

TERMINAL CLASSIC PRACTICES
REFLECTED IN DIET AND GEOLOCATION OF FAUNA:
THE B-4 PERI-ABANDONMENT DEPOSIT AT XUNANTUNICH, BELIZE

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A Thesis

Submitted in Partial Fulfillment

Of the Requirements for the Degree of

Master of Arts

In Anthropology

Northern Arizona University

May 2019

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Abstract

This study applies isotopic analyses of carbon ($\delta^{13}\text{C}_{\text{coll}}$) and nitrogen ($\delta^{15}\text{N}_{\text{coll}}$) from bone collagen, with carbon ($\delta^{13}\text{C}_{\text{ap}}$), oxygen ($\delta^{18}\text{O}$), and strontium ($^{87}\text{Sr}/^{86}\text{Sr}$) to faunal remains excavated from a peri-abandonment deposit at the ancient Maya site of Xunantunich during the Terminal Classic period. Peri-abandonment deposits represent a distinct phenomenon in the Late-to-Terminal Classic Maya society, a time of social and environmental changes. Peri-abandonment deposits differ from similar types of deposits such as caches, middens or burials, in the variety of materials they contain: utilitarian ceramics to broken tools, animal remains, items associated with burial practices or other ritual activities, and occasionally human remains. These deposits may represent human acts of resistance to change in their social and ecological environment, reorganization of previous practices, both, or neither. While numerous studies have tried to explain the practices that created these deposits, few studies have used multi-isotopic methods in studying animal remains present in these deposits. The dietary results from animal remains in this study indicate no controlled feeding of animals in the B4 deposit, with the exception of one canine which likely consumed a diet similar to its human owners. Geolocation information from these animals reflects a pattern of local sourcing, suggesting expedient acquisition from around the Belize River

Valley. In both diet and geolocation, the B4 peri-abandonment deposit fauna results correlate with processes of decentralization of authority and environmental change during the Terminal Classic period of Maya society.

Acknowledgements

This study would not have been possible without the gracious support of many individuals and institutions. This project was supported by NAU and the Madden Research Award, which provided funding for sample analyses and travel costs. Dr. Kellner and my committee provided many hours of training, discussion, feedback, and attention. Dr. Kellner patiently trained me in laboratory methods and interpretation of data, and supervised my work in the NAU Paleodiet lab, without which this study would not have been possible. Dr. Awe and the Belize Valley Archaeological Reconnaissance allowed me to destructively analyze these remains from excavations at the site of Xunantunich. The NAUFAUDAL assisted with identification of specimens, especially Dr. Burke and Gavin Wisner. The Colorado Plateau Stable Isotope Lab at NAU analyzed the prepared carbon ($\delta^{13}\text{C}_{\text{coll}}$), and nitrogen ($\delta^{15}\text{N}_{\text{coll}}$) from bone collagen, as well as carbon ($\delta^{13}\text{C}_{\text{ap}}$), oxygen ($\delta^{18}\text{O}$) samples. Dr. Frank Ramos and Nicholas Butterfield at NMSU spent hours training me in $^{87}\text{Sr}/^{86}\text{Sr}$ preparation and analyzed the prepared samples via TIMS. I also acknowledge the use of facilities within the Eyring Materials Center at Arizona State University supported in part by NNCI-ECCS-1542160. I wish to thank Taylor Lambrigger and my colleagues at the Paleodiet lab for assistance with sample preparation. Finally, I also thank Shane Montgomery for advice in preparation of figures, and support throughout the writing of this thesis.

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Chapter One: Introduction

In the Terminal Classic period of Maya society from approximately AD 750-1000, decreases in annual rainfall, periodic droughts of varying severity, inter-polity conflicts, migration, climate change and other factors impacted Maya society (Aimers 2007, Dunning et al. 2012, Kennett et al. 2017). These events and human responses resulted in the cessation of monumental building and elite rulership at many centers, decreases in population, and abandonment of sites across the Maya region (see Aimers 2007 for a comprehensive review). The processes and results of the Maya collapse have been investigated by many scholars through various lines of evidence and peri-abandonment deposits are one avenue through which scholars attempt to understand Maya activities during the Terminal Classic period. These deposits are dense concentrations of material located in ceremonial and residential spaces with contents that frequently include large quantities of ceramics (both plain and polychrome), censers (incense burners), figurines, animal bones, manos and metates (for grinding corn), animal remains, obsidian blades and chert stone tools, and occasionally human remains (see Clayton et al. 2005; Hoggarth et al. 2016; Petrozza et al. 2018 for examples). Peri-abandonment deposits differ from caches in that they are typically not intrusive or destructive, and differ from expected contents and location for middens in the Maya area (see Burke et al. 2018).

Peri-abandonment deposits also previously referred to as problematical (e.g. Clayton 2005), terminal deposits (e.g. Coe 1959), or are generally termed as ritual deposits, or special deposits. These concentrations of cultural material are explored by

researchers for their functional characteristics and as a reflection of human behaviors during the Terminal Classic period in Maya society. Researchers explain peri-abandonment deposits as refuse from squatters (Thompson 1954), secondary refuse from feasting (Clayton et al. 2005), evidence of rapid abandonment due to warfare (Barrett et al. 2005), formal termination of a structure or space (Koenig 2014), and results of ritual activities or pilgrimage (Kosakowsky 2009; Palka 2014). Due to the ideological significance of animal and human remains, uncharacteristic placement, and inclusion of significant items such as incense burners and figurines this study approaches these deposits as the remains of ritual activity around the time of site abandonment.

Similar deposits have been described at various sites in the Belize River Valley, including Caracol (Chase 1998), Baking Pot, and Cahal Pech (Awe et al. 2018) and across the Maya Lowlands (see Chase and Chase 2004; Clayton et al. 2005; Stanton et al. 2008). Scholars are exploring a variety of methods and lines of evidence within these deposits to understand their origin, possible purpose, and relationship to events in the Terminal Classic period of Maya society. These methods include faunal analyses (Burke et al. 2018), ceramic analyses (Davis 2018), and study of the human remains (Hoggarth et al 2016). At Xunantunich peri-abandonment deposits have been interpreted as “secular, post-abandonment informal deposits,” (Petrozza et al. 2018: 19). However, Petrozza and others (e.g. Burke 2018; Hoggarth 2016) have emphasized the need for detailed stratigraphic and artifact analysis to assess the variability of materials in peri-abandonment deposits and behaviors that created them.

This study analyzes the diet and geolocation of faunal remains from a peri-abandonment deposit at the ancient Maya site of Xunantunich using bone isotopic analyses of carbon ($\delta^{13}\text{C}_{\text{coll}}$, $\delta^{13}\text{C}_{\text{ap}}$), nitrogen ($\delta^{15}\text{N}_{\text{coll}}$), oxygen ($\delta^{18}\text{O}$), and strontium ($^{87}\text{Sr}/^{86}\text{Sr}$). Isotopic methods such as those used in this study have been used effectively to study various aspects of human diet (Freiwald 2010; Williams et al. 2009; Metcalfe et al. 2009), mobility (Price et al. 2014; Fullagar et al. 2014; Freiwald 2011) trade (Thorton 2011), and animal management (e.g. Sharpe et al. 2018), throughout Mesoamerica, along with occasional samples from peri-abandonment deposits (Ebert et al. 2017). However, these methods have not been applied extensively to animal remains found in peri-abandonment contexts. diet of these animals, as reconstructed using $\delta^{13}\text{C}_{\text{coll}}$, $\delta^{15}\text{N}_{\text{coll}}$, and $\delta^{13}\text{C}_{\text{ap}}$, helps to elucidate the level of human influence or control prior to the inclusion of these faunal remains in the deposit. Geolocation information from $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}$, help to clarify where these animals may have lived, and how Maya people may have acquired them through the lenses of resilience theory and practice theory.

This thesis begins with a description of the isotope geochemistry which allows for characterization of dietary and geolocation information from bone collagen and bioapatite. This is followed by a detailed discussion of the laboratory methods used to analyze bone collagen and bioapatite in this study. Next, I discuss the social and environmental context of Maya society to place the B4 peri-abandonment in context. In the final two chapters I report the results of this study and discuss their implications for the Terminal Classic at Xunantunich.

Chapter Two: Background for Isotopic Studies

Stable isotopes are measurable variants which occur throughout nature in body tissues, food webs, and environmental components such as soil and water. Four isotopic analyses are used in this study: carbon ($\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{13}\text{C}_{\text{ap}}$), nitrogen ($\delta^{15}\text{N}_{\text{coll}}$), oxygen ($\delta^{18}\text{O}_{\text{ap}}$), and strontium ($^{87}\text{Sr}/^{86}\text{Sr}$). The incorporation of these four isotopes into body tissues occurs with known rates of fractionation, the measurement of their ratios in bone collagen and bone apatite is well defined, and models for reconstructing diet and baselines for identifying geolocation are available. In this chapter, I outline how these elements can reflect diet and geolocation of organisms, and how these data may be used to help understand past human and animal behavior.

Isotopes in Nature

Isotopes are different weights of the same element, which occur due to a different number of neutrons in the nucleus of an atom. Unlike ^{14}C , a well-known carbon isotope, stable isotopes do not radioactively decay (Fry 2006). The lighter isotopes of an element tend to be slightly more reactive, resulting in a different rate of incorporation in to plant and animal tissues (O'Leary 1981). These relative rates are measurable, and have been used ecological, geological, and archaeological studies to better understand metabolic processes and food webs (see Thomas and Crowther 2015), geological processes (see Ahm et al. 2018), human and animal migration (e.g. Knudson 2008; White et al 1998), dietary trends and changes (Price et al. 1985; Kellner and Schoeninger 2012), and other topics such as trade and animal management in ancient societies (Sharpe et al. 2018). The ratios measured for stable isotopes are small, so the

differences are reports as difference from the standard, or δ . The accepted standard for carbon is Pee Dee Belamite (PDB), atmospheric nitrogen (AIR) for nitrogen (Schoeninger 1985), and standard marine ocean water (SMOW) for oxygen (Dansgaard 1964). Strontium results are reported by the ratio of ^{87}Sr to ^{86}Sr , as ^{86}Sr is non-radiogenic and has the most similar abundance (Dasch 1969).

Bone Structure

Collagen is the protein-based tissue which helps to give bones their shape, as well as some measure of flexibility. Stable isotopes of carbon and nitrogen are present in collagen, and tend to reflect the protein content of the diet more strongly (Ambrose and Norr 1993). Bone mineral, or bioapatite, is embedded in the collagen fibers which gives bone its rigidity, and functions as a reservoir for calcium and other minerals. Carbon, oxygen, and strontium isotopes are incorporated into bone mineral, and reflect the average of the whole diet (Ambrose and Norr 1993; Jim et al. 2006). Bone tissues continue to remodel throughout the life of an organism, which allows for changes in location and diet to be recorded. In some cases, these values can be compared to tooth enamel, which does not remodel and reflects the diet and location of an organism when the tooth was formed.

Carbon

Two non-radioactive isotopes of carbon present in the atmosphere, ^{12}C and ^{13}C . ^{12}C is a greater portion of the atmosphere, making up approximately 98.9% of the carbon in CO_2 , where ^{13}C is present in 1.1% percent of atmospheric CO_2 , (O'Leary

1988). Compared to Pee Dee Belamite (PDB), the standard for comparison in scientific literature, atmospheric CO₂ ranges from -6.4‰ to -7.0‰. The ratio of ¹²C and ¹³C is relatively homogenous in the atmosphere, except in recent times where human activities, in particular industrialization, have altered ratios up to -30 parts ‰ (Smith and Epstein 1971). While carbon isotopes are present in the soil, soil type does not appear to affect the ¹²C/¹³C ratios in plant tissues (Smith and Epstein 1971). For comparing ¹²C and ¹³C ratios, the difference between PDB and the sample studied is expressed as δ¹³C. The formula for this conversion is:

$$\delta^{13}\text{C}(\text{‰}) = [(R \text{ sample} / R \text{ Standard}) - 1] \times 1000,$$

where R is the ¹²C/¹³C ratio in CO₂. (Smith and Epstein 1971, O'Leary 1981).

Plants' photosynthetic processes fall into three categories, which each have different proportionate rates of incorporation of ¹²C/¹³C, or fractionation. These three processes appear to be adaptations to different climate and light regimes (Smith and Epstein 1971; Van der Merwe 1982). C₃ plants are commonly found in canopy and shaded environments, and include shrubs, some grasses, fruits, and vegetables. C₃ plants include familiar crops which humans have domesticated and used for food, such as wheat or barley, and are less enriched in ¹³C, with an average value of -28.1 (± 2.5‰) compared to PDB (O'Leary 1988). This occurs in the chloroplasts of C₃ plants, where CO₂ interacts with ribulose biphosphate and the lighter isotope, ¹²C is preferred. In sub-tropical environments with canopy cover, such as western Belize, it is expected that the majority of wild plants will utilize the C₃ photosynthetic pathway.

The second photosynthetic pathway, C₄, includes plants such as maize or amaranth, which are more enriched in ¹³C. In C₄ plants, CO₂ is diffused to mesophyll cells and undergoes a different reaction with phosphoenolpyruvate carboxylase. It later interacts with ribulose biphosphate in the C₄ photosynthetic process but is much less fractionated due to this earlier reaction. This lower fractionation rate leads to a mean value of δ¹³C -13.5 ± 1.5 (O'Leary 1981). The most frequent plant utilizing the C₄ pathway in western Belize during the Late to Terminal Classic period in Maya society would be maize and was cultivated within human modified landscapes. Because the majority of plants in uncultivated areas are C₃ based, and maize is tied closely with human activities, less negative δ¹³C values indicating consumption of C₄ plants indicates at least minimal interaction with cultivated maize. By extension, less negative δ¹³C values would suggest that animals consuming maize were either browsing in maize fields, eating maize waste such as stalks and leaves, or deliberately fed maize by humans.

Crassulacean Acid Metabolism (CAM) plants include succulents, some cycads, and some other plants. The photosynthetic process in CAM plants varies by the amount of light and temperature available, as determined by controlled experiments of a number of CAM species (Bender et al. 1973). The δ¹³C values for CAM plants range between -13.8 and -30 ‰. While it is possible that humans and animals did consume some CAM plants, cycads, succulents and cacti do not provide enough calories to be a significant contribution to overall diet.

Carbon Isotope Fractionation in animals that consume plants

Animals that consume carbohydrates in the form of C₃ and C₄ plants incorporate carbon from these foods into their body tissues. Through studies of animals with controlled diets of known isotopic composition, it was demonstrated that tissues reflect the dietary composition of ¹²C/¹³C ratios (DeNiro and Epstein 1978), with a consistent rate of change, or fractionation. However, some tissues have different fractionation rates. Lipids have δ¹³C values averaging 8.4‰ more negative than bone collagen (Ambrose 1990), where brain and hair tissues in mice have δ¹³C values which were observed to be more negative than overall diet (DeNiro and Epstein 1978). Therefore, using comparable tissues with known fractionation rates, such as bone collagen and bone apatite, will allow results to be compared to other studies of animal diet. Without these comparisons, meaningful interpretation would not be possible.

Other controlled feeding studies have demonstrated that while there is some variability between individuals, no significant differences between differently sexed members of the same species occur. DeNiro and Schoeninger conducted a study of rabbits and mink on controlled diets, which demonstrated that only small variations occur between individuals eating the same diet (DeNiro and Schoeninger, 1983). This indicates that differences between sexes in elements that were not sexed during identification, or elements of different sexes should not bias results in this study.

Carbon Isotopes in Diet Studies

The distinct isotopic ratios in C₃ and C₄ plants are visible in archaeological bone and have been used to model dietary trends in both humans (Somerville et al. 2012;

Tykot 2002) and animals (White 2005), as well as investigate animal management and long distance trade (Sharpe et al. 2018). While specific dietary inputs within the same photosynthetic group (e.g. wheat vs. barley) may not be distinguishable, bone provides a long-term picture of the overall diet, and when different individuals are compared, changes over time can be observed.

Nitrogen

Nitrogen has two known stable isotopes, ^{14}N and ^{15}N , which are present in the soil and atmosphere. The ratio between ^{14}N and ^{15}N in the atmosphere (AIR) has been determined to be a reliable standard for comparison in isotopic studies, with consistent reproducibility (Mariotti 1983), with the difference between samples studied and AIR reported as $\delta^{15}\text{N}$. Nitrogen is integral to amino acid and protein production at the cellular level, and is thus key to collagen formation in bone. When adequate levels of protein are consumed, the body will use amino acids and components from protein in the diet to synthesize collagen. Under these normal circumstances, the body does not need to synthesize new amino acids from the carbohydrate portion of the diet, and so the nitrogen and $\delta^{15}\text{N}$ ratios in collagen will be reflective of dietary protein (see DeNiro and Epstein 1980). At the same time, the lighter isotope tends to be preferred, although this fractionation rate varies by tissue and species (DeNiro and Epstein 1980).

At the most basic trophic level, $\delta^{15}\text{N}$ ratios in plants vary by available nitrogen in the soil, as well as whether or not the plant has a symbiosis with nitrogen-fixing microorganisms. Some leguminous plants have symbiotic relationships with bacteria that allow fixing of nitrogen from the atmosphere, and some nitrogen fixing bacteria live

independently in soil (Ambrose 1991). Legumes include beans, peas, alfalfa, peanuts and other species. Plants that have nitrogen fixing bacteria will have ratios closer to AIR, where non-nitrogen fixing plants may have slightly enriched ratios (Ambrose 1989). Some species of blue-green algae (Allen and Arnon 1955) and lichens (ga) may also fix atmospheric nitrogen. Modern $\delta^{15}\text{N}$ values between nitrogen fixers and non-nitrogen fixers do frequently overlap, but this may be due to the use of fertilizers in recent times (DeNiro and Hastorf, 1985).

The body tissues of animals which consume plants reflect these $\delta^{15}\text{N}$ values, although each trophic level appears to be enriched about 2-3‰ (Minigawa and Yada 1984). For example, deer in this study would be expected to be 2-3‰ more enriched than the plants that make up the majority of their diet. Secondary consumers, or those that eat animals should be further enriched. However, this variation is dependent on the ecosystem, and hotter, drier soil environments tend to have higher ratios of ^{15}N , where cooler, wetter soils tend to have lower ratios (Ambrose 1989). Differences between consumers of marine and terrestrial protein consumers can also be observed in ^{15}N and ^{14}N ratios, where consumers of marine proteins can have ratios of 4-6‰ higher than terrestrial protein consumers (Schoeninger and DeNiro 1984).

Strontium

Strontium isotopes ($^{86}\text{Sr}/^{87}\text{Sr}$) are trapped in rock during their formation, which keeps the ratio of $^{86}\text{Sr}/^{87}\text{Sr}$ stable, except for the decay of Rubidium 87 (^{87}Rb). Over time, this decay results in slight changes to the ratio of $^{86}\text{Sr}/^{87}\text{Sr}$, and local rocks have measurably different profiles depending on the time and nature of their formation

(Dasch 1969). Through erosion and weathering processes, soils are formed which maintain the $^{86}\text{Sr}/^{87}\text{Sr}$ ratios. In addition to soil formation, local water sources exposed to these soils and rocks also incorporated $^{86}\text{Sr}/^{87}\text{Sr}$ ratios. Plants take up these ratios directly through soil and water, and animals that consume plants and local water also take in ^{86}Sr and ^{87}Sr (Graustein 1989).

Mammals have metabolic processes which discriminate against strontium in favor of calcium, but strontium isotopes replace some calcium and are incorporated into bone mineral during formation and remodeling. Once local profiles have been established for a region, $^{86}\text{Sr}/^{87}\text{Sr}$ values can be compared to those in bone mineral, to determine whether the organism lived in the area long enough to consume water and food which was subsequently remodeled into bone tissue. Central America is a geologically diverse region, and profiles have been established which outline the general regions which vary in $^{86}\text{Sr}/^{87}\text{Sr}$ ratios (see Hodell et al. 2004).

Oxygen

Oxygen has three stable isotopes, the most abundant of which is ^{16}O , at 99.76% abundance. ^{18}O is the next most abundant, comprising about .2% of the remaining stable oxygen isotopes. This ratio is compared to Standard Mean Ocean Water (SMOW), and represented as $\delta^{18}\text{O}$ (Epstein and Mayeda 1953). The $\delta^{18}\text{O}$ ratio in precipitation varies in a complex manner, depending on the temperature of condensation, the amount of evaporation while precipitation is falling, and seasonal changes in the source of precipitation (Daansgard 1964). It is also important to note that the seasonal wet/dry differential in precipitation, especially in regions close to the

equator, can significantly affect the $\delta^{18}\text{O}$ ratio (Daansgard 1964). Human behaviors such as boiling, which cause additional evaporation, affect the $\delta^{18}\text{O}$ value in water, causing higher $\delta^{18}\text{O}$ values. Daansgard also reports that inland precipitation is subject to a continental effect, resulting in lower $\delta^{18}\text{O}$ values than precipitation falling closer to the ocean (Daansgard 1964).

Modern values of $\delta^{18}\text{O}$ in Central American surface water are most affected by average rainfall, distance from the Caribbean, and altitude effect. The effect of average rainfall is -1.24‰ per 100 mm increase of rainfall during a month (Lachniet and Patterson 2009), which allows for less evaporation as precipitation reaches the surface. Surface water values for $\delta^{18}\text{O}$ decrease 3 to 5‰ from the Caribbean to the Pacific Coast (Lachniet and Patterson 2009), and surface and groundwater values are similar, due to fast recharge effects of the karstic landscape (Marfia et al. 2003). Variations in rainfall in specific microclimates can create dramatically different values (Lachniet and Patterson 2009), so caution should be exercised in interpreting values in areas of changing altitude and rainfall. However, the standing water sources of obligate drinkers such as deer will likely correlate to $\delta^{18}\text{O}$ values from bone apatite.

In body tissues, oxygen is taken into the body primarily from water consumed directly, foods consumed, and oxygen inhaled. The body mass of the animal, along with related factors such as metabolic rate, water intake, and water loss through evaporation affect the rate at which oxygen is used in various processes throughout body tissues (Bryant and Froelich 1995). As body size decreases (down to 1kg), the fractionation rate of $\delta^{18}\text{O}$ increases.

Fractionation

For $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{18}\text{O}$, metabolic processes which vary between species, which contribute to differences in isotopic values incorporated into body tissues. For $^{86}\text{Sr}/^{87}\text{Sr}$, fractionation is minimal, but parts per million decrease in each successive trophic level (Price et al. 2002). In addition to species' differences, bone collagen and bone apatite also incorporate $\delta^{13}\text{C}$ at different rates.

For bone apatite, which is correlated most strongly to the total diet, $\delta^{13}\text{C}_{\text{ap}}$ is enriched approximately 9.5‰ for small mammals in controlled diet studies (DeNiro and Epstein 1978). For humans, $\delta^{13}\text{C}_{\text{ap}}$ is fractionated approximately 11‰ from the values of food consumed. Given that differences between individuals on similar diets can vary 1‰ (DeNiro and Schoeninger 1983), differences between individual species' fractionation rates for $\delta^{13}\text{C}_{\text{ap}}$ should have minimal impact on dietary interpretation. Fractionation is more complicated for $\delta^{18}\text{O}$ as the amount and sources of water consumed, the body size of the animal, and the amount of water excreted through activities such as sweating all impact the fractionation of $\delta^{18}\text{O}$ before incorporation into body tissues.

For bone collagen, $\delta^{13}\text{C}_{\text{coll}}$ fractionation rates vary from 3‰ to 5‰ (Ambrose and Knorr 1993), with a similar amount of variation individuals on similar diets (1‰). Fractionation rates for $\delta^{15}\text{N}$, are approximately 3‰. However, these values are somewhat more complicated as $\delta^{15}\text{N}$ is influenced by climate and aridity, fractionation, and trophic level. Therefore, herbivores are expected to have lower levels of enrichment, but these could be altered by climate conditions.

Models for Dietary Reconstruction

In order to distinguish between a primarily C₃, C₄, or mixed diet, and differentiate between marine or terrestrial sources of protein consumed, I use a multivariate stable isotope model as described in Froehle et. al 2011. This model is modified from an earlier bivariate model of carbon isotope values used to model dietary inputs to bone apatite and collagen (Kellner and Schoeninger 2007).

In the bivariate model (Kellner and Schoeninger 2007), the authors use $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{13}\text{C}_{\text{ap}}$ values from experimental animals with controlled diet, wild animals with known diets, and human data from sites with archaeological evidence of diet to create a model of $\delta^{13}\text{C}$ incorporation from diet into bone collagen and apatite. This model utilizes regression lines to model linear relationships between C₃ protein, marine protein, C₄ protein, with distinctions between C₃ and C₄ energy sources. Figure 1 depicts the regression lines used in the bivariate model.

This bivariate model incorporates $\delta^{13}\text{C}$ values from many different mammals including herbivores (ruminants and non-ruminants), omnivores, and carnivores, concluding that the type of digestion was more significant than body size for the incorporation of $\delta^{13}\text{C}$ values. In this case, most of the animals sampled from the B4 deposit share similar digestion processes, except for deer and some *Artiodactyla* that are ruminants. Differences between medium and large mammals sampled in the B4 deposit should have minimal impact on interpretation. Three regression lines describe the expected relationship between dietary inputs and expected $\delta^{13}\text{C}$ values:

$$\text{C3 Protein: } y = 1.74x + 21.4$$

$$\text{C4 Protein: } y = 1.17x + 10.6$$

$$\text{Marine Protein: } y = 2.18 + 18.6$$

Ruminants that may consume C₄ grasses are somewhat more ambiguous, however, that difficulty can be mitigated by the addition of $\delta^{15}\text{N}$ data in the multivariate model.

The multivariate stable isotope model for dietary reconstruction also accounts for $\delta^{15}\text{N}$ data, which is influenced by types of protein sources (e.g. plant-based, marine, and terrestrial sources) (Froehle et al. 2012). This helps to distinguish between consumers of C₄ protein from marine protein, which is otherwise difficult to discern. Similar to the bivariate model, several relationships are plotted, as shown in Figure 7. Using the multivariate functions for “Carbon” and “Nitrogen,” sample data is plotted in comparison to five dietary clusters characterized by this model. Two functions are used to quantify the effects of different dietary inputs on $\delta^{13}\text{C}_{\text{ap}}$, $\delta^{13}\text{C}_{\text{coll}}$, and $\delta^{15}\text{N}_{\text{coll}}$ proportionately. These are as follows:

$$\text{Function 1 “Carbon”} = (0.322 * \delta^{13}\text{C}_{\text{ap}}) + (.727 * \delta^{13}\text{C}_{\text{coll}}) + (0.219 * \delta^{15}\text{N}_{\text{coll}}) + 9.354$$

$$\text{Function 2 “Nitrogen”} = (-0.393 * \delta^{13}\text{C}_{\text{ap}}) + (0.133 * \delta^{13}\text{C}_{\text{coll}}) + (0.622 * \delta^{15}\text{N}_{\text{coll}}) - 8.703$$

When the resulting values are plotted against the clusters as shown in Figure, it is comparatively easy to determine the proportion of C₃ versus C₄ carbohydrates and protein, as well as distinguish C₄ protein sources from marine sources. The far left cluster represents a 100% C₃ carbohydrate and protein diet. This reflects consumption of C₃ carbohydrate sources, and would be expected for animals in this study which do not consume any maize from either source. The second cluster, outlined in grey,

represents a 70:30 C₃:C₄ diet, with at least 65% C₃ protein. This diet reflects some consumption of C₄ carbohydrates, such as maize. In this study, a deer browsing maize fields frequently may reflect this pattern. The central cluster, outlined in red, is a 30:70 C₃: C₄ diet, with at least 65% C₃ protein. The lower right cluster, in green, is a 30:70 C₃: C₄ diet, with greater than 50% C₄ protein. An example of this diet would be a canine that consumed some maize, or ate half of their meat from C₄ consuming animals. The upper right cluster is a 50:50 C₃: C₄ diet with marine protein.

Taphonomy

Taphonomy is the study of all changes and processes which follow the death of an organism and effect the condition of remains (Efremov 1940; Child 1995). These processes are of interest to archaeologists and forensic scientists for several reasons. Understanding the causes of changes in material remains, the potential for chemical contamination, and the information that can be gained from these changes are all important to validate the results of this study.

Bone contains both organic and inorganic portions, which can be affected by temperature, moisture and aridity, microorganisms and macroorganisms, plants, and chemicals in the environment. These processes are grouped into several categories, including biodegradation, biodeterioration, biostratinomy, diagenesis, and microbial decomposition (see Child 1995).

Biodegradation refers to changes in remains due to the activities of organisms, which range from carnivore gnawing (e.g. Marean and Spencer 1991) to disarticulation and transport of remains (Klippel and Synstelien 2007). These processes may affect the

mechanical integrity of the bone, increasing the potential for degradation from other avenues. Biodeterioration is closely related, however, this term is typically used for changes that negatively affect the integrity of chemistry of remains. Biostratinomy refers to changes that occur after the animal is deceased but prior to burial. Because the samples in this study were altered by humans before being deposited on a surface, biostratinomic changes are particularly relevant. Disarticulation, removal or relocation, as well as cultural behaviors such as cooking affect the quality and quantity of remains available for study. These processes can also leave material traces on bone which can be help to understand the events occurring following the death of the organism. For the Structure B4 sample, elements sampled showed little visible evidence of gnawing or cut marks, but elements were completely disarticulated. This suggests that human cultural activities resulted in disarticulation, but further effects were not visible on the bone.

Diagenesis

Diagenesis is a process by which chemical changes occur in bone mineral or collagen due to contamination from the local environment, especially while buried. Diagenetic processes can affect carbon to nitrogen ratios in bone, strontium ratios in bone, calcium concentrations, or other trace minerals present in bone. Major factors implicated in diagenesis include burning and boiling, soil chemistry and pH, microorganisms, and water in the soil and bone environment. Each of these factors can alter the isotopic ratios in bone collagen and mineral, making them important considerations for the integrity of data in any study that attempts to reconstruct past dietary or migration patterns.

Boiling and Burning

Boiling and burning are cultural modifications to bone that can have dramatic effects on the integrity of collagen and bone mineral apatite, as well as the carbon, nitrogen, strontium and oxygen isotope ratios incorporated during the life of the organism (See Munro et al. 2007 and others). Boiling, while typically lower in temperature than burning or incineration, may expose relatively de-fleshed bones to moderately high temperatures for longer period of time than roasting or burning. This may change the visible appearance of bone less than other types of heating, but have significant effects on collagen integrity, and by extension the carbon and nitrogen isotope ratios present. Roberts and colleagues boiled samples over sequences of time and found that collagen protein quantity and nitrogen values decreased as time progressed (Roberts et al. 2002). Given that bone mineral is embedded in the collagen matrix, this loss of protein could expose bone mineral to later changes in chemistry. In a controlled study of boiled and burned bone samples, temperatures above 300°C have been demonstrated to impact $\delta^{18}\text{O}$ isotopic ratios, by approximately 3 parts per mille (‰). (Monro et al. 2007). Monro and colleagues also reported that crystallinity index, or the regularity and size of crystals in the bone matrix, was only moderately altered although other chemical changes in bone mineral had occurred. As temperatures increased, calcium carbonate formed within the samples. This allowed more moisture to enter the bone and facilitated change in $\delta^{18}\text{O}$ ratios. Collins and colleagues noted the introduction of calcium carbonate plays a role in collagen loss (Collins et al. 2002). High temperatures may also impact $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, by reorganizing the crystalline structure

of bone mineral. During this process, strontium may be replaced by other minerals, such as calcium carbonate (Nelson et al. 1986).

For these reasons, samples which appeared to be burned or browned from cooking were excluded from this study. However, not all cooking processes are easily visible in the surface color of bone, therefore several measures will be taken to evaluate the quality of the B4 sample. Ratios of carbon to nitrogen in bone collagen samples will also be discussed, as this may be an indication of nitrogen loss or contamination. The IR-SF values, which reflect crystallinity index will help determine whether cooking processes not visible on the B4 samples impact their $\delta^{18}\text{O}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios. Additionally, C/P ratios will help assess whether carbonate (CO_3) has replaced potassium in the bone, which could indicate that other changes to bone chemistry may be present.

Soil Chemistry and pH

The pH and soil chemistry in a burial or deposition environment have been demonstrated to affect the rate of diagenetic processes, the likelihood that bone will absorb additional water, and the rate of microbial attack on bone. Corrosive soils affect will affect the loss of bone mineral, along with the introduction of trace minerals, as demonstrated by at multiple Holocene sites between the Baltic and Mediterranean regions (Nielsen-Marsh et al. 2002). Acidic soils appear to affect the porosity of bone without necessarily preventing the action of fungi (Nicholson 1995), which indirectly allows for additional mineral transport and deeper penetration of the bone structure. However, Nicholson's study covered a number of sites with variable results; the author

suggests that pH is not an overriding factor in bone diagenesis. Chemical reactions which occur due to soil chemistry can affect bone mineral but are apparently at least partly delayed by the presence of bone collagen (White and Hannus 1983). Adequate collagen present from bone samples would provide at least a partial protective effect, and suggest that samples in this study are less likely to be affected by porosity-related degradation and contamination.

Microorganisms

In many cases fungi, bacteria, and cyanobacteria have been shown to attack buried (or submerged, for cyanobacteria) archaeological bone. A study of 250 archaeological bones from 41 sites demonstrated linear-longitudinal and other types of tunneling, as well as fungal tunneling were demonstrated to increase the volume of pores in bone surfaces (Jans et al. 2004). Microorganisms enter the bone through existing structures, such as blood vessels and lacunae. Through depositing enzymes and consuming non-mineral portions of bone, thus degrading proteins including collagen and non-collagenous proteins (Child 1995). Once aerobic organisms have depleted the available oxygen, anaerobic organisms may continue to ferment bone protein, possibly leading to complete destruction of the collagen portion of bone (Child 1995). This process can be accelerated by the transport of water and organic material from the soil matrix into the bone, creating “hot spots” of microbial activity. “Hot spots” are areas where microbial activity increases rapidly, creating more intense changes in soil chemistry and may trigger other reactions. These are often closely related to the intrusion and death of plant roots and litter. Organisms such as earthworms also

participate in these activities. In “deep soil horizons,” leachates from decomposing plant matter are also involved. (Kuzyakov and Blegodatskaya 2015). I suspect that the activity of microbes, leaching from decomposing plant matter, and the activity of fungi all contribute to the pH of the local soil environment. While microbial activity may or may not directly affect the carbon and nitrogen ratios in bone, the destruction of collagen ultimately makes these analyses impossible in some cases. The high moisture levels and seasonal flow of rainwater endemic to the site of Xunantunich could cause increased levels of microorganisms and potentially degrade samples. In order to combat this issue, the .125 NaOH rinse described in the methods section will help remove humic acids. Additionally, other quality benchmarks described will help evaluate the quality of collagen and bone mineral present in B4 samples.

Taphonomic Issues in this Study

The area of Xunantunich is a humid subtropical environment, which produces significant amounts of leaf detritus on an annual basis. These samples were located in a deposit in an exposed area where samples were exposed to both water and decomposing plant matter during the formation of soil. This is visible in root etching on samples, as well as soil which was adhered to the exterior of the bone. Microbial activity facilitated by plant decay may have impacted the integrity of bone in this study.

In addition, some samples may have come in contact with a plaster floor which would leach calcium carbonate when exposed to water. This exposure may impact the quality if calcium carbonate from plaster was transported into the bone through fluvial action. This can occur if porosity in the bone increased due to microbial attack.

Leaching and fluvial transport could also affect the strontium ratios in bone by transporting native strontium from local soil and water into the bone, replacing the strontium which was in the bone during the life of the organism.

Chapter Three: Methods

This section outlines the sample used in this study, the process of selection, sample cleaning procedures, the processes for bone collagen extraction, bone apatite extraction, preparation for strontium analysis, and methods used for assessing the quality of bone collagen and apatite, and results expected prior to analyses.

Sample size and selection

Thirty samples of faunal remains from excavations near structure B4, at Xunantunich, were selected. Animal bone was selected for consistency and comparability across species. While there were mollusks and other marine remains in the deposit, these could not be subjected to collagen analysis. As much as possible, samples were selected to represent different strata within the deposit. These strata were separated by lenses of soil, so may have represented different events in the creation of the deposit. Selecting samples from each layer is intended to capture any consistent differences in the diet or location of the animals prior to their inclusion in the deposit. Samples were also selected to represent the range of species, including large and small mammals, as well as reptiles. Mass of the sample was a limiting factor, and samples approaching 1 gram of mass were preferred. Avian samples were limited and not of sufficient size for collagen and apatite extraction procedures. Samples of bone which were burned were excluded, due likely collagen breakdown from extreme temperatures (see Munro et al.2007), as well as potential issues with contamination for strontium analyses.

Size Classification and Genus

Samples had been previously identified at the NAU faunal identification lab by Gavin Wisner under the supervision of Dr. Chrissina Burke. Where possible, the genus and species of the sample were determined by comparison to diagnostic features each element. Elements from this deposit at B4 are largely fragmented and skeletal elements are often incomplete. Where it was not possible to identify to species level, elements were examined for criteria such as thickness of cortical bone, bone geometry, structure of cancellous bone and other visible features on the surface of the bone. If conventional genus level identification was not possible, these elements were compared to possible species, especially those known to be consumed or used by ancient Maya people, in order to provide the most likely identification. Table 1 depicts the samples selected in this study, with their context and the analyses performed for each sample.

The animals sampled in this study fall into mostly discrete categories: obligate drinker and herbivores living in a canopied jungle environment, such as deer; small to medium sized mammals, which are likely herbivores such as rabbits; reptiles, such as iguanas, and turtles or tortoises. One class, the canine/peccary group, is somewhat more ambiguous. Canines, while carnivorous, may be opportunistic and known to consume human foods, such as maize (White et al.2004). Peccary mostly consume plant foods, although they are reported to consume some insects and occasionally reptiles or amphibians (Shivley et al. 1985). As the mammals are largely herbivorous, a diet composed mainly of more negative C₃ plants and lower nitrogen values are expected for a typical wild diet. The reptiles' nitrogen values may vary more. Green iguanas are largely herbivorous, but some species are exclusively herbivorous, while

some are omnivorous (Troyer 1984). Oxygen ($\delta^{18}\text{O}$) and nitrogen ($\delta^{15}\text{N}_{\text{coll}}$) isotope ratios are key in distinguishing the origin of these organisms, as they will allow comparison between areas of low and high annual rainfall, and marine versus freshwater environments. Because Xunantunich is located in an inland region with relatively high annual rainfall (Deevey et al. 1980; Hoggarth et al. 2017), animals exhibiting $\delta^{15}\text{N}_{\text{coll}}$ values closer to marine values, or enriched $\delta^{18}\text{O}$ values correlated with lower rainfall, would likely not be local to the region.

Some studies suggest that remodeling rates decrease with age in large mammals and are somewhat more stimulated by activity (Lieberman et al. 2003). However, Lieberman and colleagues note that proximal elements (closer to the midline/anterior portion) exhibit this characteristic more than distal ends. This effect also appears to vary by the mechanical weight loaded on the element.

Sample Cleaning procedures

The samples were cleaned mechanically to remove surface dirt. Samples were dry brushed to remove dirt and any materials that adhered the surface of the bone. A Dremel drill was used to remove the outer layer of cortical bone and trabecular bone visible on the interior surface of bone. The exposed surface of cortical bone and trabecular bone (a lattice-like interior structure) are more likely to be contaminated from contact with soil and difficult to effectively clean, so they are removed to mitigate potential contamination (Cabana et al. 2013).

Next, each was submerged in a 5% nitric (HNO_3) acid solution to remove staining for four minutes each. Each was monitored for changes in sample color or sample loss.

The HNO₃ solution was decanted from the beaker containing the sample, and 40 ml of Nanopure water was added to the beaker. The Nanopure was decanted and the sample was rinsed two more times for a total of three rinses. Samples were sonicated in water for approximately five minutes each, which was followed by three rinses in 40 ml of Nanopure water. Samples were covered in foil, which was pierced to allow moisture to escape, and then dried in an incubator at 37 degrees Celsius overnight.

Collagen Extraction

Collagen extraction procedures were conducted at the Paleodiet Lab at Northern Arizona University's Flagstaff campus, under the supervision of Dr. Corina Kellner. Clean samples of whole cortical bone ranging from 600 to 1000 milligrams were selected and submerged in 1 per cent hydrochloric acid (HCl) solution at room temperature, following a modified Longin (1971) method for collagen extraction (e.g. Brown et al. 1988). This method was pioneered for collagen extraction used for radiocarbon dating and modified for stable isotope studies (Brown et al. 1988). The method used in this study is modified to gain greater collagen yield from archaeological samples, which may have lower collagen levels than modern bone. It has been further suggested that archaeological bone from tropical regions may be more degraded than bone from other climates (van Klinken 1999), so collagen yield and quality are important concerns in this study. At the same time, concerns about potential sample contamination are addressed in this method, as taphonomic factors previously discussed may impact resulting isotopic ratios.

Hydrochloric acid demineralizes the bone by breaking down carbonate and phosphate groups in bone apatite into carbonic and phosphoric acid (Hankermeyer et al. 2002). Removing the bone apatite leaves behind collagen “ghosts” which should not be significantly altered by the HCl solution, with concentrations of acid between 0.05-.2M or duration up to 120 hours in solution (Pestle 2010). Lower HCl concentrations are desirable for delicate samples which may demineralize more quickly, to prevent unexpected sample loss. Acceptable collagen “ghosts” are flexible and retain the general shape of the demineralized bone (Sealy et al. 2014). Samples in acid were visually inspected every 24-48 hours. Solution was decanted from the sample beaker, and samples were probed with a dissection needle to determine the flexibility and resistance of the sample. If the sample was still resistant, an additional 40 ml of HCl solution was added and allowed to stand for 24 hours.

After the bone sample was fully demineralized, it was rinsed with Nanopure water to neutral pH. Next, .125 molar NaOH solution was used to remove humic acids and some lipids (fats) from the collagen (see Ambrose 1990; Jorkov et al. 2007), which can affect the apparent carbon ratios, making them appear more negative (Ambrose 1990). I considered humic acids a concern in a humid sub-tropic environment, as large quantities of rainwater accelerate the decomposition process of organic material and may transport them into the bone. Lipids (or fats) in bone are less frequently preserved in archaeological samples, but carbon isotope ratios in lipids are reported to be 6 to 12 per mil more negative than collagen (Ambrose 1990). Presence of humic acids or lipids would thus skew interpretations toward a higher ratio of C₃ sources in the individual’s diet.

Samples are submerged in 40 ml of NaOH solution and allowed to remain in solution for up to one hour. This is shorter than the typical 24 hours, to prevent sample loss in delicate archaeological samples. Samples are closely monitored for sample loss, changes in sample color, and effervescence. After 1 hour, the pH of each sample was tested. NaOH solution was carefully decanted from each sample, in order to make sure the minimal amount of sample was lost. The pH of distilled Nanopure water was tested, and then 40 milliliters of Nanopure water was added to each sample. Samples were gently mixed and allowed to stand for ten minutes. The Nanopure was decanted and the pH of the solution was tested. This process was repeated until the pH of solution matched the pH of Nanopure water, a neutral pH.

After samples reached neutral pH, they were transferred with a clean metal spatula into weighed vials for drying. Vials were covered with aluminum foil to prevent contamination, which was pierced to allow moisture to escape. Initially, samples were dried in the incubator overnight at 37 degrees Celsius. Samples were visually examined after 24 hours. If the samples appeared dry, they are removed from the incubator and placed in a bell jar with desiccant for further drying. Once completely dry, each sample was weighed. The total collagen yield was calculated by subtracting the empty vial weight from the vial with dry collagen, divided by the original clean sample weight, then multiplied by 100 to convert the result to a percentage. Typical collagen yields for modern bone range from 5.7% to 28.3%. Very low yields (below 5%) may indicate collagen destruction (van Klinken 1999), with only non-collagenous proteins remaining. Alternately, yields above 25% percent may not be sufficiently demineralized, or indicate additional salts are present (Ambrose 1990).

Once dry, samples were ground with a mortar and pestle into sand sized particles. At the Colorado Plateau Stable Isotope Lab (CPSIL), samples were weighed, and one milligram portions of each sample were separated. The one milligram portion of each sample was wrapped in a foil container which was folded and pressed into a small cube. The cubes were dropped and visually examined to ensure that the foil was not torn, and no sample could escape. Then each sample was placed in a labeled section of a tray.

At CPSIL, collagen samples were analyzed for $\delta^{15}\text{N}$, $\delta^{13}\text{C}$, %C, %N, and C/N via continuous flow-mode Thermo-Finnigan Delta^{plus} Advantage gas isotope-ratio mass spectrometer interfaced with a Costech Analytical ECS4010 elemental analyzer (CPSIL website).

Strontium processing

Strontium samples were prepared under the supervision of Dr. Frank Ramos at the New Mexico State University Johnson Mass Spectrometer laboratory. Initially, samples were weighed on a microgram scale, and some samples set aside for additional cleaning. Some larger samples were split due to large size, to approximately one tenth of the original sample size. The remaining portion was reserved. Clean, split samples were then dissolved in a 6N hydrochloric solution and placed on a hot plate. After the samples are fully dissolved, they were removed from the hot plate and allowed to cool. Samples which appeared discolored or contained particles were set aside for further cleaning. A 'spike' of strontium was added to increase the overall parts per million, both to the dissolved samples and a 'blank' which did not contain any

archaeological material. Strontium spike is added to achieve an ideal range of 100-to 500 parts per million, which allows for ratios from the strontium spike in the 'blank' sample to be compared to the ratios in the dissolved bone.

After the samples have been cleaned, dissolved, and spikes, they are added to glass microcolumns which have been prepared with resin. The samples are washed with 5 microliters of 2.5 N hydrochloric acid (HCl), beginning with three drops at a time from a micropipetter. Columns were allowed to drain fully. Then a second 5 microliter wash of 2.5N HCl was added to each column and allowed to drain. During this wash, lead runoff was collected into a separate beaker. This was followed by a 100 microliter wash of 2.5N HCl, and then a 700 microliter wash of 2.5N HCl. Following this wash, separate beakers were placed under the columns to collect Rb87, which is approximately the same weight as Sr87, and would not be distinguishable by the mass spectrometer. After Rb87 collection, the columns were rinsed with 350 microliters of HCl which were not collected. A final rinse of 700 microliters was added to each sample, and separate beakers were placed beneath for the collection of strontium. Collected strontium samples were placed on a hot plate for drying. Prepared samples were then analyzed using a Thermal Ionization Mass Spectrometer (TIMS). The TIMS ionizes samples and then distinguishes their isotopic values based on atomic weight.

Bone apatite process

Processing for bone apatite was also conducted at the Paleodiet lab, under the supervision of Dr. Corina Kellner. After mechanical and wet cleaning processes were completed, small samples of bone were weighed and reserved in separate jars for bone

apatite processing. This study follows a process similar to Lee-Thorpe's (1989), where bone apatite is treated with a base wash, and acid wash, and then rinsed to neutrality.

Using a mortar and pestle, samples of 15 to 25 milligrams of bone were ground to fine powder and transferred to microcentrifuge tubes. 0.04 milliliters of one percent sodium hypochlorite solution to each milligram of powdered bone were decanted into each microcentrifuge tube. Each tube was sealed and mixed for one minute. Mixed samples were allowed to sit for twenty four hours. Next, each sample was centrifuged for two minute on one side, rotated and mixed for one additional minute, for a total of three minutes. The sodium hypochlorite solution was decanted from each microcentrifuge tube. Half of a milliliter of Nanopure water was added to each microcentrifuge tube. The samples were mixed for one minute, centrifuged and the water was decanted. This process was repeated for a total of three times. An acetic acid solution was added (99.5%) 0.04 ml to each milligram of bone sample), mixed, and allowed to sit overnight. The following morning, samples were again centrifuged, solution decanted, and Nanopure water added. This process was repeated a total of three times. Samples were dried in the incubator at 37 degrees Celsius and transferred to the bell jar for further drying.

Diagenesis

Multiple methods are used to assess diagenesis in archaeological bone, which is necessary for accurate reconstruction of diet or geolocation. Because isotopic studies rely on comparing ratios of particular isotopes in tissues, post-mortem alterations are a detriment to reliable inferences. For bone collagen, collagen yield, %C, and %N are

measured at the same time samples are analyzed for isotopic ratios For bone mineral, Fourier Transform Infrared spectroscopy (FTIR) is employed to assess crystal size and structure. Changes in structure of bone apatite, along with calcium carbonate content can be detected, which are indices of diagenesis in archaeological bone (Beasley et al. 2014).

In assessing the integrity of carbon and nitrogen, the overall yield of collagen from the bone is calculated after samples have been prepared and dried. Too little yield may indicate a lack of collagen preserved prior to excavation, or issues during the processing of samples (see van Klinken 1999; Ambrose 1990). Additionally, carbon and nitrogen ratios are measured to detect post-mortem alterations to nitrogen ratios in tissue (DeNiro et al. 198;, Ambrose 1990).

For bone apatite. Fourier Transform Infrared Spectrometry (FT-IR) was performed on all bone apatite samples at the Goldwater Materials Science Facility at Arizona State University to analyze the size and regularity of bone crystal structure, and the ratio of carbonate (CO_3) to potassium through total attenuated reflection (ATR) at the absorption band 565 and 605 cm^{-1} (Weiner and Bar-Yosef 1990). The IR-SF value, which correlates to the regularity and size of the crystals in bioapatite, is calculated with the following equation:

$$\text{IR-SF} = [565_{\text{ht}} + 605_{\text{ht}}] / 590_{\text{ht}}$$

The resulting values are compared to values from modern, fresh bone, which range from 2.5 and 3.25. The C/P ratio, another strong indicator for potential diagenesis

ranges from .23 to .34 in modern, unaltered bone. The equation to calculate C/P ratio refers to different phosphate absorbance bands, to consider different evidence for alteration. The equation for C/P ratio is:

$$C/P = 1415_{ht} / 1035_{ht}$$

as described in Wright and Schwarz (1996).

Chapter Four: Maya Archaeological Background

Maya society

Ancient Maya society has fascinated both archaeologists and the public since Stephens and Catherwood published their first manuscript in 1851, describing a tour of temples and cities in the modern-day countries of Belize, Guatemala, Mexico, and Honduras. The Ancient Maya developed impressive settlements with monumental architecture, a distinct artistic style displayed on stelae, reliefs and fine pottery, an accurate and precise calendrical system with detailed astrological correlations, a unique writing system, and extensive trade networks along with an advanced agricultural system. These achievements spanned the diversity of the Yucatan Peninsula, which contains humid subtropical forests, estuaries, highlands and elevated mountain ranges. Limestone formations underlie a significant portion of the highlands and northern Yucatán, while the Atlantic coasts of Belize and Honduras have more diverse geological profiles. Rainfall varies significantly as well, from 1000 mm of annual rainfall in the northern Yucatán, to nearly 3,000 mm annually in the south (Dunning et al. 2012). Maya political organization included large and medium sized urban centers, surrounded by extensive, scattered agricultural communities (Chase and Chase 2011). Competition between major centers, and shifting alliances between major centers, medium and smaller sized polities, were frequent, along with shifts in centers of influence (Chase and Chase 1998; Helmke and Awe 2012).

Pre-Classic to Early Classic Periods

Increase in social complexity and population in the earlier periods of Maya society relied heavily on the development of extensive agricultural systems. Numerous settlements were built near *bajos*, or depressions in the landscape which collected soil erosion and water from seasonal rainfall. Early Maya agriculturalists relied on slash and burn style cultivation, which has been detected in carbon isotope signatures and pollen records from sediment cores. These cores suggested higher levels of human disturbance through increasing quantities of pollen from opportunistic taxa associated with cleared areas, as well as comparatively high levels of maize pollen to later periods (Wahl et al. 2014). Hydrogen isotopic ratios and carbon signatures in plant waxes (Douglas et al. 2015), along with oxygen isotopic ratios (Medina-Elizalde et al. 2010) have been used to model a drying period at the end of the Pre-Classic period. This drying period, combined with deforestation which increased evaporation and soil erosion, encouraged a resettlement and re-organization into other agricultural adaptations (Dunning et al. 2012; Wahl et al 2014; Douglas et al. 2015).

The Late and Terminal Classic Periods

The Classic Period of Maya society (approx. 550-750 AD) represented the height of population density, monumental construction, production of dated monuments in the region, and influence of elite rulership. Complex trade networks existed alongside competitive polities which formed networks of alliances, with Mesoamerican influence extending to the Southwestern region of North America. Agricultural strategies were complex and varied, with intensive practices such as terracing, canal systems, and

complex water catchments used in various regions. Animal use for consumption, ritual, and other purposes was widespread and complex.

In the Terminal Classic, beginning around 750 AD, decreases in annual rainfall, periodic droughts of varying severity, inter-polity conflicts, migration, climate change and other factors impacted Maya society (Aimers 2007; Dunning et al. 2012; Kennett et al. 2017). The timing and severity of these factors varied by polity and region, in phases. At Blue Creek, erosion and precipitation of gypsum in the soil occurred over several hundred years (Luzzadder-Beach and Beach 2009). The settlement continued to prosper through the Classic, and population increased significantly. Over time, residents attempted to deal with the erosion and lowered water table by digging canals through the gypsum rich soil to the fertile soils beneath, as well as expanding into more marginal areas. These strategies allowed for continued subsistence, but by the Terminal Classic, Blue Creek's elite residences had been abandoned and numerous deposits covered the elite residences and ancestral shrines. The major polity of Copan first suffered hiatuses in monumental building construction and the production of stelae. This was followed by decreasing influence apical elites and competition between mid-status elites. Population density decreased and lead to eventual abandonment of the site core (Webster and Freter 1990). Some medium sized polities, however, gained influence during the Late Classic period (LeCount et al. 2002). In contrast, abandonment of some sites, such as Colha, may have occurred after some form of conflict.

Subsistence

Subsistence and ritual practices are closely related in ancient Maya society, as well as in modern ethnographic contexts (see Dunning et al. 2012; Gates 1978; Tedlock

1985). Everyday practices such as preparing a field for agriculture, dedicating a structure for use, and often have both pragmatic and spiritual functions, which may not be viewed as easily separated. The supernatural and natural were not necessarily recognized as fundamentally different, unlike the various dichotomies (e.g. mind-body) which are prevalent in modern Western society. Human created features functioned with the same associations as their natural counterparts (Rowan 2017; Harrison-Buck 2012). Temples or human-created mountains could be considered a *witz* (mountain) as much as a natural feature. The landscape existed on a continuum of order and chaos, described in modern Yucatec as *kol* and *kax*. Land which moved into or human-facilitated order, or *kol*, required ritual labor as well as physical labor (Dunning et al. 2012). Land which returned, or was in the process of returning to chaos (*kax*), including abandoned places presented certain kinds of dangers (Dunning et al. 2012). Activities which sought to maintain the approval of the gods, ensure sufficient rainfall, and promote successful crops were both ideological as well as pragmatic activities.

Dietary studies, ancient Maya iconography, and modern ethnographic research indicate ancient reliance on maize agriculture, with additions of complementary crops such as beans and squash (Lentz 1999, Freiwald 2010). Dietary studies have shown the proportion of maize consumed in the diet varied between the Early, Classic, and Post-Classic periods, but was consistently significant throughout these periods (White and Schwartz 1989). Other crops, such as manioc, cassava, and ramon nuts have been a topic of argument and speculation (see Puleston 1978), however they do not have the iconographic depictions and ideological significance of maize.

Animal use

The use, consumption and management of animals in the Maya area has been contested, with two recognized domesticates: dogs and turkeys. Mesoamerican societies did not have large domesticated animals like cattle and sheep, as in the Old World. However, there is recent evidence suggesting that local animals were managed or controlled. Based on $\delta^{13}\text{C}_{\text{coll}}$, $\delta^{13}\text{C}_{\text{ap}}$ and $\delta^{18}\text{O}$ values, Somerville and colleagues conclude that cottontail and jackrabbits were controlled and probably fed a diet relatively heavy in maize in Teotihuacan, a central Mexican city roughly contemporaneous with Classic Maya society (Somerville et al 2016). Some apex predators at Teotihuacan, including eagles and felines were controlled, and in some cases fed a specialized diet as early as the first century AD (Sugiyama et al. 2015). At the site of Ceibal during the Late Classic, $\delta^{13}\text{C}$ analyses performed by Sharpe and colleagues suggested that at least some turkeys were captured or reared and fed a maize influenced diet. Some peccaries and at least one dog were also tested, with higher than usual $\delta^{13}\text{C}$ values, suggesting at least crop foraging and possibly human-controlled feeding. At Ceibal, these likely animal management practices existed alongside hunting and capture practices, as evidenced by deer which exhibited a more typical diet of C^3 plants (Sharpe et al. 2018). Other evidence from the sites of Colha and Lagartero, in northern Belize and western Guatemala, respectively, suggests that a variable level of human input in the diet of deer and dogs existed (White et al. 2001; White et al. 2004). Most deer and dogs at both sites appeared to have expected wild diets, however, certain individuals had dramatically altered $\delta^{13}\text{C}$ values that indicated significant consumption of C^4 plants throughout the life of the animal. These studies demonstrate that while animal

management may not have provided a primary means for subsistence for most Maya people, these strategies were known and practiced throughout the region. The sampled animals' $\delta^{13}\text{C}$ values suggest increased consumption of maize than expected for wild diets. These animal species also had ideological significance, and maize is an ideologically significant crop. The context of some animals may correlate to ritual activities, so these studies suggest that at least some animals were fed a significant diet of maize prior to ritual activities.

Maya Cosmology

In ancient Maya cosmology, the Earth that humans walk on is compared to a large turtle or crocodile that swims in a primordial sea. Below the Earth are the realms of the Underworld, of which there are nine (Lucero and Kinkella 2015). These realms are associated with the source of water and the potentially helpful, tricky, and capricious gods of the Earth and Underworld, which need to be placated and petitioned for both rain and a successful harvest, as well as to prevent potential calamities (Gates 1978). Other deities, such as the four Chacs were more directly associated with rainfall and the sky-realms. Completing these rhythms on a cyclical basis helped to ensure a successful agricultural year, or attempted to mitigate predicted calamities based on calendrical knowledge (Gates 1978). The Earth itself is depicted as a mountain or Earth-monster, while above the Earth are the thirteen levels of the heavens. In celestial or sky imagery, birds, serpents, and iguana-dragons are depicted. The heavens are sometimes depicted as an iguana-dragon, associated with the creator deity Itzamna. Deer and dogs are often associated with the sun, fire, fertility or healing, and were used as

offerings throughout the year and during special times of need (Gates 1978; Thompson 1970, 205).

In the Colonial period creation story of the K'iche Maya, the Popul Vuh (translated by Tedlock and published in 1985), humans were the most recent creation of the gods, and were made of maize. Previous intelligent beings had been made of mud or wood, but were deemed inadequate and destroyed. This underscores the necessity of adequate relationship to the gods, who may destroy the world if humans' respect for the gods or morality was not maintained. Later in the Popul Vuh, the twin sons of the deceased Young Maize God descended to the underworld. They defeated the Lords of Death and resurrected their father who had been murdered by the Lords of Death. (Tedlock 1985). This account represents one example of a deep association between water and the underworld, accessible through caves and *cenotes*, and the resurrection or growth of maize. Humans are made of maize, and grow and consume it. Sacrifices of humans or appropriate stand-ins thus fed the gods in turn (see Gates 1978). The resurrection of the Young Maize god can also serve as an explanation for the death and re-growth of maize and humans, both of which flourish with water. Natural and artificial features including caves, sinkholes, crevices, *cenotes* (groundwater-filled sinkholes), and standing water are all liminal spaces where offerings can be made or communications pass between the realms.

Animals, Ritual Objects and Associations

Animals that live in or near water, such as turtles, conch, mollusks, and fish are often associated with water imagery (Thompson 1970). Jute (*Pachychilus*) are

freshwater snails, and have been recovered in large quantities at numerous cave sites, caches, and burials. They have also been recovered from surface contexts associated with ballcourts, alleys, and architecture (Halperin et al. 2003). Contemporary ethnographic accounts state that *jute* is considered to live in sacred water, and thus be a sacred food. The shells were often returned in thanks to the Earth, and sometimes this sacred food was buried with individuals to provide sustenance for them in the afterlife (Halperin et al 2003). *Nephronias* is a genus of freshwater mussel which has been recovered in contexts ranging from middens to burials, in both modified and unmodified forms (e.g. beads or drilled). These mussels were consumable, but likely provided a supplemental or occasional addition to Maya subsistence (Powis 2004). These mollusks thrive in a similar fast-water environment to *jute*, but are less common and more difficult to collect during the summer months, when *jute* are more prolific (Powis 2004). They may also have been considered a sacred food due to their environment, and this lends special significance to their use in ornamentation. Alternately, *spondylus* is a marine shell species used for bead and other kinds of ornamentation. Freshwater and marine shells are depicted in imagery of the gods and have all been considered important representations of the Primordial Sea (Freidel et al. 1993).

Large felines are also associated with the watery underworld, as well as divine rulership (e.g. Miller and Taube 1993, 103). Early Olmec and central Mexican art depicts human-jaguar hybrids (Coe 1970), and anthropomorphic jaguars are found in scenes of deities and rulers across Mesoamerica (Kubla 1970). Jaguar related titles or attributes may be included in the names of various political figures as well as priests

(Saunders 1994). Ethnographic accounts note that in the late twentieth century, some shamans still “[wore] headdresses of jaguar claws...necklaces of jaguar teeth, and carr[ie]d bags of jaguar fur that contain herbs, stones, and their snuffing equipment. (Reichel-Dolmatoff 1975:46).” This account further notes that shamans kept narcotic powder inside a ‘tubular’ bone of a jaguar. This description is suggestive of the tubular bone found in the B4 deposit which is partially modified, although it is a white-tailed deer radius, and not a jaguar element.

Large jars with wide brims were used for water storage and offerings, and are frequently found in archaeological cave contexts, along with other implements such as incense burners, figurines, and musical instruments associated with ritual activities. Formations in caves such as speleothems, were taken and used, as well as buried or given as offerings (see Brady et al. 1997). Alternately, underwater geological formations such as tufa would also be collected and used in ritual practices or as offerings (Lucero and Kinkella 2015).

Local Geography

The Belize River Valley is situated in the west-central region of modern-day Belize, and encompasses the Macal and Mopan rivers, which are tributaries of the Belize River (Figure 2). While geographically peripheral to the well-known Petén region, Maya society thrived in the area from the earliest farming villages (Awe 1992; Ebert et al. 2017) to the arrival of Europeans in the 16th Century. The Maya mountains mark the edge of the valley to the south. The Belize river runs east into the perennial salt marshes, and eventually to the Atlantic coast (Helmke and Awe 2012). Naranja in the

west, Caracol in the south, and Lamanai in the north are regarded as representing the cultural boundaries of the sub-region. While those represent the largest polities, numerous others include the characteristic temple pyramids, ballcourts, royal palaces, causeways, along with carved and uncarved stelae and altars (Helmke and Awe 2012). Annual rainfall is relatively high, although there is a wet/dry seasonal regime.

Xunantunich

The animal remains in this study come from Xunantunich, a fairly large Late Classic site near the border of Guatemala and Belize. Xunantunich has a north-south orientation, with a quadripartite general plan similar to other large Maya sites such as Naranjo (XAP report 1993). The core of the site, Group A, has multiple pyramids, and public buildings, and a well known massive structure called the Castillo. The Castillo is a nearly 45 meter tall structure with numerous smaller structures built on top at various elevations. While previously thought to have been a temple, it appears that the Castillo served as political center, with private residential structures and shrines overlooking the large courtyard below. The public space of the courtyard was distinguished from the elevated private space by a likely *audencia* partway up the Castillo (Helmke et al.2010). Two large sacbes, roads for ceremonial and day to day traffic, lead into the central group. Group B is a residential group approximately 150 meters to the west of the site core, and may have continued to be in use later than the site core. The majority of construction at Xunantunich, especially in the central precinct, occurred during the Late Classic period, possibly while allied with Naranjo, and possibly during a later independent period (Ashmore et al. 1993; LeCount 2002). The Mopan Valley

Preclassic Project uncovered documented Middle and Late Pre-Classic structures in their work at Group E, to the east of the site core (Brown 2009), and additional Pre-Classic evidence is located beneath the large multi-platform structure known as the Castillo (LeCount 2012). Several structures at Xunantunich have architectural elements similar to the northern Yucatan, such as circular columns, rounded corners, and a ball-court ring. This suggests that Xunantunich had multiple relationships with polities outside of the Belize River Valley, and that trade or possible emigration from the North occurred.

Ceramic, and epigraphic evidence suggest that other nearby sites, such as Actunan and Buenavista del Cayo exerted earlier influence in this part of the valley, which shifted later to Xunantunich in the Late Classic period (Helmke and Awe 2012). After the influence of Naranja waned at Xunantunich, the polity continued to erect carved stelae as late as AD 849 (Helmke et al. 2010). This suggests that Xunantunich continued to be a cohesive polity later than some central sites (Helmke et al. 2010), and was possibly inhabited in the Post-Classic (See Ashmore et al and others).

Group B

Excavation at Group B began with Thompson's 1938 excavations (Thompson 1942), which established a common ceramic chronology. No further excavations were conducted at Group B until the Xunantunich Archaeological Project (XAP) during the 1990's (Leventhal et al. 2010), although many other areas of the site had ongoing work. The XAP's excavations revealed more structures than previously expected, along with several deposits identified as ritual or termination deposits (Etheridge 1994). Work at

Xunantunich was continued by various scholars since the 1990's (e.g. LeCount et al. 2002; LeCount and Yaeger 2010), especially the Belize Valley Archaeological Reconnaissance which has ongoing conservation and research.

Group B contains multiple related structures oriented around a courtyard with a small shrine. Construction at Xunantunich reportedly increased during the Late Classic period, possibly while allied with Naranjo, and possibly during a later independent period (Ashmore et al. 1993; LeCount 2002). Some structures at Xunantunich have architectural elements similar to the northern Yucatan, such as circular columns, rounded corners, and a ball-court ring (Awe, personal comm.). This suggests that Xunantunich had trade connections to the North, and some Northerners may have immigrated to Xunantunich. A study of burial orientation with strontium and oxygen isotopes indicated that a nearly half of individuals recovered from burials at Xunantunich were of non-local origin. This includes a young adult female, recovered from Group B, whose $\delta^{18}\text{O}$ values imply a Central Peten origin. It is also noted that several geographically distant areas within the Maya region share similar strontium isotope values, suggesting that some more distant migrations may exhibit similar values to nearby locations, or multiple migrations may be obscured. Thus, some types of migration may be underestimated in these studies (Freiwald et al. 2014).

Peri-abandonment deposits

Peri-abandonment deposits have been previously referred to as terminal deposits (e.g. Coe 1959), problematical deposits (e.g. Clayton et al. 2005), ritual deposits, or special deposits. In Maya archaeology, and elsewhere in America, terminal

deposits have been described as ritual deposits that end the usage of a structure, room, or settlement. At Chaco Canyon, terminal deposits indicate the closing of one structure and dedication of a new structure superimposed over the earlier (Mills 2008). In other areas, such as Bronze Age Denmark, items with ideological status and significance were taken out of circulation and cached periodically, creating an inaccessible hoard (Levy 1995). In each of these cases, community members knew the location of objects, although they were removed from use and viewing. Different types of objects or iconography could suggest that different members of the community contributed in heterogeneous fashion to the deposits (Levy 1995). Peri-abandonment deposits in the Maya area include valuable items, but do not appear focused on sequestering wealth. Instead, the intentional destruction of many objects suggests an deliberate end of the life and use of those objects or in some cases, a structure (see Coe 1959; Stanton et al.2017). In contrast to the Chaco deposits, previous niches or storage places were not created for Maya peri-abandonment deposits, suggesting that these deposits were not planned by individuals originally constructing structures at Xunantunich. While the practices that created these deposits occurred around the time of site abandonment, but the western archaeological perspective of time may artificially compress the sequence of events, as compared to people who experienced them. People creating these deposits may or may not have viewed the actions which created these deposits as preceding abandonment of the local area. At the same time, the factors which encouraged the creation of these deposits may be interrelated with those that eventually encouraged Xunantunich's residents to move elsewhere.

Similar deposits have been described at various sites in the Belize River Valley, including Caracol (Chase 1998), Baking Pot, and Cahal Pech (Awe et al. 2018). The scope and variability of materials included in peri-abandonment deposits includes polychrome, high-quality and plain pottery, often broken, censers (incense burners), inkpots, figurines, animal bones, manos and metates (for grinding corn), animal remains, obsidian blades and chert stone tools, and occasionally human remains. The deposits excavated near Structure B4 contain similar artifacts to other deposits reported in the area (for examples, see Clayton et al. 2005; Chase and Chase 1998; Stanton et al. 2008). Species of animals in the B4 peri-abandonment deposit include white tailed deer (*Odocoileus virginianus*), brocket (*Mazama*), rabbits and hares (*Lagomorpha*), mouse opossum (*Marmosa*) various turtles (*Testudines*), armadillo (*Dasypus novemcintus*), iguana of several possible species, indeterminate mammals of various size classes, a significant quantity of mollusks including jute, some avians of small size class, at least one canine (dog), and a large feline (puma or jaguar).

The location of peri-abandonment deposits differs from caches, as peri-abandonment deposits are often found on plaster floors, near corners, stairways, or along walls of structures, sometimes over collapse or rubble (see Petrozza et al. 2018; Burke et al. 2018). It may be important that these deposits are not necessarily found inside structures, as one might expect if a building's use were terminated. The B4 deposit also included a small quantity of human cranial fragments, similar to other deposits in the region which sometimes include disarticulated human remains. The inclusion of human remains differs from typical burials in that elements may be disarticulated and co-mingled with the other materials in the deposit. The difficulties in

classification and understanding these deposits is due, in part, to their variability. In some cases, such as near Structure B4 at Xunantunich, soil accumulation is present between stratified layers of deposit, indicating that people returned to these areas over time to engage in repeated activities.

Scholars have presented explanations for peri-abandonment deposits including rapid abandonment due to warfare (Barrett et al. 2005), middens (Stanton et al. 2017), debris from squatters (Thompson 1954), ritual activities (Kosakowsky 2009), feasting (Clayton et al. 2005), ancestor worship (Brown 2011), remains associated with pilgrimages (Palka 2014), and termination of a structure's use (Koenig 2014). This study will focus on understanding Terminal Classic behaviors at Xunantunich which resulted in two related deposits near Structure B4 at Xunantunich. The deposits in this study fall into a class recently termed peri-abandonment deposits, because of their deposition around the time of Late Classic abandonment of sites (Petrozza et al 2018). The boundaries between ritual social action and domestic activities may be fluid, but material correlates for different activities will help to discern the types of actions which resulted in the remains excavated. In the cases of feasting, squatters, and middens, the composition of elements from faunal species should reflect both species common for daily consumption as well as meat-bearing elements (see Burke et al 2018). Cut marks on meat-bearing elements and burning or smoking of bones would be expected in the case of daily consumption, which are present on few of the elements in the B4 peri-abandonment deposits. However, some forms of cooking may be difficult to visually discern, such as boiling, due to the lack of direct exposure of the bone to a heat source (Brown et al. 2002). These deposits do include some number of chert tools, but not

significant in proportion to other materials, which makes warfare an unlikely cause. The B4 deposits also occur outside of structure B4, so may or may not be associated with the end of the structure's use. In the case of ritual-related activities, the species and elements present would likely reflect ideologically significant fauna. In the B4 deposits, the large feline, canines, and white tailed deer all have ideological significance in ancient Maya cosmology (See Gates 1978, Thompson 1945). As discussed above, felines have strong ideological associations with shamans, the underworld, and elite status; deer are associated with sun and fire in the Dresden Codex; and canines may be acceptable stand-ins for human sacrifice. A number of the elements are long bones, however elements of turtle carapace, cranial fragments, teeth, carpals, ribs, and vertebrae, and dermal scutes (bony plates covering the skin) are included. Other materials included in the B4 deposits, such as broken censers, figurines, a possible bone-tube preform, a spondylus bead, and worked bone awl or hairpin, suggest a ritual association rather than a domestic one.

Chapter Five: Theoretical Background and Expectations

Through exploring the isotopic evidence of diet and source location of animals, this thesis seeks to examine aspects of peri-abandonment deposits that have not been fully investigated. In this study, peri-abandonment deposits are viewed as a social action, meant to effect changes in the world of the participants. Information about the diet and sources of significant animals reveals data about the process leading up to this deposit, and possibly some criteria important for Maya undertaking this social action. The resources of cultural memory can be reorganized in novel ways which respond to, resist, maintain, or innovate in the face of social and environmental cycles. Resistance and innovation are viewed as related to the concepts of practice and agency in Bourdieu's *Theory of Practice* (1977) The ability of individuals to respond to these limits, or their *agency*, shapes the reproduction and transformation of practices over time. Late Classic Maya people may have faced a number of challenges relevant today: changing climatic regimes, water shortages, effects of deforestation, relatively large scale migration, and conflict within and between communities. For these reasons, the cycle of a panarchy as described in resilience theory (ex. Holling 1973) is appropriate for viewing the broad trends and processes operating in Maya society.

Resilience theory differs from environmental determinism in that human choices are not determined by the environment. Instead, humans engage in a reciprocal relationship with their environment. The phases of release and reorganization, as described below, are particularly relevant for describing the context of resistance or adaptation that may be occurring during the deposition of this and other peri-abandonment deposits. This perspective is important for archaeology, as this project

and similar studies can help better understand how people maintain, change, or reconfigure social actions in the face of social and environmental changes. How past people responded to these issues is informative to people today, as long term effects of human actions can be explored in the deep past of the archaeological record.

As a complement to the adaptive cycle of resilience theory, the attention to human perceptions, culturally developed understandings, and ability to act in response to or resist changes described in practice theory is also valuable here. Ancient Maya people had a cosmological order, or *doxa* which enabled them to develop strategies based on prior knowledge and understandings. Depending on their social status, experiences, and cultural capital, humans acquire dispositions that can be thought of as *habitus*. These dispositions can “produce an infinite number of practices that are relatively unpredictable, but also limited in their diversity (Bourdieu 1977: 55)” Values derived from prior experience influence these actions’ appropriateness for individuals based on their roles and relationships. *Habitus* can guide individuals’ decisions to enact rituals in particular ways, and help select changes that cohere or change the meaning of a practice. This extends to social actions described by archaeologists as ritual, so that exact patterns of action may change over time. However, these patterns likely cohere with an internal logic that incorporates past correspondences with transformation over time.

The cycle of panarchy in Maya Society

The panarchy, a core concept in resilience theory, is an ecological model developed to understand how organisms and environments relate on a variety of scales

and speeds (see Holling et al. 2002). The panarchy incorporates the cumulative actions and changes over time of species, recognizing that no static equilibrium is achieved within system. Rather than dramatic changes once a single threshold is reached, a variety of relations drive social and environmental changes. These changes prompt further adaptations with varying consequences, potential for success, and potential for failure (Wood, in press). As a framework for understanding broad changes, it can incorporate human responses and effects, as well as environmental changes. It also allows for acknowledgement of different rates of change in processes, and interaction between related systems or communities. In particular, the concepts of resilience or rigidity help to describe the manner in which some communities are able to reorganize while retaining essential functions (Holling 1973), while other communities do not. The panarchy has four main phases: growth, conservation, release, and reorganization.

Release and the Pre-Classic

At the end of the Pre-Classic in Maya society, there was a period of release. A combination of human induced environmental changes, population increase, and a long drying period caused dissolution of existing patterns of behavior and relationships (Wahl et al. 2014; Ebert 2017; Kennett et al. 2012). Human induced changes, such as deforestation and increased erosion from agricultural practices accumulated and put pressure on existing communities. Increased population and insufficient rainfall in some areas further exacerbated the situation, causing some formerly prosperous communities to become depopulated. Significant migration out of some communities also took place, probably in response to these issues. Overall, the movement of people and breakdown

of existing relationships lead to a release of energy. An ecological example of release is the natural or human induced clearing of land through fire. The fire consumes the existing biomass and dissolves existing relationships, releasing energy during this process (Holling 1973). After this clearing has occurred, significant space and transformed resources exist with a smaller portion of relatively unchanged existing organisms and resources.

After the release phase, space has been cleared for new or altered organisms and relationships. This phase is called reorganization, where genetic material, organisms, and behaviors are frequently recombined to meet the new circumstances created following release (Holling et al 2002). A community that tries to engender a new culture which addresses concerns in the form of a revitalization movement (e.g. Wallace 1956) may recombine ideas and practices from the past, which can be viewed as reorganization. Alternately, in disturbed areas, some types of plants and animals may benefit, forming new small enclaves of differing communities. In Early Classic Maya society, humans adapted new strategies which included: growing and (sometimes) consuming more maize (Ebert 2017; White et al. 1993: and Piehl 2006); increased political centralization in some areas (Kennett et al. 2012; Medina-Elizalde et al. 2010); and new alliances, diplomatic relationships, and centers of influence (see Munson and Macri 2009). Ability to reorganize after a release of energy, or to exploit multiple strategies in response to varying cycles is termed *resilience*. This differs from other uses of the word resilience, where it implies returning to a single equilibrium quickly after disturbance (Peeples et al 2006).

Growth and the Classic Period

During the Early to Middle Classic Period, many polities' population steadily grew, agriculture was extensified and/or intensified, and the landscape was transformed through architecture, monuments, terraces, and other features. The site of Caracol, in modern-day southern Belize is reported to have water control features, extensive terracing, and possibly 100,000 citizens by AD 650, which were developed over the preceding several centuries (Chase et al. 2014). The moderately large site of Cahal Pech in the Belize River Valley has a deep occupation history, with evidence of early settlement around 1200 BP. Cahal Pech continued to grow through the Classic period in both population and architectural monuments, becoming an important influence in the valley (Ebert 2017). At the Peten site of Tikal, sections of massive earthworks were built between the Early and Late Classic periods. These are dated based on ceramic fill in and around the earthworks, along with settlement survey and excavation in households nearby. These features were in addition to significant monumental construction in the center (Webster et al. 2007). It is not clear whether this unique construction was completed, but could follow the common pattern of periodic maintenance and accretion common in Maya construction from the Middle to Late Classic. The Early Classic occupation at Xunantunich was comparatively sparse, but construction beginning around AD 600 continued over the course of nearly 200 years (LeCount et al. 2002).

The Late Classic Period and Conservation

Once a sufficient amount of biomass has been accumulated and interdependent relationships form, there is a tendency for systems to gravitate towards an equilibrium. This equilibrium is not stable or steady state, but is instead subject to periodic changes and perturbations which provoke responses in community members (Wood in press). In human society, this tends to be reflected in increasing social complexity, and intensification in particular subsistence practices (see Hegmon et al. 2008). For the Middle to Late Classic Maya people, this was expressed in varying agricultural strategies including canal systems, terraces, *chimampas*, and other forms of intensification. In addition, long distance trade networks, alliances between polities, and increased social stratification all facilitated a more complex, interdependent system. The creation of terraces at Blue Creek, for example, increased dependence on the agricultural system in that area. Alternately, it mitigated some of the changes occurring over several hundred years of continuous occupation and maintain a kind of status quo (Beach et al. 2006).

A Comparative Example: Conservation in Norse Greenland

Sometime between 800 and 1000 AD, Norse communities colonized areas around the North Atlantic, including Iceland and Greenland. When first beginning to expand, the settlers brought domestic animals and plant species with them, along with community strategies for subsistence. Over the following several centuries, colonists adapted the type and ratio of stock animals, engaged in cooperative community labor, and exploited a wide base of wild resources. When unpredictable climate changes

threatened the overall production system, the Norse adapted and increased their use of marine resources. The change in diet was confirmed by changes in nitrogen isotope ratios from human remains that demonstrated a significant shift from nitrogen values associated with consumption of land animals to marine species. Additionally, the proportion of marine faunal remains excavated in settlements increased. This adaptation covered some shortfalls, and mitigated the likely deficit in food production from long term damage to pasture areas and likely culling of herds during hard winters. However, trips to the northern hunting grounds were increasingly dangerous and probably required community labor investment that drew energy from other pursuits (Dugmore et al. 2011). This phase of colonization is typical of a conservation phase, where strategies are modified or intensified. Group cooperation and dependent relationships become more common, and these interdependent relationships are usually successful for some time. However, this interdependence often lacks diversity in strategies and complex relationships and can become rigid like Hegmon and colleagues describe in the Prehistoric Southwest (Hegmon et al. 2008). When rigid, communities lack the means to alter strategies in response to external shocks and may become vulnerable to collapse or abandonment. This is sometimes correlated with hierarchical societies, where elites or important decision makers may be insulated from effects of change and have a motivation to maintain social control or suppress innovation (Hegmon et al. 2008).

Terminal Classic Release

During the Terminal Classic, a similar pattern emerged to the Late Pre-Classic in the form of decreased annual rainfall and periodic droughts. Oxygen and other isotopes from cave stalagmites have been dated closely and reflect changes in annual precipitation which correlated with the end of monumental construction and probable population decline at sites throughout the region (Medina-Elizalde et al 2010, Kennett et al. 2012, Webster et al. 2008). These climate records suggest that the effect varied by location, with some areas (such as the Vaca Plateau, as studied by Webster and colleagues) affected slightly earlier or later (see Dunning et al. 2012). Areas in the Lowlands may have suffered the most dramatic decrease in rainfall, in contrast to typically higher levels of precipitation. These were probably exacerbated by human effects on the landscape including erosion, clearing of forested areas which would intensify drying (Webster, personal comm.), and intensive focus on maize production at the expense of other strategies.

The Terminal Classic at Xunantunich

Xunantunich had local cycles which operated at a different scale, although not totally independent from, processes of the larger Maya region. The decline of larger polities such as Tikal or Naranjo may have created opportunities for Xunantunich to expand (LeCount et al. 2002). At the same time, individuals in declining communities may have been dealing with a variety of sociopolitical results, including class conflict, inter-polity warfare, and inadequate responses from elites (Aimers 2007), as well a

regional migration (Dunning et al. 2012). Xunantunich had generally higher annual rainfall during the Classic period than many Central Petén and Northern Yucatán sites, although some evidence suggests that Lowland sites may have been more drastically impacted by drying trends and periodic droughts in the Late to Terminal Classic Periods than northern sites. The Macal and Mopan river systems nearby may have provided some access to additional water and fallback foods such as *nephronias*, and access to trade which allowed for various strategies to be employed than in the interior of the Yucatan (Dunning et al. 2012). Polities such as Xunantunich may have been less rigid in their adaptation, from their ability to utilize a variety of strategies. At the same time, cascading effects at different levels of society and nearby regions may have affected Xunantunich later than other polities.

Practice theory and Agency

Where panarchies describe interactions on various scales, practice theory deals with social contexts and responses. In practice theory, human understanding of the world is conditioned by a background cosmology (or *doxa*), and past experiences. The Maya *doxa* would associate correspondences between the natural and social worlds, such as the complex of traits which describe jaguars as also being relevant to priests/shamans and ancient royal kings (Saunders 1994). A familiar comparison would be the tendency for an archaeologist to interpret tool-use as consistent with their own experience of similar looking objects. These would not likely operate on a conscious level, but seem like self-apparent or natural ways of understanding the world.

Learned skills, such as appropriate linguistic and social choices, skills, and identity or status markers form a kind of social capital. Combined with experience, these inform a *habitus*, or set of dispositions which guide the choices available to the individual (Bourdieu 1977). Factors such as gender, social status, and relationships are important here, as individuals' acculturated notions of behavior are driven by their identity, past experience, and social capital.

For peri-abandonment deposits, Maya understanding of the cosmos and its functions are critical to interpretation. While we cannot be completely certain of specific meanings, functionalist interpretations have so far only negatively defined the possible implications. Determining that these deposits differ in contents and context from known behaviors, such as deposition in middens, leaves us with little new information. By considering how Maya people may have associated items and their preparation, further insight may be gained of the circumstances surrounding the creation of these deposits.

Expectations Based on Resilience Theory and Practice Theory

Despite some similarities to caches or other known ritual behavior, peri-abandonment deposits appear to be absent prior to the Late Classic in Maya society. This implies an adaptation or reorganization of past ritual forms, including coherence with some aspects of prior practices, but new combinations of material and contextual elements. Given the variability between deposits located throughout the Belize River Valley and potentially elsewhere, these appear to be organized at the community level. This may mean that groups of community members or other social groups coordinated their efforts, or that individual households organized the processes which resulted in

their deposition. It seems important, at this point, to express caution about determining which members of Maya society had influence in this process.

If previous roles and authority has broken down, I expect limited access to trade goods, or the ability to control the diet of multiple ideological animals. Individual contributions to the deposit may include curated items, including ritual paraphernalia, remains of ancestors, or animal remains with special modifications and/or significance. In the case of community contributions with or without fairly recent migrants, these remains would probably display variation in dietary signatures, including typical wild dietary signatures or evidence of foraging, and mostly local source locations. These results would suggest reorganization, and a reevaluation of practices and roles in the community.

In contrast, if individual households had sufficient clout to produce the majority of the deposit, I expect more consistency in values of diet and source location. The main exceptions to this would marine organisms, whose specific source outside of the local area would likely be difficult to discern through nitrogen or strontium isotope values (thus why they have not been sampled here). Seawater has relatively consistent $\delta^{15}\text{N}_{\text{coll}}$ and $^{87}\text{Sr}/^{86}\text{Sr}_{\text{ap}}$ values, so one coastal area may resemble the others. If dietary signatures reflected human influence, this would further imply that either trade access or individual wealth was significant enough to produce or acquire these animals. In this case, it would seem that at least some households were more prosperous in the Late to Terminal Classic than previously imagined. It seems unlikely that the deposits were a single termination event, considering the lens of soil between significant quantities. This would correspond more closely with a conservation phase in the panarchy, with

individuals or communities attempting to resist potential degradation through ritual intensification.

Chapter Six: Results

Introduction

The results of isotopic analyses from animal bone in the peri-abandonment deposit near structure B-4 at Xunantunich ($\delta^{13}\text{C}_{\text{coll}}$, $\delta^{13}\text{C}_{\text{ap}}$, $\delta^{15}\text{N}_{\text{coll}}$, $^{87}\text{Sr}/^{86}\text{Sr}_{\text{ap}}$ and $\delta^{18}\text{O}_{\text{ap}}$) are discussed in this chapter. Indicators of sample quality and integrity are addressed first, including data from FT-IR spectrometry, carbon and nitrogen ratios, and sample yield. Comparisons of differences within and between taxonomic classification and level within the deposit are made.

Collagen Quality Indicators

Several indicators are used to determine whether bone collagen has been altered post-mortem, including collagen yield (%), carbon to nitrogen ratio (C:N), carbon percent (%C), and nitrogen percent (%N) (Ambrose 1989). Collagen yields from unaltered modern bone range from 5%-25% (van Klinken 1999; Ambrose 1990), so lower yields may indicate collagen loss in the bone. Alternately, higher yields may indicate the sample was not sufficiently demineralized (See Ambrose 1990: van Klinken 1999). The carbon (%C) and nitrogen percent (%N) of modern animal bone varies from 15.3-47% and 5.5-17.3% respectively, with a C:N ratio between 2.9 and 3.5 (Ambrose

1990; DeNiro 1985). Most of the samples were within these guidelines except for three, which were excluded from this analysis (Table 6.1). Two samples, DS-103 and DS-106, were excluded for insufficient collagen yield. Two other samples yielded less than usual collagen, DS-102 with 2.5%, and DS-126 with 4%. Both DS-102 and DS-126 had typical C/N ratios of 2.8, and 2.9, respectively. The %C for DS-102 and DS-126 are 46.3% and 42.6%, while the %N values are 16.5% and 14.8%. These %C, %N and C:N ratios are within the expected values as compared to fresh, modern bone. DS-107 had a high collagen yield of 38%. DS-107 has a typical C:N ratio, but the C/P ratio is elevated at .47. This sample is unusually enriched in $\delta^{18}\text{O}_{\text{ap}}$ and has been excluded from further analyses. Some of the collagen yield information was lost during the processing, however, these samples exhibited sufficient C/N ratios and percentages and were included in these analyses (Table 6.1).

Apatite Quality Indicators

In bone apatite, indicators such as C/P ratio (carbonate to phosphate reflectance ratio) and IS-RF ratio (size and organization of crystals) are used to assess sample alteration from in vivo bone (Beasley et al. 2014). Values of C/P from modern bone typically fall between 0.23 and 0.34 (Beasley et al. 2014). Values in this study range from .25 to .47, which are mostly typical (Table 6.1). The mean C/P ratio for the all samples is .37, just above reported ranges for modern bone (Table 6.1). Nine samples are slightly elevated in comparison to modern values. The C/P ratio of DS-102 is slightly elevated, at 3.8, with an IR-SF value of 2.8. The C/P ratio for DS-126 is also within acceptable parameters, at .33. Bone collagen is affected by changes post-mortem before bone apatite, and may have a protective effect on bone apatite (see Hedges

2002; Collins et al. 2002). The lack of indicators for post-mortem change in collagen and bone apatite for DS-102 and DS-126 indicates minimal alteration and so these samples have been kept for further analyses. Other samples in this study with elevated C/P values have acceptable ratios for C:N, %C, %N, and IS-RF, suggesting minimal alteration from their values during the life of the organism (Hedges 2002; Collins et al. 2002). DS-107 had an anomalous $\delta^{18}\text{O}_{\text{ap}}$ and elevated C/P ratio, so this sample was excluded from $\delta^{13}\text{C}_{\text{ap}}$ as well as other analyses. Samples DS-103 and DS-106 which were excluded because of issues with collagen yield were also removed from $\delta^{13}\text{C}_a$, $\delta^{18}\text{O}_{\text{ap}}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ analyses.

Collagen Carbon and Nitrogen

The average value for the total faunal sample for $\delta^{13}\text{C}_{\text{coll}}$ is -17.6‰ ($\pm 4.4\text{‰}$) and a range of 13.9‰ (Table 2), while the average value in $\delta^{15}\text{N}_{\text{coll}}$ is 6.5‰ ($\pm 2.1\text{‰}$) and a range of 9.8‰ . Since these average values consist of several different species, the wide range in both $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}_{\text{coll}}$ is reflective of species-level dietary differences. Overall, these average values point to mixed C_3/C_4 diets and plant consumption similar to herbivores (see Kellner and Schoeninger 2007; Jim et al. 2004; Tieszen et al. 1983).

All of the deer (*Odocoileus sp.* $n = 7$) $\delta^{13}\text{C}_{\text{coll}}$ values in this study fall within a typical C_3 diet with an average $\delta^{13}\text{C}_{\text{coll}}$ value of -20.8‰ ($\pm 0.7\text{‰}$), and a range of 1.9‰ . This indicates a diet corresponding to consumption of wild C_3 plants common in the area of the Belize River Valley. The range of deer is slightly wider than expected for animals eating the same diet, suggesting slight inter-individual differences in plant consumption (DeNiro and Schoeninger 1983). This wild diet may indicate that consumption and ritual needs did not require deer that were fed a certain diet. The

$\delta^{15}\text{N}_{\text{coll}}$ values for deer average 5.8‰ ($\pm 1.4\text{‰}$), with a range of 4.2‰. This range is wider than a trophic level (Schoeninger 1985), suggesting different sources of nitrogen or possible effects of climate. However, this wide range is mostly because of one individual, DS-116, who is relatively enriched in $\delta^{15}\text{N}_{\text{coll}}$ at 8.5‰. A standard deviation greater than 1‰ indicates that differences between these individuals are greater than inter-individual metabolic differences, and DS-116 exceeds this threshold where other *Odocoileus* are clustered around the average value of 5.8‰. There are two possible explanations for this difference. An arid, hotter environment for several years could produce a relatively enriched $\delta^{15}\text{N}_{\text{coll}}$ value (Evans and Ehleringer 1994). Additionally, some wetlands in Belize are reported as having enriched $\delta^{15}\text{N}_{\text{coll}}$ values from cyanobacterial mats (Rejmánková et al. 2004). These effects may be concurrent, as during a series of dry and hot years, deer may gravitate toward wetland areas where vegetation has been less impacted.

The two iguanas (*Squamata sp.*) $\delta^{13}\text{C}_{\text{coll}}$ values average 15.2‰ ($\pm 1.8\text{‰}$), with a wide range of 9‰, suggesting significant interindividual dietary differences. These values for the iguanas suggest the consumption of a mixed diet including both C_3 and C_4 carbohydrate sources. One of these individuals, DS-126, is consuming a primarily C_3 based diet which is reflected in the $\delta^{13}\text{C}_{\text{coll}}$ value of -19.7‰. In contrast, DS-108 has a significantly less negative $\delta^{13}\text{C}_{\text{coll}}$ value of 10.7‰. This indicates significant consumption of C_4 foods. DS-108 may have lived near human maize fields and consumed C_4 foods, as some iguanas have been spotted near human settlement. The two iguanas have $\delta^{15}\text{N}_{\text{coll}}$ values of 6.1‰ and 8.5‰, respectively. These values are within the expected range for herbivorous species. The difference between the two

individuals' $\delta^{15}\text{N}_{\text{coll}}$ values is similar to the variation seen between individuals in controlled diet studies (see Godley et al. 1998, DeNiro and Schoeninger 1983).

The turtles (*Testudines*, n=3) have an average $\delta^{13}\text{C}_{\text{coll}}$ value of -21.0‰ ($\pm 3.2\text{‰}$), with a wide range of 7.1‰ , suggesting significant interindividual dietary differences. Turtle species in Belize include both marine and river species, which may be either herbivorous or omnivorous (Polisar and Horwich 1994). Herbivorous river turtles were consumed as food and some were used as musical instruments (Gates 1978). It is likely that the range of $\delta^{13}\text{C}_{\text{coll}}$ values from -23.5‰ to -16.4‰ indicates consumption of mostly C_3 wild foods, with some individuals consuming C_3 and C_4 foods. The $\delta^{15}\text{N}_{\text{coll}}$ values for *Testudines* vary from 3.1‰ to 8.0‰ , which may be representative of species differences between the three individuals. The lower value of 3.1‰ likely represents a freshwater species, where $\delta^{15}\text{N}_{\text{coll}}$ values closer to 8.0‰ resemble those of herbivorous marine turtles (Godley et al 1998). Given the presence of both freshwater mollusks and marine species within the B4 peri-abandonment deposit, individuals from both freshwater and marine species of *Testudines* is plausible.

The four rabbits (*Lagomorpha sp.*, n=4) have an average value for $\delta^{13}\text{C}_{\text{coll}}$ of -16.5‰ ($\pm 5.8\text{‰}$), with a range of 11.5‰ , exhibiting significant inter-individual variation. The range of these values spans expected ratios for herbivores consuming either a primarily wild C_3 based diet to a mixed C_3/C_4 diet. The mixed diet signatures could be explained by rabbits foraging in maize fields, and may suggest opportunistic capture of these animals. The average $\delta^{15}\text{N}_{\text{coll}}$ value of *Lagomorpha* is 4.9‰ ($\pm 1.7\text{‰}$), with a range of 5.6‰ . These individuals are within expected ranges for herbivores in a

terrestrial environment (Ambrose 1991), with the expectation that $\delta^{15}\text{N}_{\text{coll}}$ enrichment is somewhat lower for animals which require lower quantities of water consumption.

The canine has a $\delta^{13}\text{C}_{\text{coll}}$ value of -9‰ , which indicates consumption C_4 foods, or flesh of an animal which consumed C_4 foods. The canine $\delta^{15}\text{N}_{\text{coll}}$ value is 11.9‰ , which reflects a trophic level above herbivores. This suggests a more carnivorous diet and less plant-based foods. Thus, this animal is likely consuming animals that are C_4 plants. Canines are known to have consumed food in and around human households. In the Preclassic period of Maya society, some canines were fed a maize based diet for ritual purposes (White et al. 2001). It is possible that maize feeding could represent selection criteria for canines included in this deposit, however it is difficult to distinguish commensal maize consumption from intentional feeding in this case.

The two peccaries (*Tayassu sp.*) have an average $\delta^{13}\text{C}_{\text{coll}}$ value of -16.3‰ ($\pm 6.6\text{‰}$), with a range of 9.3‰ . This range suggests different diets of C_3 and C_4 foods between the two individuals. Their average $\delta^{15}\text{N}_{\text{coll}}$ value is 6.9‰ ($\pm 3.0\text{‰}$) with a range of 4.2‰ . This range suggests some kind of trophic enrichment. Peccary may range into human settlements to seek fruits or tubers when fruits are less available (Keuroghlian and Eaton 2008), and so their diet may be similarly influenced. Neither of these appear to be directly controlled by humans, but that may not erode the significance of their eating of maize or other human foods.

The armadillo (*Cingulata*) has a $\delta^{13}\text{C}_{\text{coll}}$ value of -19.7‰ , and a $\delta^{15}\text{N}_{\text{coll}}$ value of 5.9‰ . This reflects a C_3 based diet which is expected for a wild capture. The lone *Mazama* has a $\delta^{13}\text{C}_{\text{coll}}$ value of -21.3‰ , and a $\delta^{15}\text{N}_{\text{coll}}$ value of 5.2‰ . This individual consumed a diet expected for a wild herbivore reliant on C_3 foods.

The group of animals without specific genus or species designations is included in the *Artiodactyla* group, which may include both herbivores and omnivores such as deer, sheep, pigs, and peccaries. Because of the breadth of potential diets within this group, more variation is expected within the wild diet. The mean $\delta^{13}\text{C}_{\text{coll}}$ value of the *Artiodactyla* group is -13.7‰ ($\pm 2.9\text{‰}$), with a range of 7.4‰ . These values are less negative than the probable consumption of either C_4 or CAM plants, which does not necessarily indicate direct human influence, but could include browsing of maize or amaranth from cultivated areas. The $\delta^{15}\text{N}_{\text{coll}}$ of the *Artiodactyla* group are similar to each other, with an average value of 8.7‰ ($\pm 0.5\text{‰}$), and range of 1‰ . This value appears consistent with other mammals that may consume animal protein in this study. However, it is within the reported range for obligate drinkers (Ambrose 1991), and comparable to other herbivores in this study. It is therefore possible that these individuals were subject to an effect of a drier environment, foraging in wetland areas, or are omnivorous.

When comparing $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}_{\text{coll}}$ values, we see two rough groupings of animals suggestive of different diets (Figure 4). The *Odocoileus sp.* (medium size deer, $n = 7$) group shows less variation in $\delta^{13}\text{C}_{\text{coll}}$ than the group of *Testudines* (turtle, $n=3$) although both groups have variable $\delta^{15}\text{N}_{\text{coll}}$ values. These variations within and between groups thus represent differences of diet rather than metabolic differences between different individuals (DeNiro and Schoeninger 1983). The deer (*Odocoileus sp.*) are closely grouped together, suggesting very similar diets with minor inter-individual variation. The differences between peccary and canine in this sample are visible here, with the canine showing higher C_4 consumption than the deer, *Mazama*, *Cingulata*, and

most others. In contrast, the peccary have more negative $\delta^{13}\text{C}_{\text{coll}}$ values correlating with greater wild C_3 plant consumption and lower $\delta^{15}\text{N}_{\text{coll}}$ values reflecting a greater reliance on plant protein. Turtles show within-group variation possibly reflecting species' differences and regional differences. The lone brocket deer (*Mazama sp.*) has a more negative $\delta^{13}\text{C}_{\text{coll}}$ value in comparison to *Odocoileus*, which reflects a C_3 dominated wild diet and possibly inter-species differences in diet as compared to *Odocoileus* (Serbent et al. 2011).

Carbon and Oxygen from Apatite

Values for $\delta^{13}\text{C}_{\text{ap}}$ are most closely related to the overall dietary composition and are more greatly fractionated than $\delta^{13}\text{C}_{\text{coll}}$ values (Ambrose and Knorr 1993). The fractionation of $\delta^{18}\text{O}_{\text{ap}}$ is known to vary based on the body size of the animal, along with the source of water consumed and evaporation from surface waters and in the body. When compared between groups correlating to body size of the animal (size class), there are within-group differences indicating variation in drinking water sources. These differences, ranging from 2-5‰, overlap with other size classes and do not appear to correlate directly to $^{87}\text{Sr}/^{86}\text{Sr}$ values.

The $\delta^{13}\text{C}_{\text{ap}}$ value of the Structure B4 peri-abandonment samples have an average value of -9.5‰ (± 2.5 ‰) and a wide range of 9.0‰, largely reflecting significant inter-species dietary differences. Variation in the standard deviation of $\delta^{13}\text{C}_{\text{ap}}$ indicates that animals within the sample are consuming different sources of dietary carbohydrates. However, as with the collagen values, these ranges are due to species level differences in diet and water consumption. The average value of $\delta^{18}\text{O}_{\text{ap}}$ -3.4‰

($\pm 1.4\text{‰}$), with a range of 5.4‰ . This is significant variability which indicates different sources of drinking water between individuals.

The $\delta^{13}\text{C}_{\text{ap}}$ values for white-tailed deer (*Odocoileus sp.*) in this study have an average value of -11.0‰ ($\pm .6\text{‰}$), and a range of 4.0‰ . These values are less negative than $\delta^{13}\text{C}_{\text{coll}}$ due to the greater fractionation between $\delta^{13}\text{C}_{\text{ap}}$ and diet. Similarly to $\delta^{13}\text{C}_{\text{coll}}$ values, these are characteristic of C_3 diets with minor variation between individuals' diets. The $\delta^{18}\text{O}_{\text{ap}}$ values for *Odocoileus* average -5.1‰ ($\pm 1.2\text{‰}$), with a range of 3.4‰ . The baseline value for $\delta^{18}\text{O}_{\text{ap}}$ in the Belize River valley is -2.9 ($\pm .99\text{‰}$), so values which fall outside of this range likely consumed water from different drinking sources. Several of these *Odocoileus* fall outside of the expected range for the area local to Xunantunich.

The $\delta^{13}\text{C}_{\text{ap}}$ for iguana (*Squamata sp.*) has an average value of -8.6‰ ($\pm 2.3\text{‰}$) and range of 3.2‰ . As there are only two in this study, this could represent some individual differences or reflect dietary preferences between common species in Belize. The average $\delta^{18}\text{O}_{\text{ap}}$ value for iguanas is -3.4‰ ($\pm 0.8\text{‰}$), with a range of 1.1‰ , which is comparable to the Belize River Valley baseline and suggests similar drinking water.

The $\delta^{13}\text{C}_{\text{ap}}$ values for turtles in this study (*Testudines sp*) have an average value of -9.1‰ , with a range of 5.0‰ . When accounting for the differences in fractionation, this reflects a C_3 dominated diet. The average $\delta^{18}\text{O}_{\text{ap}}$ value for *Testudines* is -3.3‰ ($\pm 1.4\text{‰}$), with a range of 2.6 . These values are also within the expected range for the Belize River Valley.

Rabbits (*Lagomorpha sp.*) in this study have an average $\delta^{13}\text{C}_{\text{ap}}$ value of -8.9‰ and range of 6.8‰ ($\pm 3.1\text{‰}$), with a range of 7.2‰ . The least negative value is DS-

115b, which is -5.3‰. This individual differs from the group in some C₄ consumption in the diet, possibly from foraging near maize fields. The *Lagomorpha* have an average $\delta^{18}\text{O}_{\text{ap}}$ value of -3.3‰ ($\pm 1.1\text{‰}$) and range of -2.7‰. Most of these values fall within the expected range for the Belize River valley, with the exception of DS-104, at -4.9‰. The similarity of these values to the local range for $\delta^{18}\text{O}_{\text{ap}}$ values suggests an opportunistic capture of these rabbits near human settlements.

The canine in this study has a $\delta^{13}\text{C}_{\text{ap}}$ value of -6.3‰, and a $\delta^{18}\text{O}_{\text{ap}}$ value of -2.4‰. This relatively less negative $\delta^{13}\text{C}_{\text{ap}}$ value suggests an overall diet significantly influenced by consumption of C₄ foods, in line the with $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}_{\text{coll}}$ values discussion above.

The peccary in this study have an average $\delta^{13}\text{C}_{\text{ap}}$ value of -7.4‰ ($\pm 1.3\text{‰}$), with a range of 1.9‰. This relatively narrow range reflecting similar diets with mixed C₃ and C₄ foods. The average $\delta^{18}\text{O}_{\text{ap}}$ value is -4.8‰ ($\pm 0.9\text{‰}$), with a range of 1.3‰. These values are relatively similar, although the $^{87}\text{Sr}/^{86}\text{Sr}$ values discussed below suggest different home areas.

The individual armadillo (*Cingulata*), DS-109, has a $\delta^{13}\text{C}_{\text{ap}}$ value of 14.3‰, and a $\delta^{18}\text{O}_{\text{ap}}$ value of -1.5‰. The individual brocket deer (*Mazama sp.*) has a $\delta^{13}\text{C}_{\text{ap}}$ value of -12.3‰ and a $\delta^{18}\text{O}_{\text{ap}}$ value of -2.2‰. These values reflect overall diets dominated by C₃ sources of carbohydrates and protein, and expected values for $\delta^{18}\text{O}_{\text{ap}}$.

The *Artiodactyla* in this group have an average $\delta^{13}\text{C}_{\text{ap}}$ value of 8.0‰ ($\pm 2.9\text{‰}$), with a range of 5.8‰. This average value suggests diets dominated by C₃ sources of carbohydrates and protein. However, the range of these values suggests some variation based on species differences within the group. The average $\delta^{18}\text{O}_{\text{ap}}$ value is -3.4‰ (\pm

1.5‰), with a range of 3.0‰. This range is relatively narrow, and could reflect inter-species differences in fractionation within the group.

Simple Carbon Isotope Model

The simple carbon model (Kellner and Schoeninger 2007) plots $\delta^{13}\text{C}_{\text{coll}}$ against $\delta^{13}\text{C}_{\text{ap}}$ values, giving a more robust understanding of the sources of dietary carbohydrates and protein. By plotting these animal data on the C_3 , C_4 , and marine protein regression lines, different proportions of dietary elements can be estimated.

When $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{13}\text{C}_{\text{ap}}$ values are plotted together in a scatter, they form two loose clusters (Figure 6). The larger group, dominated by herbivores, fall around the C_3 regression line on the left side. A smaller cluster falls between the marine protein regression line (towards the center) and the C_4 protein regression line (towards the right).

Multivariate Carbon and Nitrogen Isotope Model

The multivariate carbon and nitrogen model (Froehle et al. 2012) uses two formulas to plot $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{13}\text{C}_{\text{ap}}$ data with $\delta^{15}\text{N}_{\text{coll}}$ for comparisons with five major dietary clusters. These clusters group the relative proportions of dietary inputs from C_3 and C_4 carbohydrates and protein, as well as the proportion of marine and terrestrial protein sources and gives more detailed information on dietary components, including type and amount of protein. However, these boxes were made in references to human diets.

The far left box, outlined in red, corresponds to a 100% C_3 diet for both carbohydrate and protein sources. In the Belize River Valley, this would reflect a diet

dominated by wild C₃ sources of carbohydrates and protein. The second box from the left, outlined in purple, represents a 70 C₃ to C₄ diet with at least 65% C₃ protein. This would suggest some mixed consumption, possibly from foraging in maize fields or consuming amaranth that may colonize disturbed areas. The central box, outlined in blue is a 30:70 C₃ to C₄ diet, with at least 65% C₃ protein. These values would likely suggest significant maize consumption, although the protein sources are from plants utilizing the C₃ pathway, or animals that consumed those plants. The lower right box, outlined in green, is a 30:70 C₃ to C₄. The upper right box depicts the range of a 50:50 C₃ to C₄ diet with marine protein. This would indicate consumption of marine resources, unlikely for animals local to the Xunantunich area.

The samples fall into two loose clusters, as in the bivariate model described earlier. The left cluster falls below a projected value for 100% C₃ diet ratio, which may result from physiological differences between some of these animals and humans in combination with types of food preferences. These values most closely resemble extreme diets in humans, suggesting these values are all from herbivores that consume no animal protein. Physiological differences between these animals, especially reptiles and deer, could be reflected in these values. The second grouping, which includes the canine, two peccary, one *Squamata* and one *Lagomorph* fall well within the lower right box, indicating these animals consumed a significant amount of C₄ carbohydrates, but the majority of their protein came from C₃ plants or animals which consumed C₃ plants. The samples falling in this second category include DS-108 (*Squamata*), DS-115a (*Lagomorpha?*), DS-122 (*Artiodactyla?*), DS-123 (*Canine?*), and DS-129 (*Peccary*). It is possible these animals (with the exception of the canine) may have been captured

during garden hunting near maize fields, which is a practice documented in both ancient and ethnohistoric contexts. The canine, as previously discussed, may have been consuming a diet similar to its human owners. With these dietary results, it is also clear that all *Testudines* present were consuming a herbivorous diet with no marine influence. This makes it more likely these were riverine species, common in the Belize River Valley. While other marine species were present within the deposit, these turtles appear to be acquired in the local area.

Strontium and Geolocation

Strontium ($^{87}\text{Sr}/^{86}\text{Sr}$) values in bone are incorporated from the soil plants are grown in and the water consumed and as such are good indicators of migration patterns (Bentley 2006). The Belize River Valley's geology is extremely complex and varied (Freiwald et al 2014), and Xunantunich is near the border of several metamorphic provinces. For humans and species with larger home ranges, crossing between these provinces could create intermediate $^{87}\text{Sr}/^{86}\text{Sr}$ values. In addition, values represented in the Belize River Valley are also identifiable across the Yucatán. The combined $^{87}\text{Sr}/^{86}\text{Sr}$ values in this study have an average value of .7088, a standard deviation of .0005, and a range of .7080 to .7108. Within the Maya region, mean differences between different the five major geographic locations are \pm .002 (Hodell et al. 2004). Variation in $^{87}\text{Sr}/^{86}\text{Sr}$ values within the 3rd decimal point indicates significant locational information for the samples under study (see Bentley 2006 for a comprehensive review). However, the local area of the Belize River Valley has significant heterogeneity, and many of the values present within the valley are similar to those elsewhere in the region (compare Hodell et al. 2004 to Freiwald et al 2011, 2014). These local values come from a second

baseline (Freiwald et al. 2011, 2014), using modern local fauna from sites around the Belize River Valley. The variation between these sites is frequently small with an average value of .7086.

Two main sources of baseline data for $^{87}\text{Sr}/^{86}\text{Sr}$ determinations of source material are frequently used in faunal studies. A major source is the regional baseline created by Hodell and colleagues (2004), which relies heavily on modern soil, water and plant tissue samples from across the region. This broad baseline allows for comparisons between regions, although it does not capture the local heterogeneity of the Belize River Valley. Alternately, some researchers (Freiwald 2011; Freiwald et al. 2014) have used local modern fauna as a baseline for comparison to archaeological samples. One important question is how to define local or non-local in the Belize Valley. By the strictest definition, all of these samples fall within potential local ranges for the Belize River Valley, or the Southern Lowlands more broadly. However, in this study, values outside of the site of Xunantunich proper are still of interest.

Eight of the samples fall within the $^{87}\text{Sr}/^{86}\text{Sr}$ baseline in Freiwald et al. 2014, from .7082 to .7087 (Table 2, Figure 8). Considering the narrowness of this band, values just outside this range may still be considered local. Four additional samples have values of .7088 to .7089, and $\delta^{18}\text{O}_{\text{ap}}$ values within the expected range for the Belize River Valley between -2.2‰ and -3.5‰. One additional sample, DS-105, has a $^{87}\text{Sr}/^{86}\text{Sr}$ value of .7081 and a $\delta^{18}\text{O}_{\text{ap}}$ value of -2.1‰, also within the Belize River Valley range.

Several samples with borderline $^{87}\text{Sr}/^{86}\text{Sr}$ values also have more negative $\delta^{18}\text{O}_{\text{ap}}$ values than expected for the home range of 2.99 ± 1.0 ‰ (Freiwald et al 2011). Samples DS-104, DS-110, DS-117, DS-121, DS-127, and DS-128 have $\delta^{18}\text{O}_{\text{ap}}$ values

that range from -6.9‰ to -4.7‰. These include two *Odocoileus*, one probable *Lagomorph*, and one *Testudines*. These animals may have been collected during a period of higher rainfall or may have come from an area outside of the Belize River Valley, such as near the site of Caracol or the area of the Vaca Plateau.

Three samples have $^{87}\text{Sr}/^{86}\text{Sr}$ values which are present within the Belize River Valley range as reported in Freiwald et al. 2014, however they also correlate to areas far outside the Belize River Valley. DS-108, a *Squamata*, has a $^{87}\text{Sr}/^{86}\text{Sr}$ value of .7094, which correlates to values from the Northern Lowlands. Given the relatively small home range of this species, and the evidence of influence from the Northern Lowlands at the site of Xunantunich, it is possible that this individual came from outside the local area. DS-109, the *Cingulata*, has a $^{87}\text{Sr}/^{86}\text{Sr}$ value of .7095, comparable to values reported for Chaa Creek or Saturday Creek, and relatively close to modern seawater, but also possibly from outside the area given a comparatively enriched $\delta^{18}\text{O}_{\text{ap}}$ value of -1.5‰. Sample DS-129 has a $^{87}\text{Sr}/^{86}\text{Sr}$ value of .7108, and a $\delta^{18}\text{O}_{\text{ap}}$ value of -5.5‰, which most closely resembles values reported for Mountain Pine Ridge or the Maya Mountains.

While these values are all plausibly present in the Southern Lowlands, and probably near to Xunantunich, the wide variation in values and a non significant correlation (linear regression: $R^2 = .001$, $F(.016, 1)$, $p = .901$) between $\delta^{18}\text{O}_{\text{ap}}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ values suggests a scattering of sources from surrounding areas. If all the $^{87}\text{Sr}/^{86}\text{Sr}$ values were closely clustered with similar $\delta^{18}\text{O}_{\text{ap}}$ values, it would be plausible to suggest they were brought together or transported as a group. Differences in $\delta^{18}\text{O}_{\text{ap}}$ can be related to different types of drinking water sources (e.g. rainfall, streams, and standing water), and biological factors such as the size of the animal and required

quantity of water. Different sources of drinking water are subject to different levels of evaporation, such as *aguadas* which may significantly evaporate during the dry season. Animals which rely on streamwater and other sources may vary in comparison to human values who used captured water such as an *aguada* like the one present at Xunantunich. This $\delta^{18}\text{O}_{\text{ap}}$ variation could also reflect seasonal differences due to dry season evaporation. The $\delta^{18}\text{O}_{\text{ap}}$ variation present in the Structure B4 deposit supports a more dispersed pattern of acquisition, rather than one focused on a single restricted area. Given the $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}_{\text{ap}}$ variation present in this sample, the quantity of remains present, and the presence of marine species not sampled in this study, it is likely that these animals were brought from multiple areas around Xunantunich.

Chapter Seven: Discussion and Conclusions

The data present here from the B4 peri-abandonment deposit show general similarities in their pattern of diet and geolocation as compared to other values from the Southern Lowlands. A few additional conclusions and suggestions for future research may be drawn from the small sample of the B4 peri-abandonment deposit. The context and materials of the B4 deposit are distinct from other types of deposits, however it is difficult to distinguish them isotopically from other contexts. This is primarily due to the lack of multi-isotope studies that utilize $\delta^{13}\text{C}_{\text{ap}}$ data alongside $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}_{\text{coll}}$ values. This suggests that the potential differences in protein sources and dietary carbohydrates are not clear in studies that utilize only $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}_{\text{coll}}$ values. Exploring these data would allow for an additional line of evidence in relevant in many different research designs.

As discussed in the previous chapter, the animals sampled in the B4 peri-abandonment deposit do not show evidence of controlled feeding, with the exception of one canine likely consuming foods similar to its human owners. A few animals show evidence of C_4 consumption, which may reflect expedient acquisition from area near human settlement. While there is evidence that domestication or controlled feeding were known at practiced at different times throughout Mesoamerica as discussed elsewhere (e.g. Sharpe et al. 2018, Sugiyama et al. 2016), the lack of controlled diets for animals used for ritual purposes is consistent with a breakdown of affluence and authority during the Late to Terminal Classic periods. The variation in $\delta^{15}\text{N}_{\text{coll}}$ and $\delta^{18}\text{O}$ in particular may reflect the effects of the Terminal Classic drying trend or a periodic drought, consistent with an intensification and possible shift in ritual practices in

response to environmental and social changes (see Moyes et al. 2009). The variability in $\delta^{18}\text{O}_{\text{ap}}$ values may also be related to different types of drinking water sources, or seasonal changes in rainfall and aridity.

Additionally, the quantity and different source locations of animals sampled here suggest no central source or authority but are difficult to pinpoint due to the extreme variation of $^{87}\text{Sr}/^{86}\text{Sr}$ values in the Xunantunich area. The majority of the samples have values local to the Belize River valley area, but not necessarily the immediate area of Xunantunich. The variability in source locations further suggests that these animals or their remains were not directly imported from a single area but were brought from several different locations around and possibly from outside the Belize River Valley.

The B4 peri-abandonment deposit contains a large volume of material and was potentially the result of multiple instances of deposition as evidenced by the lens of soil between layers of the deposit. The distinct layers of the deposit combined with the geographic variability of the animals' source locations suggests contributions from multiple sources rather than the direction of one authority. It is also possible that animals deposited were not all killed at the same time, and possibly some were curated for a period before inclusion in the deposit.

One plausible explanation for the variation in dietary and geolocation values in this study is pilgrimage activity, where individuals or groups returned to the site of Xunantunich post-abandonment of the site core. Ruins, such as impressive abandoned sites like Xunantunich, are recorded in scholarly literature as destinations for pilgrimage from prehistoric times to the present day (Lucero and Kinkella 2015, Palka 2014). The importance of these sites, and their connection to Maya identity is compounded by ritual

activities conducted during visits to sites and natural features (Palka 2014). This could reflect ritual intensification independent of past elite activity at the site, consistent with a breakdown in social hierarchy during the Terminal Classic period.

Xunantunich may have been selected for its visibility on the landscape, as well as the characteristics from Maya cosmology which are embodied in the architecture, features, and layout of the site. The large pyramids may be considered *witz*, a personification of Earth or mountains. By ascending the pyramid, one reaches the celestial realms. Areas below the pyramids, especially any watery areas, would be connected to the realms of the underworld. Group B contains a nearby shrine and drain, which increase the potential for association with underworld and water elements. If individuals or groups returned, they may have been accessing or re-creating this sacred landscape. During the Terminal Classic period, environmental changes, specifically a lack of rainfall may have coupled with a lack of central authority. Maya people might have recombined familiar elements of past practices with new elements to create order in the landscape and ensure continued survival. This would reflect a correlation between the reorganization phase of a panarchy and the Terminal Classic period at Xunantunich.

The B4 Faunal Isotopic Data in Regional Context

When compared to other published isotopic data from studies during the Late and Terminal Classic periods, the Structure B4 dietary data shows broad similarities, as depicted in Figure 9. These data are drawn from sites in the Southern Lowlands (White et al. 2004; White et al. 2001; Ebert et al. 2018), which have different site chronologies

but share cultural similarities to sites across the Maya region. These data show a comparable pattern to the B4 deposit fauna, with most animals falling into a C₃ dominated cluster. A smaller proportion of animals are consuming C₄ foods, with more animals from the Preclassic site of Colha falling into this second cluster. Some of the data from Colha appear to fall between the two clusters, suggesting mixed consumption of C₃ and C₄ foods. This greater range of values suggests differences between the Preclassic practices at Colha, and Terminal Classic practices in the Belize River Valley.

Deer and canine diets from the Preclassic to Terminal Classic periods have been studied the most thoroughly, due to the higher proportion of these remains found in middens, and the presumption that these two animals' diets were more likely to be influenced by humans. Other studies have covered small quantities of armadillo and peccary, although these species are reported in much smaller quantity in both midden and other contexts (see Yaeger and Freiwald 2009; Van der Merwe et al. 2000).

At Copan, several samples from cache in ceremonial center, a shaman burial in Plaza A, the burial of ruler 12, Altar Q and midden contexts were analyzed for $\delta^{13}\text{C}_{\text{coll}}$, $\delta^{13}\text{C}_{\text{ap}}$, $\delta^{15}\text{N}_{\text{coll}}$, $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}_{\text{ap}}$ values (Sugiyama et al 2018). These samples included a puma, numerous deer, heavily fragmented jaguar, crocodile, owl, spoonbill, and turkey. Of the felines in this study, some exhibited clear wild dietary signatures indicating prey consuming mostly C₃ species. Alternately, one puma exhibited consumption of C₄ -fed prey. Some deer sampled had $\delta^{18}\text{O}_{\text{ap}}$ values indicating possible relocation during their lifetimes, although they could not be definitively identified as non-local. In short, this study indicated that animal management practices at Copan utilized a variety of

strategies to manage animal populations for different purposes, including probable sacrifice, consumption, and use for resources such as pelts. However, these were all likely elite contexts, and distinct in their placement and the other materials from peri-abandonment deposits.

Figure 10 is a scatterplot of $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}_{\text{coll}}$ values from fauna in peri-abandonment deposits at B4 and from Ebert et al. 2017. When comparing dietary values from these three studies between contexts, few differences are apparent. They show a similar dietary pattern with one cluster of C_3 consuming herbivores, and another group reflecting of C_4 consumption, or some kind of animal protein. These data are partly ambiguous as a group due to the lack of $\delta^{13}\text{C}_{\text{ap}}$ values to compare total diet to the protein portion of the diet. Given the large number of deer in these samples, it is possible some are consuming C_4 plant species. However, this is unclear in the canines, who could be consuming either human food waste or different types of animal protein.

Peri-abandonment Deposits and Middens

Several studies have reported $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}_{\text{coll}}$ data from Late and Terminal Classic midden contexts. White and colleagues reported $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}_{\text{coll}}$ values for deer and dogs in various from the sites of Tikal, Copan and Largetero (White et al. 2004), A recent study from Ebert and colleagues (2017) also reported $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}_{\text{coll}}$ values from deer, rabbit, brocket, dogs, and turkey at Baking Pot and Cahal Pech. The Baking Pot and Cahal Pech data includes generic deposits, peri-abandonment deposits, ceramic deposits a cache, and one tomb (Ebert et al.2017). Figure 9. A scatterplot depicts $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}_{\text{coll}}$ values from fauna in peri-

abandonment deposits at B4 and from Ebert et al. 2017, against values from middens at Tikal, Copan, and Lagartero (White et al. 2004). This scatter suggests no pattern in dietary values between different contexts.

Comparing Locational Studies

Few studies using isotopic methods for geolocation data in the Maya region utilize both $^{87}\text{Sr}/^{86}\text{Sr}$ values and $\delta^{18}\text{O}_{\text{ap}}$ values. While the $^{87}\text{Sr}/^{86}\text{Sr}$ values appear to show a similar distribution of local with a few non-local individuals, it is not possible to compare the variation of $\delta^{18}\text{O}_{\text{ap}}$ values seen in the Structure B4 peri-abandonment deposit to these published data. It appears that similar practices were used to acquire animals from these contexts, however the possible correlation to seasonal changes and different sources of drinking water could still be explored in future studies. This could help clarify Scherer and colleagues' (2015) observation that $\delta^{18}\text{O}_{\text{ap}}$ values show significant wet and dry season differences, in contrast to the broad model used by Lachniet and Patterson (2009). The $\delta^{18}\text{O}_{\text{ap}}$ values in this study were compared to Freiwald (2014), where a local human baseline for $\delta^{18}\text{O}_{\text{ap}}$ values was used as was discussed above.

Yaeger and Freiwald collected a sample of 44 *odocoileus* and small numbers of peccary and tapir from sites across the Belize River Valley and compared $^{87}\text{Sr}/^{86}\text{Sr}$ values to known local ranges (Yaeger and Freiwald 2009). These values are depicted in bar graphs, so direct values are not available for comparison. The $^{87}\text{Sr}/^{86}\text{Sr}$ values showed a similar pattern to the B4 peri-abandonment deposit, with a mixture of local, non-local, and ambiguous values. One site discussed, the San Lorenzo site, has eight

non-local *Odocoileus*, where all of the *Odocoileus* in the Structure B4 deposit show local $^{87}\text{Sr}/^{86}\text{Sr}$ values. The Xunantunich peccary, *Mazama* and *Odocoileus* have a similar range of $^{87}\text{Sr}/^{86}\text{Sr}$ values from .7078-.7095. Their graph from the Chan site also has a similar range of .7080-.7090. However, they state that their upper range is from nearer to the Macal River. The authors suggest this represents acquisition of game from both local and outlying areas (Yaeger and Freiwald 2009). The similar pattern in the B4 deposit could indicate that environmental stress encouraged hunting and other activities farther from Xunantunich than might be expected, but still within the range of people making shorter journeys on foot.

Thorton (2011) sampled 131 specimens, including 46 modern animals and 85 large and medium sized animals such as deer and peccary from a variety of sites across the Maya region. The modern animals included species with restricted home ranges such as land snails, in order to approximate the biologically available $^{87}\text{Sr}/^{86}\text{Sr}$ near polities and settlements. While most of the deer and peccary sampled have local values, the author noted several at each of the sites with values from outside the local ranges of their context. Four sites from this study reported values from Belize, as depicted in Figure 12. The two individuals from the site of Colha have the reported $^{87}\text{Sr}/^{86}\text{Sr}$ values of .7082 and .7083, respectively. These are similar to Belize River Valley values, although the site of Colha is relatively far away toward the coast of Belize. The sites of Tipu and Lamanai both have similar reported local ranges, each with a few outliers of possible non-local individuals. However, the heterogeneity of local geology is reflected in the local ranges reported for Lamanai (.7072-.7087) and Tipu (.7085-.7147).

Based on these data, the author concluded that more animals had been acquired through trade than previously thought (Thorton 2011). These data are somewhat complicated by the heterogeneous $^{87}\text{Sr}/^{86}\text{Sr}$ values of the Southern Lowlands, which also have comparable values to the Northern Yucatan. Use of $\delta^{18}\text{O}_{\text{ap}}$ values could help to clarify this heterogeneity, but fewer studies in the Maya region have utilized $\delta^{18}\text{O}_{\text{ap}}$ from faunal samples for geolocation.

Conclusions

This study of diet and geolocation from the B4 peri-abandonment deposit represents a relatively novel application of isotopic methods which are frequently used and well-characterized in Maya archaeology. Dietary and geolocation information from these B4 fauna correlate with a reorganization of practices during a period of social and environmental change analogous to the reorganization phase of a panarchy in the Terminal Classic. The general lack of controlled feeding practices contrasts with studies of Preclassic deer and dog feeding (White 2001), as well as deposition of C_4 fed animals in caches (Sugiyama et al. 2015) and animal husbandry practices (Sharpe et al. 2018). The variation in $\delta^{15}\text{N}_{\text{coll}}$ and $\delta^{18}\text{O}_{\text{ap}}$ values is consistent with changes in annual rainfall or increased evaporation of local drinking water sources. These data suggest that different criteria were used to select the animals for peri-abandonment deposits than for some earlier ritual activities, while the species selected for inclusion in ritual deposits did not change dramatically during the Terminal Classic period at Xunantunich. Systematic investigation of dietary and geolocation information from peri-abandonment deposits will reveal more information about ritual and possible pilgrimage practices to sites which are

known and accessed, but not contemporaneously inhabited during the Terminal Classic period. Expansion of these data may also reveal more information about intensification of water-related rituals, such as those documented in caves (Moyes et al. 2009). These data will integrate well with other studies in the Maya region regarding trade, animal husbandry, and human diet. In addition, studies of human practices and responses to social and environmental change have broad relevance for anthropologists and other scholars today, given the dramatic changes brought on by globalization.

Appendix: Tables and Figures

Figure 1. A depiction of the regression lines for the bivariate model of dietary reconstruction, following Kellner and Schoeninger 2007.

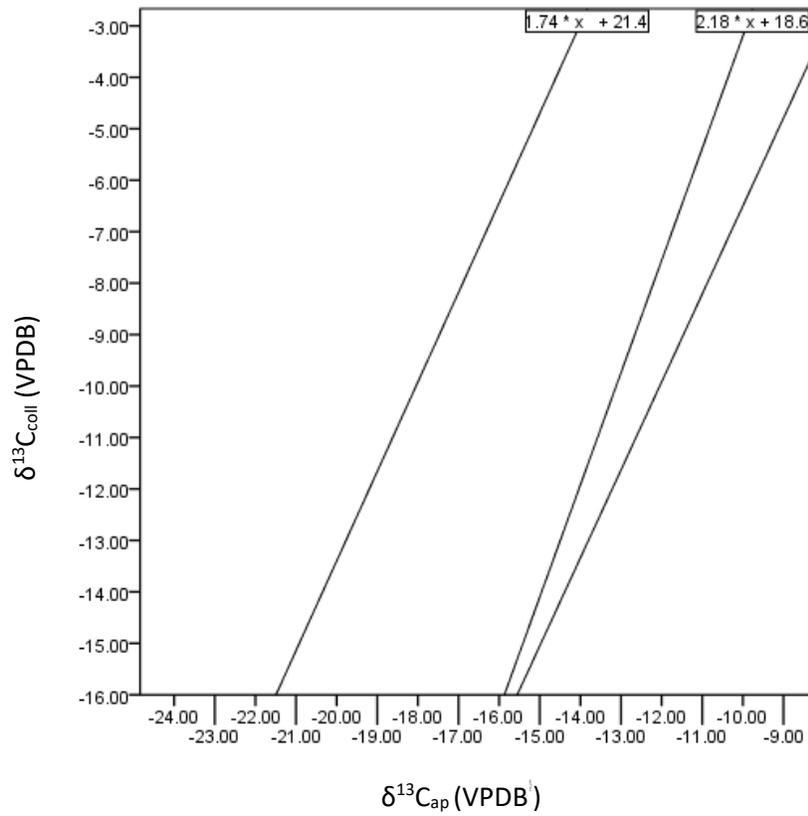


Table 1. A table of all samples from the Structure B4 peri-abandonment deposit, with their context and the analyses performed on each sample.

Sample Number	Sample Context	Species/Taxon	Bone Collagen Analyses	Bone Mineral Analyses
DS-101	Feature 1 deposit	Odocoileus (White tailed deer)	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-102	Feature 2 deposit	Mazama (Brocket deer)	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-103	Feature 2 deposit	Testudines (Turtle/tortoise)	Insufficient collagen yield	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-104	Below Feature 1 deposit	Lagomorpha?	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-105	Below Feature 1 humus	Testudines	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-106	Feature 1 (humus)	Testudines	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-107	Feature 1 deposit	Odocoileus?	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-108	Feature 2 deposit	Medium reptile	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-109	Below Feature 1 deposit	Cingulata Dasypus (Armadillo carapace)	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O
DS-110	Below Feature 1 deposit	Odocoileus	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-112	Feature 2 deposit	Peccary?	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-113	Floor 1	Artiodactyla?	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-115a	Humus	Lagomorpha?	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-115b	Humus	Lagomorpha?	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$

DS-116	Feature 1 deposit	Odocoileus	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-117	Feature 1 (humus)	Odocoileus	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-119	Feature 1 deposit	Testudines	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-120	Feature 1 deposit	Testudines	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-121	Feature 1 deposit	Odocoileus	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-122	Humus	Artiodactyla?	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-123	Feature 1 deposit	Canine?	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-124	Feature 1 deposit	Canine/Peccary?	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-125	Humus	Odocoileus Virginianus	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-126	Humus	Reptilia Squamata (Iguana)	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-127	Feature 2 deposit	Testudines	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-128	Humus	Artiodactyla?	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-129	Feature 2 deposit (humus)	Peccary?	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$
DS-130	Feature 2 deposit	Lagomorpha Sylvila (Rabbit, Cf. jackrabbit)	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	$\delta^{13}\text{C}$, ^{18}O , $^{87}\text{Sr}/^{86}\text{Sr}$

Figure 2. A map of the Belize River Valley. The inset map shows the Belize River valley within Belize and the Southern Lowlands. Figure by Shane Montgomery.

Archaeological Sites of the Upper Belize River Valley

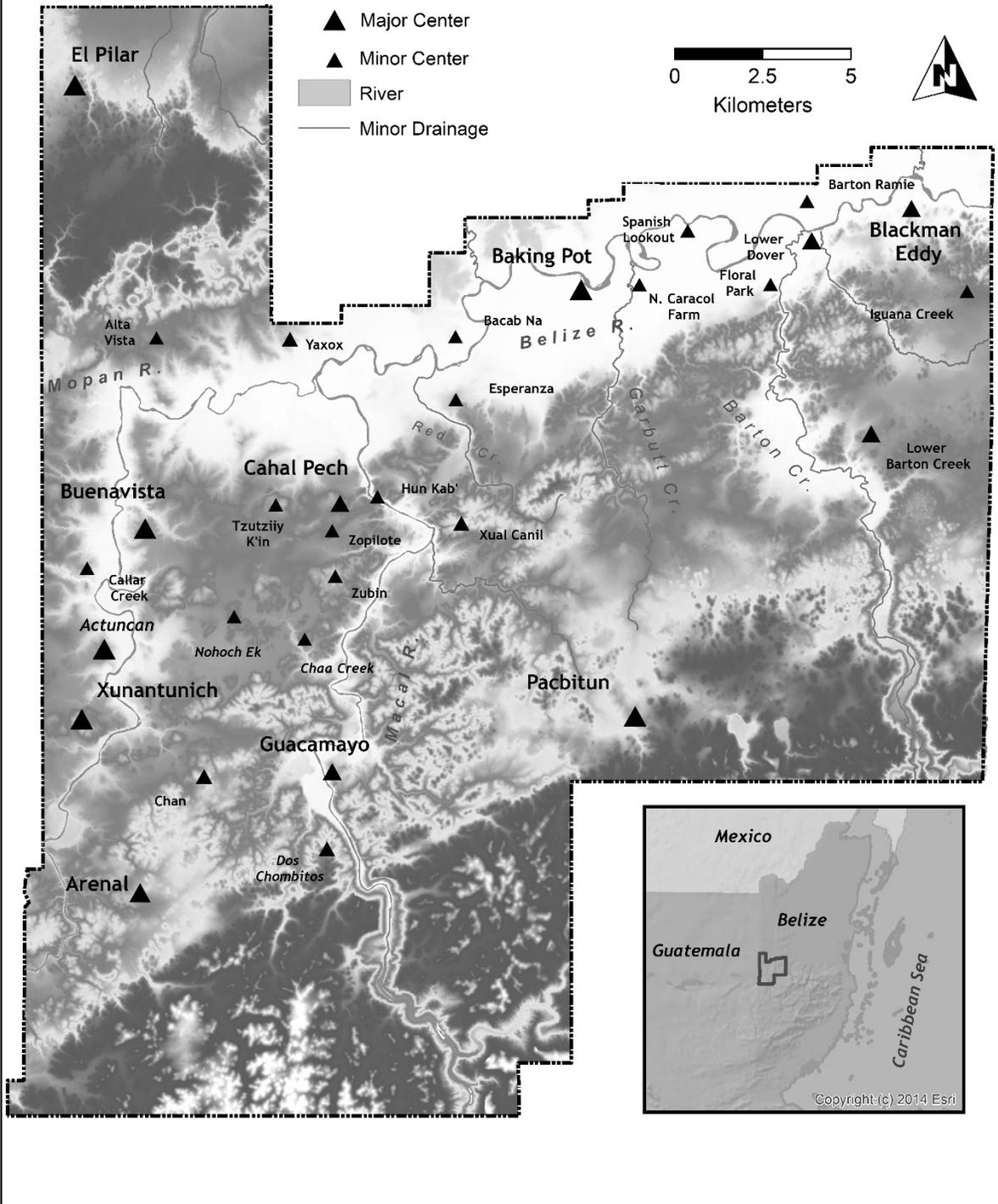


Table 2 Table of all Values. Some data for collagen yield was lost during processing, however samples were visually examined for yield. Values with an (*) were excluded from final analyses.

Sample	Size Class	Genus	$\delta^{13}\text{C}_{\text{ap}}$	$\delta^{13}\text{C}_{\text{coll}}$	$\delta^{15}\text{N}$	Collagen Yield %	%C	%N	C: N	C/P ratio	$\delta^{18}\text{O}$	$^{87}\text{Sr}/^{86}\text{Sr}$
ds-101	Large Mammal	Odocoileus	-10.1	-19.7	6.1	18.1	38.1	13.1	2.9	.30	-3.5	.7088
ds-102	Large Mammal	Mazama	-12.3	-21.3	5.2		46.3	16.5	2.8	.38	-2.2	.7088
ds-103	Reptile	Testudines	-6.4	.	.	*	.	.	.	.42	.	.7084
ds-104	Medium Mammal	Lagomorpha	-7.8	-16.9	4.2	2.5	45.5	15.9	2.9	.46	-4.9	.7080
ds-105	Reptile	Testudines	-8.8	-16.4	3.1	6.2	46.2	16.8	2.8	.47	-2.1	.7081
ds-106	Reptile	Testudines	-8.8	.	.	*	.	.	.	.32	.	.7090
ds-107	Large Mammal	Odocoileus	-14.1	-20.8	4.5	*	43.3	14.4	3.0	.47	41.8	.7089
ds-108	Reptile	Squamata	-7.0	-10.7	8.5	18.6	44.0	15.2	2.9	.38	-2.8	.7094
ds-109	Armadillo	Cingulata Das.	-14.3	-19.7	5.9		44.5	15.9	2.8	.41	-1.5	.7095
ds-110	Large Mammal	Odocoileus	-11.8	-19.7	5.5	11.8	42.9	15.4	2.8	.36	-4.4	.7089
ds-112	Medium Mammal	Peccary	-8.4	-21.0	4.8		43.6	15.0	2.9	.41	-4.3	.7087
ds-113	Large Mammal	Artiodactyla	-11.1	-18.1	8.1		45.8	16.4	2.8	.33	-3.0	.7092
ds-115a	Medium Mammal	Lagomorpha	-12.5	-10.6	7.7		46.7	15.7	3.0	.32	-3.0	.7091
ds-115b	Medium Mammal	Lagomorpha	-5.3	-22.1	5.6		45.3	15.8	2.9	.36	-2.7	.7089
ds-116	Large Mammal	Odocoileus	-11.3	-19.5	8.5		36.4	11.1	3.3	.36	-5.9	.7084
ds-117	Large Mammal	Odocoileus	-11.2	-19.7	5.6	10.1	46.1	16.5	2.8	.39	-4.9	.7089

ds-119	Reptile	Testudines	-9.7	-	7.9		44.	15.	2.8	.44	-4.4	.
				21.3			8	9				
ds-120	Reptile	Testudines	-11.4	-	7.4		41.	14.	2.9	.37	-2.2	.7083
				22.8			2	2				
ds-121	Large Mammal	Odocoileus	-10.8	-	4.2		46.	15.	3.0	.	-6.9	.7090
				21.4			8	5				
ds-122	Large Mammal	Artiodactyla	-7.5	-	8.8	9.2	46.	16.	2.8	.35	-2.2	.7088
				11.5			0	4				
ds-123	Medium Mammal	Canine	-6.3	-9.6	11.		46.	16.	2.9	.26	-2.4	.7090
					9		2	2				
ds-124	Medium Mammal	Canine/Peccary	-7.1	-	7.2	6.1	44.	15.	2.8	.33	-3.1	.7087
				11.1			7	9				
ds-125	Large Mammal	Odocoileus	-10.9	-	6.1	5.2	45.	15.	2.9	.25	-5.2	.7083
				19.8			5	9				
ds-126	Reptile	Squamata	-10.2	-	6.1	4.0	42.	14.	2.9	.33	-3.9	.7087
				19.7			6	8				
ds-127	Reptile	Testudines	-9.7	-	5.1		45.	16.	2.8	.27	-4.7	.7092
				23.5			8	3				
ds-128	Large Mammal	Artiodactyla	-5.3	-	9.1	6.3	42.	15.	2.8	.41	-5.2	.7085
				11.6			3	1				
ds-129	Medium Mammal	Peccary	-6.5	-	9.1		46.	16.	2.8	.38	-5.5	.7108
				11.6			3	7				
ds-130	Medium Mammal	Lagomorpha	-10.0	-	2.1	21.0	46.	16.	2.8	.36	-2.9	.7090
				19.0			3	4				

Figure 3. $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}_{\text{coll}}$ by classification

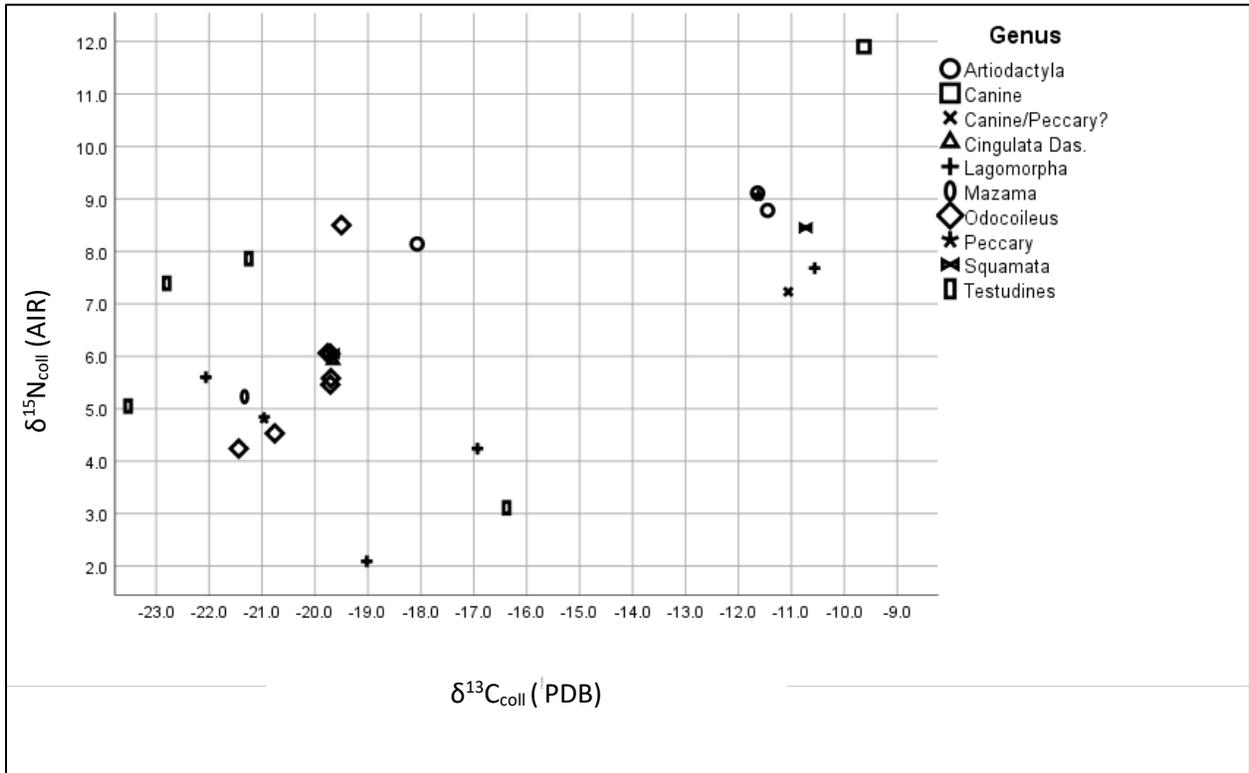


Figure 4 $\delta^{13}\text{C}_{\text{cap}}$ and $\delta^{13}\text{C}_{\text{coll}}$ by identification.

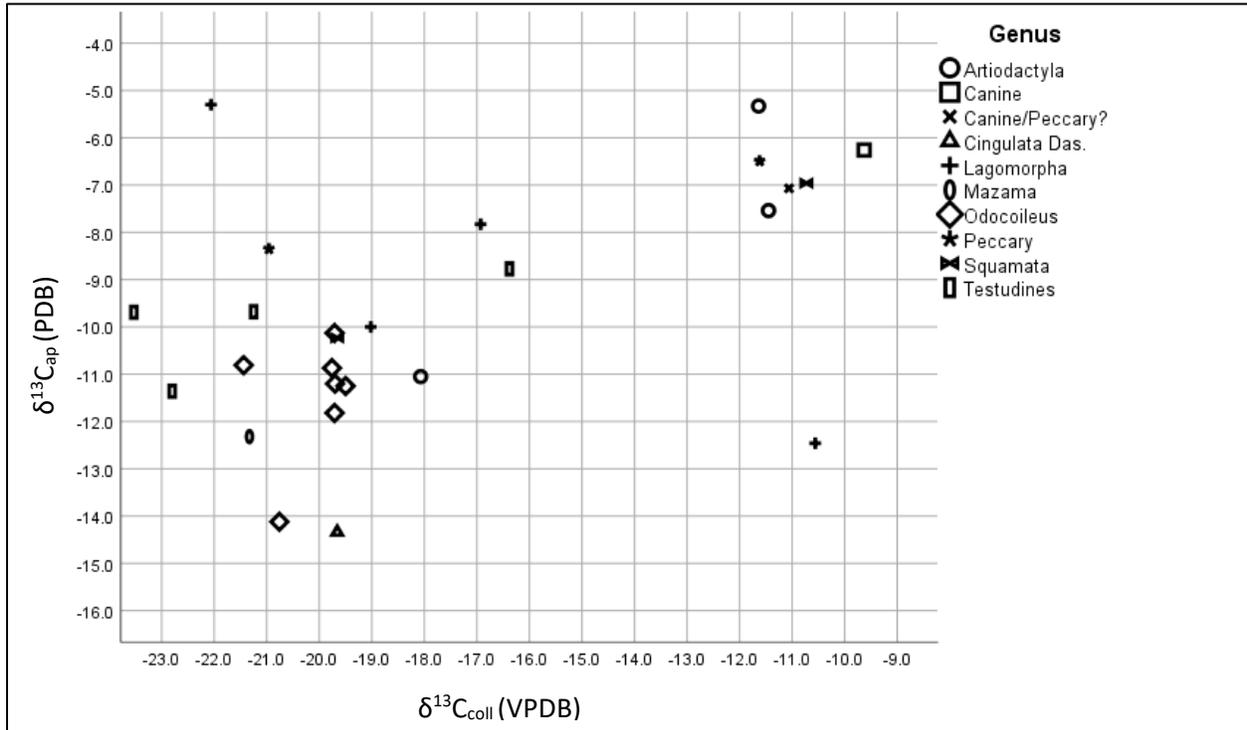


Figure 5 Scatterplot $\delta^{13}\text{C}_{\text{ap}}$ and $\delta^{18}\text{O}_{\text{ap}}$ for all B-4 deposit samples by genus/species identification.

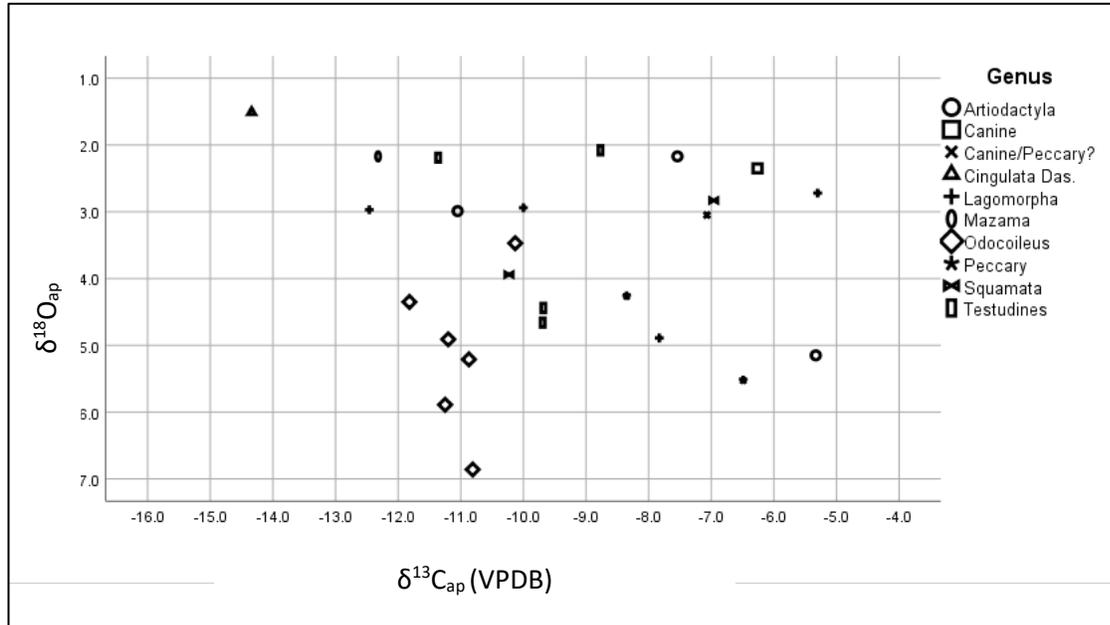


Figure 6. $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{13}\text{C}_{\text{ap}}$ with regression lines from simple carbon isotope model

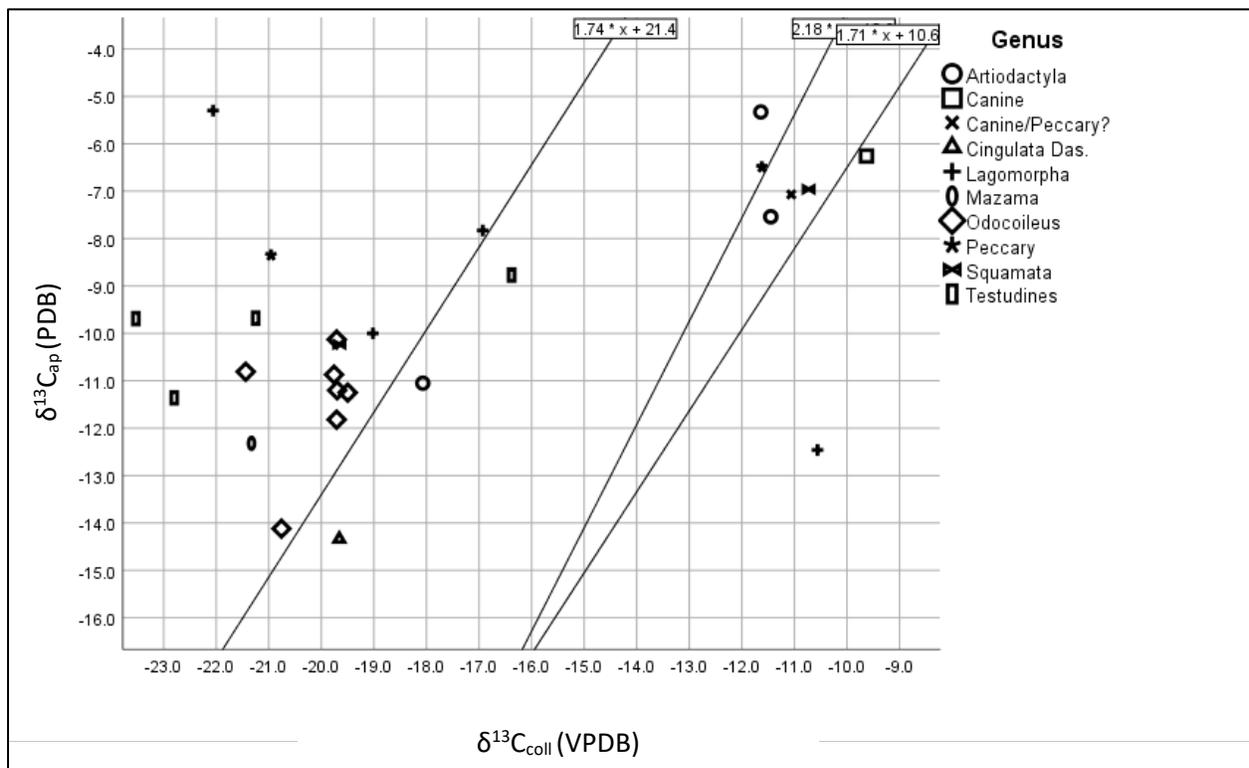


Figure 7. The results of multivariate functions plotted against dietary clusters.

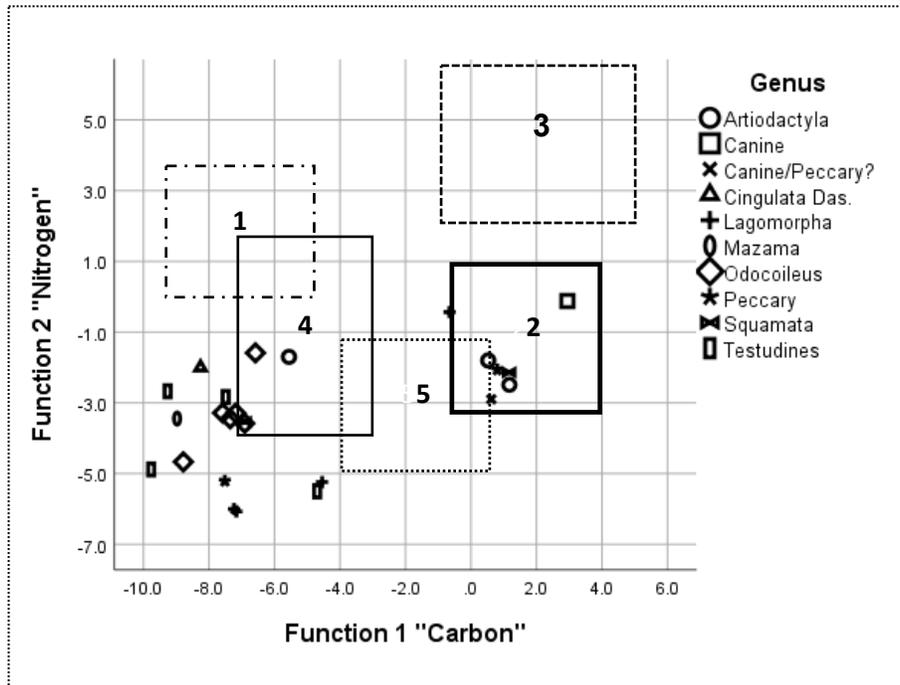


Figure 8. $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}$ by identification, with bars depicting the local ranges by Freiwald 2014.

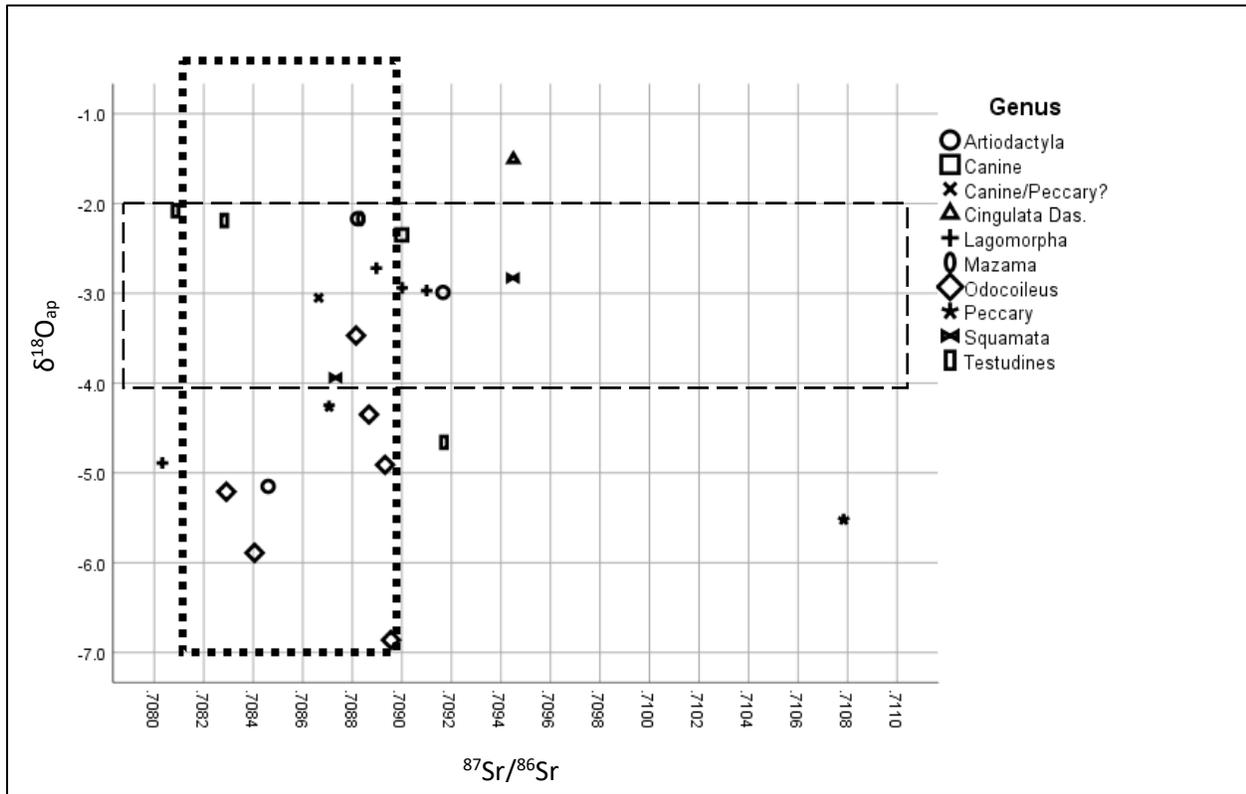


Figure 9. A comparison of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for the B4 Peri-abandonment deposit during the Terminal Classic, and reported values from Ebert et al. 2017 at the sites of Baking Pot and Cahal Pech, values from Tikal and Copan in the Southern Lowlands during the Late Classic period (White et al. 2004), and Preclassic values for deer and dogs from the site of Colha.

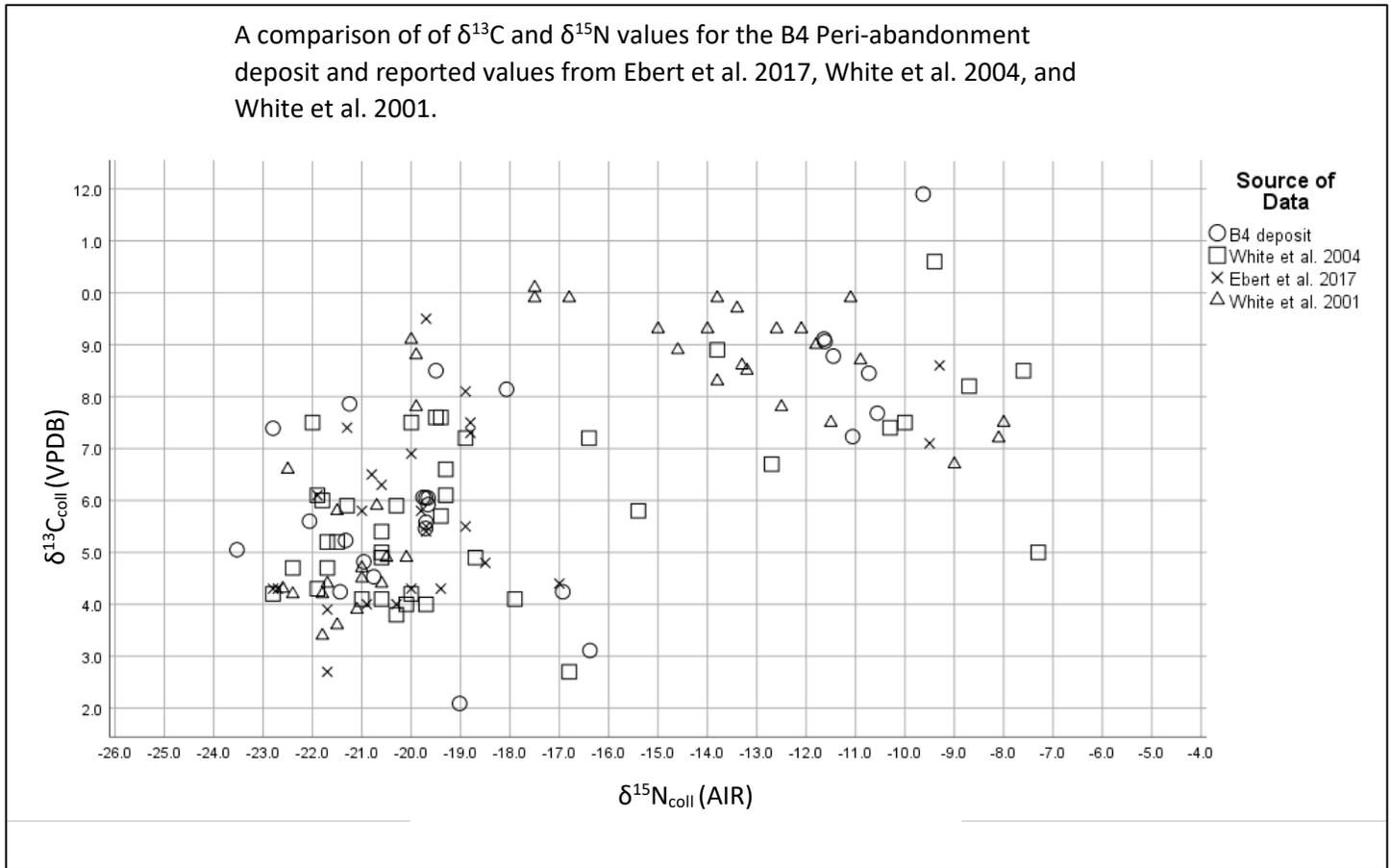


Figure 10. A comparison of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for the B4 Peri-abandonment deposit and reported values from Ebert et al. 2018.

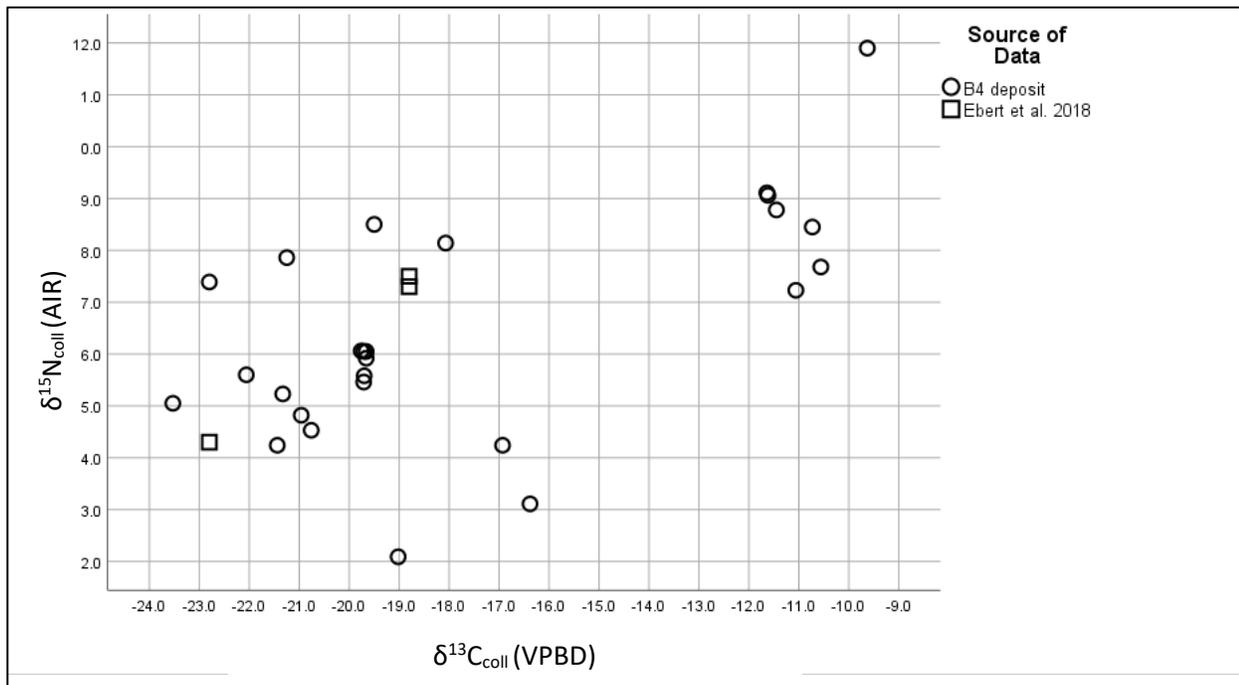


Figure 11. A scatterplot depicting of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for the B4 Peri-abandonment deposit and Ebert et al. 2017, compared to fauna from middens in White et al. 2004.

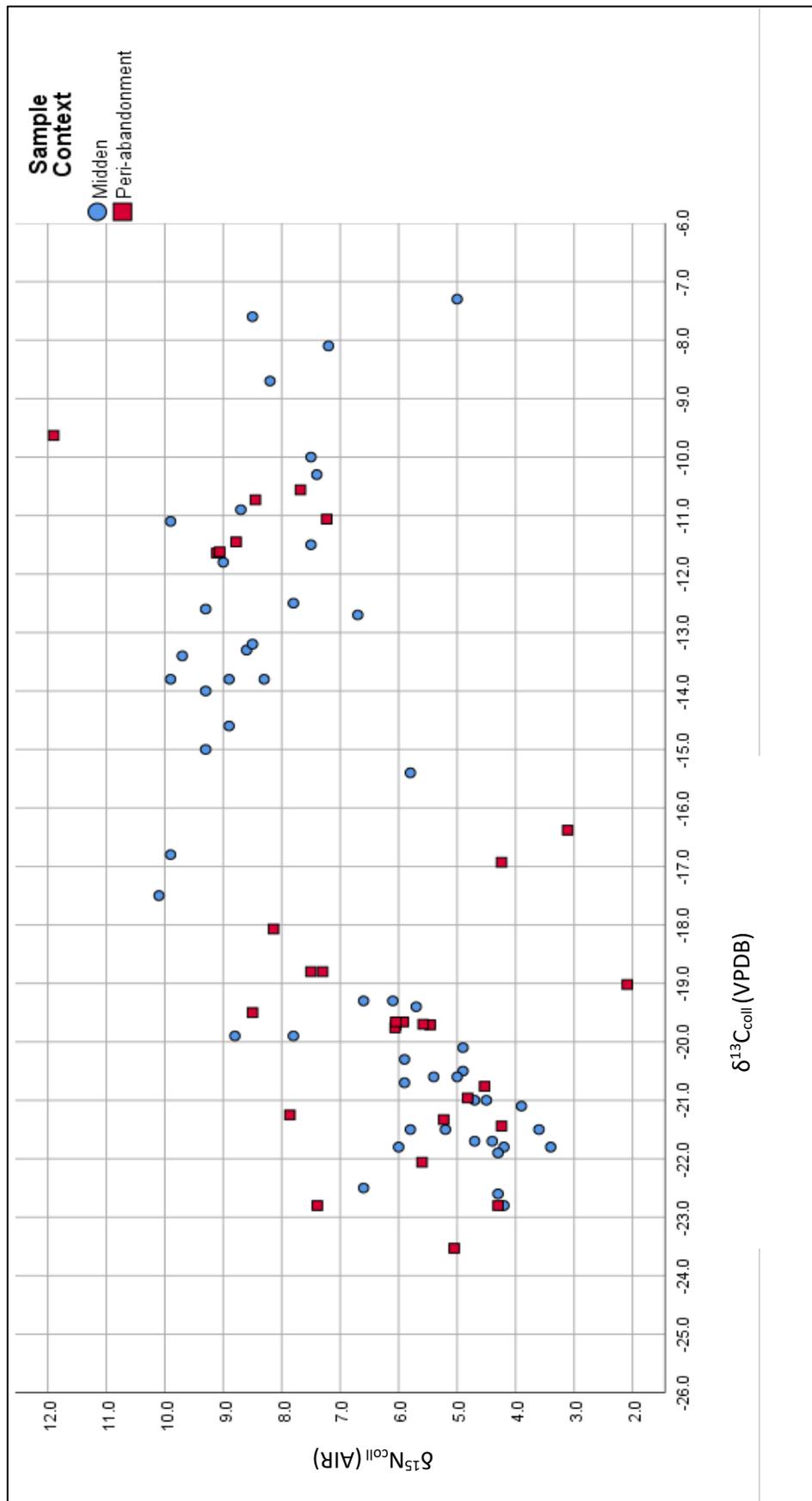
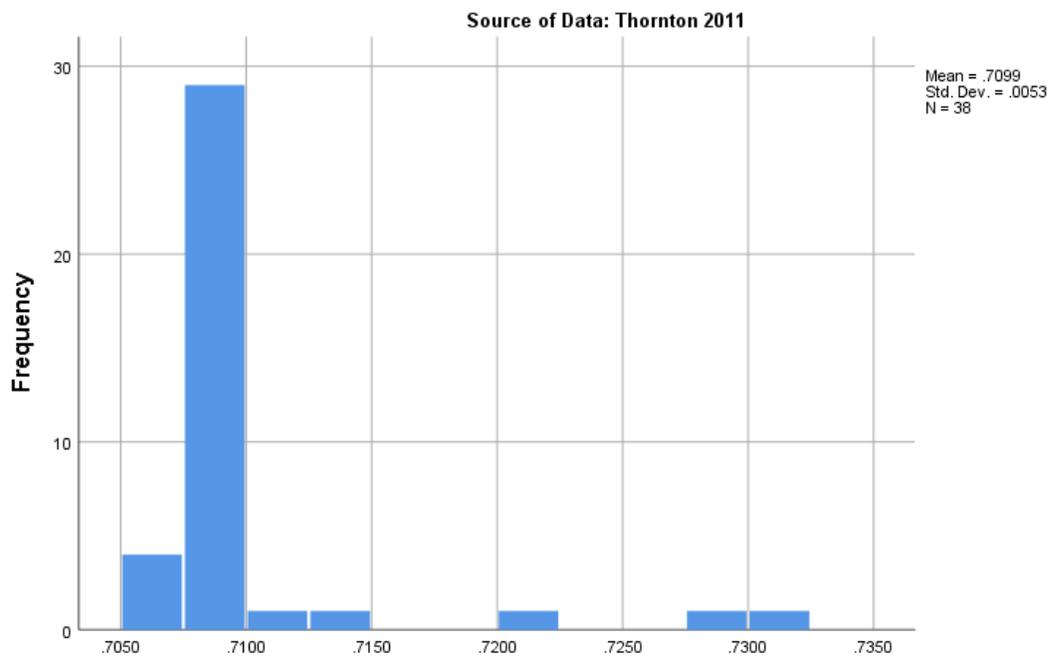
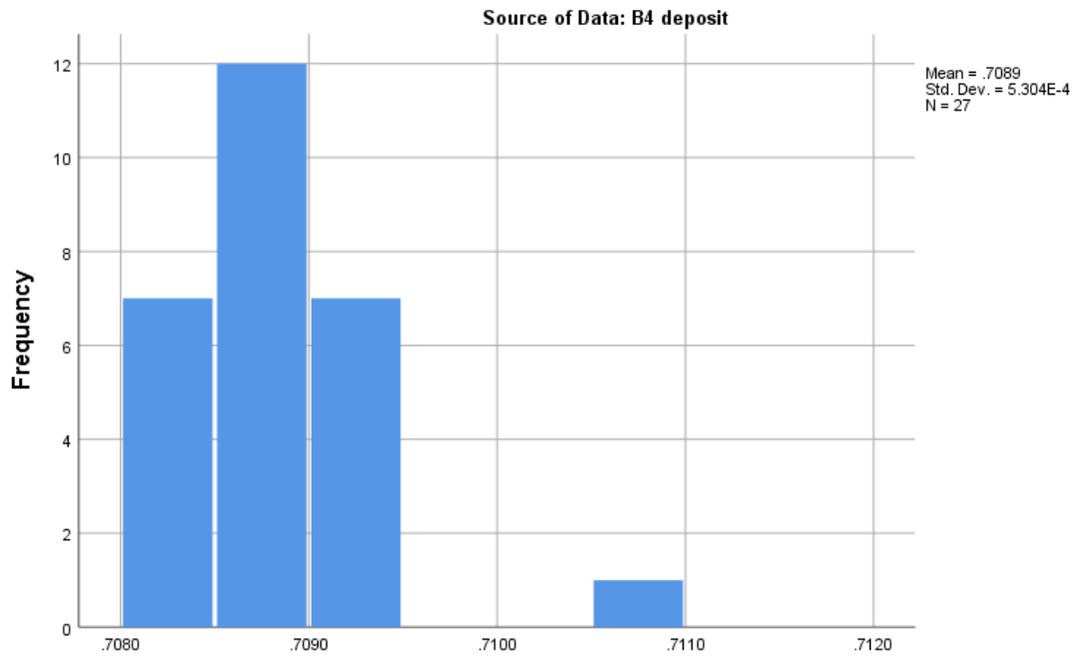


Figure 12. These two histograms depict the frequency of $^{87}\text{Sr}/^{86}\text{Sr}$ values of the B4 Peri-abandonment deposit and values reported for the sites of Colha, Tipu, Lubaantun, and Lamanai in Belize.



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