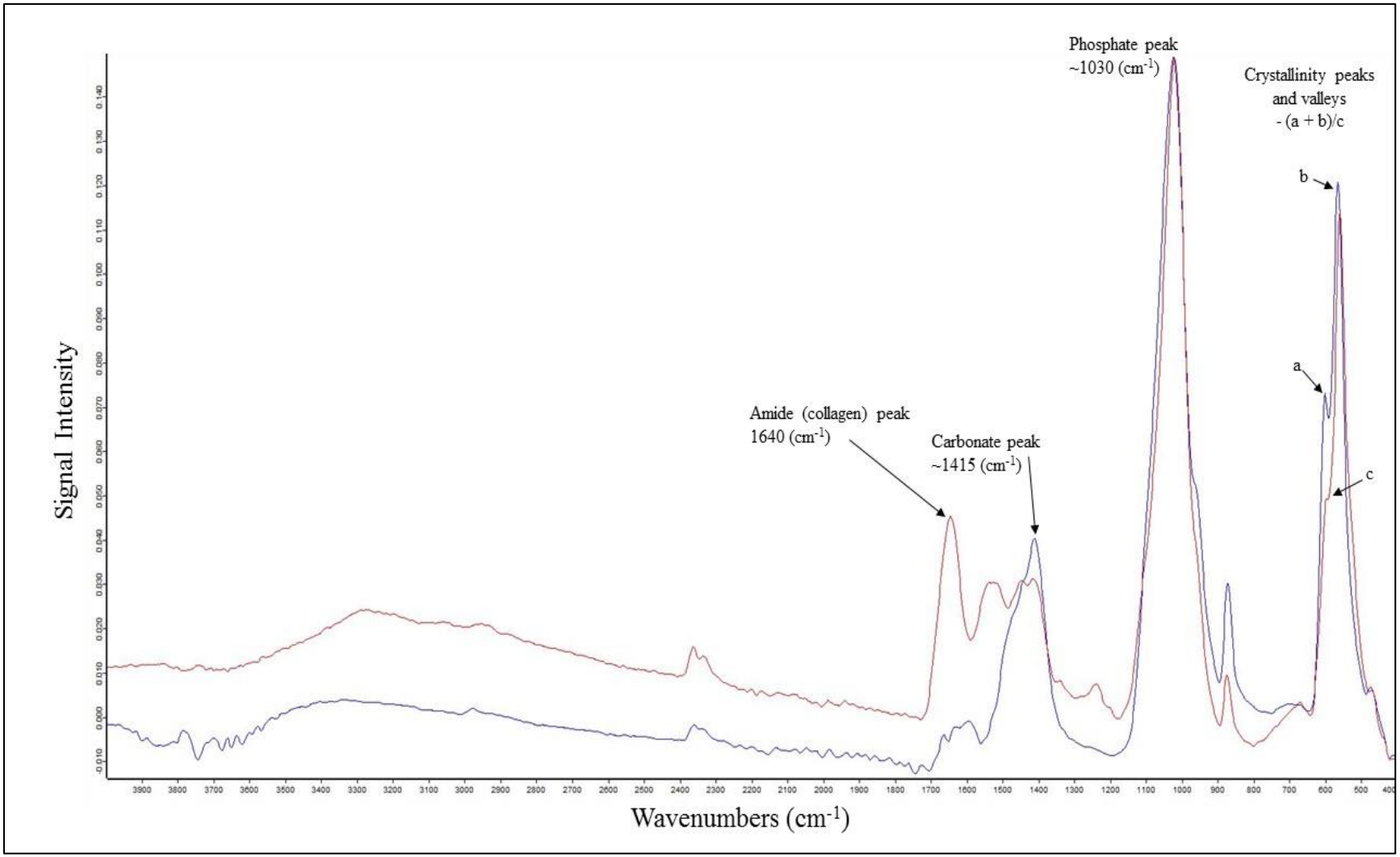


**Figure 7.** FTIR-ATR spectra for a modern dentin sample (red) and archaeological dentin sample (blue) demonstrating peaks of interest for measures of preservation.

# Chapter 4: RESULTS

## Sample Preservation

### *Collagen Samples*

Nine of the human samples and 19 of the faunal samples produced no collagen, though all of the samples for which collagen data was acquired met all of the criteria for sample preservation (see Appendix A). The collagen yield for the human samples ranged from 1% to 14.6% with a mean of 7.5 ± 3.5%. For the five animal samples, the collagen yields ranged from 3.7% to 5.8% with a mean of 4.5 ± 0.9%. All had acceptable collagen yields at 1% or above. The atomic C/N ratios for humans ranged from 3.2 to 3.4 with a mean of 3.2 ± 0.1, and ranged from 3.3 to 3.4 with a mean of 3.3 ± 0.0 for animals, which all fall within the acceptable range of 2.9 to 3.6 (DeNiro 1985). For humans, carbon content (wt % C) ranged from 14.3% to 43.2% with a mean of 38.8 ± 6.9%, and nitrogen content (wt % N) ranged from 4.9% to 16.0% with a mean of 14.0 ± 2.6 %. For animals, the wt % C ranged from 13.5% to 40.5% with a mean of 34.4 ± 11.7% and the wt % N ranged from 4.9% to 14.4% with a mean of 12.1 ± 4.0%. All of these values fall within acceptable ranges (above 4.8% for carbon content and above 13% for nitrogen), and none were excluded from this study.

### *Carbonate Samples*

The human bone carbonate samples that were analyzed using FTIR-ATR had crystallinity indices (CI) that ranged from 3.9 to 5.1 with a mean of 4.4 ± 0.3 (see Appendix C). The CI for tooth dentin samples ranged from 3.9 to 5.2 with a mean of 4.3 ± 0.3. The CI for the enamel samples ranged from 3.9 to 4.5 with a mean of 4.1 ± 0.2. Only one of the bone samples had a CI of 4.0 or below, ten out of 29 tooth dentin samples had a CI of 4.0 or below, and 26 of the 29 enamel samples had a CI of 4.4 or below. There was no correlation found between the CI and the

$\delta^{13}C_{carb}$ values (p=0.2518, $r^2$:0.029), but a weak correlation was found between the CI and the $\delta^{13}C_{en}$ values (p=0.0528, $r^2$:0.132), as is shown in Figure 8.

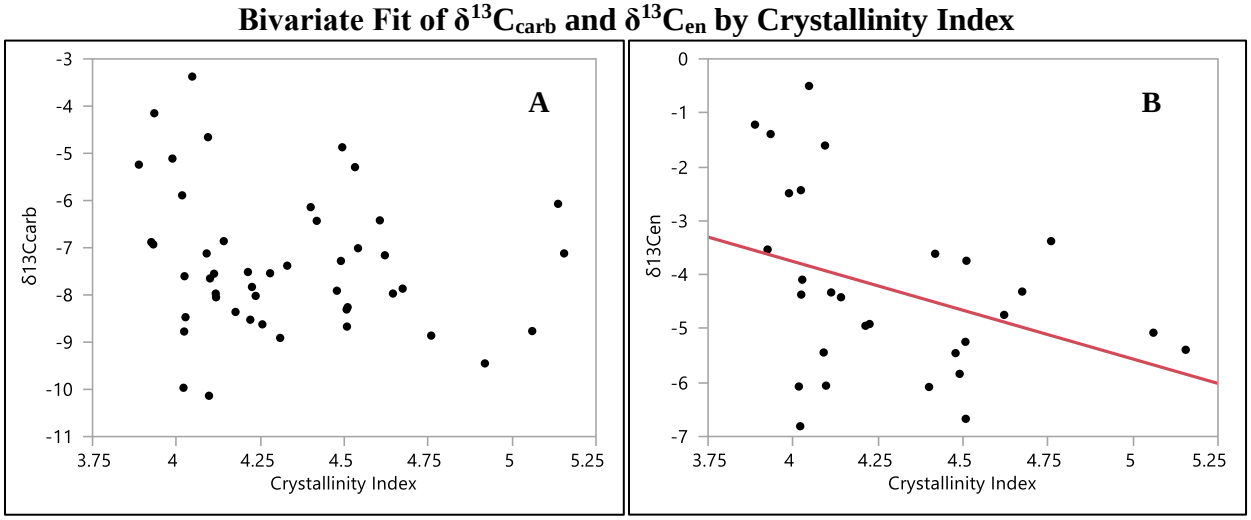


**Figure 8.** (A) bivariate plot of $\delta^{13}C_{carb}$ by Crystallinity index, and (B) bivariate plot of $\delta^{13}C_{en}$ by Crystallinity index.

Stable Isotope Results

The mean $\delta^{13}C_{col}$ value for all samples is -10.63 ± 1.50‰ (n=47) with a range between -14.35 and -7.43‰. The mean $\delta^{15}N$ value for all samples is 8.88 ± 0.73‰ (n=47) with a range between 7.38 and 10.73‰. The mean $\delta^{13}C_{carb}$ value for all samples is -7.34 ± 1.48‰ (n=47) with a range between -10.14 and -3.37. The mean $\delta^{13}C$ value for enamel carbonates ($\delta^{13}C_{en}$) -4.28 ± 1.68‰ (n=29) with a range between -6.81 and -0.50‰. Averages for each site can be found in Tables 6, and 7, and the full results for each individual can be found in Appendix B.

**Table 6.** Data averages for $\delta^{15}N$, $\delta^{13}C_{col}$, $\delta^{13}C_{carb,}$ and $\delta^{13}C_{en}$ for all samples combined and for each site separately.

| Site | N | Mean $\delta^{15}N$ (‰) | Mean $\delta^{13}C_{col}$ (‰) | Mean $\delta^{13}C_{carb}$ (‰) | N | Mean $\delta^{13}C_{en}$ (‰) |
|---|---|---|---|---|---|---|
| All samples | 47 | 8.88±0.73 | -10.63±1.50 | -7.34±1.48 | 29 | -4.28±1.68 |
| Pakal Na | 8 | 9.41±0.35 | -8.55±0.90 | -4.85±0.81 | 5 | -1.44±0.72 |
| Augustine Obispo | 2 | 10.01 | -11.66 | -9.06 | 1 | -6.67 |
| Hershey | 6 | 8.77±1.12 | -10.40±0.79 | -7.94±0.75 | 3 | -4.12±0.61 |
| Pook's Hill | 9 | 8.53±0.61 | -11.18±1.08 | -7.39±0.61 | 5 | -4.74±0.78 |
| Kaax Tsaabil | 1 | 9.04 | -11.95 | -7.97 | 0 | -- |
| Caves Brach Rockshelter | 6 | 8.88±1.00 | -12.30±1.66 | -7.77±0.79 | 0 | -- |
| Sapodilla Rockshelter | 3 | 8.76±0.38 | -10.64±0.55 | -6.30±0.50 | 3 | -5.52±0.96 |
| Actun Kabul | 12 | 8.68±0.49 | -10.60±1.06 | -8.37±0.98 | 12 | -4.80±1.23 |

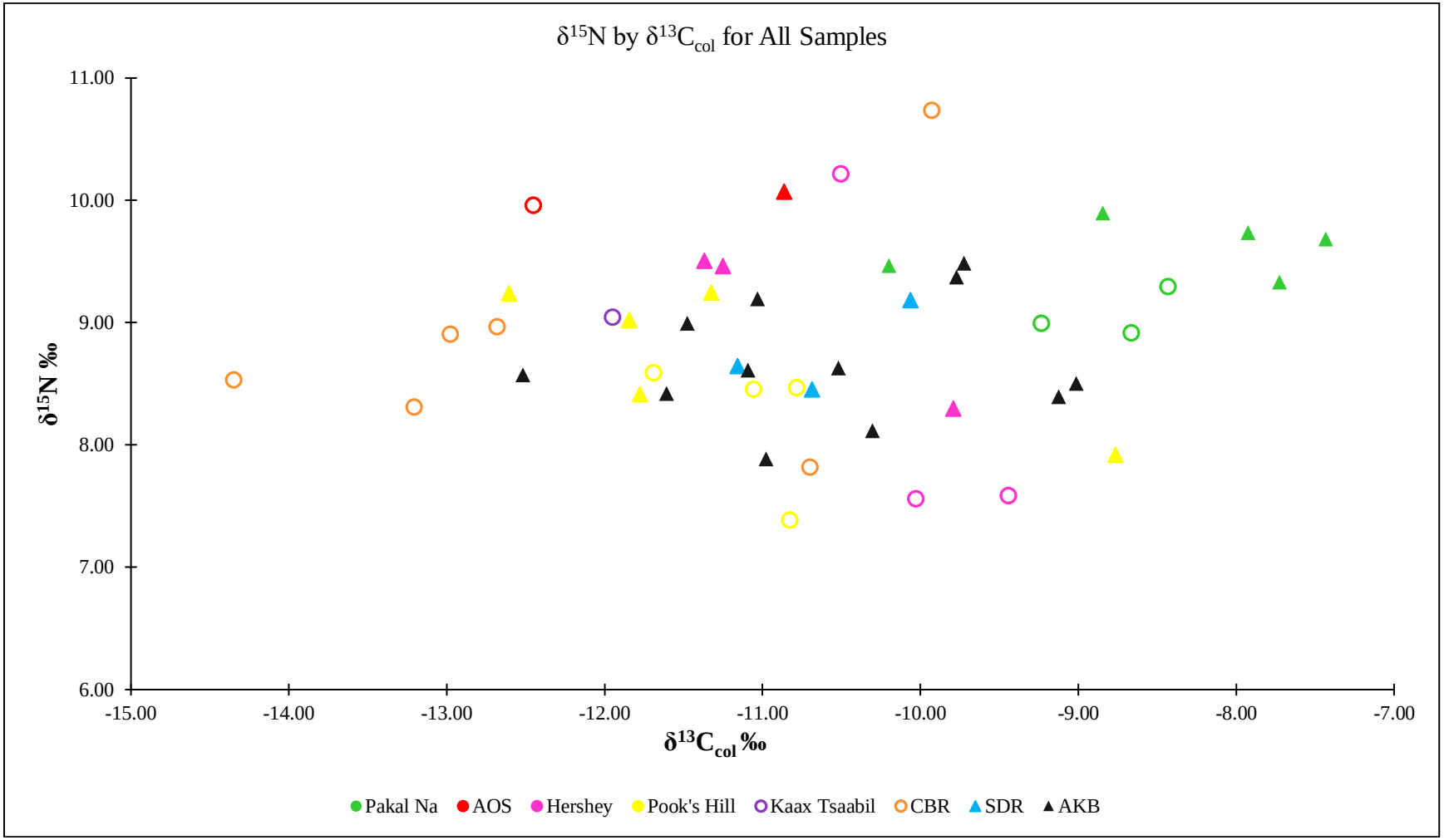


**Figure 9.** Biplot of $\delta^{13}C_{col}$ and $\delta^{15}N$ results for 47 samples. Samples of tooth dentin are marked by triangles and samples of bone are marked by circles.

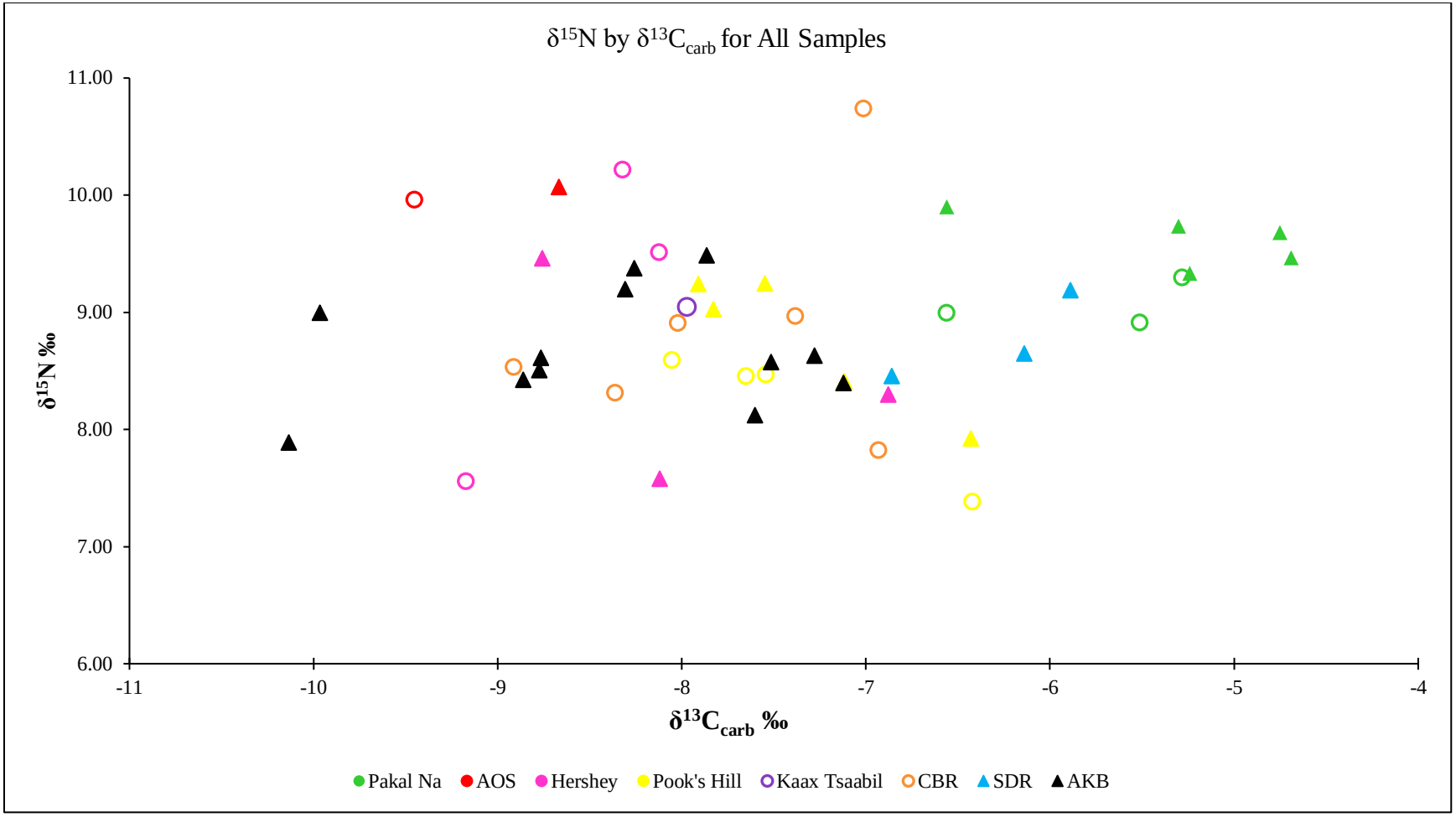


**Figure 10.** Biplot of $\delta^{13}C_{carb}$ and $\delta^{15}N$ results for 47 samples. Samples of tooth dentin are marked by triangles and samples of bone are marked by circles.

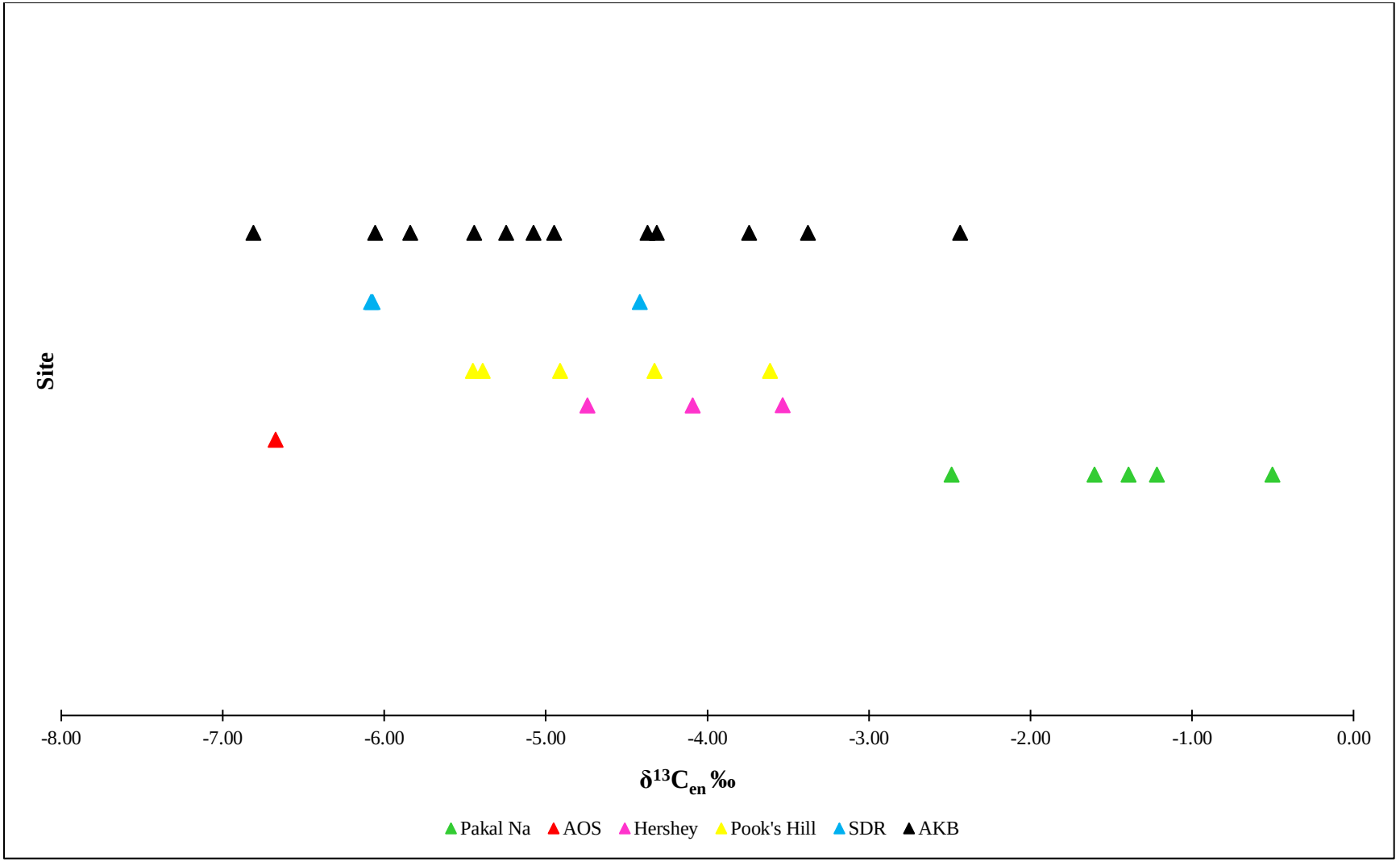


**Figure 11.** $\delta^{13}C_{en}$ results for 29 samples.

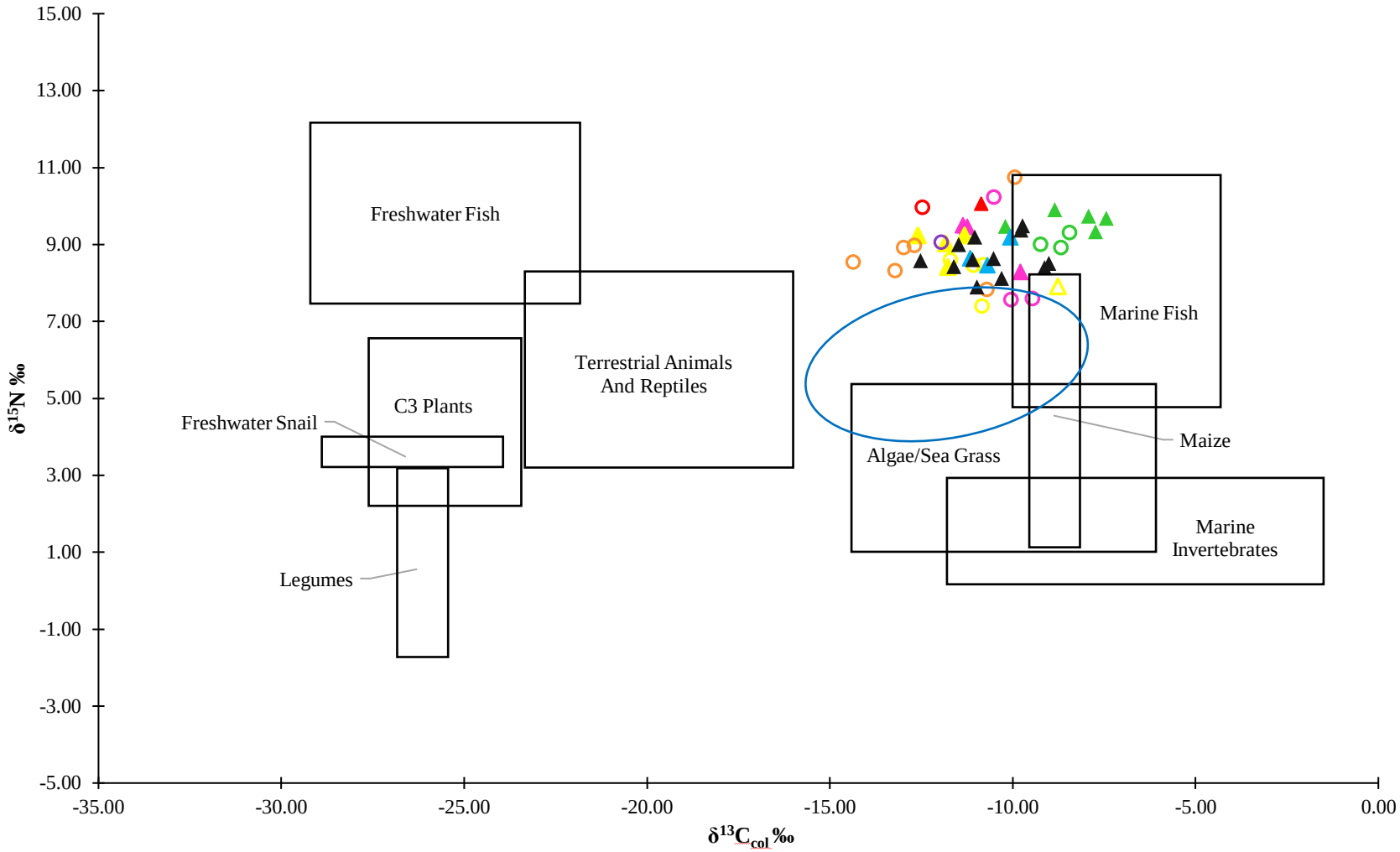


**Figure 12.** Maya foodweb with raw human data from this study and an ellipse showing correction for diet (adjusting -3‰ for fractionation between trophic levels for $\delta^{15}N$ and -1‰ fractionation between trophic levels for $\delta^{13}C_{col}$).

## Diet Reconstruction

### *Maya Foodweb*

Figure 12 displays the raw $\delta^{15}N$ and $\delta^{13}C_{col}$ data plotted onto the generalized Maya foodweb. An ellipse was also added to adjust the isotopic composition by one trophic level to allow for direct comparisons to diet. To estimate the isotopic composition of the diet, the raw $\delta^{15}N$ values were adjusted -3‰ and the raw $\delta^{13}C_{col}$ values were adjusted -1‰ to account for trophic level fractionation (DeNiro and Epstein 1981; Schoeninger and Moore 1992). Based on this foodweb, it appears that these individuals had variable diets that were higher in $C_4$ and/or marine resources compared to $C_3$ and freshwater sources.

### *Froehle et al. Multivariate Isotope Model for Diet*

A multivariate isotope model by Froehle and colleagues (2012) incorporates collagen $\delta^{15}N$ values, $\delta^{13}C_{col}$ values, and $\delta^{13}C_{carb}$ values from each sample. This model was utilized because bivariate models using only $\delta^{13}C_{col}$ and $\delta^{13}C_{carb}$ values suffered from an inability to distinguish the difference between $C_4$ consumers and marine consumers, as both have similar (and higher) $\delta^{13}C$ ratios. The $\delta^{15}N$ value was added to help solve this problem as it may help separate terrestrial from marine resources.

Individuals from this data set were plotted using the model and functions from Froehle et al. (2012) in Figure 13. According to this model, most individuals fall within cluster two, indicating that they had a diet consisting of 70% $C_4$ overall with around 50% of the protein coming from $C_4$ sources. There is overlap between clusters 2 and 5, however, with some individuals from Pook's Hill, Kaax Tsaabil, AKB, and CBR falling within this overlap. Cluster 5 indicates a diet of 70% $C_4$ overall with greater than 65% of the protein coming from $C_3$ sources.

Three of the individuals from CBR fall firmly within cluster 5. One individual from Pakal Na falls outside the known diet clusters (the tooth sample from Pakal Na Burial 1A/1C).

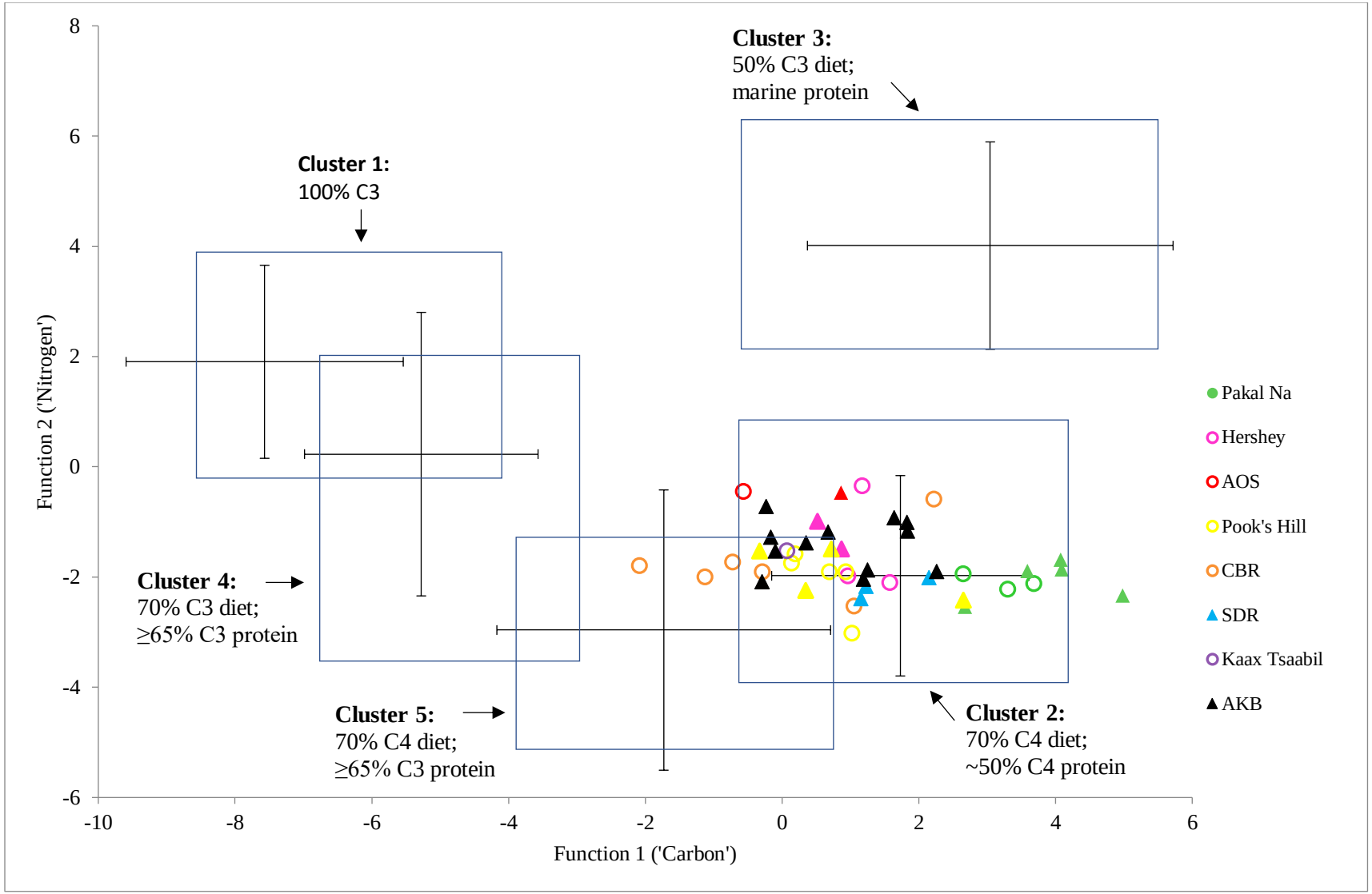


**Figure 13.** F1 and F2 discriminant function values from individuals in this data set. Model and functions provided by Froehle et al. (2012). Samples of tooth dentin are marked by triangles and samples of bone are marked by circles, with each color representing a different site.

Research Question 1: Geographical Differences in Diet

Statistical tests were conducted to test the question regarding differences in diet for the sampled individuals based on geographic differences. Tests were run on bones and teeth separately because some individuals were represented by both sample types, and also so differences related to age would not factor into the interpretation. Analyses compared the isotopic differences between each site, excluding AOS and Kaax Tsaabil, because their sample sizes were too small. Many differences were found between Pakal Na and the other sites, and significant differences were also found for $\delta^{13}C_{carb}$ between SDR and AKB.

*Differences between each site- $\delta^{13}C_{col}$*

A large amount of variation was found in the $\delta^{13}C_{col}$ values within the bone samples at CBR, and within the tooth samples at AKB, Pakal Na, and Pook's Hill. Pakal Na had the highest values in both bone and tooth dentin samples. For the bone samples, analysis of variance (ANOVA) detected a statistically significant difference in $\delta^{13}C_{col}$ between the sites ($p=0.0047$, $r^2$:0.647), and Tukey's honestly significant difference (HSD) test determined that the differences were found between Pakal Na and Caves Branch Rockshelter ($p=0.0039$) (Figure 14). ANOVA detected significant differences in $\delta^{13}C_{col}$ for the tooth samples as well ($p=0.0049$, $r^2$:0.463) and Tukey's HSD test determined that the differences were found between Pakal Na and Pook's Hill ($p=0.0040$) and Pakal Na and Actun Kabul ($p=0.0096$) (Figure 15).

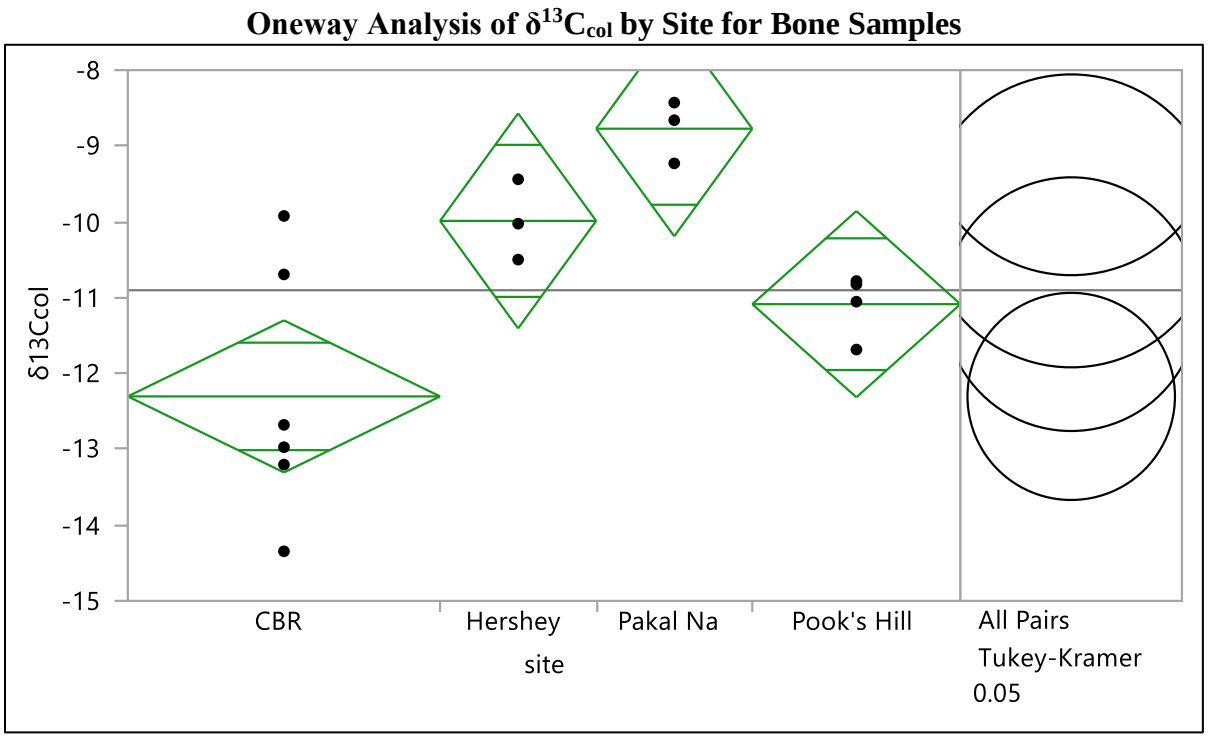


**Figure 14.** Oneway Analysis of $\delta^{13}C_{col}$ by site for bone samples only.

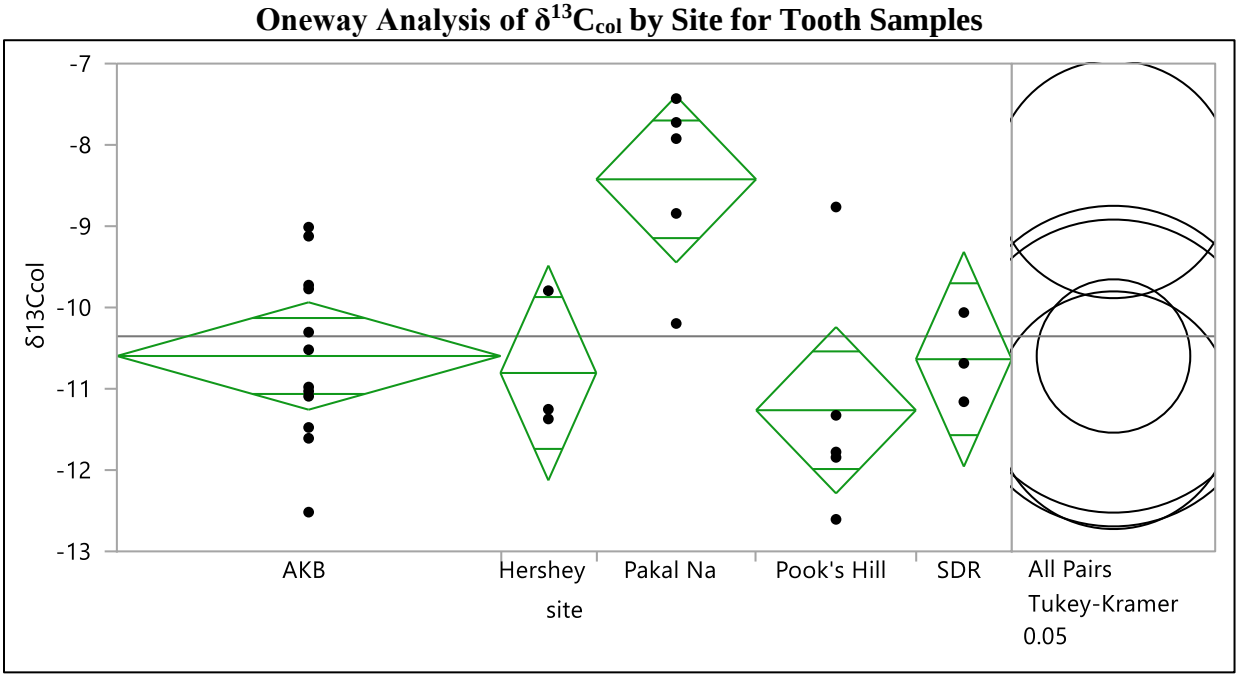


**Figure 15.** Oneway Analysis of $\delta^{13}C_{col}$ by site for tooth samples only.

*Differences Between Each Site- $\delta^{13}C_{carb}$*

Pakal Na had the highest values for the $\delta^{13}C_{carb}$ values in bone and dentin samples. CBR showed a large range of variation for the bone samples and AKB showed a large range of variation in the tooth samples. For the bone samples, ANOVA detected a statistically significant difference in $\delta^{13}C_{carb}$ between the sites (p=0.0009, $r^2$:0.734), and Tukey's HSD test determined that the differences were found between Pakal Na and Hershey (p=0.0009), Pakal Na and CBR (p=0.0018), and Pakal Na and Pook's Hill (p=0.0109) (Figure 16). ANOVA detected significant differences in $\delta^{13}C_{carb}$ for the tooth samples as well (p=<0.0001, $r^2$:0.773) and Tukey's HSD test determined that the differences were found between Pakal Na and AKB (p=<0.0001), Pakal Na and Hershey (0.0006), Pakal Na and Pook's Hill (p=0.0002) and SDR and AKB (p=0.0072) (Figure 17).

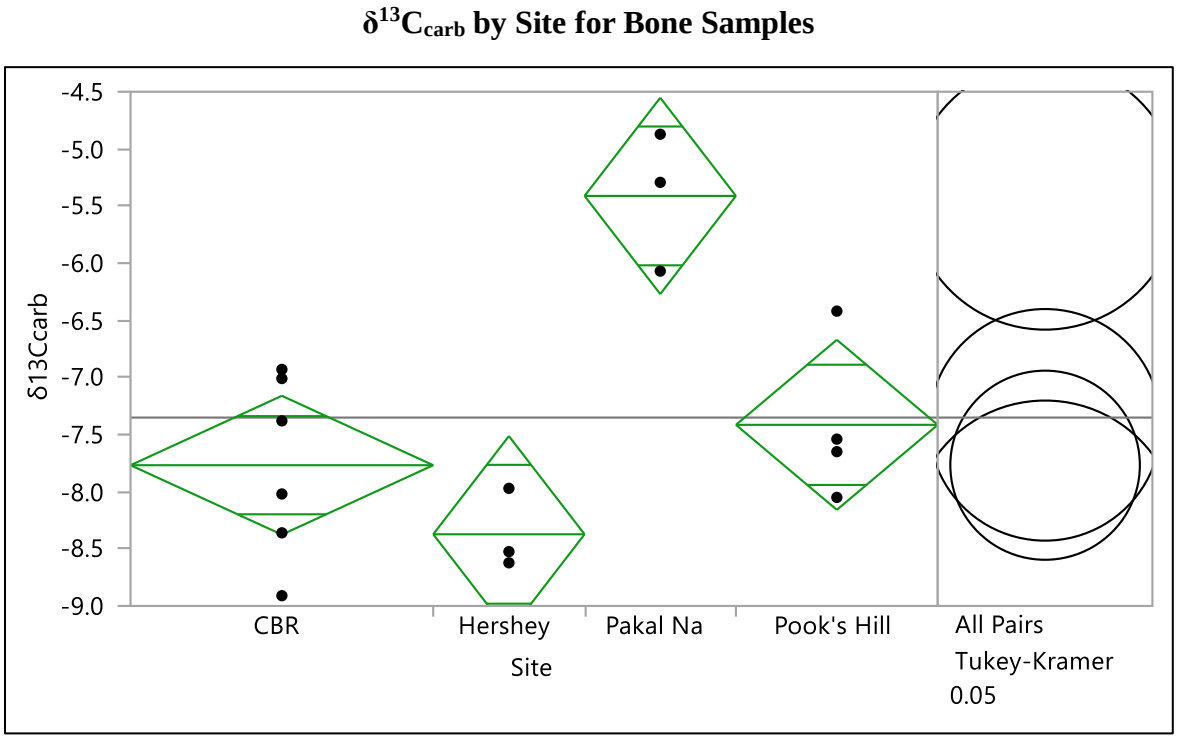


**Figure 16.** Oneway Analysis of $\delta^{13}C_{carb}$ by site for bone samples only.

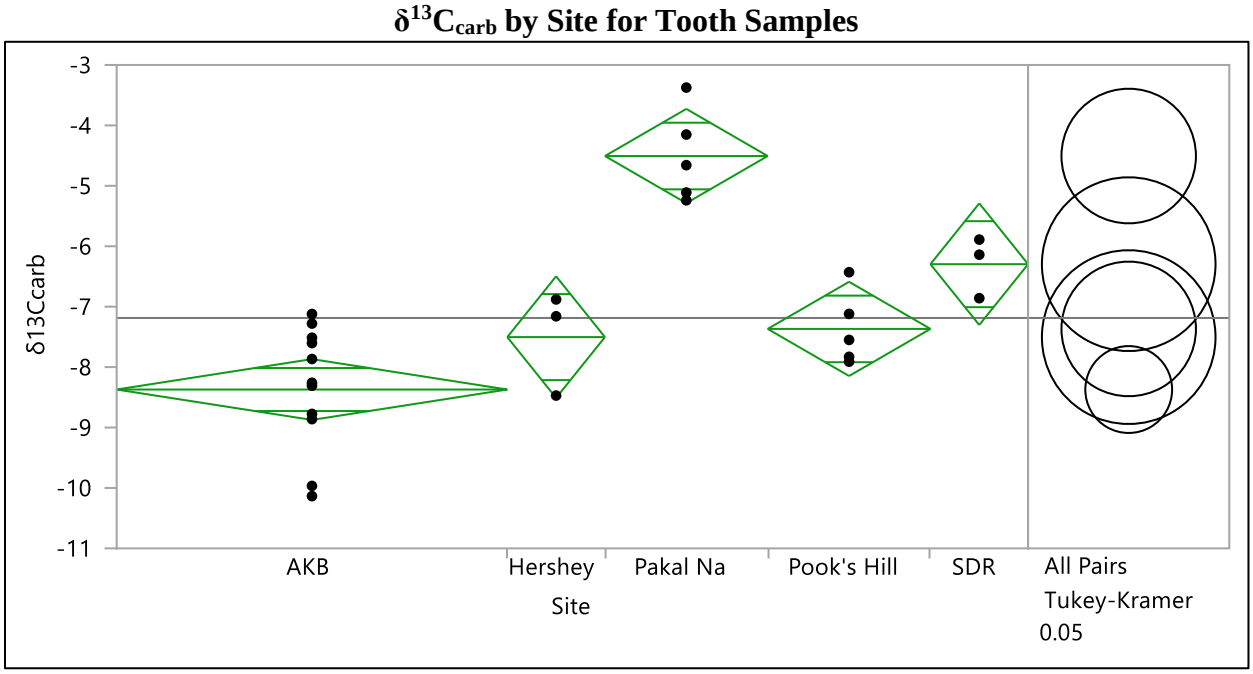


**Figure 17.** Oneway Analysis of $\delta^{13}C_{carb}$ by site for tooth samples only.

*Differences Between Each Site- $\delta^{13}C_{en}$*

The $\delta^{13}C_{en}$ values for AKB demonstrated high variability. Pakal Na included the highest $\delta^{13}C$ values. ANOVA detected a statistically significant difference in $\delta^{13}C_{en}$ values between the sites ($p=<0.0001$, $r^2$:0.676), and Tukey's HSD test found that the differences were between Pakal Na and all other sites included in the test: Pakal Na and SDR ($p=0.0001$), Pakal Na and AKB ($p=<0.0001$), Pakal Na and Pook's Hill ($p=0.0003$), and Pakal Na and Hershey ($p=0.0112$). No other statistically significant differences were found between the other sites (Figure 18).

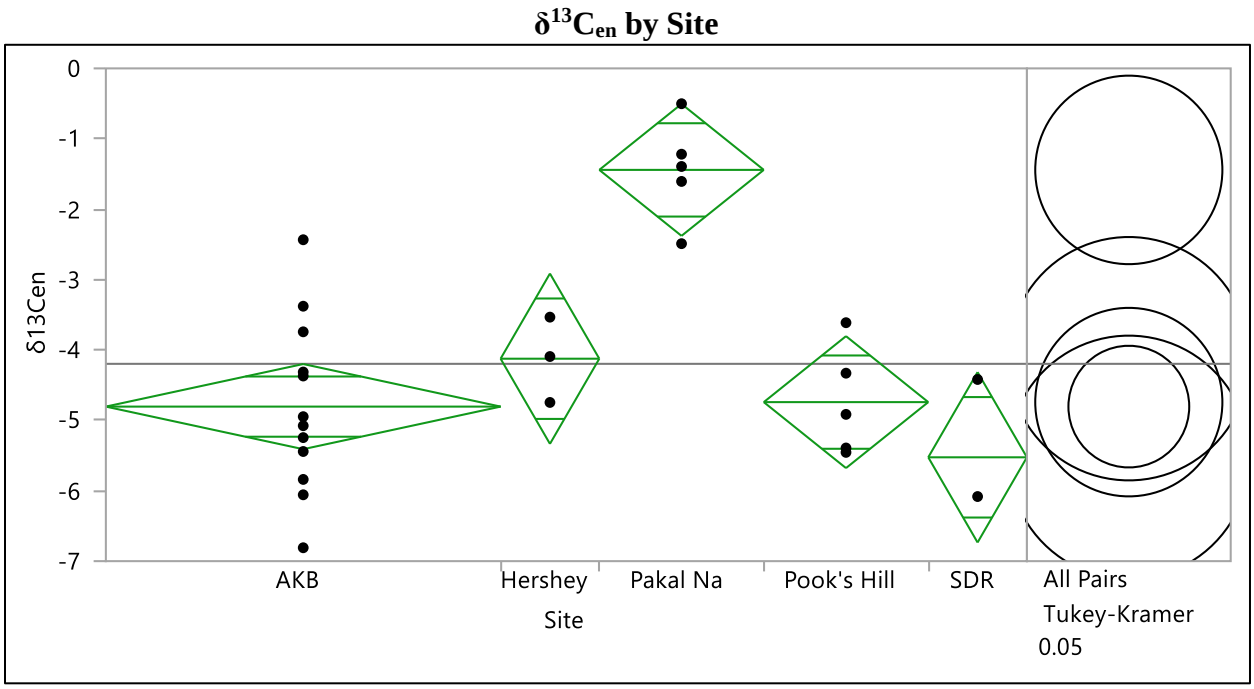


**Figure 18.** Oneway Analysis of $\delta^{13}C_{en}$ by site.

*Differences Between Each Site- $\delta^{15}N$*

The highest $\delta^{15}N$ value for the bone samples was found at CBR, but the CBR and Hershey values were variable. For the tooth samples, high variability was also seen at AKB, Hershey, and Pook's Hill. ANOVA failed to detect any significant difference in $\delta^{15}N$ values for the bone samples ($p=0.6129$, $r^2$:0.135) (Figure 19). For tooth samples, ANOVA did find significant differences ($p=0.0205$, $r^2$:0.384), and Tukey's HSD test found that the differences were between Pakal Na and Actun Kabul ($p=0.0113$) (Figure 20).

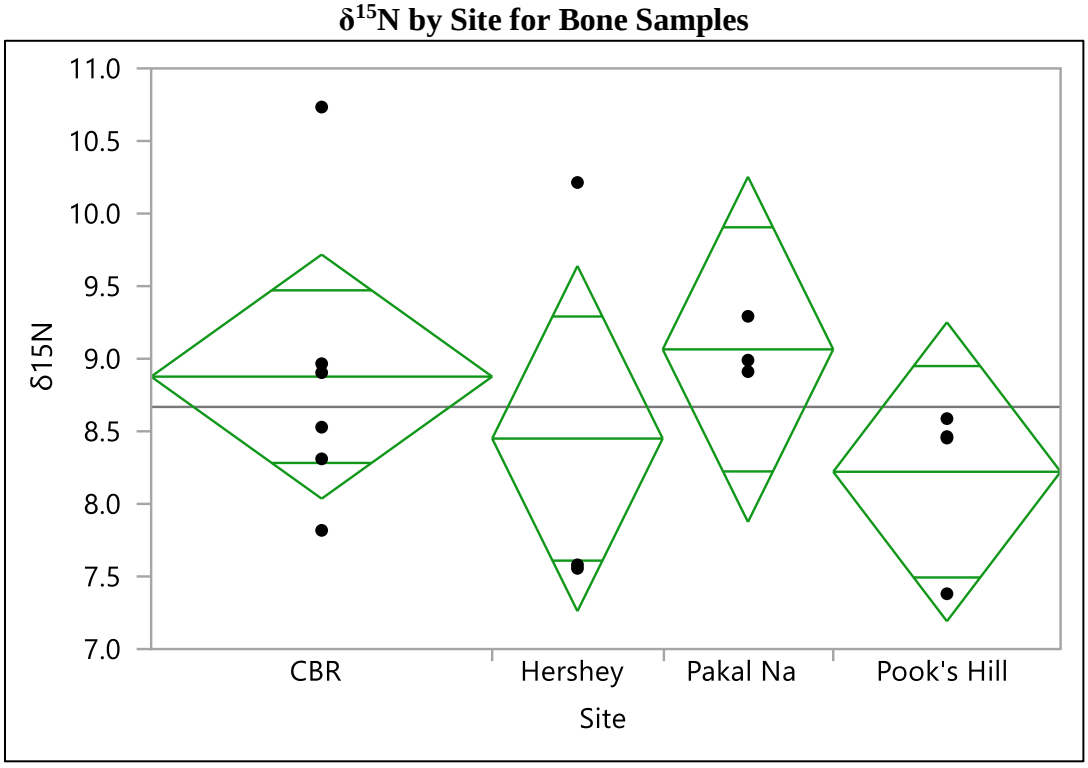


**Figure 19.** Oneway Analysis of $\delta^{15}N$ by site for bone samples only.

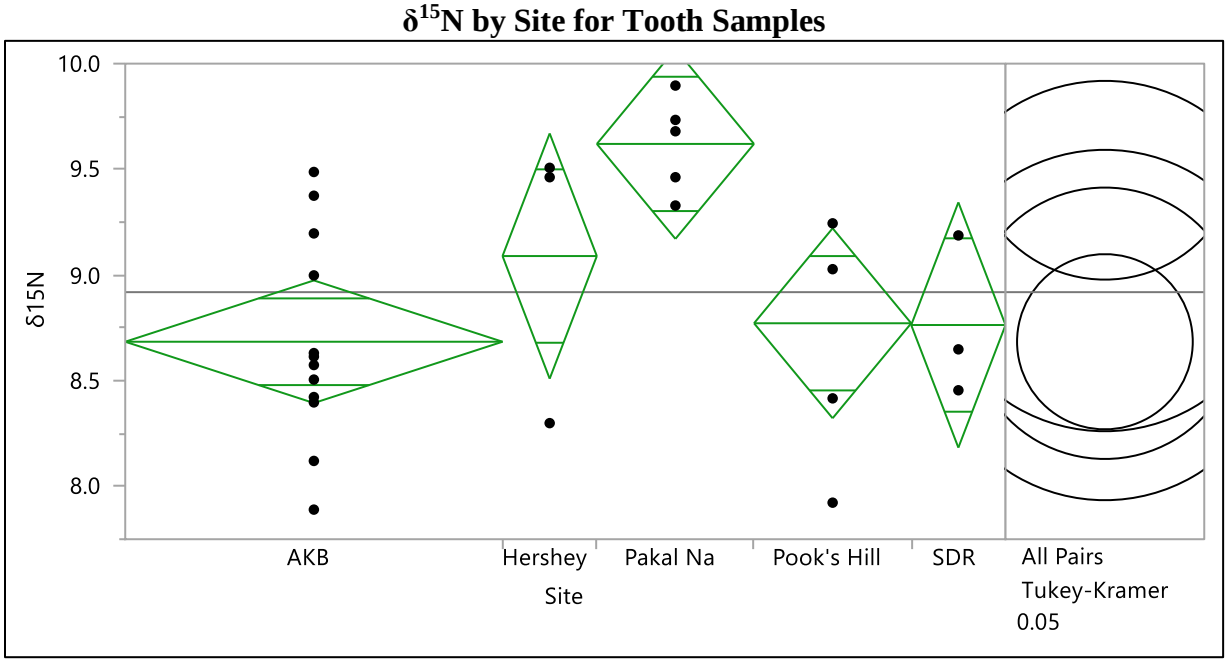


**Figure 20.** Oneway Analysis of $\delta^{15}N$ by site for tooth samples only.

Summary of Research Question 1

The tests performed on the $\delta^{13}C$ values between each site showed that there was variability both within the sites and between them. The individuals at Pakal Na have the highest $\delta^{13}C$ values. These higher values found at Pakal Na suggest that these individuals were consuming foods enriched in $^{13}C$ compared to individuals at other sites. The tests performed on the $\delta^{15}N$ values also demonstrated high variability within some of the sites. The variation within the $\delta^{15}N$ values made the trends difficult to see, though differences were detected between Pakal Na and AKB. This difference between Pakal Na and AKB suggests that the individuals at Pakal Na were eating foods enriched in $^{15}N$ compared to AKB.

Research Question 2: Diet Change in Central Belize over Time

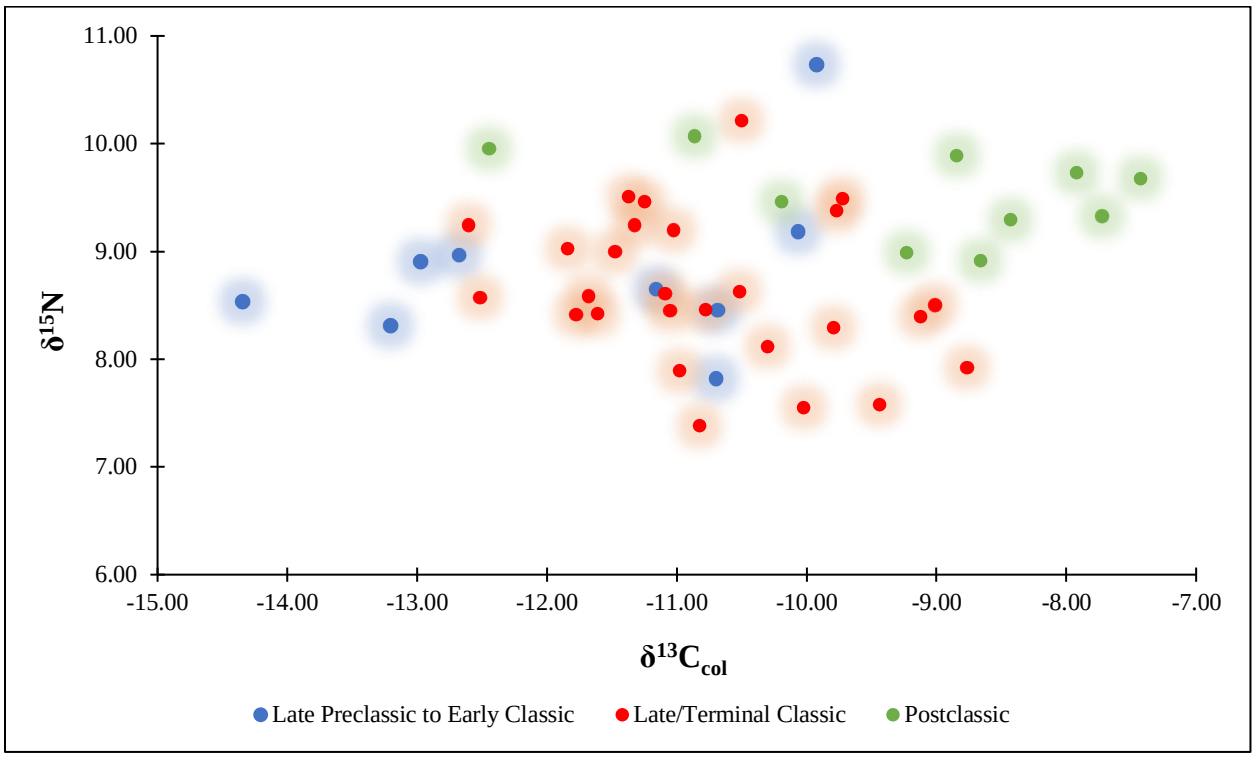


**Figure 21.** Biplot of $\delta^{13}C_{col}$ and $\delta^{15}N$ comparing individuals from the three different time periods sampled.

This question is challenging because no one site covers all of the time periods (Figure 3). Instead, individuals were divided into three different time period groups: Late Preclassic to Early Classic, which includes SDR and CBR; Late/Terminal Classic, which includes AKB, Hershey, and Pook's Hill; and individuals who potentially lived during the Postclassic period which includes Pakal Na, AOS, and Kaax Tsaabil (Figure 21). These divisions of time are not without potential issues because exact chronology is uncertain, but they will help to explore potential differences between the earlier and later occupied sites. Again, the statistical tests were conducted on samples of bones and teeth separately, to test for differences in $\delta^{13}C_{col}$, $\delta^{15}N$, $\delta^{13}C_{carb}$, and $\delta^{13}C_{en}$ between the time periods. In general, there appears to be a pattern of

increasing $\delta^{13}C$ over time, though there is high variability in some time periods. Significant differences were found between the Postclassic group and the other two groups, but no significant differences were found for $\delta^{13}C_{col,}$ $\delta^{15}N$, $\delta^{13}C_{carb}$, or $\delta^{13}C_{en}$ between the Late Preclassic to Early Classic group and the Late/Terminal Classic group.

*Differences Between Time Periods- $\delta^{13}C_{col}$*

High variability within the bone samples is seen within the Late Preclassic to Early Classic samples and the Postclassic samples, and is also seen within the Late/Terminal Classic and Postclassic samples in the tooth dentin samples. It appears that there is a trend towards increasing $\delta^{13}C_{col}$ values through time. For the bone samples, ANOVA failed to detect any statistically significant differences in $\delta^{13}C_{col}$ between the three time periods ($p=0.0551$, $r^2$:0.320) (Figure 22). For the tooth samples, ANOVA did detect significant differences between the $\delta^{13}C_{col}$ ($p=0.0043$, $r^2$:0.342). Tukey's HSD test determined that the differences were the Postclassic and the Late/Terminal Classic ($p=0.0032$) (Figure 23).

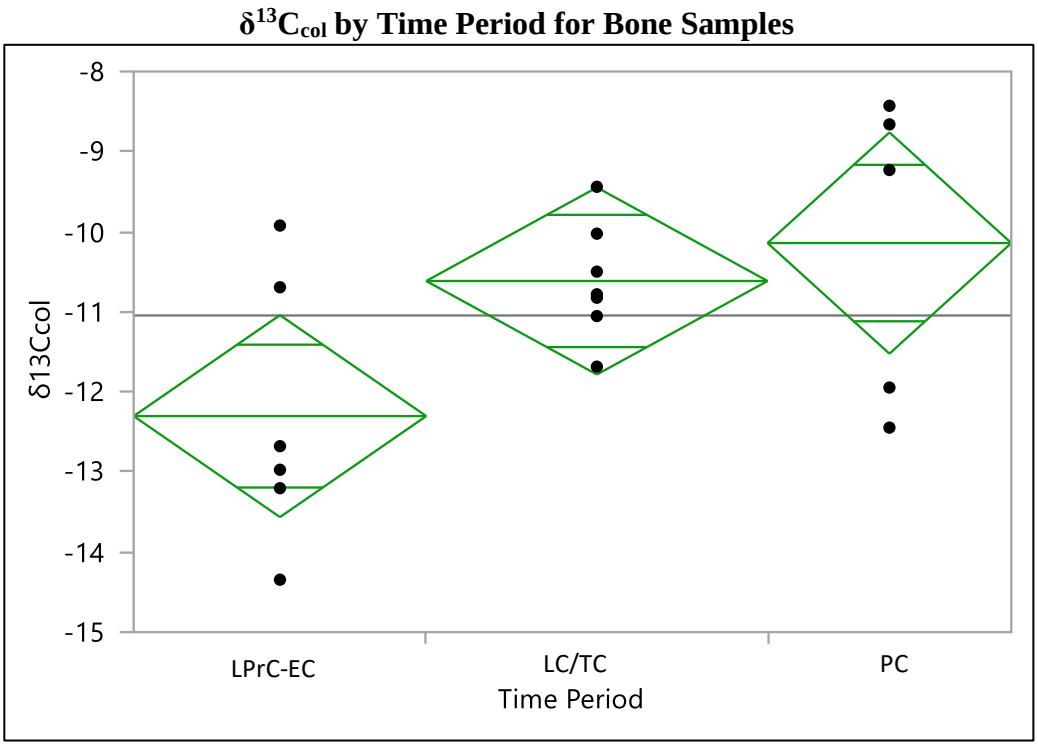


**Figure 22.** Oneway analysis of $\delta^{13}C_{col}$ by time period for bone samples only. Abbreviations are as follows: LPrC-EC stands for Late Preclassic to Early Classic, LC/TC stands for Late/Terminal Classic, and PC stands for Postclassic.

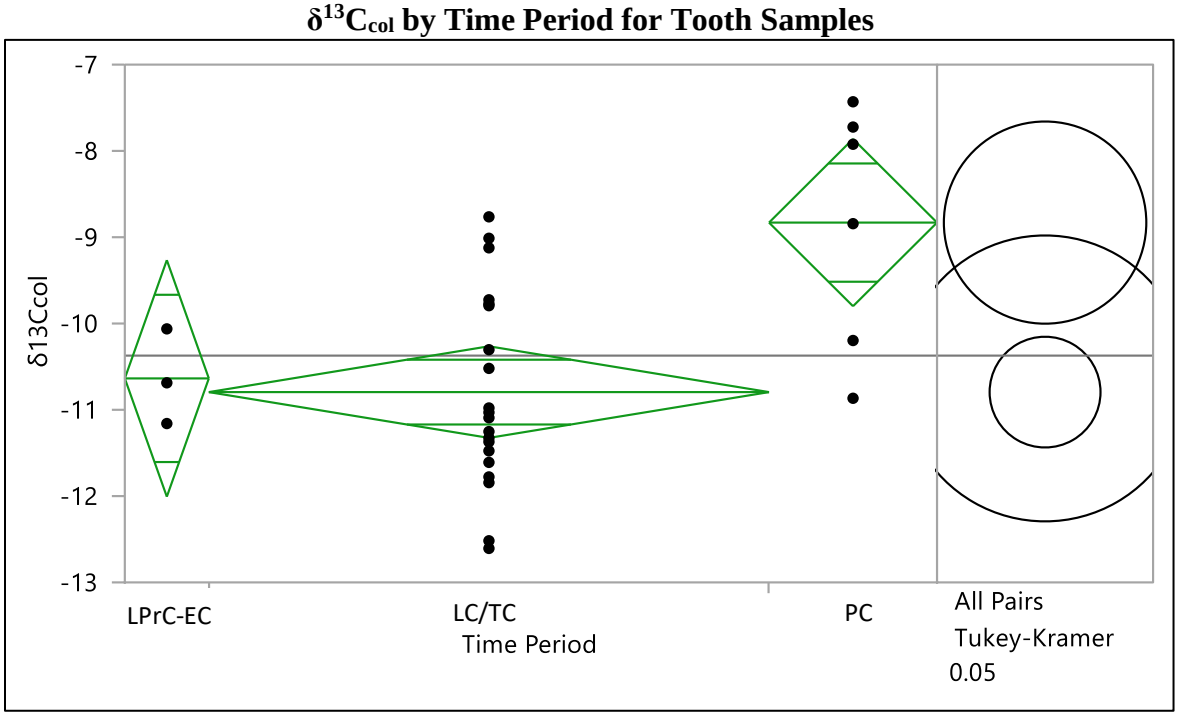


**Figure 23.** Oneway analysis of $\delta^{13}C_{col}$ by time period for tooth samples only.

*Differences Between Time Periods- $\delta^{13}C_{carb}$*

The Postclassic individuals had the highest $\delta^{13}C_{carb}$ values within both the bone and tooth samples, but also had a large range of variation. The tooth samples from the Late/Terminal Classic were also variable. ANOVA was unable to detect significant differences in $\delta^{13}C_{carb}$ values in the tooth samples between the time periods (p=0.2650, $r^2$:0.162) (Figure 24), but ANOVA did detect significant differences in the $\delta^{13}C_{carb}$ for the tooth samples (p=<0.0001, $r^2$:0.525) (Figure 25). Tukey's HSD test determined that the differences were found between the Postclassic and the Late/Terminal Classic (p=<0.0001).

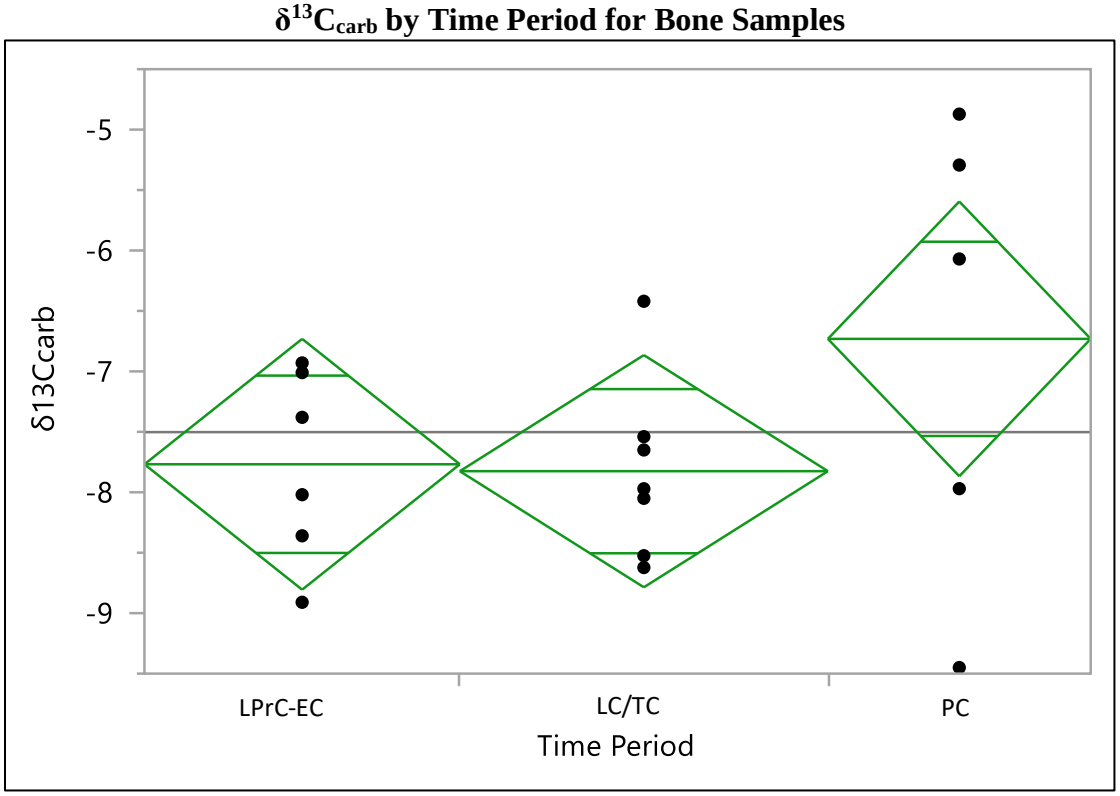


**Figure 24.** Oneway analysis of $\delta^{13}C_{carb}$ by time period for only bone samples.

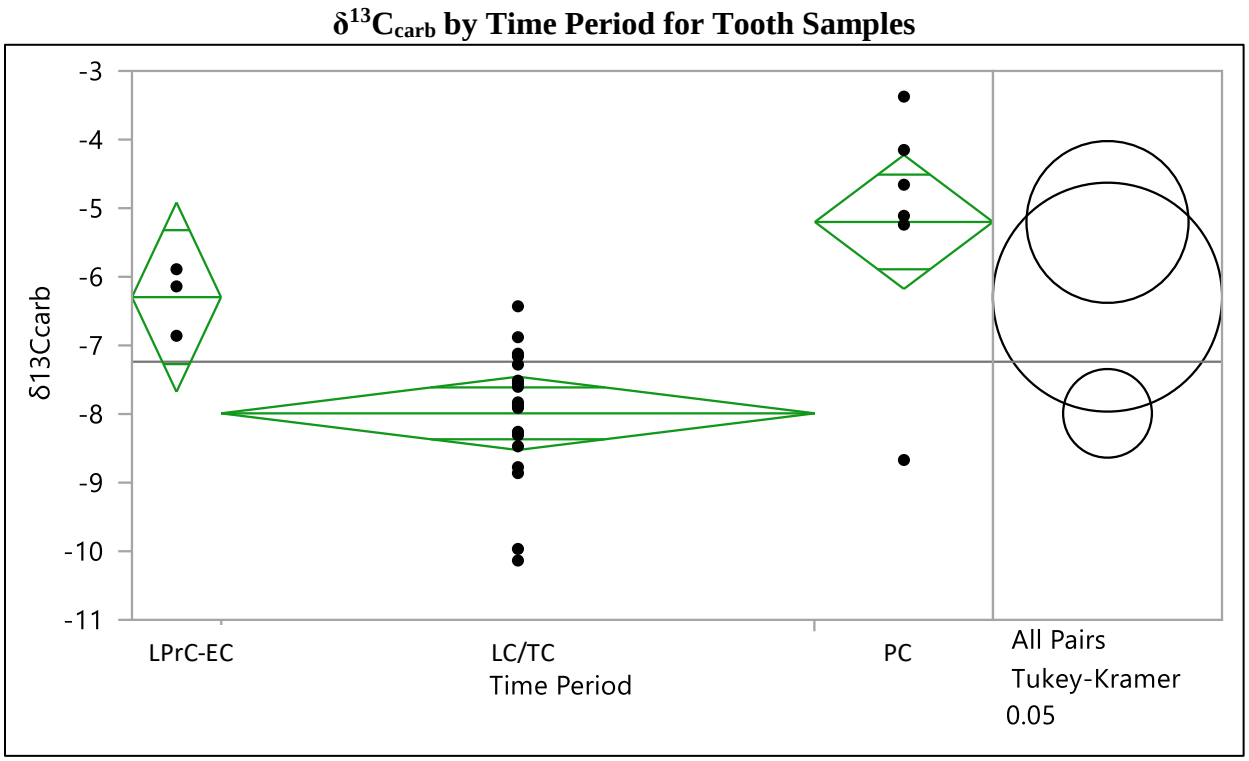


**Figure 25.** Oneway analysis of $\delta^{13}C_{carb}$ by time period for only tooth samples.

*Differences Between Time Periods- $\delta^{13}C_{en}$*

The Postclassic samples had the highest $\delta^{13}C_{en}$ values, suggesting an increase over time, but there was also a high variance in the $\delta^{13}C_{en}$ values. ANOVA detected differences in the $\delta^{13}C_{en}$ as well (p=0.0014, $r^2$:0.396) and Tukey's HSD test determined that the differences were between the Postclassic and the Late Preclassic to Early Classic (p=0.0066), and the Postclassic and the Late/Terminal Classic (p=<0.0024) (Figure 26).

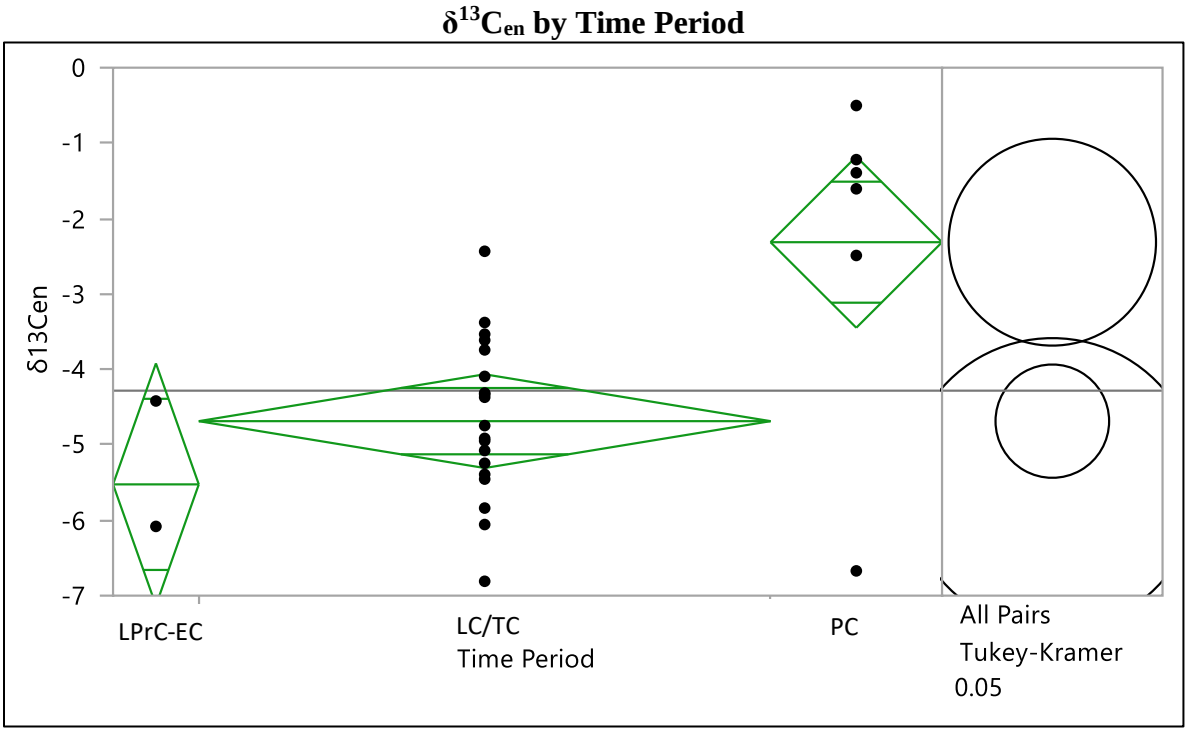


**Figure 26.** Oneway analysis of $\delta^{13}C_{en}$ by time period.

*Differences Between Time Periods- $\delta^{15}N$*

The $\delta^{15}N$ displays high variance within the first two time periods, with lower variance and overall higher values in Postclassic samples. For samples of bone, ANOVA failed to detect significant differences in $\delta^{15}N$ between the time periods (p=0.2174, $r^2$:0.184) (Figure 27). ANOVA detected significant differences in $\delta^{15}N$ between the tooth samples, though (p=0.0011, $r^2$: 0.407). Further examination using Tukey's HSD test was able to determine that the differences were between the Postclassic and Late Preclassic to Early Classic (p=0.0282) and the Postclassic and the Late/Terminal Classic (p=0.0009) (Figure 28).

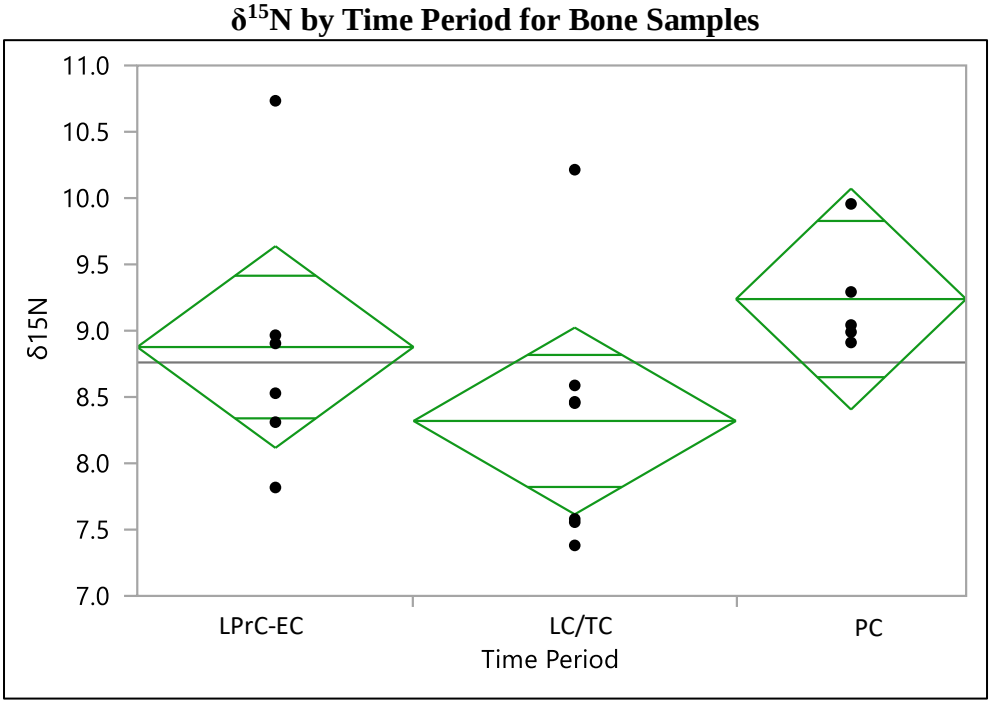


**Figure 27.** Oneway analysis of $\delta^{15}N$ by time period for bone samples only.

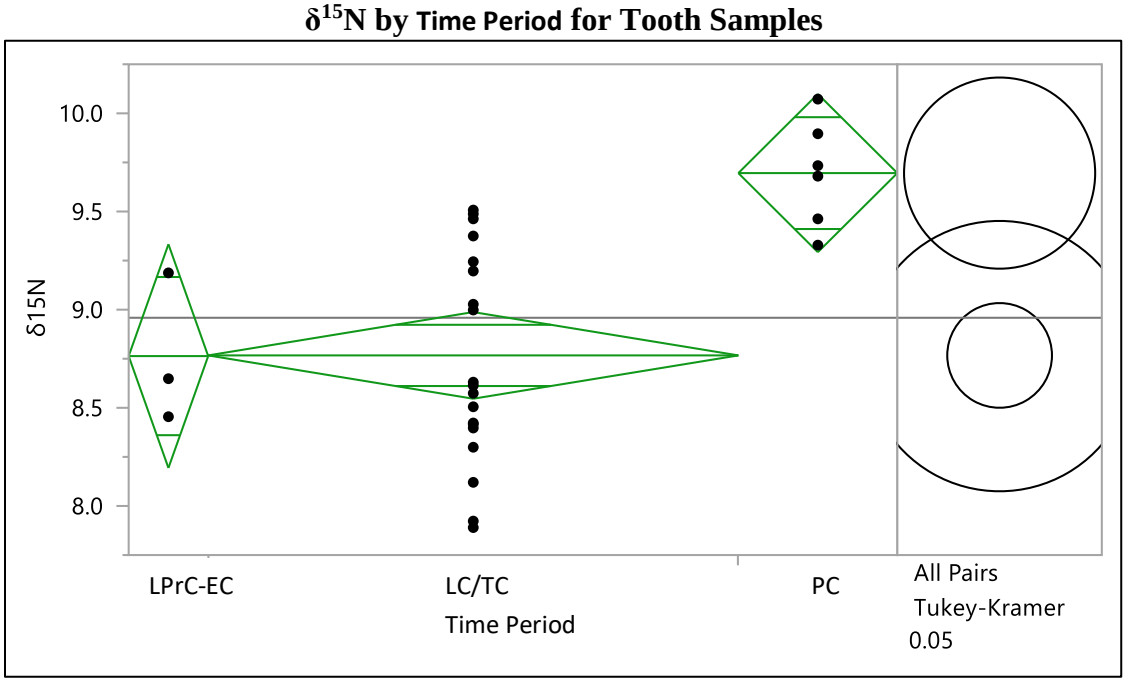


**Figure 28.** Oneway analysis of $\delta^{15}N$ by time period for tooth samples only.

Summary of Research Question 2

The majority of the samples came from the Late/Terminal Classic period, which appears to be variable in both $\delta^{13}C$ and $\delta^{15}N$. The smaller sample sizes for the Late Preclassic to Early Classic and the Postclassic groups may not reveal the true level of variation, which could be fixed in the future with a greater number of samples. No differences were detected between the Late Preclassic to Early Classic and the Late/Terminal Classic groups, but differences were found between the Postclassic group and the other two groups. This suggests that although there was variation, average diet did not change significantly between the Late Preclassic to the Terminal Classic, but it did change in the Postclassic.

Research Question 3: Dietary Difference in Site Type

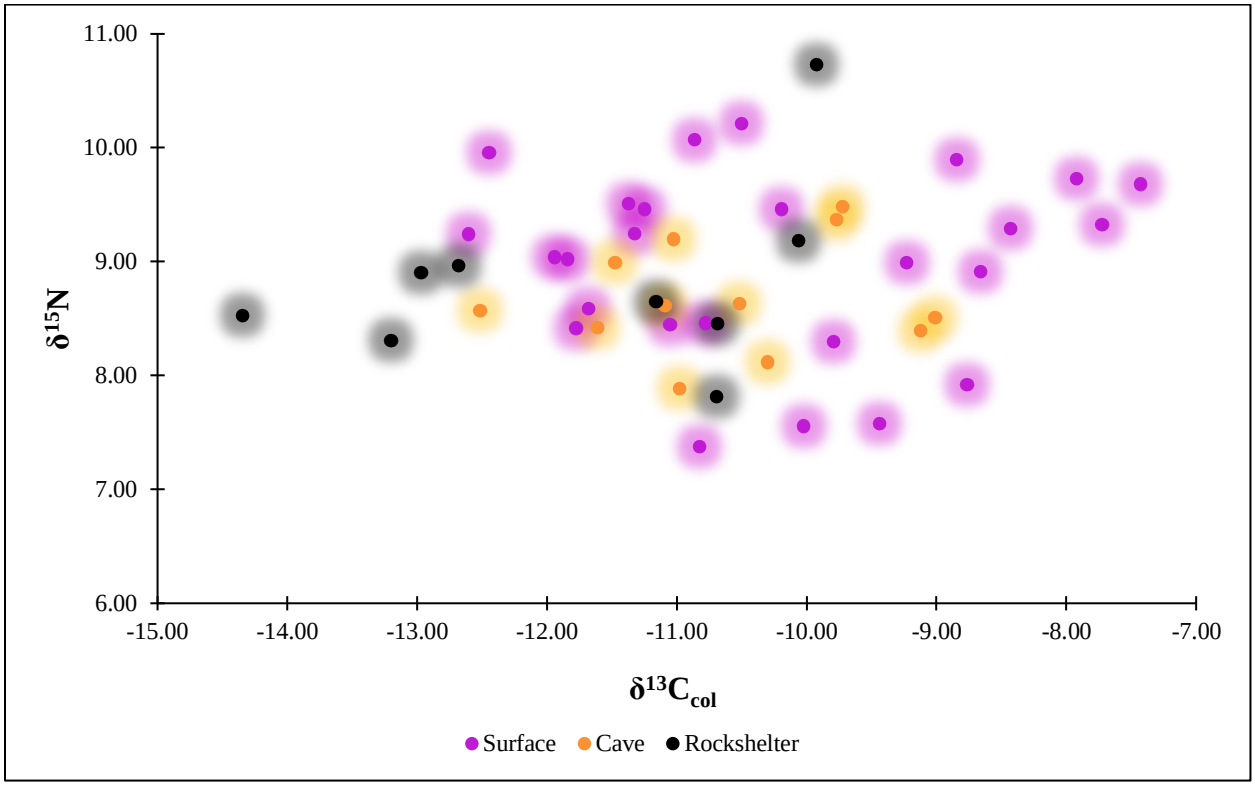


**Figure 29.** Biplot of $\delta^{13}C_{col}$ and $\delta^{15}N$ comparing individuals from the three different types of sites sampled.

The surface sites, rockshelters, and cave sites were compared to each other in order to determine if there were differences between the three different types of sites (Figure 29). Because the cave site and one of the rockshelters included only tooth samples, and the other rockshelter site included only bone samples, the teeth and bones from each site type were pooled together. Pakal Na was removed from the pool of surface site samples because their values were skewing the data from the surface sites, because Pakal Na was known to be an outlier among the surface sites from the previous tests. ANOVA failed to find significant differences in the $\delta^{13}C_{col}$ ($p=0.0993$, $r^2$:0.120) (Figure 30), $\delta^{13}C_{en}$ ($p=0.5668$, $r^2$:0.052) (Figure 32), or $\delta^{15}N$ ($p=0.8801$,

$r^2$:0.007) (Figure 33). Differences were detected, however, between the $\delta^{13}C_{carb}$ (p=0.0310, $r^2$:0.175) and Tukey's HSD test determined that the differences were found between the Rockshelter and Cave groups (p=0.0251) (Figure 31).

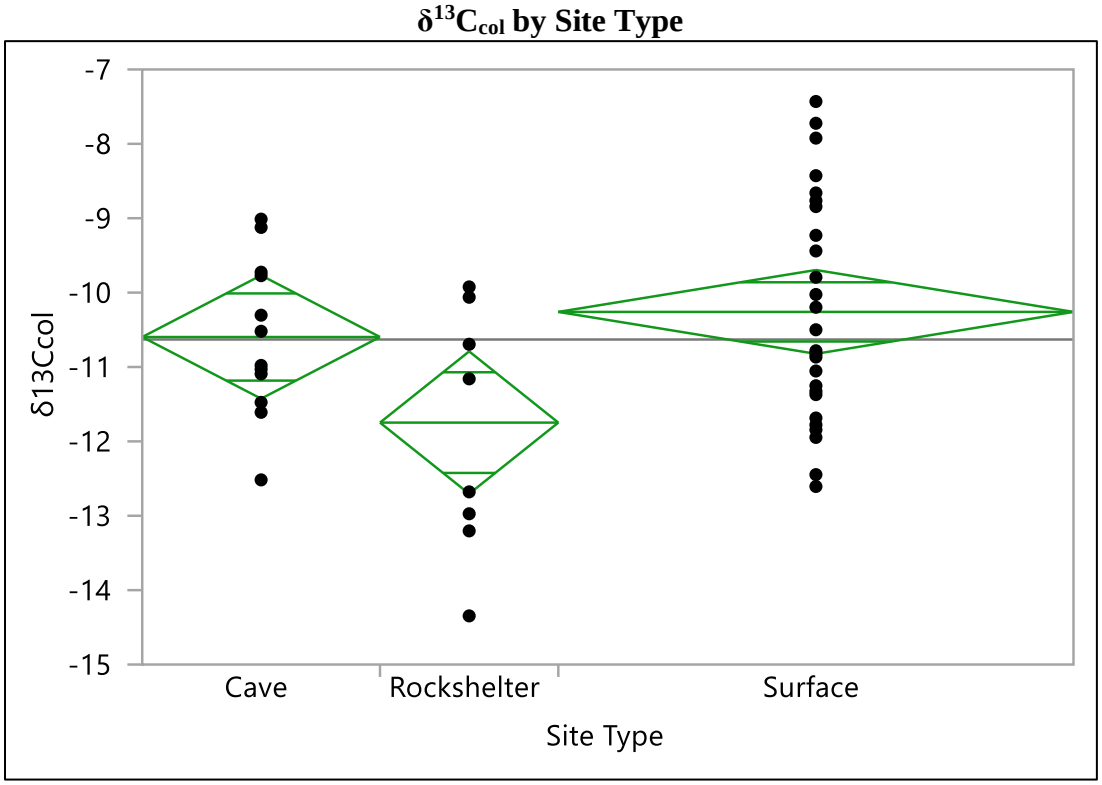


**Figure 30.** Oneway Analysis of $\delta^{13}C_{col}$ by site type.

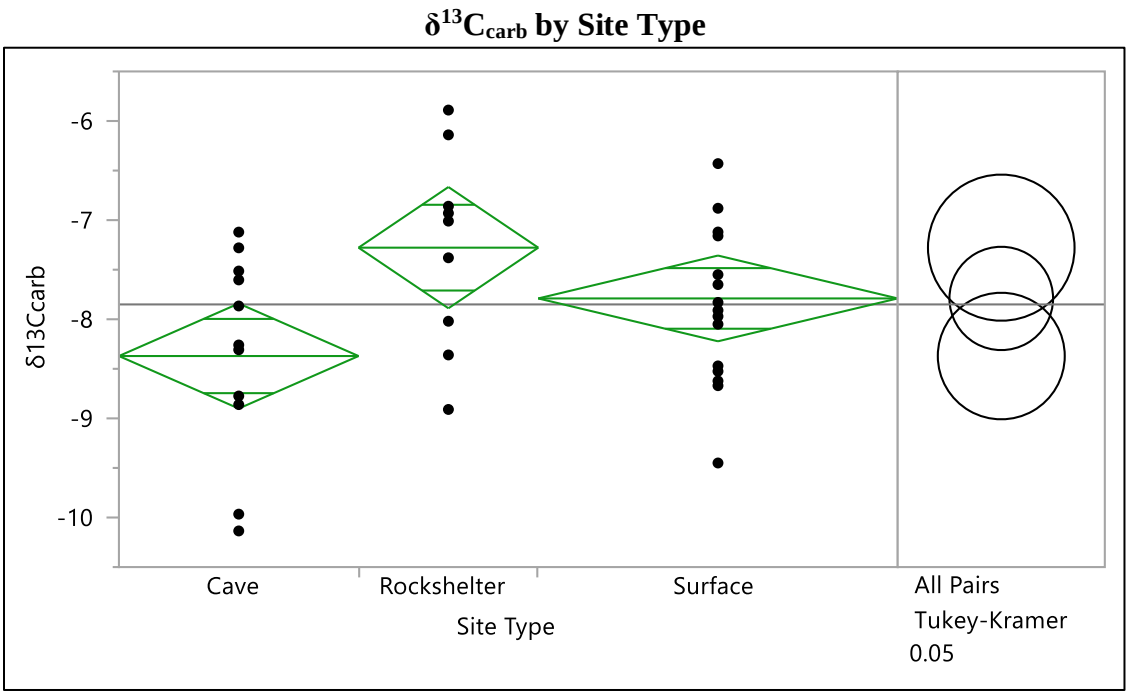


**Figure 31.** Oneway Analysis of $\delta^{13}C_{carb}$ by site type.

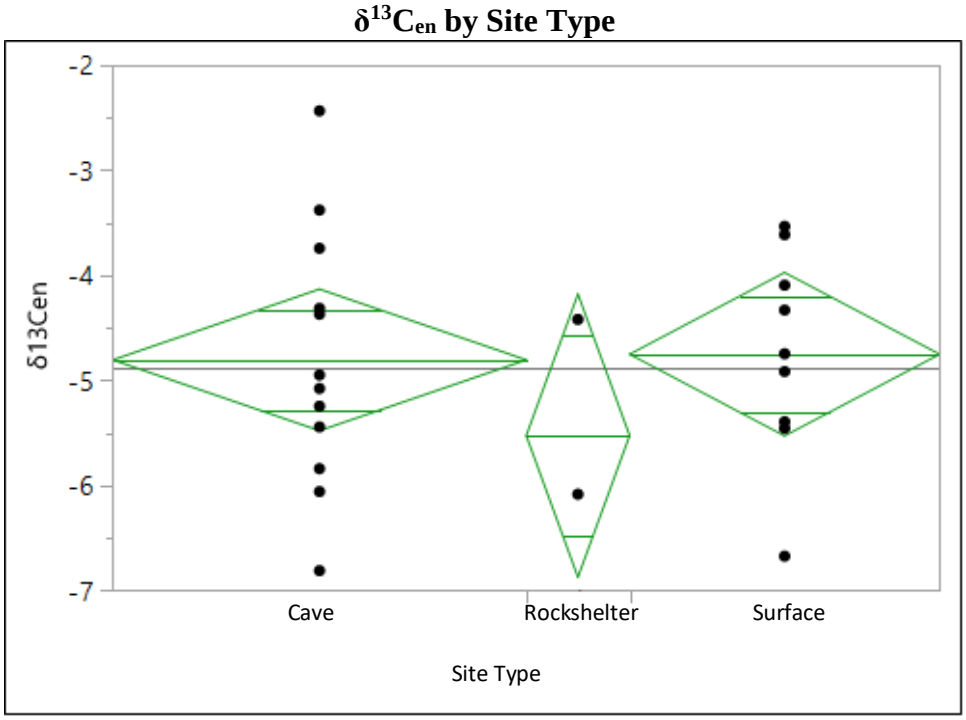


**Figure 32.** Oneway Analysis of $\delta^{13}C_{en}$ by site type.

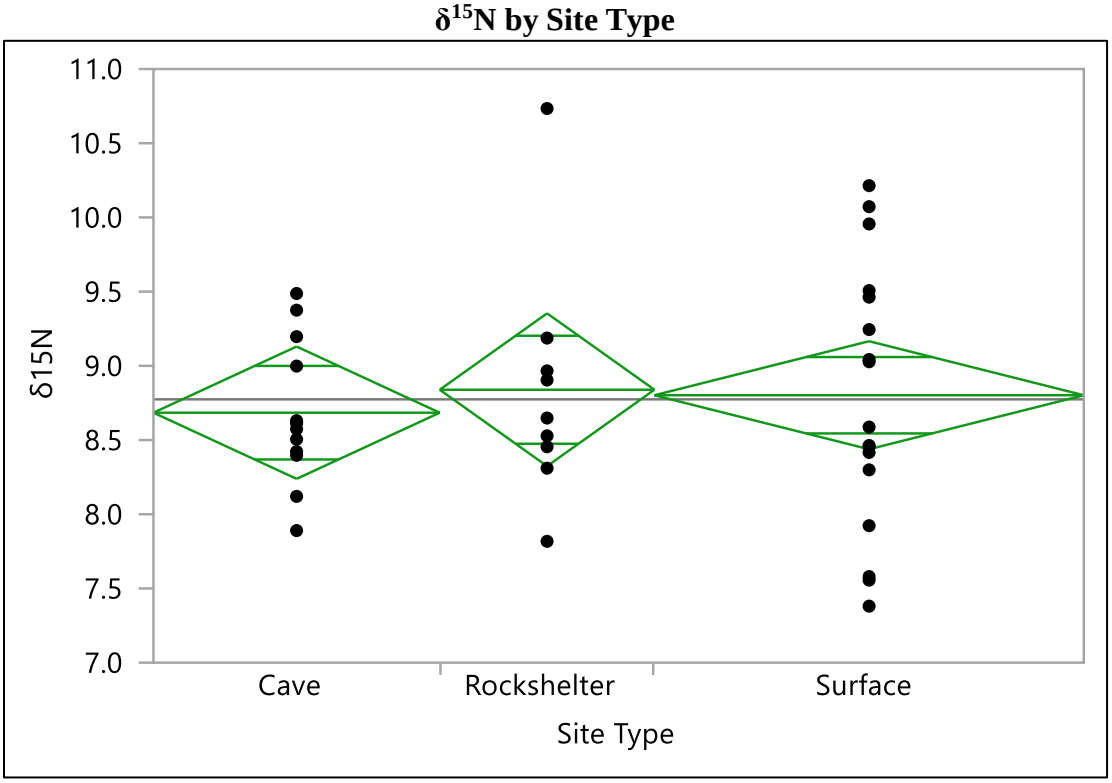


**Figure 33.** Oneway Analysis of $\delta^{15}N$ by site type.

Summary of Research Question 3

A large amount of variation was detected within each of the three types of sites in both $\delta^{13}C$ and $\delta^{15}N$. Because of this large range, trends were difficult to detect. Because there were no differences in the $\delta^{13}C_{col}$, $\delta^{13}C_{en}$, or $\delta^{15}N$, differences in the protein portion of the diet ($\delta^{13}C_{col}$ and $\delta^{15}N$) and the whole diet for young children ($\delta^{13}C_{en}$) is not supported. The difference detected in $\delta^{13}C_{carb}$ between the cave site and the rockshelter sites does suggest a difference in whole diet, with the highest $\delta^{13}C_{carb}$ values found among the rockshelter individuals.

Research Question 4: Individual Changes throughout Life

For nine of the individuals, both bone and tooth were sampled. This reflects how diet changed from childhood to adulthood. Changes in $\delta^{15}N$ and $\delta^{13}C$ were observed, but were inconsistent between the sites. Augustine Obispo (AOS) Burial 3 was an adult male, Hershey (HS) Zone 1 was of unknown age and sex, Hershey Zone 3 was of unknown age and sex, Pook's Hill (PH) Str. 4A-2 was a young adult between 20-25 of unknown sex, Pook's Hill Str. 4A-4 was a young adult between 16-20 of unknown sex, Pook's Hill Str. 4A-5 was a middle-aged adult and probable male, Pook's Hill Str. 4A-6 was a young adult male, Pakal Na (PN) Burial 2 was an over 40 year old male, and Pakal Na Burial 1A/1C was an over 60 year old male.

*Changes in $\delta^{13}C_{col}$*

At Augustine Obispo, Burial 3's $\delta^{13}C_{col}$ became over 1.5‰ depleted from childhood to adulthood (Figure 34). Both individuals from Hershey experienced a small enrichment in $\delta^{13}C_{col}$. At Pook's Hill, individuals from Str. 4A-2, 4A-5, and 4A-6 follow a pattern of slight increasing $\delta^{13}C_{col}$ values, but Str. 4A-4 does not follow this pattern. Instead, their $\delta^{13}C_{col}$ became depleted by over 2‰. For both of the individuals at Pakal Na, their $\delta^{13}C_{col}$ was depleted as they got older. About half of these differences were less than 1‰, which suggests that the $\delta^{13}C$ values of the dietary protein for half of the individuals did not change from childhood to adulthood, but did change for the other half.

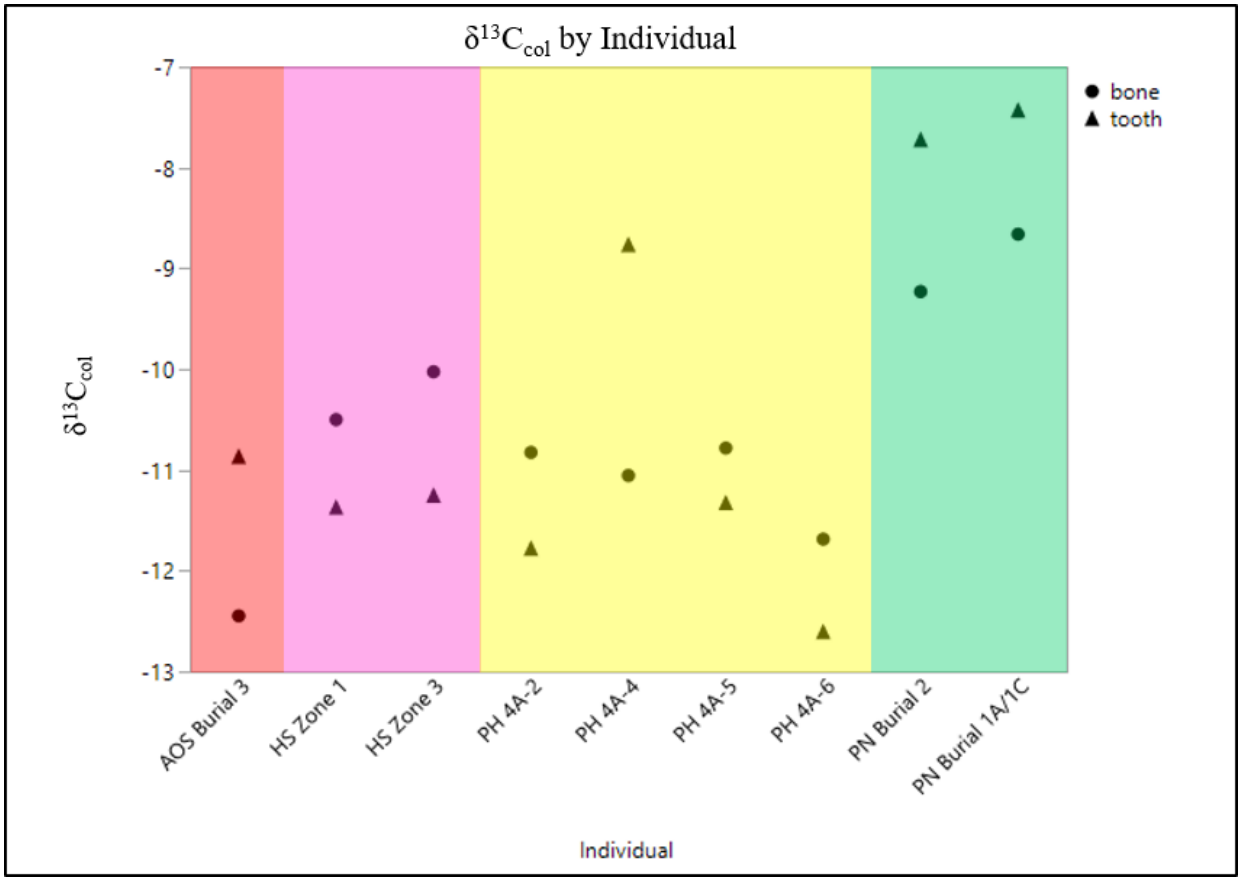


**Figure 34.** Changes in $\delta^{13}C_{col}$ through individuals' lives. The teeth are marked by triangles, which will represent the individual's childhood diet, and the bones are marked by circles, which will represent the diet of the last several years of the individual's life.

*Changes in $\delta^{13}C_{carb}$ and in $\delta^{13}C_{en}$*

When comparing the $\delta^{13}C_{carb}$ values found in tooth dentin and bone with the $\delta^{13}C_{en}$ values, a pattern emerged for four out of the nine individuals (Figure 35). For AOS Burial 3, Hershey Zone 1, Pook's Hill Str. 4A-4, Pakal Na Burial 2, and Pakal Na Burial 1A/1C, their $\delta^{13}C_{en}$ values were the most enriched, followed by the tooth $\delta^{13}C_{carb}$, and then the bone $\delta^{13}C_{carb}$ values were the most depleted. Pook's Hill Str. 4A-2 is similar, except their tooth dentin is slightly more depleted in $^{13}C$ than their bone. For Hershey Zone 3, Pook's Hill Str. 4A-5, and

Pook's Hill Str. 4A-6, their $\delta^{13}C_{en}$ values are a bit more enriched than their $\delta^{13}C_{carb}$ values, but their bone and tooth dentin $\delta^{13}C_{carb}$ values are almost identical to each other.

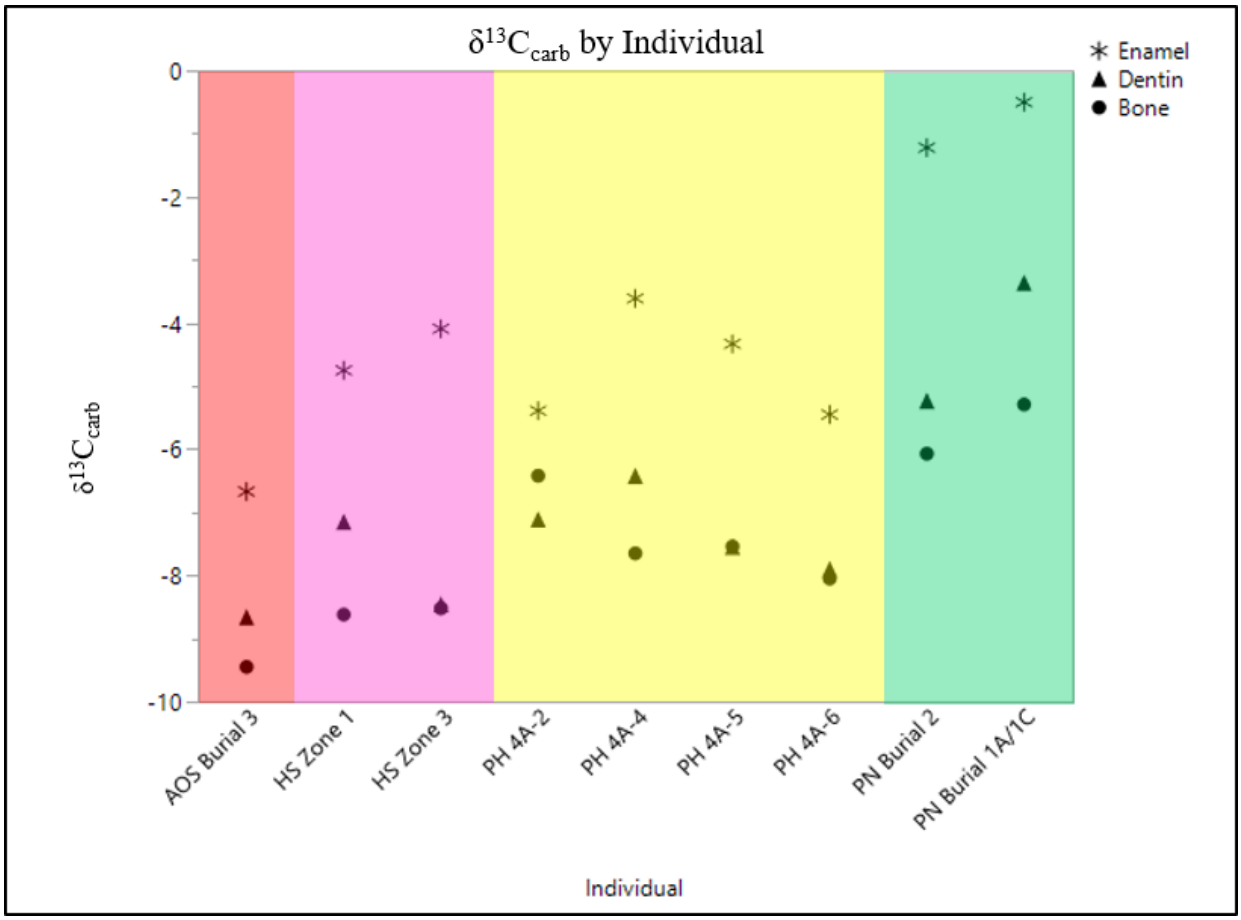


**Figure 35.** Changes in $\delta^{13}C_{carb}$ through individuals' lives. Raw values have not been adjusted to reflect differential fractionation for different tissue types.

*Changes in $\delta^{15}N$*

At Augustine Obispo, Burial 3's $\delta^{15}N$ remained the same from childhood to adulthood (Figure 36). At Hershey, Zone 1's $\delta^{15}N$ became slightly more enriched, while Zone 3's became about 2‰ more depleted from childhood to adulthood. At Pook's Hill, individuals from Str. 4A-2, 4A-5, and 4A-6 follow a pattern of slight decreasing $\delta^{15}N$, except for Str. 4A-6, whose $\delta^{15}N$

became slightly more enriched. For both of the Individuals at Pakal Na, their $\delta^{15}N$ was depleted as they got older. Only two of these changes are larger than 1‰, suggesting that the tropic level of the foods from childhood to adulthood remained the same for the majority of these individuals.

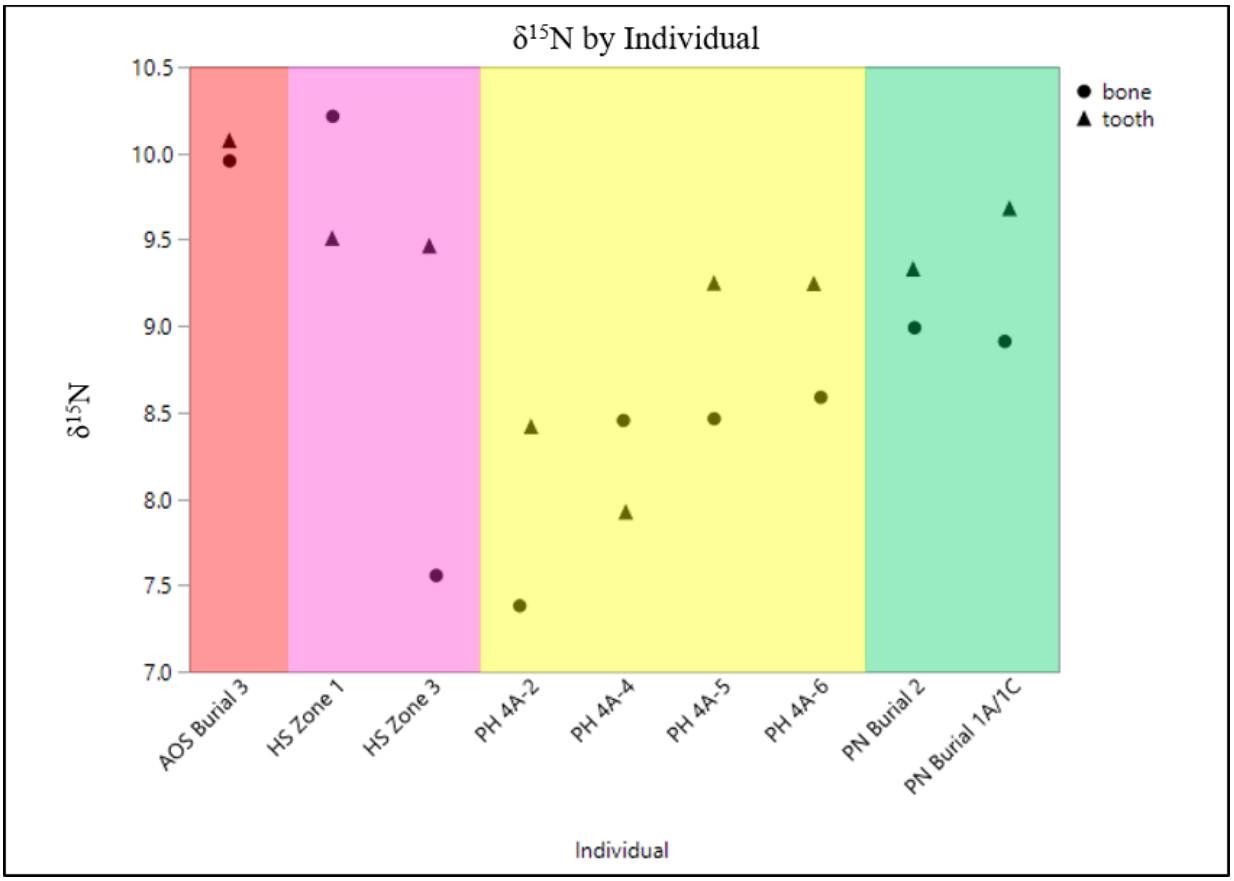


**Figure 36.** Changes in $\delta^{15}N$ through individuals' lives. The teeth are marked by triangles, which will represent the individual's childhood diet, and the bones are marked by circles, which will represent the diet of the last several years of the individual's life.

Summary of Research Question 4

While some patterns were detected, it appears that diet was variable from childhood to adulthood both between the sampled sites and within them. Some individuals had considerable changes in $\delta^{13}C_{col}$ or collagen $\delta^{15}N$ values from childhood to adulthood, though it appears that the majority did not. Most of the measured changes in these were less than 1‰. For the differences between bone $\delta^{13}C_{carb}$ and tooth $\delta^{13}C_{carb}$, only three of the individuals displayed changes larger than 1‰, while most changed very little. The changes between the enamel $\delta^{13}C_{carb}$ and the bone and tooth dentin $\delta^{13}C_{carb}$ are likely due to differences in fractionation and do not necessarily reflect differences in diet. Overall, though there is not much evidence to support a systematic change in diet from childhood to adulthood for these sites, it is apparent that there was variation, and diet did change for some of the individuals.

# Chapter 5: DISCUSSION

## State of Sample Preservation

The FTIR-ATR results indicate that most of the samples have been significantly altered by the burial environment. The enamel samples were the best preserved, followed by the tooth dentin samples, and then the bone samples. This was not surprising due to the tropical climate in Belize. It is possible that because of recrystallization, the isotopic compositions found in the carbonate samples may be inaccurate, but it is expected that archaeological samples will have a higher CI than modern samples. No correlation was found between CI and the $\delta^{13}C_{carb}$ values, suggesting that the level of crystallinity in the sample has not affected the isotope ratio values, but there was a correlation between the CI and then or $\delta^{13}C_{en}$. This was unexpected, due to the fact that enamel is more resistant to diagenetic alteration than bone and tooth dentin (Lee-Thorp and van der Merwe 1987). It is possible that the correlation between CI and $\delta^{13}C_{en}$ indicates alteration by the burial environment, but because the majority of the CI values for the enamel samples are below the generally accepted values for preservation, it is also possible that the correlation is falsely significant. Because the correlation discovered between the CI and $\delta^{13}C_{en}$ is not believed to have affected the isotope ratios in the enamel, and because no correlation was found between the CI and the $\delta^{13}C_{carb}$ values, the data from the carbonate samples was used.

## General Diet in This Study

According to the isotopic food web, the individuals in this study consumed foods high in $\delta^{13}C$ and relatively high in $\delta^{15}N$. The mean $\delta^{13}C$ values indicate a strong dependence on maize or maize-fed/marine resources, and the mean $\delta^{15}N$ value is consistent with the consumption of animal proteins. Those at Pakal Na fall more toward a diet of $C_4$/marine reliance, while others fall toward a more mixed $C_3/C_4$ diet. The majority of the individuals from CBR (four out of six)

exhibit the least reliance on maize/marine of the individuals sampled here. The food web is useful in demonstrating variation in both $\delta^{13}C_{coll}$ and collagen $\delta^{15}N$ values for these individuals. The mean $\delta^{13}C_{en}$ value also suggests a heavy reliance on maize or marine during the time of enamel formation, especially for Pakal Na Burial 1A/1C ($\delta^{13}C_{en}$ value of -0.50‰) who appears to have consumed an almost completely $C_4$ or marine diet during this time.

The Froehle et al. (2012) model used in this study was also helpful in broadly defining diet and is generally consistent with the inferences above. The model's power lies in its ability to discern what the main components of an individual's diet was, based on five potential types of diets. Based on this model, it appears that all individuals' diets, as a whole, consisted of mostly $C_4$ maize, with a mixture of $C_3$ and $C_4$ protein sources. Success using this model on studies of the ancient Maya are limited, though. The biggest potential issue for its application in this region is that the $\delta^{15}N$ values for the marine animals living in the tropical reefs off the coast of Belize have been found to be lower than expected (Schoeninger et al. 1983). Though this has been accounted for in the foodweb included in this study, it is not factored into Froehle et al.'s (2012) multivariate model. The individuals who consumed marine foods will have $\delta^{15}N$ values much lower than individuals in other parts of the world. Because of this, it is possible to confuse marine derived proteins and $C_4$ proteins in Belize even when using this multivariate isotope model. Somerville et al. (2013) applied the multivariate model to isotopic data from Coastal Belize, the Southern Maya Lowlands, and the Northern Maya Lowlands, and noted that the individuals from Coastal Belize fell outside of the known data clusters (they plotted outside of cluster 2, to the right). Rand et al. (2015) caution against the use of this model to reconstruct ancient Maya diet because of this fact. If the Coastal Maya were eating a significant amount of marine resources (50% of their diet), which they likely were, they should have fallen within the

marine protein dietary cluster on this model (Cluster 3), but they did not. This indicates that the model should be used with discretion in Mesoamerica because it can neither confirm nor deny the consumption of marine resources. Although none of the individuals, even those living in a coastal area or in an area with evidence of coastal trade, appear to have a predominantly marine-based diet, it is possible that the Pakal Na individual who fell outside of the known data cluster consumed marine proteins. This model does show differences between the individuals, but sorting out marine vs. $C_4$ proteins is unclear, especially for the individual who fell outside the known clusters.

A potential solution to the issue of deciphering between the consumption of $C_4$ vs. marine proteins is measuring the spacing between the $\delta^{13}C_{carb}$ and the $\delta^{13}C_{col}$ values ($\Delta^{13}C_{carb\text{-}col}$). The collagen-to-carbonate spacing is believed to be related to diet, and will be roughly 7‰ for herbivores, 5‰ for omnivores, and 3-4‰ for carnivores (Krueger and Sullivan 1984; Lee-Thorp et al. 1989; Ambrose 1993). Marine based diets have been found to generate even smaller $\Delta^{13}C_{carb\text{-}col}$ values, often being less than 3‰ (Lee-Thorp et al. 1989).

Figure 37 displays the $\Delta^{13}C_{carb\text{-}col}$ values for each of the individuals in this study plotted against the $\delta^{15}N$ values. The results are also in Appendix B. Three of the individuals have $\Delta^{13}C_{carb\text{-}col}$ values less than 3‰, indicating that they may have had a marine-based diet. Two of the individuals were from Pakal Na (the tooth sample from Burial 1A/1C, which was the sample that fell outside the know diet clusters, and the tooth sample from Burial 2) and one was from Pook's Hill (the bone sample from Str. 4A-2). The rest of the individuals' $\Delta^{13}C_{carb\text{-}col}$ values display a large degree of variation. This suggests that diet was variable across the sampled individuals.

Low $\Delta^{13}C_{carb\text{-}col}$ values do not always mean marine protein consumption, however. They may also be the result of the combination of isotopically enriched terrestrial proteins and depleted terrestrial lipids/carbohydrates (i.e. $C_4$ proteins and $C_3$ carbohydrates and lipids) (Lee-Thorp et al. 1989). Conversely, large collagen-to-carbonate spacings can be caused by the protein source being depleted in $^{13}C$ compared to the carbohydrates and lipids (i.e. $C_3$ proteins and $C_4$ carbohydrates/lipids), as well as being a signal of herbivory. This does not appear to be the case for the three individuals with $\Delta^{13}C_{carb\text{-}col}$ values less than 3‰ based on the indications of high maize consumption, so it is more likely to be a consequence of the consumption of marine foods. The consumption of marine resources is supported by the zooarchaeological data from Pakal Na, but there is limited evidence of fish bones and marine shells at Pook's Hill. Marine-based diets are not supported for the other individuals in this study based on the $\Delta^{13}C_{carb\text{-}col}$ values. It is possible that some marine resources were consumed by the others, but it would have been at a lower frequency than the three individuals who display the lowest $\Delta^{13}C_{carb\text{-}col}$ values. This suggests that during childhood for the individuals from Pakal Na Burial 1A/1C and Burial 2, and during adulthood for the individual from Pook's Hill Str. 4A-2, they were eating a diet different from the others around them, or they were living somewhere potentially closer to the coast with more access to marine resources during that time.

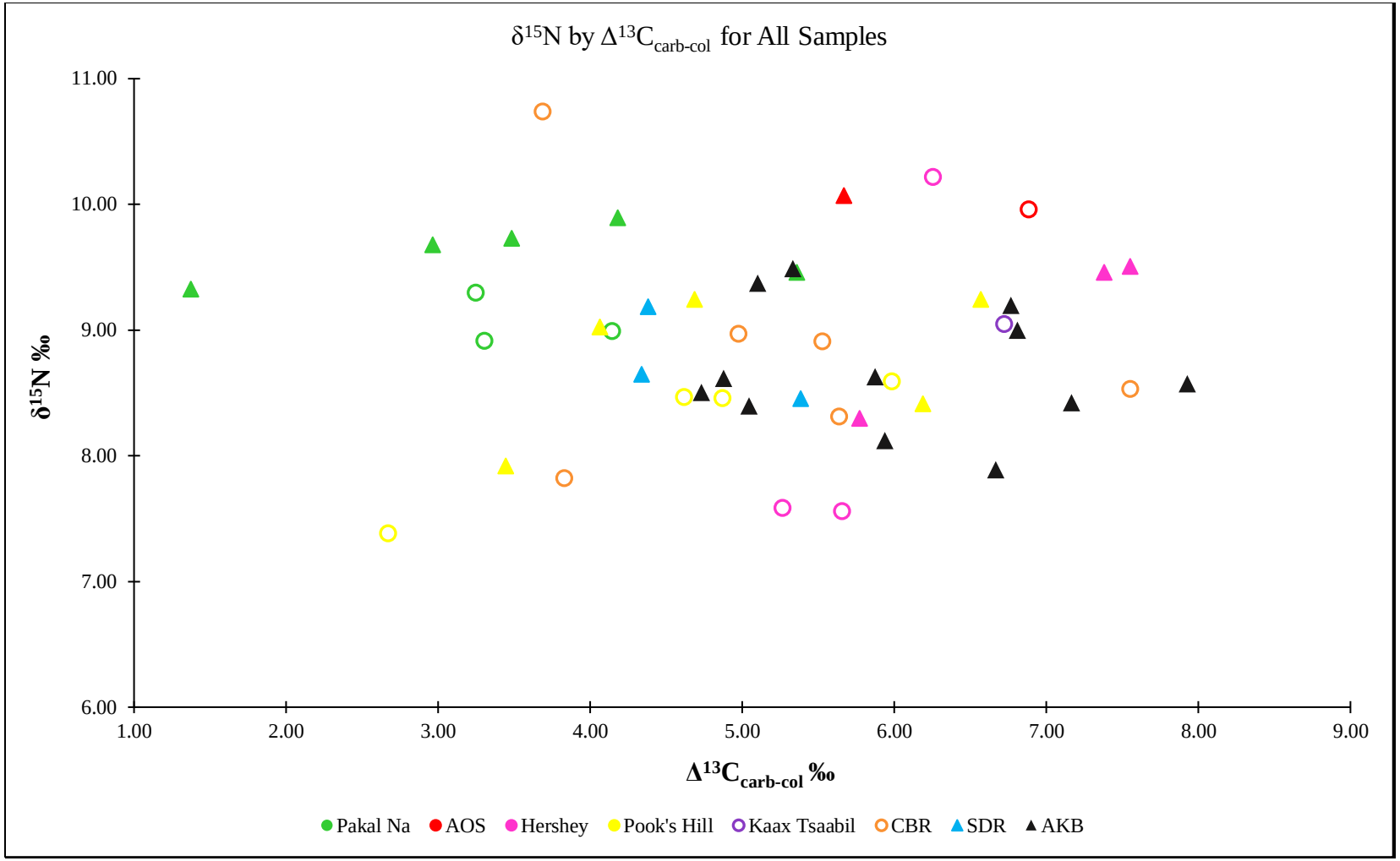


**Figure 37.** Biplot of $\Delta^{13}C_{carb\text{-}col}$ and $\delta^{15}N$ results for 47 samples. Samples of tooth dentin are marked by triangles and samples of bone are marked by circles.

Dietary Variation by Geographic Location/Site

Statistically, Pakal Na is different from the other sites. The statistical tests found differences between Pakal Na and several other sites in this study, suggesting that the individuals who lived at this site were consuming different foods than the individuals from surrounding sites. The much higher $\delta^{13}C_{col}$ (mean $\delta^{13}C$ of -8.55‰), $\delta^{13}C_{carb}$ (mean $\delta^{13}C$ of -4.85‰), and $\delta^{13}C_{en}$ values (mean $\delta^{13}C$ of -1.44‰) found at Pakal Na suggest that they were much more reliant on maize and/or marine resources than the other sites in the surrounding area. The only comparable $\delta^{13}C_{col}$ values in Belize are found at the coastal sites of Chac Balam and San Juan (mean $\delta^{13}C_{col}$ of -8.3‰), which are believed to be attributed to the consumption of marine resources, and were accompanied by higher $\delta^{15}N$ values (mean $\delta^{15}N$ of 11.4‰) than those at Pakal Na. The rest of the sites in this study exhibit more of a mixed diet that is less reliant on maize and $C_4$/marine protein than Pakal Na, and the individuals found at Pakal Na were eating a diet not typical for others living in Central Belize. Pakal Na is perhaps most like Homul found in Guatemala, but with slightly more enriched $\delta^{13}C_{col}$ values. In terms of $\delta^{13}C_{carb}$ values, they are most similar to Minanaha. The hypothesis that there are differences in diets between the sites is accepted based on the significant differences found during the statistical tests.

The lowest $\delta^{13}C_{col}$ values found at CBR suggest that those individuals were the least reliant on maize out of the sampled individuals. It is unclear at this time if these lower $\delta^{13}C_{col}$ values were caused by status differentiation, the time period in which they lived, the availability of local resources, or another factor. The individual from Kaax Tsaabil is similar. CBR and Kaax Tsaabil both have $\delta^{13}C_{col}$ values that are comparable to Yaxuná in Mexico, but have higher $\delta^{15}N$ values, indicating the consumption of higher trophic level animals, freshwater fish, or more

animal proteins compared to legumes. See Figure 38 for the average $\delta^{13}C_{col}$ and $\delta^{15}N$ values in this study compared to 14 other Maya sites.

Although not included in the statistical analyses comparing the different sites due to being the only individual from AOS, AOS Burial 3 also appears to deviate from the mean. This may be caused by the consumption of a larger amount of freshwater or marine fish than the others. While it is not possible to draw any significant conclusions about diet at the site of AOS as a whole from only one sampled individual, it is likely that Burial 3 consumed more of a riverine or marine based diet than those at other locations, evidenced by the highest mean $\delta^{15}N$ values from the sample set. Because Burial 3's $\delta^{13}C_{col}$ and $\delta^{13}C_{carb}$ values are lower than the mean, the consumption of freshwater fish is more likely, but this individual could have also consumed a combination of marine proteins and $C_3$ plants.

When plotted alongside the other sites from previous studies, Hershey, SDR, and AKB fall in between several sites, but are closest to Minanha and Pacbutun. This demonstrates that while these individuals did consume large amounts of maize and $C_4$ animals/marine resources, they also ate a variety of other $C_3$ and foods. The slightly lower $\delta^{15}N$ values at Hershey, SDR, and AKB compared to Minanha and Pacbitun suggests the consumption of more lower-level proteins or less fish.

Pook's Hill appears to be similar to Barton Ramie in Belize in terms of $\delta^{15}N$, $\delta^{13}C_{col}$, and $\delta^{13}C_{carb.}$ Gerry (1993) concluded that the individuals at Barton Ramie were consuming a variety of resources, and were less reliant on maize than individuals from other areas in Mesoamerica. Gerry (1993) determined that at Barton Ramie, about 65% of the carbon in the individual's collagen and just under 50% of the carbon in their carbonate is $C_4$. Compared to the sites in the

Petén and the Copán Valley, Barton Ramie had the most negative $\delta^{13}C_{col}$ values. Their $\delta^{15}N$ values are relatively enriched, indicating a higher meat to legume ratio.

The average $\delta^{13}C_{carb}$ values from Hershey, Kaax Tsaabil, CBR, and AKB are slightly more negative than those at similar sites, and appear to be more like to those found at and Altun Ha. This could be caused by the consumption of more $C_3$ foods in the overall diet. SDR, on the other hand, has $\delta^{13}C_{carb}$ values like those found at Lamanai in Belize and Seibal in Guatemala.

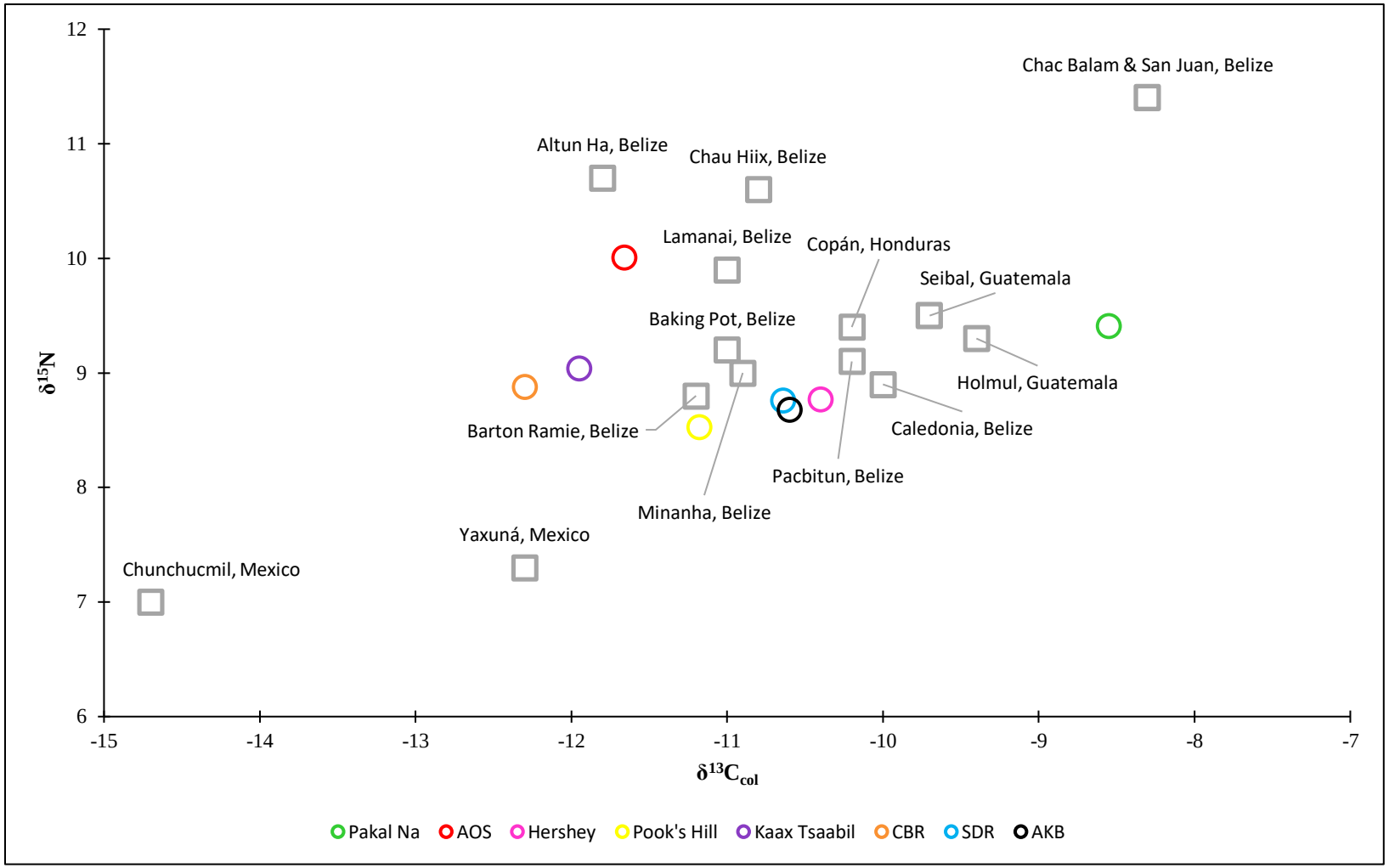


**Figure 38.** Biplot of $\delta^{13}C_{col}$ and $\delta^{15}N$ data from fourteen other Maya sites (same data as Figure 5), with average values for each site in this study as well.

Diachronic Dietary Variation

No significant differences in $\delta^{13}C_{col}$, $\delta^{15}N$, or $\delta^{13}C_{carb}$ values were found between the time periods for the samples of bone, but differences were detected in all three values for the tooth samples. Diet appeared to be variable within each time period. While there were no trends in adult diet as evidenced by the bone samples, the tooth samples showed that childhood diet significantly changed throughout time. This is also supported by the statistically significant differences found between the Postclassic individuals and the other two groups in terms of $\delta^{13}C_{en.}$

This hypothesis was more difficult to test, however due to the nature of the sample set. The relevant culture historical periods in which some of the individuals lived is uncertain (for example, the individuals at Pakal Na lived anywhere from the Late Classic into the Postclassic) and the sample size was small for the Preclassic to Early Classic set. It is also possible that the variation discovered between the time periods may be caused by differences between sites themselves instead of differences caused by time.

The statistically significant differences between the culture historical periods is likely caused by the differences between the site of Pakal Na and the other sites, instead of differences between the time periods themselves, because it has already been established that the site of Pakal Na is an outlier. No significant differences were found between any of the other time periods, suggesting that diet in Central Belize, while variable, did not change in any specific way throughout time.

These results should be taken with caution, for at least two reasons. The first reason is that the sample size for two of the time periods is small. Because of this, the true range of variation is likely not represented in these samples. A more robust sample size would definitely

address this issue. The second possible cause for error comes from the fact that all of the samples from the Preclassic to Early Classic came from the two rockshelter sites, while the Late/Terminal Classic and Postclassic samples came from the surface sites and a cave, so the true cause for the differences may be obscured by interactions of multiple variables. Even though it appears that childhood diet, as evidenced by significant differences found in the tooth samples, varied, the hypothesis that there are differences in diets across time in the study area of Central Belize can neither be accepted nor rejected at this time.

Dietary Variation by Site Type

The only statistically significant difference found between the three site types, once Pakal Na was removed from the pool of surface sites, was in the $\delta^{13}C_{carb}$ values between the rockshelter sites and the cave site. No statistically significant differences were found in $\delta^{13}C_{col}$ or $\delta^{15}N$. This means that it is possible that while there were no major differences in protein sources between the site types, there were differences in whole diet between the individuals buried in the cave and those buried in the rockshelter, with the cave individuals consuming more $C_4$. This follows the distinction between high status and low status maize consumption, found in other Maya studies mentioned above, with the higher class (cave individuals) individuals consuming more maize than the lower class (rockshelter individuals). The hypothesis that diet will be different based on differences in site type is supported based on the statistically significant differences in $\delta^{13}C_{carb}$ found between AKB and SDR/CBR.

Individual Dietary Changes Through Life

To test how individuals' diets changed throughout their lives, samples of bone, tooth dentin, and tooth enamel from the same individual were analyzed and compared to each other. The tooth enamel records diet very early in life, the tooth dentin records childhood diet a little later, and the bone records diet during the last several years of life. Based on the isotopic evidence, some changes were detected within the lives of the sampled individuals.

The average absolute value of change in $\delta^{13}C_{col}$ is 1.24‰, with change from tooth to bone ranging from -2.29 to +1.23‰. The changes in $\delta^{13}C_{col}$ are split, with four individuals exhibiting a depletion in $\delta^{13}C_{col}$ values over the lifespan, one showing an enrichment, and four showing little to no change. According to these changes, AOS Burial 3, Pook's Hill Str. 4A-4, Pakal Na Burial 1A/1C, and Pakal Na Burial 2 were likely consuming more $C_4$/marine protein as children, and more $C_3$ protein as adults. In conjunction with the $\delta^{15}N$ data, the protein source appears to change for these individuals, but not the trophic level. The opposite is true for Hershey Zone 3, whose diet may have become more reliant on $C_4$ or marine protein as they got older, and when considering the $\delta^{15}N$ data as well, was consuming higher-order proteins.

Most individuals did not have large changes in their overall diets from childhood to adulthood as evidenced by $\delta^{13}C_{carb}$ values (Figure 35). The average absolute value of change from dentin $\delta^{13}C_{carb}$ to bone $\delta^{13}C_{carb}$ is 0.79‰ with a range from -1.92 to +0.70. Three of the individuals (Hershey Zone 1, Pook's Hill Str. 4A-4, and Pakal Na Burial 1A/1C) displayed a change larger than 1‰, while the others exhibited very little or no change in $\delta^{13}C_{carb}$ between dentin and bone. Except for Hershey Zone 1, this is consistent with the $\delta^{13}C_{col}$ changes above.

Because there is currently uncertainty about the difference in isotopic fractionation values between enamel carbonate and bone/tooth dentin carbonate, raw values were used. Because the

values are uncorrected, differences in $\delta^{13}C$ values between carbonate and enamel samples may not inevitably mean difference in diet. The average absolute value of change from $\delta^{13}C_{en}$ to bone $\delta^{13}C_{carb}$ is 3.51‰ with a range from -1.03 to -4.85‰. The average absolute value of change from $\delta^{13}C_{en}$ to dentin $\delta^{13}C_{carb}$ is 2.88‰ with a range from -1.73 to -4.38‰. All $\delta^{13}C_{en}$ values were higher than the bone and dentin $\delta^{13}C_{carb}$ values.

The average absolute value of change in $\delta^{15}N$ values is 0.76‰, with actual change from tooth to bone ranging from -1.91 to +0.71‰ (Figure 37). For the majority of the samples (7 out of 9), the $\delta^{15}N$ did not change from childhood to adulthood. Only two of the individuals (Hershey Zone 3 and Pook's Hill 4A-2) had changes greater than 1‰, indicating actual change. For these two individuals, this demonstrates that they may have consumed more higher-level animals or marine resources as children than they did as adults. While it is possible for higher $\delta^{15}N$ values in dentin collagen to be caused by the consumption of breast milk during infancy, this is unlikely to be the case for these samples. Care was taken during preparation to sample the apical portion of the tooth root, which will record the later, post-weaning diet, compared to the dentin under the crown of the tooth. Because of this, the breastfeeding signal should not be present in the dentin samples. If the breastfeeding signal was present, the nitrogen isotope ratio in the infant's bone or dentin collagen would be about 2-4 ‰ enriched compared to the mother's (Fogel et al. 1989).

Individual 4A-4 was a 16-20-year-old of unknown sex, and appears to be an outlier in terms of dietary change from childhood to adulthood. The tooth sampled from 4A-4 was a $LP_2$, which according to Table 3, is initially calcified at age 2.25-2.5 and is finished growing by age 13-14. 4A-4's dietary change was opposite of the others from Pook's Hill, and it appears from this data that their diet shifted markedly during the last couple years of their life. Interestingly,

their adult diet appears similar to the other individuals from Pook's Hill, while their childhood diet appears to be different. This case is unusual compared to the other individuals and warrants further research.

The hypothesis that there would be change in diet throughout the life of sampled individuals is supported because some of the individuals had isotopically detectable changes in diet. The differences between juvenile and adult diet at AOS, Pook's Hill, Hershey, and Pakal Na supports the idea that dietary differences between the age classes is site-specific, as has been demonstrated by previous studies including those at Chau Hiix, Pacbitun, Chac Balam and San Juan, and Lamania. At Chau Hiix in Belize, it was determined that children were eating more maize than adults from the Early Classic period to the Historic period (Metcalfe et al. 2009). This is contrasted with the results found at Pacbitun, where the juveniles were found to have eaten far fewer $C_4$ foods than the adults (mean difference in $\delta^{13}C_{col}$ of 2.5‰) (White et al. 1993). At the sites of Chac Balam and San Juan on Ambergris Caye in Belize, though, no significant differences were found between the diets of juveniles and adults during the same time periods (Parker 2011). No age-related dietary differences were found between juveniles and adults at Lamanai either (White 1986, 1988; White and Schwarcz 1989; White et al. 1994).

# Chapter 6: CONCLUSION AND FUTURE DIRECTIONS

This study provides information about the lives of individuals living in Central Belize from the Late Preclassic to Postclassic periods through the analysis of stable carbon and nitrogen isotopes found in human skeletal remains. It was found that most of the individuals in the sample set had a diet high in $C_4$ with a mixture of $C_3$ and $C_4$ or marine protein sources, and that diet was not uniform across the sampled time or space. This research supports previous studies which show that ancient Maya diet varied intersite, intrasite, and through time, and provides a valuable additional data set to the isotopic knowledge we have about the ancient Maya.

To help distinguish between the consumption of $C_4$ and marine-derived proteins, the collagen-to-carbonate spacing was analyzed. These values revealed that three of the individuals in this study (Pakal Na Burial 1A/1C, Pakal Na Burial 2, and Pook's Hill Str. 4A-2) may have had a marine-based diet. the collagen-to-carbonate spacing also showed that there were a variety of different diets eaten by these individuals, with varying levels and combinations of $C_3$ and $C_4$ protein, carbohydrate, and lipid consumption.

For the individuals with paired bone and tooth samples, it was discovered that their overall diets did not change much from childhood to adulthood. In terms of protein source, the results were mixed. While it appears that most of the individuals consumed foods with similar $\delta^{15}N$ values throughout life, the $\delta^{13}C_{col}$ values appeared to change over time. This suggests that while the individuals likely had similarities in changes of whole diet from childhood to adulthood, the changes in protein sources throughout life varied.

Dietary variation was discovered within the sampled individuals, and by testing the first three hypotheses, it was found that the variation could have been caused by site location, time period, type of burial (which may be informative of social status), or a combination of factors.

The sample set utilized for this thesis is not ideal for providing definitive answers about spatial, temporal, or status-based differences in diet. This is because there are many variables to consider at once (i.e. different location, different time period, different site type, and different social status), and it may not be clear which variable is causing the potential dietary differences. This is not a fatal flaw however, because it demonstrates that the causes for dietary variation are not always simple, but are likely often multifactorial.

The ancient Maya had access to a variety of resources because of the varying environments in which they lived throughout Mesoamerica. In the Southern Lowlands of Central Belize, many different types of foods were available through hunting, farming, and trade. The rivers in Central Belize that many sites were situated near provided both freshwater resources and access to the Caribbean Sea, and the fertile land allowed for productive agricultural projects. This study reveals that although maize appears to have been very important, their diets were also rounded out with many other types of foods, and that there was a lot of individual variation between diets.

This research is important not only because of the data set that it produced, but also for several other reasons. It has confirmed the importance of sampling multiple elements and multiple phases of skeletal material. It also provides more information about what life was like for individuals living outside of the main Maya centers. Understanding more about the individuals living in the periphery is useful because that data can be used to find commonalities and differences in the ways of life between the rulers and others. This can allow archaeologists to see how live experiences were different between different segments of society, which will provide a clearer picture of the ancient Maya as a whole.

Future Directions

While this study did provide a valuable data set and a greater understanding of the diet in Central Belize, future research should be done to further clarify the questions posed here. Deeper sampling would alleviate many of the issues encountered in this study by creating a larger sample set. More representation across all variables (site types, time periods, different skeletal components) would aid in evaluating all the hypotheses in this study. A larger sample set has the potential to make trends more readily apparent, and would aid in more accurate interpretations of means and variations.

To provide even more information about the lives of these individuals, the analysis of stable strontium isotopes will soon be conducted on the tooth enamel samples, which will be informative on if these individuals were local or non-local to the area. As has been discussed, food availability is largely controlled by environmental factors, so the migration patterns of individuals throughout their lives may help explain dietary variability within a group. At this time, it is unknown if each individual was local to the area where they were buried.

To fully be able to put these results into context, stable isotope analyses should be conducted on site-specific archaeological floral and faunal remains in the future. Because isotopic values in plant and animal tissues may vary based upon environmental conditions, isotopic values for the food sources for this particular environment must be established to create the most accurate dietary reconstruction.

In most ancient Maya studies, chronology is established based on ceramic sequences, which sometimes produce large date ranges. Smaller ranges would be better for isotopic studies, which can be accomplished through the radiocarbon dating of some of the individuals.

Radiocarbon dating would help establish a tighter range of dates for site occupation and would allow for a better understanding of dietary change through time.

There will always be a need for future research in this area. A larger sample size, the inclusion of more elements, a more specific and accurate foodweb, and more precise dates would all make this study, and future studies in the Maya area, better and more complete. When all of these potential issues have been addressed, a clearer picture of ancient Maya life can be achieved, and these questions may be readdressed.

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## APPENDIX A: Information on Central Belize Skeletal Collection Used for This Study

| Site | Burial # | Operation/Location/ Lot # | Sample Type | Age | Sex | Social Status | Excavator |
|---|---|---|---|---|---|---|---|
| Pakal Na | Burial 1A | OP 22 | bone frag. | Over 60 | Male | Elite | XARP |
| Pakal Na | Burial 1C | OP 22 | $M_1$ | Over 60 | Male | Elite | XARP |
| Pakal Na | Burial 1B | OP 22 | $M_3$ | Older Adult | Male | High | XARP |
| Pakal Na | Burial 1D | OP 22 | bone frag. | Over 35 | Male | High | XARP |
| Pakal Na | Burial 1E | OP 22 | $M_3$ | Over 35 | -- | High | XARP |
| Pakal Na | Burial 2 | OP 22 | bone frag. | Over 40 | Male | High | XARP |
| Pakal Na | Burial 2 | OP 22 | $LC_1$ | Over 40 | Male | High | XARP |
| Pakal Na | Burial 1C | OP 22 | $M^3$ | Over 35 | Male | High | XARP |
| Augustine Obispo | Burial 3 | OP 33, Z 17, Sq. C | femur | Adult | Male | Elite | XARP |
| Augustine Obispo | Burial 3 | OP 33, Z 17, Sq. C | $LM^2$ | Adult | Male | Elite | XARP |
| Hershey | Zone 1 | OP 54, Z 1, Sq. A | bone frag. | -- | -- | Elite | XARP |
| Hershey | Zone 1 | OP 54, Z 1, Sq. A | $RM_1$ | -- | -- | Elite | XARP |
| Hershey | Zone 3 | OP 54, Z 3, Sq. A | Bone frag. | -- | -- | Elite | XARP |
| Hershey | Zone 3 | OP 54, Z 3, Sq. A | $RM^1$ | -- | -- | Elite | XARP |
| Hershey | Zone 4 | OP 54, Z 4, Sq. A | bone frag. | Juvenile | -- | Elite | XARP |
| Hershey | Zone 5 | OP 54, Z 5, Sq. A | RP | -- | -- | Elite | XARP |
| Pook's Hill | Str. 4A-2 | OP 4A | fibula | 20-25 | -- | High | BVAR |
| Pook's Hill | Str. 4A-2 | OP 4A | $RI^1$ | 20-26 | -- | High | BVAR |
| Pook's Hill | Str. 4A-4 | OP 4A | fibula | 16-20 | -- | High | BVAR |
| Pook's Hill | Str. 4A-4 | OP 4A | $LP_2$ | 16-20 | -- | High | BVAR |
| Pook's Hill | Str. 4A-5 | OP 4A | fibula | Middle Adult | Male? | High | BVAR |
| Pook's Hill | Str. 4A-5 | OP 4A | $RP_1$ | Middle Adult | Male? | High | BVAR |
| Pook's Hill | Str. 4A-6 | OP 4A | fibula | Young Adult | Male | High | BVAR |
| Pook's Hill | Str. 4A-6 | OP 4A | $RP_1$ | Young Adult | Male | High | BVAR |
| Pook's Hill | Str. 4A-7 | OP 4A | Fibula | -- | -- | High | BVAR |
| Pook's Hill | Str. 4A-7 | OP 4A | $RP_1$ | -- | -- | High | BVAR |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Caves Branch Rockshelter | Burial 1A | -- | rib | 20-35 | Female | Non-elite | BVAR |
| Caves Branch Rockshelter | Burial 2 | Lot 709 | fibula | 35-50 | Female | Non-elite | BVAR |
| Caves Branch Rockshelter | Burial 9 | -- | rib | 20-35 | Male | Non-elite | BVAR |
| Caves Branch Rockshelter | Burial 10 | -- | fibula | 35-50 | Female | Non-elite | BVAR |
| Caves Branch Rockshelter | Burial 11 | Lot 812 | fibula | <40 | Male | Non-elite | BVAR |
| Caves Branch Rockshelter | Burial 12 | Lot 814 | rib | 35-50 | -- | Non-elite | BVAR |
| Caves Branch Rockshelter | Burial 13 | -- | femur | Adult | Male | Non-elite | BVAR |
| Caves Branch Rockshelter | Burial 14A | Lot 817 | fibula | 35-50 | Female | Non-elite | BVAR |
| Caves Branch Rockshelter | Burial 14B | Lot 817 | humerus | 2-4 | -- | Non-elite | BVAR |
| Caves Branch Rockshelter | Burial 19 | Lot 710 | clavicle | 5-7 | -- | Non-elite | BVAR |
| Caves Branch Rockshelter | Burial 28 | Lot 808 | rib | Adult | Female | Non-elite | BVAR |
| Sapodilla Rockshelter | Burial 2 | OP 1C, SDR 11-15-170 | $LI^1$ | Older Adult | Male | Non-elite | CBAS |
| Sapodilla Rockshelter | Burial 10 | OP 1B, SDR 11-41-371 | $RP_2$ | Adult | -- | Non-elite | CBAS |
| Sapodilla Rockshelter | Burial 13 | OP 1B | $LI_2$ | Adult | Male | Non-elite | CBAS |
| Kaax Tsaabil | Burial 1 | OP 14 | fibula | ~30-50 | Female | Elite | BREA |
| Actun Kabul | "Dent G" | AKB 11-4-28 | $LP_1$ | 18+ | -- | High | CBAS |
| Actun Kabul | Main Burial Chamber | AKB 11-12-44 | $LP_1$ | -- | -- | High | CBAS |
| Actun Kabul | "Dent C" | AKB 11-4-28 | $LP_1$ | 9-12 | -- | High | CBAS |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Actun Kabul | Terminal Burial Chamber Rimstone Dam #2 | AKB 13-15-97 | $LP_1$ | -- | -- | High | CBAS |
| Actun Kabul | Scatter A, Portion 1 Terminal Burial Chamber Rimstone Dam #4 | AKB 13-16-40 | $LP_1$ | -- | -- | High | CBAS |
| Actun Kabul | Area: 6 | AKB-11-9-45 | $LP_1$ | -- | -- | High | CBAS |
| Actun Kabul | Scatter A, Portion 3 Lot 16, Rimstone Dam #2 | AKB 13-16-41 | $LP_1$ | -- | -- | High | CBAS |
| Actun Kabul | Scatter JJ | AKB 13-15-124 | $LP_1$ | -- | -- | High | CBAS |
| Actun Kabul | Scatter GG | AKB 13-15-136 | $LP_1$ | 11-12 | -- | High | CBAS |
| Actun Kabul | Main Burial Chamber Lot 10 | AKB 11-10-40 | $LP_1$ | -- | -- | High | CBAS |
| Actun Kabul | -- | AKB 11-13-32 | $LP_1$ | -- | -- | High | CBAS |
| Actun Kabul | -- | AKB Surface Collection | $LP_1$ | -- | -- | High | CBAS |

Abbreviated excavators: XARP= Xibun Archaeological Research Project. BVAR= Belize Valley Archaeological Reconnaissance Project. CBAS= The Central Belize Archaeological Survey Project. BREA= Belize River East Archaeology Research Project.

## APPENDIX B: Collagen and Carbonate Results for Human Samples

| Site and Burial/Zone/Individual | Sample Type | $\delta^{13}C_{col}$ | $\delta^{15}N$ | Collagen Yield % | %N | %C | C/N | $\delta^{13}C_{carb}$ | $\delta^{13}C_{en}$ | $\delta^{18}O_{carb}$ | $\delta^{18}O_{en}$ | $\Delta^{13}C_{carb-col}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Pakal Na** | | | | | | | | | | | | |
| Burial 1A | Bone frag. | -8.66 | 8.91 | 4.9 | 11.5 | 32.6 | 3.3 | -5.29 | -- | -5.35 | -- | 3.31 |
| Burial 1C (same individual as 1A) | Bone frag. | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Burial 1C (same individual as 1A) | $M_1$ | -7.43 | 9.68 | 8.7 | 15.1 | 42.1 | 3.3 | -3.37 | -0.50 | -4.47 | -3.48 | 2.96 |
| Burial 1B | Bone frag. | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Burial 1B | $M_3$ | -7.92 | 9.73 | 11.2 | 15.5 | 43.0 | 3.2 | -5.11 | -2.49 | -4.44 | -3.28 | 3.48 |
| Burial 1D | Bone frag. | -8.43 | 9.29 | 5.7 | 14.5 | 40.7 | 3.3 | -4.87 | | -5.18 | | 3.25 |
| Burial 1E | $M_3$ | -8.84 | 9.90 | 7.3 | 15.3 | 43.1 | 3.3 | -4.66 | -1.61 | -4.66 | -3.62 | 4.18 |
| Burial 2 | Bone frag. | -9.23 | 8.99 | 5.1 | 13.4 | 37.0 | 3.2 | -6.07 | | -5.08 | | 4.15 |
| Burial 2 | $LC_1$ | -7.72 | 9.33 | 12.2 | 15.7 | 43.1 | 3.2 | -5.24 | -1.22 | -6.35 | -3.84 | 1.37 |
| Burial 1C (skull mask, different than 1A) | Maxilla | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Burial 1C (skull mask, different than 1A) | $M^3$ | -10.2 | 9.46 | 10.3 | 13.8 | 38.6 | 3.3 | -4.15 | -1.39 | -4.84 | -3.60 | 5.36 |
| **AOS** | | | | | | | | | | | | |
| Burial 3 | Femur | -12.45 | 9.96 | 8.6 | 11.8 | 32.7 | 3.2 | -9.45 | -- | -5.56 | -- | 6.89 |
| Burial 3 | $LM^2$ | -10.87 | 10.07 | 5.1 | 13.1 | 36.2 | 3.2 | -8.67 | -6.67 | -5.56 | -2.40 | 5.67 |
| **Hershey** | | | | | | | | | | | | |
| Zone 1 | Bone frag. | -10.5 | 10.21 | 7.3 | 14.8 | 41.9 | 3.3 | -8.62 | -- | -4.24 | -- | 6.26 |
| Zone 1 | $RM_1$ | -11.37 | 9.51 | 6.3 | 6.3 | 17.9 | 3.3 | -7.16 | -4.75 | -3.82 | -2.90 | 7.55 |
| Zone 3 | Bone frag. | -10.03 | 7.56 | 4.4 | 14.5 | 41.2 | 3.3 | -8.52 | -- | -4.37 | -- | 5.66 |
| Zone 3 | $RM^1$ | -11.25 | 9.46 | 6.9 | 6.5 | 19.0 | 3.4 | -8.47 | -4.09 | -3.87 | -3.53 | 7.38 |
| Zone 4 | Bone frag. | -9.44 | 7.58 | 4.8 | 14.3 | 40.8 | 3.3 | -7.97 | -- | -4.17 | -- | 5.27 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Zone 5 | RP[?] | -9.79 | 8.30 | 12.0 | 15.5 | 43.5 | 3.3 | -6.88 | -3.53 | -4.02 | -2.84 | 5.77 |
| **Pook's Hill** | | | | | | | | | | | | |
| Str. 4A-2 | Fibula | -10.82 | 7.38 | 5.6 | 4.9 | 14.3 | 3.4 | -6.42 | -- | -8.15 | -- | 2.67 |
| Str. 4A-2 | RI[1] | -11.78 | 8.42 | 2.8 | 14.9 | 41.4 | 3.2 | -7.12 | -5.39 | -5.59 | -2.93 | 6.19 |
| Str. 4A-4 | Fibula | -11.05 | 8.45 | 10.1 | 15.5 | 42.6 | 3.2 | -7.65 | -- | -6.18 | -- | 4.87 |
| Str. 4A-4 | $LP_2$ | -8.76 | 7.92 | 4.9 | 14.8 | 40.8 | 3.2 | -6.43 | -3.61 | -5.32 | -2.88 | 3.44 |
| Str. 4A-5 | Fibula | -10.78 | 8.46 | 6.0 | 13.4 | 37.2 | 3.2 | -7.54 | -- | -6.16 | -- | 4.62 |
| Str. 4A-5 | $RP_1$ | -11.33 | 9.25 | 9.4 | 15.3 | 43.8 | 3.3 | -7.55 | -4.33 | -6.64 | -3.43 | 4.69 |
| Str. 4A-6 | Fibula | -11.69 | 8.59 | 12.4 | 15.5 | 42.4 | 3.2 | -8.05 | -- | -5.70 | -- | 5.99 |
| Str. 4A-6 | $RP_1$ | -12.61 | 9.24 | 7.9 | 15.4 | 42.5 | 3.2 | -7.91 | -5.45 | -6.04 | -3.06 | 6.57 |
| Str. 4A-7 | Fibula | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Str. 4A-7 | $RP_1$ | -11.84 | 9.03 | 9.3 | 15.6 | 42.8 | 3.2 | -7.83 | -4.91 | -7.78 | -3.64 | 4.06 |
| **CBR** | | | | | | | | | | | | |
| Burial 1A | Rib | -14.35 | 8.53 | 1.2 | 13.9 | 38.8 | 3.3 | -8.91 | -- | -6.79 | -- | 7.56 |
| Burial 2 | Fibula | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Burial 9 | Rib | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Burial 10 | Fibula | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Burial 11 | Fibula | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Burial 12 | Rib | -13.2 | 8.31 | 1.5 | 14.2 | 39.6 | 3.2 | -8.36 | -- | -7.56 | -- | 5.64 |
| Burial 13 | Femur | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Burial 14A | Fibula | -12.68 | 8.97 | 1.0 | 14.6 | 41.2 | 3.3 | -7.38 | -- | -7.70 | -- | 4.98 |
| Burial 14B | Humerus | -9.92 | 10.73 | 6.3 | 13.9 | 38.2 | 3.2 | -7.01 | -- | -6.23 | -- | 3.69 |
| Burial 19 | Clavicle | -10.69 | 7.82 | 11.1 | 14.8 | 40.7 | 3.2 | -6.93 | -- | -6.86 | -- | 3.83 |
| Burial 28 | Rib | -12.97 | 8.90 | 3.1 | 13.5 | 37.9 | 3.3 | -8.02 | -- | -7.44 | -- | 5.53 |
| **SDR** | | | | | | | | | | | | |
| Burial 2 | LI[1] | -10.06 | 9.19 | 11.0 | 15.8 | 43.2 | 3.2 | -5.89 | -6.07 | -5.68 | -3.66 | 4.38 |
| Burial 10 | $RP_2$ | -10.69 | 8.45 | 9.6 | 15.5 | 42.5 | 3.2 | -6.86 | -4.42 | -5.30 | -2.89 | 5.39 |
| Burial 13 | $LI_2$ | -11.16 | 8.65 | 9.7 | 15.2 | 41.6 | 3.2 | -6.14 | -6.08 | -6.82 | -2.86 | 4.34 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Kaax Tsaabil** | | | | | | | | | | | | |
| Burial 1 | Fibula | -11.95 | 9.04 | 8.2 | 15.2 | 42.0 | 3.2 | -7.97 | -- | -5.22 | -- | 6.73 |
| **AKB** | | | | | | | | | | | | |
| "Dent G" | $LP_1$ | -9.12 | 8.40 | 14.6 | 16.0 | 43.5 | 3.2 | -7.12 | -5.44 | -4.08 | -3.36 | 5.05 |
| Main Burial Chamber | $LP_1$ | -11.09 | 8.61 | 4.5 | 15.1 | 41.5 | 3.2 | -8.77 | -5.08 | -6.21 | -4.02 | 4.88 |
| "Dent C" | $LP_1$ | -9.73 | 9.49 | 5.4 | 15.1 | 41.2 | 3.2 | -7.87 | -4.31 | -4.39 | -1.68 | 5.34 |
| Terminal Burial Chamber Rimstone Dam #2 | $LP_1$ | -9.01 | 8.51 | 6.0 | 14.6 | 40.3 | 3.2 | -8.77 | -2.43 | -4.28 | -4.01 | 4.73 |
| Scatter A, Portion 1 Terminal Burial Chamber Rimstone Dam #4 | $LP_1$ | -10.98 | 7.89 | 4.2 | 14.8 | 40.7 | 3.2 | -10.14 | -6.06 | -4.31 | -2.83 | 6.67 |
| Area: 6 | $LP_1$ | -11.03 | 9.20 | 12.3 | 16.0 | 43.5 | 3.2 | -8.31 | -5.24 | -4.26 | -3.22 | 6.77 |
| Scatter A, Portion 3 Lot 16, Rimstone Dam #2 | $LP_1$ | -9.77 | 9.38 | 7.2 | 15.4 | 41.8 | 3.2 | -8.26 | -3.74 | -4.67 | -3.10 | 5.10 |
| Scatter JJ | $LP_1$ | -10.3 | 8.12 | 14.2 | 15.7 | 42.6 | 3.2 | -7.60 | -4.37 | -4.37 | -3.17 | 5.94 |
| Scatter GG | $LP_1$ | -11.48 | 9.00 | 2.8 | 13.5 | 37.3 | 3.2 | -9.97 | -6.81 | -4.66 | -2.67 | 6.81 |
| Main Burial Chamber | $LP_1$ | -10.52 | 8.63 | 9.6 | 15.8 | 43.1 | 3.2 | -7.28 | -5.84 | -4.64 | -3.09 | 5.88 |
| AKB 11-13-32 | $LP_1$ | -11.61 | 8.42 | 4.0 | 15.1 | 41.4 | 3.2 | -8.86 | -3.38 | -4.44 | -3.89 | 7.17 |
| AKB Surface Collection | $LP_1$ | -12.52 | 8.57 | 13.1 | 7.8 | 21.6 | 3.2 | -7.51 | -4.95 | -4.59 | -2.30 | 7.93 |

## APPENDIX C: Information and Collagen Results for Animal Samples

| Site | Operation/Zone | Catalogue # | Animal and Sample Type | $\delta^{13}C_{col}$ | $\delta^{15}N$ | Collagen Yield % | %N | %C | C/N |
|---|---|---|---|---|---|---|---|---|---|
| Pakal Na | OP 22, Z 5, Sq. B | -- | ~10 lb mammal Scapula | -21.89 | 3.50 | 5.1 | 14.4 | 40.5 | 3.3 |
| Pakal Na | OP 22, Z 6, Sq. B | -- | ~20 lb carnivore Canine Tooth | -- | -- | -- | -- | -- | -- |
| Pakal Na | OP 22, Z 7, Sq. B | -- | Deer or Dog Metapodial | -20.16 | 4.11 | 7.5 | 4.9 | 13.5 | 3.3 |
| Hershey | OP 54, Z 7, Sq. A | -- | Unknown mammal Long bone frag. | -24.70 | 4.24 | 3.7 | 13.8 | 40.2 | 3.4 |
| SDR | OP 1B, Darkzone | SDR F003 | Paca Molar Tooth | -- | -- | -- | -- | -- | -- |
| SDR | OP 1B, Light Zone Central | SDR F023 | Paca Astragalus | -- | -- | -- | -- | -- | -- |
| SDR | OP 1B, Light Zone Central | SDR F026 | Paca Metapodial | -- | -- | -- | -- | -- | -- |
| SDR | OP 1J | SDR F182 | Parrotfish Skull | -20.38 | 4.85 | 8.6 | 14.0 | 39.7 | 3.3 |
| SDR | OP 1J | SDR F183 | Parrotfish Maxilla | -- | -- | -- | -- | -- | -- |
| SDR | OP 1B | SDR F033 | Turkey Phalanx | -18.52 | 5.81 | 7.5 | 13.3 | 38.0 | 3.3 |
| SDR | OP 1994 | SDR F036 | Peccary Molar Tooth | -- | -- | -- | -- | -- | -- |
| SDR | OP 1B, Light Zone Central | SDR F050 | Peccary Metacarpal | -- | -- | -- | -- | -- | -- |
| SDR | OP 1C, Light Zone Central | SDR FO63 | Peccary Rib | -- | -- | -- | -- | -- | -- |
| SDR | South Area | SDR F157 | White Tailed Deer Metapodial | -- | -- | -- | -- | -- | -- |
| SDR | OP 1B, Light Zone Central | SDR F031 | White Tailed Deer Thoracic Vert. | -- | -- | -- | -- | -- | -- |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SDR | OP 1B, Light Zone Central | SDR F032 | Brocket Deer Metapodial | -- | -- | -- | -- | -- | -- |
| SDR | OP 1B, Light Zone Central | SDR F028 | Brocket Deer Astragalus | -- | -- | -- | -- | -- | -- |
| SDR | OP 1G, South Area | SDR F155 | Brocket Deer Phalanx | -- | -- | -- | -- | -- | -- |
| SDR | OP 1C, Light Zone Central | SDR F112 | Coati Molar Tooth | -- | -- | -- | -- | -- | -- |
| SDR | OP 1C, Light Zone Central | SDR F113 | Coati Mandible | -- | -- | -- | -- | -- | -- |
| CBR | OP 1G | CBR F018 | White Tailed Deer Phalanx | -- | -- | -- | -- | -- | -- |
| DVY | OP 4, Junction of D1 and D2 | DVY F001 | Parrotfish Pharyngeal jaw | -- | -- | -- | -- | -- | -- |
| BTE | OP D1 | BTE F001 | Parrotfish Pharyngeal jaw | -- | -- | -- | -- | -- | -- |
| BTE | OP D1 | BTE F002 | Parrotfish Maxilla | -- | -- | -- | -- | -- | -- |

## APPENDIX D: FTIR-ATR Crystallinity Index Results for Human Carbonate Samples

| Individual | Sample Type | Bone CI | Dentin CI | Enamel CI |
|---|---|---|---|---|
| PN Burial 1A | Bone frag. | 4.5 | | |
| PN Burial 1C | $M_1$ | | 4.0 | 4.1 |
| PN Burial 1B | $M_3$ | | 4.0 | 3.9 |
| PN Burial 1D | Bone frag. | 4.5 | | |
| PN Burial 1E | $M_3$ | | 4.1 | 4.1 |
| PN Burial 2 | Bone frag. | 5.1 | | |
| PN Burial 2 | $LC_1$ | | 3.9 | 4.1 |
| PN Burial 1C | $M^3$ | | 3.9 | 4.1 |
| AOS Burial 3 | Femur | 4.9 | | |
| AOS Burial 3 | $LM^2$ | | 4.5 | 4.1 |
| HS Zone 1 | Bone frag. | 4.3 | | |
| HS Zone 1 | $RM_1$ | | 4.6 | 4.0 |
| HS Zone 3 | Bone frag. | 4.2 | | |
| HS Zone 3 | $RM^1$ | | 4.0 | 4.2 |
| HS Zone 4 | Bone frag. | 4.1 | | |
| HS Zone 5 | $RP^?$ | | 3.9 | 4.0 |
| PH Str. 4A-2 | Fibula | 4.6 | | |
| PH Str. 4A-2 | $RI^1$ | | 5.2 | 4.1 |
| PH Str. 4A-4 | Fibula | 4.1 | | |
| PH Str. 4A-4 | $LP_2$ | | 4.4 | 4.5 |
| PH Str. 4A-5 | Fibula | 4.3 | | |
| PH Str. 4A-5 | $RP_1$ | | 4.1 | 4.0 |
| PH Str. 4A-6 | Fibula | 4.1 | | |
| PH Str. 4A-6 | $RP_1$ | | 4.5 | 4.1 |
| PH Str. 4A-7 | $RP_1$ | | 4.2 | 4.1 |
| CBR Burial 1A | Rib | 4.3 | | |
| CBR Burial 12 | Rib | 4.2 | | |
| CBR Burial 14A | Fibula | 4.3 | | |
| CBR Burial 14B | Humerus | 4.5 | | |
| CBR Burial 19 | Clavicle | 3.9 | | |
| CBR Burial 28 | Rib | 4.2 | | |
| SDR Burial 2 | $LI^1$ | | 4.0 | 4.0 |
| SDR Burial 10 | $RP_2$ | | 4.1 | 4.3 |
| SDR Burial 13 | $LI_2$ | | 4.4 | 4.1 |
| KT Burial 1 | Fibula | 4.6 | | |
| AKB "Dent G" | $LP_1$ | | 4.1 | 4.2 |
| AKB Main Burial Chamber | $LP_1$ | | 5.1 | 4.0 |
| AKB "Dent C" | $LP_1$ | | 4.7 | 4.2 |

| | | | | |
|---|---|---|---|---|
| AKB Terminal Burial Chamber Rimstone Dam #2 | $LP_1$ | | 4.0 | 4.1 |
| AKB Scatter A, Portion 1 Terminal Burial Chamber Rimstone Dam #4 | $LP_1$ | | 4.1 | 3.9 |
| AKB Area: 6 | $LP_1$ | | 4.5 | 4.3 |
| AKB Scatter A, Portion 3 Lot 16, Rimstone Dam #2 | $LP_1$ | | 4.5 | 4.3 |
| AKB Scatter JJ | $LP_1$ | | 4.0 | 4.5 |
| AKB Scatter GG | $LP_1$ | | 4.0 | 4.5 |
| AKB Main Burial Chamber Lot 10 | $LP_1$ | | 4.5 | 4.0 |
| AKB 11-13-32 | $LP_1$ | | 4.8 | 4.3 |
| AKB Surface Collection | $LP_1$ | | 4.2 | 4.2 |

## APPENDIX E: Collagen Data from Animal Samples Used in the Creation of the Generalized Maya Foodweb

| Resource Type | Species | Modern $\delta^{13}C$ | Corrected/ Archaeological $\delta^{13}C$ | $\delta^{15}N$ | Reference |
|---|---|---|---|---|---|
| C3 | Dioscorea sp. (Yam) | -25.1 | -23.6 | 7.6 | Keegan and DeNiro 1988 |
| C3 | Dioscorea sp. (Red Yam) | -26.3 | -24.8 | 3.7 | Keegan and DeNiro 1988 |
| C3 | Dioscorea sp. (White Yam) | -27.0 | -25.5 | 5.2 | Keegan and DeNiro 1988 |
| C3 | Dioscorea sp. (Black Yam) | -27.3 | -25.8 | 2.8 | Keegan and DeNiro 1988 |
| C3 | Xanthosoma sp. (Cocoyam) | -26.1 | -24.6 | 4.3 | Keegan and DeNiro 1988 |
| C3 | Manihot esculenta (Manioc) | -27.6 | -26.1 | 2.4 | Keegan and DeNiro 1988 |
| C3 | Unidentified tuber (Eddoe) | -24.4 | -22.9 | 3.2 | Keegan and DeNiro 1988 |
| C3 | Ipomaea batatas (Sweet Potato) | -25.7 | -24.2 | 3.8 | Keegan and DeNiro 1988 |
| C3 | Capsicum sp. (Chili Pepper) | -30.1 | -28.6 | | Wright 2006 |
| C3 | Brosimum alicastrum (ramon) | -27.7 | -26.2 | | Wright 2006 |
| C3 | Brosimum alicastrum (ramon tortilla) | -25.17 | -23.67 | | Wright 2006 |
| C3 | Astrocaryum mexicanum (Chapay nut) | -31.44 | -29.94 | | Wright 2006 |
| C3 | Astrocaryum mexicanum (Chapay nut) | -31.62 | -30.12 | | Wright 2006 |
| C3 | Orbignya cohune (corozo nut) | -29.65 | -28.15 | | Wright 2006 |
| C3 | Orbignya cohune (corozo nut) | -28.3 | -26.8 | | Wright 2006 |
| C3 | Pouteria mamosa (Zapote fruit) | -27.1 | -25.6 | | Wright 2006 |
| C3 | Pouteria mamosa (Zapote seed) | -27.82 | -26.32 | 0.56 | Wright 2006 |
| C3 | Bixa orellana (achiote seeds) | -29.71 | -28.21 | | Wright 2006 |
| C3 | Ipomaea batatas (Camote/Potato) | -26.44 | -24.94 | | Wright 2006 |
| C3 | Capsicum sp. (Chili Pepper) | -27.75 | -26.25 | | Wright 2006 |
| C3 | Annona sp. (anona fruit) | -28.98 | -27.48 | | Wright 2006 |
| C3 | Annona muricara (Soursop) | -27.72 | -26.22 | 5.21 | Wright 2006 |
| C3 | Carica sp. (wild papaya) | -26.37 | -24.87 | 5.49 | Wright 2006 |

| | | | | | |
|---|---|---|---|---|---|
| C3 | Theobroma cacao (Cacao) | -34.14 | -32.64 | 3.69 | Wright 2006 |
| C3 | Pouteria mamosa (Zapote fruit) | -28.13 | -26.63 | | Wright 2006 |
| C3 | Pouteria mamosa (Zapote seed) | -30.04 | -28.54 | | Wright 2006 |
| C3 | Brosimum alicastrum (ramon) | -27.03 | -25.53 | | Wright 2006 |
| C3 | Dioscorea alicastrum (macal/yam) | -25.06 | -23.56 | | Wright 2006 |
| C3 | Lingua de vaca (epiphyte) | -26.81 | -25.31 | | Wright 2006 |
| C3 | Psidium guajava (gauva) | -27.27 | -25.77 | | Wright 2006 |
| C3 | Licania platypus (sunzapote) | -29.28 | -27.78 | | Wright 2006 |
| C3 | (Junco palm leaf) | -26.66 | -25.16 | 4.01 | Wright 2006 |
| C3 | Cucurbita sp. (Pepitoria squash) | -27.35 | -25.85 | 8.78 | Wright 2006 |
| C3 | Byrsonima crassifolia (nance) | -27.1 | -25.6 | | Wright 2006 |
| C3 | Cucurbita sp. (Pepitoria squash) | -27.12 | -25.62 | 7.53 | Wright 2006 |
| C3 | water lily | -24.55 | -23.05 | | Wright 2006 |
| C3 | Dioscorea sp. (Yam) | -28.6 | -27.1 | 1.9 | Norr 1991 |
| C3 | Manihot esculenta (Manioc) | -26.1 | -24.6 | | Norr 1991 |
| C3 | Brysonima crassifolia (nance) | -28.3 | -26.8 | | Norr 1991 |
| C3 | Bactris gasipaes (peach palm) | -27.1 | -25.6 | 2.4 | Norr 1991 |
| C4 | Zea mays (Maize) | -10.1 | -8.6 | 10 | Keegan and DeNiro 1988 |
| C4 | Zea mays (Maize) | -11.2 | -9.7 | 6.07 | Wright 2006 |
| C4 | Zea mays (Maize) | -11.02 | -9.52 | 3.5 | Wright 2006 |
| C4 | Zea mays (Maize) | -9.7 | -8.1 | | Norr 1991 |
| C4 | Zea mays (Maize) | -9.6 | -8.3 | 1.8 | Norr 1991 |
| C4 | Zea mays (Maize) | -10.1 | -8.6 | | Norr 1991 |
| C4 | Zea mays (Maize) | -9.8 | -8.3 | 1.4 | Norr 1991 |
| Legume | Phaseolus vulgaris (beans) | -27.12 | -25.62 | | Wright 2006 |
| Legume | Dialium guianense (wild tamarind) | -26.11 | -24.61 | | Wright 2006 |
| Legume | Phaseolus vulgaris (beans) | -27.75 | -26.25 | 3.94 | Wright 2006 |
| Legume | Phaseolus vulgaris (beans) | -26.8 | -25.3 | 0.5 | Norr 1991 |
| Legume | Phaseolus vulgaris (beans) | -28.6 | -27.1 | 0 | Norr 1991 |
| Legume | Phaseolus lunatus (lima bean) | -28 | -26.5 | -2.2 | Norr 1991 |
| Mammal | Mazama americana (Brocket deer) | | -24.3 | 3.7 | Williams, White, and Longstaffe 2009 |

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|---|---|---|---|---|---|
| Mammal | Mazama americana (Brocket deer) | | -19.9 | 8.1 | Williams, White, and Longstaffe 2009 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -19.8 | 6.2 | Williams, White, and Longstaffe 2009 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -19.3 | 4.6 | Williams, White, and Longstaffe 2009 |
| Mammal | Mazama americana (Brocket deer) | | -20.42 | 4.31 | White et al. 1993 |
| Mammal | Odocoileus virginianus White-Tailed deer) | | -23.74 | 15.8 | White et al. 1993 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -21.55 | 7.03 | White et al. 1993 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -19.54 | 5.05 | White et al. 1993 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -17.54 | 10.76 | White et al. 1993 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -13.57 | 9.42 | White et al. 1993 |
| Mammal | Tayassu tajacu (Collared Peccary) | | -13.57 | 7.84 | White et al. 1993 |
| Mammal | Canis familiaris (Dog) | | -8.23 | 7.29 | White et al. 1993 |
| Mammal | ~10 lb mammal | | -21.89 | 3.50 | Current Study |
| Mammal | Dog or deer | | -20.16 | 4.11 | Current Study |
| Mammal | Unknown Mammal | | -24.70 | 4.24 | Current Study |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -18.13 | 5.6 | Wright 2006 |
| Mammal | Cervidae | | -21.64 | 2.23 | Wright 2006 |
| Mammal | Mazama americana (Brocket deer) | | -21.5 | 3.1 | Wright 2006 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -21.48 | 6.6 | Wright 2006 |
| Mammal | Mazama americana (Brocket deer) | | -14.04 | 5.08 | Wright 2006 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -21.4 | 4 | Wright 2006 |
| Mammal | Tayassu pecari (White-lipped Peccary) | | -21.4 | 3.3 | Wright 2006 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | -21.86 | -20.36 | 7.2 | Wright 2006 |

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|---|---|---|---|---|---|
| Mammal | Odocoileus virginianus (White-Tailed deer) | -23.63 | -22.13 | 7.86 | Wright 2006 |
| Mammal | Mazama americana (Brocket deer) | -24.26 | -22.76 | 5.92 | Wright 2006 |
| Mammal | Tayassu tajacu (Collared Peccary) | -12.99 | -11.49 | 6.07 | Wright 2006 |
| Mammal | Tayassu tajacu (Collared Peccary) | -17.6 | -16.1 | 6.32 | Wright 2006 |
| Mammal | Tayassu pecari (White-lipped Peccary) | -23.66 | -22.16 | 4.73 | Wright 2006 |
| Mammal | Tayassu pecari (White-lipped Peccary) | -24.17 | -22.67 | 4.29 | Wright 2006 |
| Mammal | Agouti paca (Paca) | -22.97 | -21.47 | 5.78 | Wright 2006 |
| Mammal | Agouti paca (Paca) | -22.64 | -21.14 | 5.28 | Wright 2006 |
| Mammal | Dasypus novemcinctus (Armadillo) | -21.62 | -20.12 | 8.66 | Wright 2006 |
| Mammal | Felis pardalis (Ocelot) | -19.64 | -18.14 | 11.58 | Wright 2006 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -18.5 | 2.3 | Norr 1991 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -21.2 | 3.5 | Norr 1991 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -20.6 | 3.5 | Norr 1991 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -19.7 | 3 | Norr 1991 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -20.8 | 3.2 | Norr 1991 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -20 | 2.5 | Norr 1991 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -29.2 | 4 | Norr 1991 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -22.2 | 3.2 | Norr 1991 |
| Mammal | Odocoileus virginianus (White-Tailed deer) | | -21.7 | 2.8 | Norr 1991 |
| Mammal | Tayassu tajacu (Collared Peccary) | | -22.2 | 3.2 | Norr 1991 |
| Mammal | Dasyprocta punctata (Agouti) | | -21.2 | 4 | Norr 1991 |
| Mammal | Mazama americana (Brocket deer) | | -21.6 | 4.7 | White and Schwarz 1989 |

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|---|---|---|---|---|---|
| Mammal | Mazama americana (Brocket deer) | | -22 | 4.3 | White and Schwarz 1989 |
| Mammal | Tapirus bairdii (Tapir) | | -23.2 | 4.9 | White and Schwarz 1989 |
| Mammal | Canis familiaris (Dog) | | -10.7 | 8.9 | White and Schwarz 1989 |
| Bird | Meleagris gallopavo (Wild Turkey) | | -18.52 | 5.81 | Current Study |
| Bird | Meleagris gallopavo (Wild Turkey) | -9.93 | -8.43 | 8.29 | Wright 2006 |
| Reptile | Iguana Iguana (Iguana) | | -19.1 | 5.8 | Williams, White, and Longstaffe 2009 |
| Reptile | Dermatemys mawii (River turtle) | | -20.2 | 5.6 | Williams, White, and Longstaffe 2009 |
| Reptile | Trachemys scripta (Pond turtle) | | -19.5 | 4.3 | Williams, White, and Longstaffe 2009 |
| Reptile | Crocydylus (Crocodile) | | -18.2 | 8.9 | Williams, White, and Longstaffe 2009 |
| Reptile | Cyclura carinata (Iguana) | -19.5 | -18.0 | 6 | Keegan and DeNiro 1988 |
| Reptile | Crocodylus moreleti (Crocodile) | | -22.1 | 11 | Wright 2006 |
| Reptile | Porphidium nummifer (Mexican jumping viper) | -24.35 | -22.85 | 17.76 | Wright 2006 |
| Reptile | Bothrops asper (Fer-de-lance snake) | -22.37 | -20.87 | 10.01 | Wright 2006 |
| Reptile | Iguana Iguana (Iguana) | | -19.7 | 5.6 | Norr 1991 |
| Reptile | Iguana Iguana (Iguana) | | -21.6 | 3.9 | Norr 1991 |
| Reptile | Iguana Iguana (Iguana) | | -21.3 | 4.3 | Norr 1991 |
| Reptile | Iguana Iguana (Iguana) | | -19.6 | 5.8 | Norr 1991 |
| Freshwater snail | Pachychilus glaphrus (Jute snail) | -33.59 | -32.09 | 4.87 | Wright 2006 |
| Freshwater snail | Pachychilus glaphrus (Jute snail) | -30 | -28.5 | 5.49 | Wright 2006 |
| Freshwater Fish | Parrotfish | | -20.38 | 4.85 | Current Study |
| Freshwater fish | Colorada fish | -28.6 | -27.1 | 9.2 | Wright 2006 |
| Freshwater fish | Colorada fish | -27.39 | -25.89 | 10 | Wright 2006 |
| Freshwater fish | Guapote fish | -30.8 | -29.3 | 9.3 | Wright 2006 |
| Freshwater fish | Guapote fish | -29.86 | -28.36 | 11.51 | Wright 2006 |

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|---|---|---|---|---|---|
| Freshwater fish | Petenia splendida (Bay Snook) | -29.6 | -28.1 | 11.9 | Wright 2006 |
| Freshwater fish | Ictalurus (Catfish) | -22.28 | -20.78 | 11.59 | Wright 2006 |
| Estuarine fish | Arius (River catfish) | | -6.4 | 11.2 | Williams, White, and Longstaffe 2009 |
| Algae | Laurencia sp. (Brown Alga) | -15.7 | -14.2 | 6.2 | Keegan and DeNiro 1988 |
| Algae | Laurencia sp. (Brown Alga) | -15.7 | -14.2 | 6.1 | Keegan and DeNiro 1988 |
| Algae | Batophera sp. (Green Alga) | -5.8 | -4.3 | 1.7 | Keegan and DeNiro 1988 |
| Algae | Halimeda sp. (Calcareous Green Alga) | -12.0 | -10.5 | 2.2 | Keegan and DeNiro 1988 |
| Algae | Unidentified Encrusting Red Alga | -14.3 | -12.8 | 2.3 | Keegan and DeNiro 1988 |
| Sea Grass | Thalassia testudinum (Turtle Grass) | -6.2 | -4.7 | 0.9 | Keegan and DeNiro 1988 |
| Sea Grass | Syringodim filiforme (Manatee Grass) | -12.8 | -11.3 | 2 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Unidentified ecrusting black sponge | -5.4 | -3.9 | 3.9 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Adocia carbonaria (sponge) | -15.0 | -13.5 | 0.1 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Chondrilla nucula (sponge) | -13.3 | -11.8 | 5.2 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Porites porites (finger coral) | -12.5 | -11.0 | 3.7 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Condylactis gigantea (anemone) | -11.5 | -10.0 | 4.8 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Unidentified Serpulidae (worm) | -12.1 | -10.6 | 3.8 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Tripneustes esculentus (urchin) | -4.5 | -3.0 | 2.5 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Tripneustes esculentus (urchin) | -6.7 | -5.2 | 2.3 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Diadema antillarium (black urchin) | -9.3 | -7.8 | 2.4 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Unidentified Holothuriidae (sea cucumber) | -10.3 | -8.8 | 5 | Keegan and DeNiro 1988 |

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|---|---|---|---|---|---|
| Marine Invertebrate | Unidentified Holothuriidae | -13.0 | -11.5 | 6.3 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Bittium varium (gastropod) | -10.9 | -9.4 | 3.7 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Atrina rigida (pelecypod) | -13.4 | -11.9 | 2.3 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Tellina listeri (pelecypod) | -9.8 | -8.3 | 2.6 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Nerita versicolor (littoral gastropod) | -5.7 | -4.2 | 2.1 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Nerita versicolor (littoral gastropod) | -7.8 | -6.3 | 2.9 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Nerita versicolor (littoral gastropod) | -15.8 | -14.3 | 3.3 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Chiton squamosus (littoral amphineuran) | -8.2 | -6.7 | 3.3 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Chiton squamosus (littoral amphineuran) | -8.9 | -7.4 | 3.5 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Chiton squamosus (littoral amphineuran) | -8.9 | -7.4 | 4.1 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Strombus gigas (megagastropod) | -12.6 | -11.1 | 2.1 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Codakia orbicularis (pelecypod) | -22.3 | -20.8 | 2 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Codakia orbicularis (pelecypod) | -23.8 | -22.3 | 1.9 | Keegan and DeNiro 1988 |
| Marine Invertebrate | Codakia orbicularis (pelecypod) | -22.8 | -21.3 | 0.4 | Keegan and DeNiro 1988 |
| Offshore fish | Balistes (Triggerfish) | | -7 | 7.1 | Williams, White, and Longstaffe 2009 |
| Offshore fish | Sphryaena (Barracuda) | | -5.9 | 11.1 | Williams, White, and Longstaffe 2009 |
| Offshore fish | Mycteroperca (Grouper) | | -8.1 | 8.7 | Williams, White, and Longstaffe 2009 |
| Offshore fish | Mycteroperca (Grouper) | | -6.7 | 10.2 | Williams, White, and Longstaffe 2009 |

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| Offshore fish | Mycteroperca (Grouper) | | -5.3 | 7.9 | Williams, White, and Longstaffe 2009 |
| Offshore fish | Chondrichthyes (Shark) | | -9.2 | 11.8 | Williams, White, and Longstaffe 2009 |
| Reef fish | Trachinotus (Pompano) | | -6.2 | 16.6 | Williams, White, and Longstaffe 2009 |
| Reef fish | Caranx (Jackfish) | | -4.4 | 10 | Williams, White, and Longstaffe 2009 |
| Reef fish | Caranx (Jackfish) | | -5 | 12.4 | Williams, White, and Longstaffe 2009 |
| Reef fish | Scarus (Parrotfish) | | -5.6 | 8.8 | Williams, White, and Longstaffe 2009 |
| Reef fish | Acanthurus (Surgeon fish) | | -10.4 | 5.8 | Williams, White, and Longstaffe 2009 |
| Reef fish | Haemulon (Grunt) | | -4.8 | 4.6 | Williams, White, and Longstaffe 2009 |
| Reef fish | Haemulon flavolineatum (Yellow Grunt) | -7.0 | -5.5 | 5.7 | Keegan and DeNiro 1988 |
| Reef fish | Haemulon flavolineatum (Yellow Grunt) | -7.0 | -5.5 | 5.3 | Keegan and DeNiro 1988 |
| Reef fish | Haemulon flavolineatum (Yellow Grunt) | -8.2 | -6.7 | 5.4 | Keegan and DeNiro 1988 |
| Reef fish | Haemulon parra (Sailor's choice) | -7.5 | -6.0 | 5.1 | Keegan and DeNiro 1988 |
| Reef fish | Lutjanus mahogani (hog snapper) | -8.5 | -7.0 | 4.3 | Keegan and DeNiro 1988 |
| Reef fish | Lutjanus analis (Mutton Snapper) | -4.7 | -3.2 | 6.4 | Keegan and DeNiro 1988 |
| Reef fish | Lutjanus jocu (Dog Snapper) | -8.0 | -6.5 | 6.6 | Keegan and DeNiro 1988 |
| Reef fish | Epinephelus guttatus (Nassau grouper) | -11.6 | -10.1 | 7.5 | Keegan and DeNiro 1988 |
| Reef fish | Epinephelus striatus (red hind) | -8.4 | -6.9 | 6.5 | Keegan and DeNiro 1988 |
| Reef fish | Balistes vetula (Queen Triggerfish) | -7.1 | -5.6 | 5.9 | Keegan and DeNiro 1988 |
| Reef fish | Ocyurus chrysurus (yellowtail snapper) | -7.7 | -6.2 | 6.1 | Keegan and DeNiro 1988 |
| Reef fish | Anisotremus virginicus (porkfish) | -9.4 | -7.9 | 5.7 | Keegan and DeNiro 1988 |
| Reef fish | Priacanthus cruentatus (bigeye) | -12.1 | -10.6 | 5.6 | Keegan and DeNiro 1988 |
| Reef fish | Hemiramphus sp. (half beak) | -14.1 | -12.6 | 8.4 | Keegan and DeNiro 1988 |
| Reef fish | Hemiramphus sp. (half beak) | -14.3 | -12.8 | 8.5 | Keegan and DeNiro 1988 |
| Reef fish | Haemulon ( Grunt) | | -4.9 | 6.6 | Keegan and DeNiro 1988 |
| Reef fish | Albula vulpes (bonefish) | | -3.8 | -1.4 | Keegan and DeNiro 1988 |
| Reef fish | Albula vulpes (bonefish) | | -4.5 | 5 | Keegan and DeNiro 1988 |

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|---|---|---|---|---|---|
| Reef fish | Sparisoma (parrotfish) | | -7.8 | 3.9 | Keegan and DeNiro 1988 |
| Reef fish | Calamus (porgy) | | -8.2 | 9.2 | Keegan and DeNiro 1988 |
| Reef fish | Caranx ruber (Jackfish) | | -1.3 | 8.1 | Keegan and DeNiro 1988 |
| Reef fish | Caranx ruber (Jackfish) | | -1.3 | 8.3 | Keegan and DeNiro 1988 |
| Reef fish | Sphryaena barracuda (Barracuda) | | -3.9 | 8.5 | Keegan and DeNiro 1988 |
| Reef fish | Sphryaena barracuda (Barracuda) | | -3.8 | 8.2 | Keegan and DeNiro 1988 |
| Reef fish | Ginglymostoma curratum (nurse shark) | | -6.1 | 10 | Keegan and DeNiro 1988 |
| Reef fish | Ginglymostoma curratum (nurse shark) | | -8.3 | 8 | Keegan and DeNiro 1988 |
| Reef fish | Carcharhinus (Requiem shark) | | -9.3 | 10.3 | Keegan and DeNiro 1988 |
| Reef fish | Aetobatis narinari (spotted eagle ray) | | -10.6 | 5.9 | Keegan and DeNiro 1988 |
| Reef fish | Aetobatis narinari (spotted eagle ray) | | -13.5 | 4.2 | Keegan and DeNiro 1988 |
| Reef fish | Euthynnus (tuna) | | -14.6 | 15.8 | Keegan and DeNiro 1988 |